EGAS MONIZ SCHOOL of HEALTH & SCIENCE | INSTITUTO UNIVERSITÁRIO EGAS MONIZ

# INSTITUTO UNIVERSITÁRIO EGAS MONIZ

## MESTRADO INTEGRADO EM MEDICINA DENTÁRIA

# CRANIOFACIAL ANATOMY DURING CHILDHOOD: PEDIATRIC ANATOMY AND CLINICAL APPLICATIONS


Trabalho submetido por

**MOHAMED LAROUSSI BELARBI**

para a obtenção do grau de Mestre em Medicina Dentária


**junho de 2024**

# INSTITUTO UNIVERSITÁRIO EGAS MONIZ

## MESTRADO INTEGRADO EM MEDICINA DENTÁRIA

# CRANIOFACIAL ANATOMY DURING CHILDHOOD: PEDIATRIC ANATOMY AND CLINICAL APPLICATIONS

Trabalho submetido por
**Mohamed Laroussi Belarbi**
para a obtenção do grau de Mestre em Medicina Dentária

Trabalho orientado por
**Prof. Doutor José Manuel Feliz**

**junho de 2024**

ACKNOWLEDGEMENT

I express my gratitude to my supervisor, Doutor Jose Manuel Feliz, for his time, availability, critique, advice, and most importantly, my deepest thanks for his perseverance and patience.

I wish to express my profound appreciation to the Egas Moniz University Institute, to all the professors, staff, and collaborators who accompanied me throughout this academic journey and contributed to my personal and professional development.

# DEDICATION

To my beloved family,

My mother Hafsia, my father Lazher , my brother Aymen and my sisters Imen, Manel and Arij, whose unwavering support and encouragement have been my foundation throughout this journey.

To my incredible friends,

Mayssa Selima Fadwa Daly Kais Mourad Oussema Hichem Hechem Fourat Rami Ragheb Rym Oumaya Myriam Hela Sahbi and Mounir;

Thank you for your unwavering support, encouragement, and camaraderie throughout this journey. Your collective strength and positivity have been my anchor, and I am profoundly grateful for each one of you.

For my assistant Maissa,

you're a lifesaver! From keeping the clinic afloat to crushing the thesis, your dedication goes above and beyond. Thanks for being my rock during tough times too. You're incredible!

This thesis is a testament to all of you, and I am deeply grateful for your presence in my life.

ABSTRACT:

The growth and development of craniofacial structures have been extensively studied, as many clinical disciplines and research in the fields of pediatric dentistry, orthodontics, and craniofacial surgery rely on understanding these processes for diagnosis, timing, and treatment planning.

Recent studies in craniofacial research have focused on face growth, facial asymmetry, and gender and age differences, examining changes in size and shape. These studies contribute to a better understanding of growth patterns.

Many researchers agree that craniofacial systems tend to have an unusual number of developmental abnormalities, and therefore gaining a deeper understanding of the physiological and anatomical characteristics related to age will guide clinicians in diagnosis, treatment planning, and prediction of post-treatment outcomes.

The advancement in imaging techniques, like as computed tomography and magnetic resonance imaging (MRI), have allowed the acquisition of three-dimensional images of craniofacial structures, providing a more accurate insight into the growth and development of these systems.

The research will be conducted in the Pubmed, b-on, Google scholar, Sciencedirect, and Mendeley search databases. The terms to be used for the query are: Growth, Maturation, Craniofacial Bones, Therapy, and the data will be accessed from October 2023 to February 2024.

Keywords: Childhood, Adult, Anatomy, Growth.

RESUMO:

O crescimento e desenvolvimento das estruturas craniofaciales têm sido extensivamente estudados, considerando que muitas disciplinas clínicas e pesquisas nas áreas de odontologia pediátrica, ortodontia e cirurgia craniofacial dependem da compreensão desses processos para diagnóstico, cronometragem e planejamento do tratamento.

Recentemente, estudos craniofaciales abordam o crescimento facial, assimetria facial e diferenças de gênero e idade, examinando alterações no tamanho e na forma, contribuindo para uma melhor compreensão do crescimento.

Muitos pesquisadores concordam que os sistemas craniofaciales apresentam uma tendência para um número incomum de anormalidades de desenvolvimento e portanto, obter um conhecimento mais profundo das particularidades fisiológicas e anatômicas relacionadas à idade irá guiar os clínicos através do diagnóstico, planejamento do tratamento e predição de resultados pós-tratamento.

O avanço nas técnicas de imagem, como a tomografia computadorizada e a ressonância magnética, tem possibilitado a obtenção de imagens tridimensionais das estruturas craniofaciales, fornecendo uma visão mais precisa do crescimento e desenvolvimento desses sistemas.

A pesquisa será efetuada nas bases de dados Pubmed, b-on, Google scholar, Sciencedirect e Mendeley shearch. Os termos a serem usados para a consulta serão: Crescimento,Maturação,Ossos craniofaciales ,terapia e os dados serao acessados de outubro de 2023 a fevereiro de 2024.

Palavras-Chave: Infancia , Adulto, Anatomia, Crescimento.

## TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF ACRONYMS

| | |
|---|---|
| 3D | : Three-Dimension |
| 3DFM | : Three-Dimensional Facial Morphometry |
| ANS | : Anterior Nasal Spine |
| Ba | : Basion |
| BoNT/A | : Botulinum Neurotoxin |
| CCD | : Charge Coupled Device |
| Cm | : Centimeter |
| CT | : Computer Tomography |
| DP3u | : Distal Phalanx of the third finger Union ( fusion) |
| EFA | : Elliptical Fourier Analysis |
| FA | : Fourier Analysis |
| GA | : General Anesthesia |
| Go | : Gonion |
| HRL | : Horizontal Reference Line |
| IANB | : Inferior Alveolar Nerve Block |
| IMPA | : Incisor Mandibular Plane Angle |
| IUL | : IntraUterine Life |
| LA | : Long-face Adult |
| LC | : Long-face Child |
| Li | : Labrale Inferius |
| Li' | : Lower Lip |
| Ls | : Labrale Superius |
| Ls' | : Upper Lip |
| MBF | : Maximum Biting Force |
| Me | : Menton |
| Mm | : Millimeter |
| MP3cap | : Middle Phalanx of the third finger Capping |
| N | : Nasion |
| NA | : Normal Adult |
| NC | : Normal Child |
| Pg | : Pogonion |

| | |
|---|---|
| Pn-Sn | : Nasal protrusion |
| PNS | : Posterior Nasal Spine |
| PRN | : Pronasal |
| Pr | : Pronasal |
| S | : Sella |
| Sn | : SubNasale |
| SSC | : Stainless-Steel-Crown |
| T | : Tuberculum sella |
| TMJ | : Temporo-Mandibular Joint |

# I Introduction

Human anatomy is a scientific field that focuses on the practical and applied science of understanding physical performance and body health (DeGraaff V., 2001). One of the remarkable advancements in the field of human science and anatomy is the exploration of growth processes and the unique anatomical characteristics found in both children and adults. The examination of typical growth and development patterns of the human head and face is a highly intriguing area of study that involves the observation and documentation of anatomical, anthropological, and clinical data (Dellavia et al., 2010). The selection of treatment strategies for patients with anteroposterior and/or vertical disparities would depend, in a part, on a thorough understanding of the processes that occur during different stages of growth, identification of the specific timeframes in which significant facial growth takes place, and determination of the periods in which growth is deemed to be fully accomplished (Rajbhoj et al., 2023). Clinicians, such as plastic and maxillofacial surgeons and orthodontists, have consistently demonstrated a keen interest in understanding the transformations of the face throughout its embryonic stage, as well as during childhood, adolescence, and adulthood. This interest stems from the recognition that an imbalanced development can lead to facial distortions.

# II Development

## 1 Growth and Aging

“Growth is a normal process by which an organism increases in size as a result of the accretion of cells and tissues similar to those already present within organs” (DeGraaff V., 2001). According to Moyers, growth is defined as the typical changes in the quantity of a living substance. On the other hand, Moss defines growth as any alteration in morphology that falls within a measurable range.

Growth can lead to alterations in proportion or form, enlargement or reduction in size, modifications in texture, and increased complexity. Therefore, it may be said that growth refers to the typical alterations in dimensions that occur throughout a specific time frame. In essence, growth denotes a modification or disparity in quantity.

The concept of development underscores the progressive level of structure, primarily associated with alterations in the natural environment. Development spans the entirety of life's changes, starting from conception and continuing through the existence of the individual as a single cell. It then progresses to the elaboration of the individual as a multifunctional unit, ultimately leading to death.

The fundamental distinction between development and growth, according to Profit (Sridhar Premkumar, 2011), is that growth is an "anatomic phenomenon" and development is a "physiological and behavioral phenomenon." In contrast, other authors define growth as continuous sequences of physiologic and anatomic changes occurring from the beginning of prenatal life and ending with senility. They don’t really consider growth and development as separate entities (Sridhar Premkumar, 2011).

Currently, there is a particular focus on comprehending the process of human aging, especially as it relates to the face profile. It is observed that aging does not proceed gradually, but rather in sudden bursts and at various stages of life (Garib et al., 2021; Koudelová et al., 2019). Furthermore, it is apparent that growth is a fundamental component of the developmental process that persists into adulthood, contingent upon adequate nutrition and the harmonious interaction of various hormones (chemicals synthesized by endocrine glands), such as growth hormone, insulin, and sex hormones (during adolescence)(DeGraaff V., 2001). Maturation can be defined as the point in development where the growth curve becomes more even and horizontal after the period of rapid growth that occurs during adolescence. The term "developmental changes" pertains to the qualitative transformations that take place during the process of maturation or aging. Each of the body systems undergoes maturity as a result of this growth process. During early childhood, this maturation occurs at a rapid pace, while in later childhood, it occurs at a slower pace. During adolescence, there is a growth spurt, which persists at a consistent and gradual pace until old age (Figures 1 and 2).

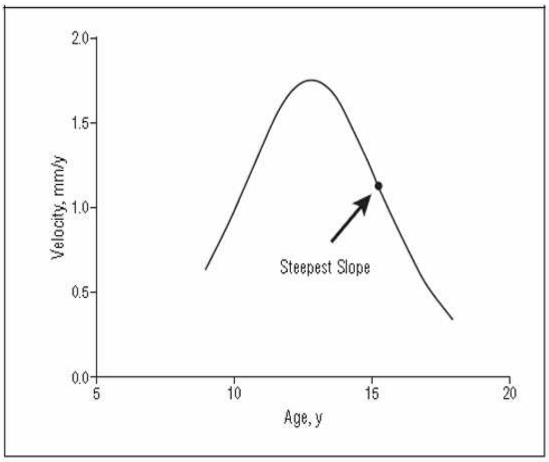



Figure 1: Data plotted as a function of age. At approximately the age of maximum growth velocity. Adapted from (Van Der Heijden et al., 2008).

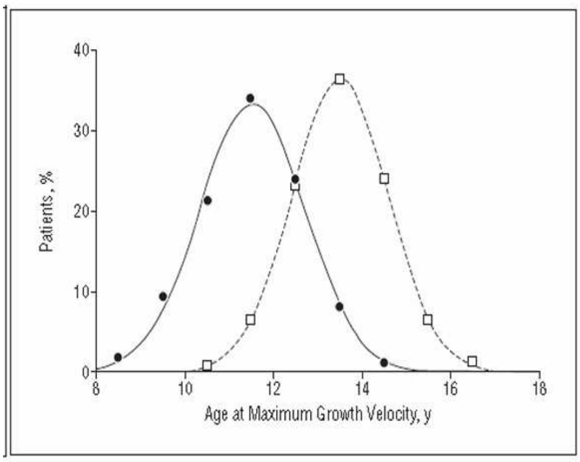



Figure 2: Distribution of the age of maximum height growth velocity for adolescent girls (solid circles) and adolescent boys (open squares). Adapted from (Van Der Heijden et al., 2008).

Data were taken for white adolescent boys and adolescent girls and shows the maximum of the curve is at the age of 11.5 years for girls and 13.5 years for boys (Van Der Heijden et al., 2008).

The maturity criterion is determined by the age at which the growth velocity curves exhibit the most pronounced downward slope. Starting at that age, the rate of growth rapidly declines to almost 0 (DeGraaff V., 2001; Van Der Heijden et al., 2008).

Frequently, it is difficult to fully differentiate the alterations caused by the process of "aging" from those brought about by growth and development. During the third decade of life, facial morphology typically remains unchanged, and the signs of aging have not yet appeared. Additional research conducted by Levine et al. (2003) and Wen et al. (2017) has shown a significant rise in some facial dimensions, namely bizygomatic diameter, face height, ear length and nose length, among individuals aged 21 to 60 years over a span of 10 years (Bishara et al., 1984). Despite the underlying bone growth and skeletal enlargement, soft tissue descent and volume loss have been shown to progress in senescence (Levine et al., 2003; Wen et al., 2017).

Aside from visible signs of aging including graying, hair loss, skin wrinkles, tooth loss, and decreased muscle mass, the internal cellular changes associated with aging are less evident and not yet fully comprehended. Some organelles encounter changes with age. The mitochondria, for instance, can undergo alterations in both their structure and quantity, whereas the Golgi complex may undergo fragmentation. Several writers provide solid evidence supporting the notion that specific cell types possess a predefined number of mitotic divisions, which are regulated by genetic factors. This genetic regulation plays a crucial role in determining the overall vitality and lifespan of an organ. If this is the case, it may be possible to identify and manipulate genetically the "aging gene" (DeGraaff V., 2001).

It has to be mentioned that the ontogenesis of dentofacial complex depends on controlling elements and the main factors described by authors, Gurkeerat Singh and Sridhar Premkumar, are: Genetics, Cartilage, Multifactorial Interaction, Sutural Growth, Endocrine Control, Function, Disruptive Factors, Secular Trend, Socioeconomic Status, Diseases, General Body Growth and Age.

**Age and Racial Differences**: Both size and shape dentofacial measurements do modify with the increasing age and exhibit black and white differences (in the American population) at any age. Black people have constantly longer mandibles and wider rami. It has also been evident that both, their lower dental and lower alveolar heights, decrease with age. Such studies proved that a number of differences do exist in the distributions of the Steiner (whose analysis is based on angular measurements) variables in two populations. These size and shape differences showed in both racial groups, strongly suggest that different orthodontic norms may be necessary to adequately treat both races (Gurkeerat Singh, 2015; Sridhar Premkumar, 2011).

## 2 Prenatal Craniofacial Growth Particularities

During the fetal period, changes in craniofacial measurements are gradual and smaller than they are after birth, for that the quantitative assessment of the shape before birth has proved more difficult. Cambridge University study of facial shape changes demonstrated a clear progressive alteration in shape with age.

Yet, attempts to assess changes in shape before birth involving the use of angles between lines joining defined anatomical points, is much harder in a fetus. It has been determined that points A and B are not observable in the fetal skeleton, particularly during the initial phases, "embryonic form is bent like the letter C, hence, anterior cranial base and mandible are retrusive" (Sridhar Premkumar, 2011). In this case, the tooth buds are examined to evaluate the sagittal relationship regarding to the notable change in the anteroposterior relationship between the embryonic and fetal stages. The assessment of the maxillomandibular relationship involved measuring the angle formed by lines from the maxillary to the mandibular incisor bud to the nasion (Mxl-N-Mdl). The Mxl-N-Mdl angle, which has been observed to be positive and large (10°) prior to the development of the secondary palate, might be considered as the postnatal counterpart to the ANB. Over time, as the face moves away from the prominence of the heart, the Meckel's cartilage grows and the mouth opening reflexes begin to develop during embryonic development, along with muscular contraction, the maxillary growth declines while the obvious spurt in mandibular growth leading to the descent the of tongue and a dramatic decrease of the maxillomandibular relation down to -3°. Thereafter, with palatal elevation taking place, mandibular growth lags behind maxillomandibular angle is regained up to 8° and maintained at 12 weeks of IUL. The fetus expands. Sagittal angle increases by 15° as a result of the very limited growth of the jaw. Subsequently, there is only isometric growth, following the allometric scaling of the mandible during the prenatal maxillomandibular relationship in the vertical, sagittal, and transverse planes. The first trimester is characterized by a significant sagittal expansion, which results in the development of new maxillary prominence and a change in facial profile. This growth is sustained by an increase in width during the second and third trimesters.

Humphrey studied a larger number of human fetuses across different gestational ages and he inferred that, immediately after the tongue shifts and rests on the floor of the mouth, the mandible starts to grow farther forward and continues to increase despite the fact that the palatal shelves are widely separated or didn't even get into contact when they become horizontal (Katsube et al., 2021).

Based on these observations of the human fetus, the fusion of palatal shelves doesn't justify or meet the foregoing conclusions of some authors who stated that the mandible is retrognathic prior to palate closure, or that "the mandible grows more rapidly forward than the upper jaw and becomes prognathic around the time of palatal closure", but the primary distinction between retrognathic and normal fetuses lies in the positioning of the tongue within the oral cavity, rather than any alterations in position or fusion of palatal shelves. This disparity arises as the mandible grows, resulting in a size increase similar to that observed when the palate is closed, and can significantly reduce if the tongue remains between the shelves. As a result, the mandible grows at a faster rate than the maxilla, resulting in a slightly prognathic mandible for a brief duration. The accelerated growth rate is observed during the period of active jaw closure and the initiation of reflexes involving facial expression muscles. This phenomenon is believed to be facilitated by enhanced blood circulation and the development of blood vessels in the mandibular region, resulting from both jaw movements and interactions between oral mucosa and the tongue.

It's been also well known that lack of movement of the extremities may lead to ankylosis of the joints throughout the process of development. However, Moffet (Garib et al., 2021) in a notable study conducted by the researcher, it was shown that the initiation of reflex movement in the mandible during the initial stages of development does not required the existence of the Temporo-mandibular joint (TMJ) though it occurs beforehand, however, mandibular movements contribute to normal differentiation of this joint as is believed by some investigators.

According to Katsube et al.(Katsube et al., 2021), certain researchers have observed that the trajectory of postnatal growth is established at an early stage in the fetal development of humans. Furthermore, it has been suggested that the growth pattern of postnatal facial profiles can be anticipated as early as the second trimester. However, as development progressed, the expansion in the upper face exceeded that of the mandible. One potential explanation for the observed increase in development in the maxillary region could be attributed to the emergence of dynamic facial movements, particularly in the maxillary area, as well as the involvement of temporal and masseter muscles situated in the upper facial region (Sridhar Premkumar, 2011). The reflex activity of the muscles appears to have a significant impact on the development of cartilaginous and skeletal structures in both the upper face area and the mandible. In addition, it has been proposed that the muscles undergo enlargement due to their activity, which in turn affects the facial framework. It is concluded then, “that function plays a role in the craniofacial development of the fetus” (Katsube et al., 2021). Nevertheless, the prenatal effect of prenatal function on the series of morphologic development has triggered different opinions. Some of which deny the functional role in structural development and approving the dependency of their growth on "inherited, intrinsic factors". Others however, establish a reciprocal relation between structures and function regarding that an “adequate morphologic maturation leads to function, which in turn influences further structural development” (Katsube et al., 2021).

## 3 Assessing Facial Growth and Development

Anthropometry, cephalometry as well as the recently applied stereophotogrammetry, are different means to quantify changes in the general facial profile that occur during growth and also analyze facial abnormality (Sridhar Premkumar, 2011). In clinical practice, the morphology of facial surface is usually quantified using soft tissue landmarks by anthropometric means, however, skeleton analysis is done using cephalometry (Anas et al., 2019).

### 3.1 Direct Assessment of Growth Using Facial Anthropometry

It is the measurement of the proportion and size of the human body and it literally means: man (anthro) measurements (metrics). In contrast to clinical research, the direct measurement of facial landmarks, also known as anthropometry or anthropometrically oriented studies, enables a comprehensive examination of the soft tissue face profile in a three-dimensional manner. Regrettably, this method is deemed to be laborious due to the necessity of directly measuring each subject and repeatedly customizing the same landmarks. Additionally, the landmark coordinates cannot be recorded to facilitate subsequent measurements. Longitudinal studies are hard to make using anthropometry because data acquisition is hard as the study evaluates changes during maturation and over time and participants may fail to return for recall.

Consequently, anthropometric studies of facial profiles have been few and cross-sectional in design due to the difficulty of data acquisition in longitudinal studies, making them easier to perform and allow less-costly investigations (Häner et al., 2021).

### 3.2 Cephalometric and Growth

Cephalograms have been widely employed in the evaluation of active growth across many developmental stages, ranging from infancy to childhood and adolescence. They help discover the regions where growth has occurred by superimposing the cephalometric radiographs at certain reference lines which are the least affected by growth. Cephalometry helps in providing a documentation of the patient’s data at various points of time which actually is of a great use in longitudinal growth studies. This possibility of repeated observations and assessments make of cephalometric, by far, one of the most practical mean in the studying and interpreting of craniofacial growth (Sridhar Premkumar, 2011).

### 3.3 Three Dimensional Methods to Assess Craniofacial Growth

There are limitations in the accuracy of anthropometric investigations, as cephalometric radiographs and pictures only offer two-dimensional depictions of growth.

When growth is examined in terms of volume, developmental changes and progress are measured three-dimensionally. Current methods for studying growth involve the use of stereophotogrammetry and 3-dimensional facial morphometry. Nevertheless, these techniques have certain limitations in terms of capturing the coordinates of cutaneous locations, and there is a possibility of information loss during the reconstruction of the face inside a coordinate system, commonly referred to as "facial extraction." The utilization of stereophotogrammetry enables the generation of a computerized facial map and facilitates linear measurements, which can subsequently be integrated to quantify volume. This approach has been employed in longitudinal investigations to ascertain the period of rapid growth in facial soft tissues during adolescence.

Ferrario and colleagues recently utilized mesh diagram analysis to examine three-dimensional (3D) soft-tissue data and developed an alternative approach, known as 3-

Dimensional Facial Morphometry (3DFM), for calculating facial volume and investigating soft tissue growth. The ELITE television image analyzer, also known as the 3DFM system, has two high-resolution infrared-sensitive cameras and a charge coupled device (CCD) for image recording. CCD video cameras are employed to determine the three-dimensional coordinates of the center of gravity for soft tissue landmarks. This is achieved by putting a reflective marker to the center of each point using an adhesive plaster. This allows the acquisition of calibrated metric coordinates x, y, and z data, which are subsequently utilized for digital reconstruction. The 3DFM approach uses wireless markers placed on specific facial landmarks to accurately determine their three-dimensional coordinates. Then, the person is positioned in front of the cameras to capture images from various perspectives. Following that, the landmarks undergo translation using the ELITE system, followed by the reconstruction of the face using the x, y, and z coordinates (Hallgrimsson et al., 2015; J. Zhao et al., 2023).

### 3.4 Fourier Analysis for Assessing Changes in Shape

The application of Fourier analysis has been observed in the disciplines of biology and medicine in recent years (Ferrario et al., 1999; Hallgrimsson et al., 2015). The utilization of this method in growth studies has been suggested due to its ability to mathematically represent the contour of an object, quantitatively evaluate the overall shape characteristics, and facilitate the comparison of alterations in the outlines of various objects or the same object over time, without being influenced by factors such as size, spatial orientation, or relative to reference planes. An orthogonal camera system is used to simultaneously record scanned frontal and profile photos for analysis. The digital extraction of facial features is followed by the computing of forms utilizing FA and Fourier descriptor software.

In order to overcome the limitations of traditional Fourier analysis (FA), a novel technique called Elliptical Fourier Analysis (EFA) was recently developed. EFA allows for the examination of complicated morphological shapes without relying on centroids, landmarks, or the consistent alignment of structures. Regarding growth, EFA permits the measurement of variations in shape and the examination of disparities in dentofacial growth. The study revealed that the most significant variation in body form was observed during the initial year of life, spanning from 1 to 17 years of age. After that, the disparities gradually diminished, reaching insignificant variations after the age of 15. Nevertheless, the analysis of EFA might pose challenges, and studies with a limited sample size may be constrained in their scope. Tracing and point identification errors may occur, particularly in areas with overlap or significant contour changes. However, the quantitative research of biologic forms in dentistry has already demonstrated successful application of both standard Fourier series and elliptic Fourier analysis (Ferrario et al., 1999; Hallgrimsson et al., 2015).

## 4 Postnatal Growth Particularities of theCraniofacial Skeleton

The observed high development in the immediate postnatal period can be attributed to the continuation of the prenatal growth rates, which are considerably more rapid (Liu et al., 2010). In the early stages of development, the face of a newborn is situated beneath the cranial bones, with a ratio of approximately 1:8. However, as the child grows older, the face gradually emerges from the cranium. The dimensions of the face are symmetrical, resulting in an infant's facial structure exhibiting a nearly round shape. During the period of growth, the facial height doubles compared to the early postnatal period, since the face length increases more than the width and depth in average persons. The process of remodeling, specifically through apposition/resorption, is responsible for the development of adult facial structures. As a result, structures like as the chin, zygomatic bone, and superciliary arches grow and become more obvious with age.

The study of craniofacial skeletons focuses on the examination of cranial and face skeletal structures. This study involves the examination of the face skeleton, namely the mandible, Temporo-Mandibular Joint and nasomaxillary complex. The cranium also has a significant impact in facial growth. Indeed, the expansion of the temporal lobe results in the displacement of the orbit from the lateral to the anterior region, so causing the maxilla and mandible to descend downwards (Figure 3) (Sridhar Premkumar, 2011).

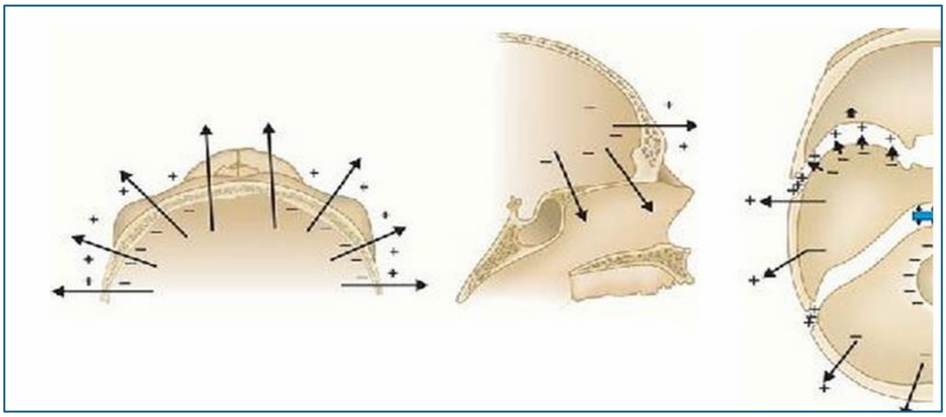


Figure 3: The frontal bone grows anteriorly as a result of frontal lobe expansion. Deposition occurs on the ectocranial surfaces, while resorption is visible in the fossa. The cranial floor grows forward as a result of proliferative activity in the synchondrosis. Adapted from (Sridhar Premkumar, 2011).

## 4.1 Review of the Literature

A study conducted by Ortiz and Brodie (Liu et al., 2010) in 1949 examined newborn infants at regular intervals from birth to 3 years of age. The findings revealed that the cranial base and facial skeleton gradually moved downwards over time. Furthermore, the downward and forward trajectory of the facial skeleton was followed by facial landmarks such the anterior nasal spine, inferior orbital point, and all maxillary teeth.

Enlow and Hans (Enlow & Hans, 2008) reported the neurocranium, and particularly the cranial base, represents the foundation for the human face. At the junction of each of the cranial-base bones (the occipital, the sphenoid and the ethmoid), there’s what we call a synchondrosis, which is essentially the closest thing that we get to an epiphyseal growth in the skull. In terms of growth and development this means that the cranial base can increase in length by the growth at these couple of synchondroses, and just like long bones, at some stage of growth these Synchondroses fuse and stop growing (the sphenoethmoid synchondrosis fuses first at around 7, while the sphenooccipital fuses at 13).

The anterior cranial base supports the Nasomaxillary complex, meaning the anteriorly directed growth of the anterior cranial base at the sphenoethmoid synchondrosis leads to a secondary displacement of the maxilla and carries it forward. Whereas, the posterior cranial base is associated with the mandible through the TMJ articulation, thus, the growth of the sphenooccipital synchondrosis highly affects the opposition of bone and growth in the mandible.

In their initial investigations on craniofacial growth, Hellman (Hellman, 1927) and Goldstein (Goldstein, 1936) observed significant changes in size and shape within the initial 5 years. Their findings indicated that the most substantial increase in facial depth took place between the ages of 3 and 6. Furthermore, facial development was accompanied by a rapid acceleration in growth rate during early infancy and late infancy, coinciding with the completion of the deciduous dentition. After then, there was a slowdown from late infancy to childhood, which coincided with the emergence of the first permanent molars. A number of writers (Liu et al., 2010) have also documented a higher degree of craniofacial growth within the initial 5 years compared to the rest of postnatal years (Figure 4). Indeed, by the age of 5, the head's development, involving its width, length, and circumference, has almost approximated its adult dimensions (Liu et al., 2010).

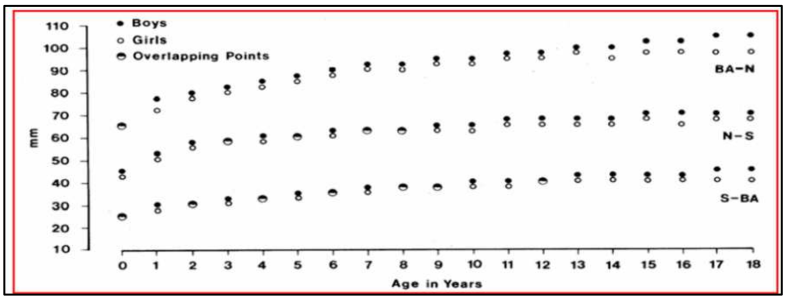



Figure 4: Growth changes in cranial base lengths. Adapted from (Liu et al., 2010).

## 4.2 Nasomaxillary Complex

The Nasomaxillary complex is made up of the maxilla (including the palate), nasal bone, zygomatic bone, and a portion of the frontal bone (orbital roof). The system of sutures elaborates and ensures contact between all the bones.
On the other hand, it has been suggested that facial attractiveness is derived from the presence of symmetrical, balanced, and harmonic proportions. The restoration of proportional face structures and the eradication of disproportionate relationships are necessary for the reestablishment of facial harmony. Therefore, the Maxilla should not be regarded as an independent bone, but rather as part of the broader Nasomaxillary complex or midface.

Enlow and Bang (Sridhar Premkumar, 2011) stated that during bone growth by primary displacement that "specific local areas come to occupy new actual positions in succession, as the entire bone enlarges involving corresponding and sequential remodeling adjustments in order to maintain the same shape, relative positions and constant proportions of each individual area in the maxilla as a whole".

The main cause of maxilla displacement is the growth of maxillary tuberosity (Figure 5). At this specific site, cortical tissue deposition applies pressure on the posterior structures, with a counter-anterior thrust that ultimately produces primary displacement. The posterior growth only contributes to the elongation of the maxillary dental arch.

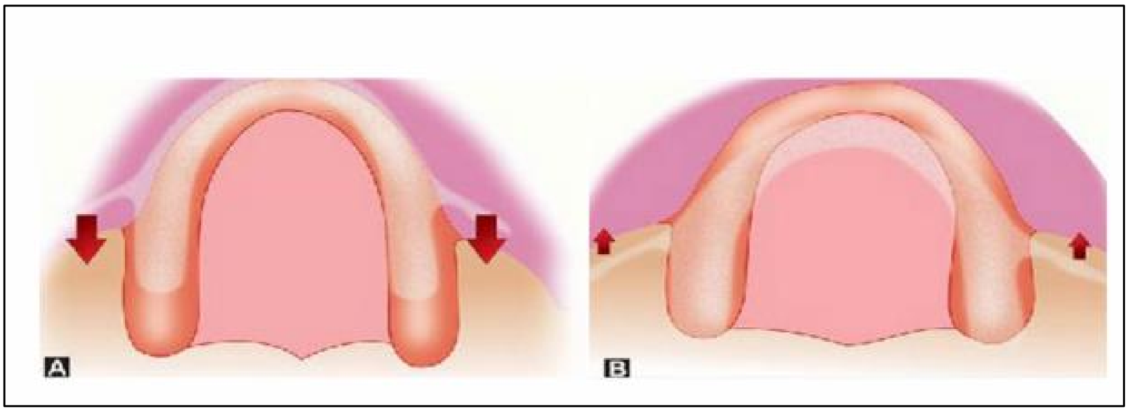



Figure 5: Depiction of posterior growth at tuberosity (A) and anterior displacement (B). Adated from (Sridhar Premkumar, 2011).

The phenomenon of secondary displacement, which refers to the movement of the complete bone, takes place when the cranial base undergoes anterior and superior growth, while the midface experiences anterior and inferior growth. The growth of synchondrosis at the cranial base results in its elongation. It was believed that proliferation of osteogenic tissue at the sutures, induces tension in the sutural area, splits the suture apart leading to a growth movement that pushes the bone with a later fill-in. This was thought to be providing an anterior thrust to the midface (Figure 6). However, the suture theory of growth has been rejected. According to Moss's functional matrix theory of facial growth as it applies to the cranium, the maxilla and the mandible, soft tissue is primarily. Moss's theory holds that the growth of the cranium is due to the expansion of the brain (soft tissue) that grows within. Concerning the maxilla, the functional matrix (soft tissue) can secondarily displace it in space, a result of the respiratory function, and specifically the nasal respiration, that drives midfacial growth (Poosti et al., 2012; Sridhar Premkumar, 2011).

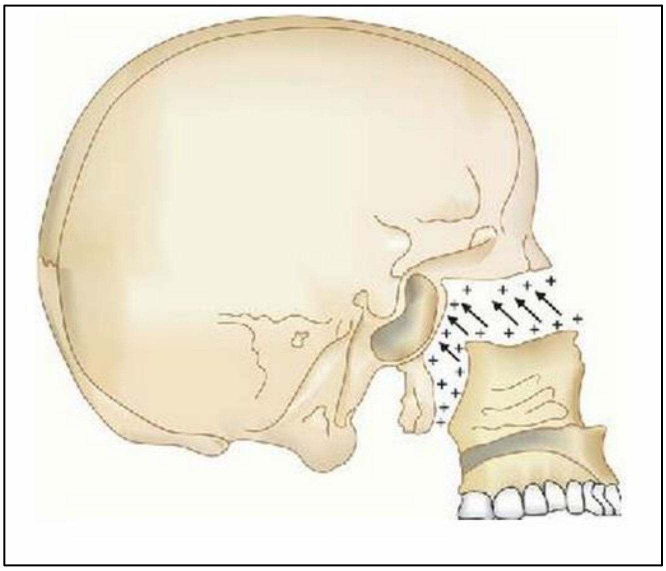


Figure 6: The theory of the Nasomaxillary complex moving forward and downward and secondary adaptive deposition at the sutures. Adapted from (Sridhar Premkumar, 2011).

Cortical apposition at the posterior end reattaches the cranial base to the midfacial bones. An expanding V shape is formed by the upper face's upward and forward growth and the lower face's downward and forward growth (Sridhar Premkumar, 2011).

However, the aging of the facial profile is not a steady phenomenon; rather, it manifests in intermittent bursts and at various stages of life. A cross-sectional study conducted by Sridhar Premkumar (Sridhar Premkumar, 2011) aimed to investigate the age-related changes of the Nasomaxillary complex in Iranian adolescent boys aged 12 to 15 years, this age range is considered significant as it coincides with the development and growth spurt of craniofacial structures in boys, resulting in a relatively balanced jaw and labial complex due to the transition from primary to permanent dentition. The study demonstrated that there is an anticipated increase in nasal width rather than nasal length.

However, there were no significant changes observed in nasal root slope angle, nasal index and philtrum height. This suggests that a wider range of ages may be required to accurately define the peak of lip growth. However, there was a noticeable reduction in the nasolabial angle between the ages of 13-14 and 14-15. This drop can be related to the downward growth of the nose from 13 to 15 years. A study conducted by Mulharrem Akguner (Mulharrem Akguner, 1998) demonstrated that the age at which the nose develops in Iranians and Turks is comparable. Nevertheless, white North Americans exhibit a commensurate increase in both the length and width of their nose. The noticed variations in the growth of the Nasomaxillary complex can be attributed to racial disparities, as well as environmental and genetic factors. This observation implies that the anthropometric standards employed for a specific population inside a particular country may not be universally applicable across other countries globally (Poosti et al., 2012).

### 4.2.1 The Maxilla

The two maxillae are connected to other bones through a complicated sutural system, as previously stated. Remarkably, when the maxilla advances, the posterior end consistently retains touch with adjacent bones. According to Enlow and Hans (Enlow & Hans, 2008), the phenomenon of downward and forward displacement occurs concurrently with an upward and posterior remodeling activity, specifically bone deposition, at the surface of the tuberosity. The anterior surface of the maxilla undergoes resorption to preserve its form and configuration. The theory of V expansion states that the maxilla experiences downward growth due to the deposition on the inner side of the maxillary arch and palate, while resorption occurs on the outer side. This idea holds significant importance in comprehending the development of the maxilla.

The cartilaginous nasal septum is thought to have an important role in regulating the development of the maxilla and other nearby bones during facial growth. The forward and downward expansion of this septum would facilitate the movement of the maxilla, resulting in the separation of its different sutures and the promotion of new bone formation on these same sutural surfaces. The impact of soft-tissue expansion on sutural growth has been a subject of study. It has been suggested that the growing tongue, eye and brain generate a continuous separation of sutures above them, which promotes bone growth at their exposed edges. This is especially important for sutures that connect with the frontal, zygomatic, ethmoid, and palatine bones, which are thought to have a major role in maxillary growth (Savoldi et al., 2021; Sridhar Premkumar, 2011).

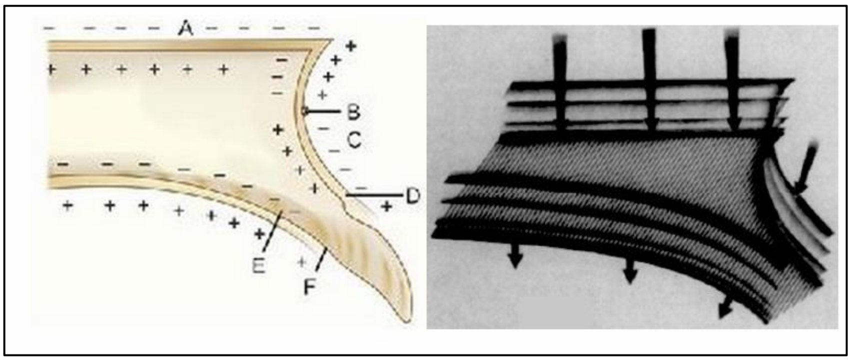



Figure 7: Maxilla anterior remodeling pattern. Adapted from (Sridhar Premkumar, 2011).

The maxilla's remodeling pattern is quite intricate, resulting in significant diversity solely on the anterior surface. In Figure 7, it can be shown that the periosteal concavity at the anterior concave surface of the maxilla is depository from ANS to point 'A', while the periosteal surface from point 'A' to the alveolar edge is resorptive. In contrast, the endosteal side of the cortex has a resorptive upper half and a depository lower half. The key ridge serves as a significant location for the processes of remodeling and reversal. The maxilla's anterior surface, extending to the key ridge region, has a resorptive and concave shape, oriented downwards and expanding in an inferior direction. Conversely, the lateral surface of the maxilla, located posterior to the key ridge, as well as the lateral side of the tuberosity, have a depository nature, growing laterally and facing upwards. Reversal occurs in the key ridge region, which is approximately the first molar region (Figures 8 and 9).

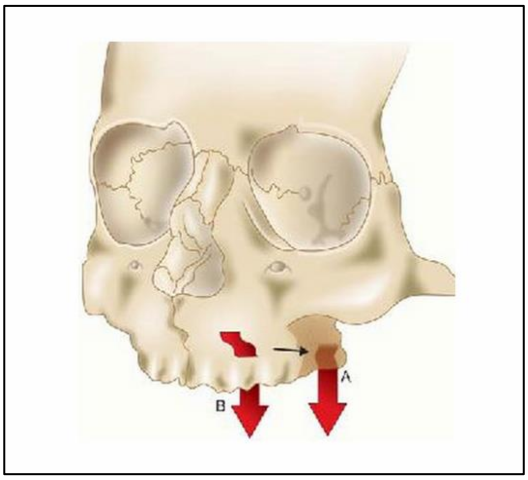



Figure 8: The maxilla's anterior surface has different remodeling, with a reversal at the key ridge. Whereas part "A" grows through periosteal deposition, part "B" is concave and resorptive. Adapted from (Sridhar Premkumar, 2011)

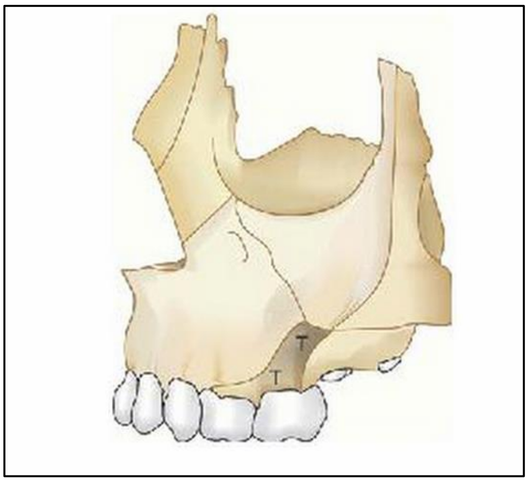



Figure 9: The distribution of periosteal (dark crosshatch) and endosteal (light crosshatch) bone deposits on the anterior maxilla during remodeling. The T or key ridge region is a variable endosteal-periosteal transition zone. Adapted from (Sridhar Premkumar, 2011)

The expansion of the osseous structures around the nasal cavity contributes to the enlargement of the nasal cavities, as well as the movement of the orbital floor. This process also results in an increase in the anterior and vertical dimensions of the nose. The adjacent nasal bones likewise adhere to this identical growth pattern. The maxillary sinus undergoes a selective remodeling process in response to the lateral expansion of the nasal fossa. This process results in the medial surface of the sinus becoming repository, while the other surfaces are resorptive.

The anterior aspect of the frontal process of the nasal bone and the maxilla, which together constitute the bridge of the nose, are depository. The determination of this bridge aspect occurs during early stages of development, and there is minimal variation in the distance between the inner canthus as the individual grows (the width of the nasal bridge remains relatively stable with age). The frontal process's orbital side exhibits resorptive characteristics, and during its maturation, it follows a posterior trajectory similar to that of the zygomatic process in the maxilla. Age is associated with an increase in the distances between the pterygomaxillary suture to the orbital, inferior zygoma, and lateral orbit. Therefore, it may be deduced that the anterior maxillary wall undergoes anterior displacement over the course of an individual's lifespan, with the vertical length of the maxilla increasing (Lacruz et al., 2015).

The growth of the human maxilla after birth is similar to that of the mandible in terms of the overall movement of the developing bone in a forward and downward direction. This growth pattern is among various adaptations observed in response to the presence of teeth in the mandible and maxilla. It involves the formation of new bone on the posterior surfaces, accompanied by the repositioning of the entire bone in a forward direction. Because the maxillary tuberosity surface is oriented posteriorly and somewhat laterally, when new bone is deposited on its periosteal surface, it promotes growth in these directions, which allows the dental arch to elongate at its distal extremities. This phenomenon results in a gradual elongation and a minor expansion of the maxillary arch towards its posterior extremity, facilitating an augmentation in the number of teeth (as seen in Figure 5A) that exclusively manifests at the rear extremities of the dental arch.

However, it is important to keep in mind that the overall pattern of maxillary growth is significantly more complicated than the simplistic generalization that suggests the maxilla grows simply by depositing bone on its posterior and superior sides. The maxilla presents diverse growth patterns, with individual sections exhibiting a wide range of orientations and movements, including mesial (anterior), distal (posterior), superior, inferior, medial (lingual or palatal), and lateral (labial or buccal) (Savoldi et al., 2021).

#### 4.2.1.1 The Zygomatic Bone of the Maxilla

The maxillary growth process involves the deposition of new appositional bone deposits on the posterior surface of the zygomatic process, which is situated within the temporal fossa. This region exhibits a mostly posterior trajectory, characterized by minimal lateral expansion as the maxillary arch undergoes longitudinal expansion. During these processes of remodeling and growth, the zygomatic arch undergoes a mix of bone deposition on the lateral surface and a corresponding resorption from the medial side. This results in the widening of the entire arch as it moves posteriorly (Figure 10). In juxtaposition to the previous configuration of the posterior surface, the facial (anterior) portion of the zygomatic process and the periosteal surfaces facing anteriorly demonstrate a resorptive nature. Consequently, the previously mentioned facial regions exhibit a posterior movement. This growth activity appears to be in contradiction with the principle that the maxilla develops "forward and downward" movement. However, the crucial aspect for understanding the fundamental theory behind this movement is rooted in the remodeling principle known as "area relocation".

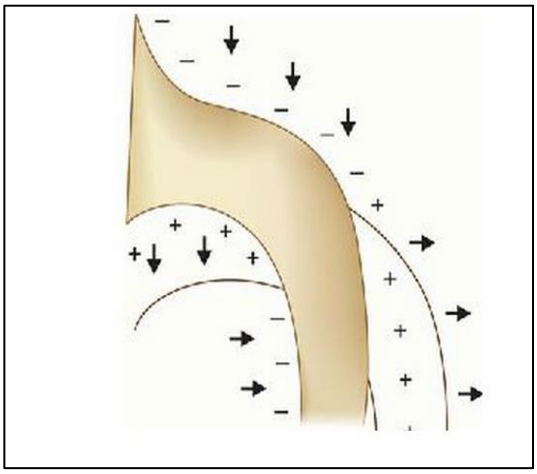


Figure 10: Zygomatic bone remodeling is characterized by: deposition at the posterior and lateral surface and resorption on the anterior and medial surfaces. Zygoma points laterally, and inter-zygomatic width increases. Adapted from (Sridhar Premkumar, 2011).

In order to ensure consistent relative positions of the different parts of the maxilla as new bone is added to the back surfaces, corresponding shifts are made in all existing areas to prevent any potential imbalances between the new and old parts of the maxilla. The maintenance of stable relative positions in the growing maxilla as a whole is achieved through the continuous posterior migration of the entire anterior surface of the zygomatic process of the maxilla and the facial surface of the maxillary body. Consequently, the zygomatic bone undergoes a backward displacement simultaneously with the posterior expansion of the maxillary body (tuberosity) to preserve its position within the overall facial complex.

#### 4.2.1.2 The Palate

The palate of a newborn is shallow, and the dental arch, which is shaped like a horseshoe, has equal length and width. The adult does not preserve the shallow appearance of the palate. As age advances, both the resorptive nasal floor and depository nasal roof are concomitant with the bone deposition on the palatal roof (Figure 11). This bone remodeling leads to extensive downward drift of the palate along with an increase in the length of nasal floor. Palatal growth can be understood using the expanding V concept, wherein deposition occurs on the inner side of the palatal roof, while resorption takes place on the outer aspect, known as the nasal floor. This process results in the expansion of the palatal roof towards the open end. As the eruption of teeth leads to an increase in the vertical height of the alveolar bone and the depth of the palate, the width of the palatal bone expands laterally. As a result, the palate experiences an increase in both height and width due to the deposition of the leading surface towards growth.

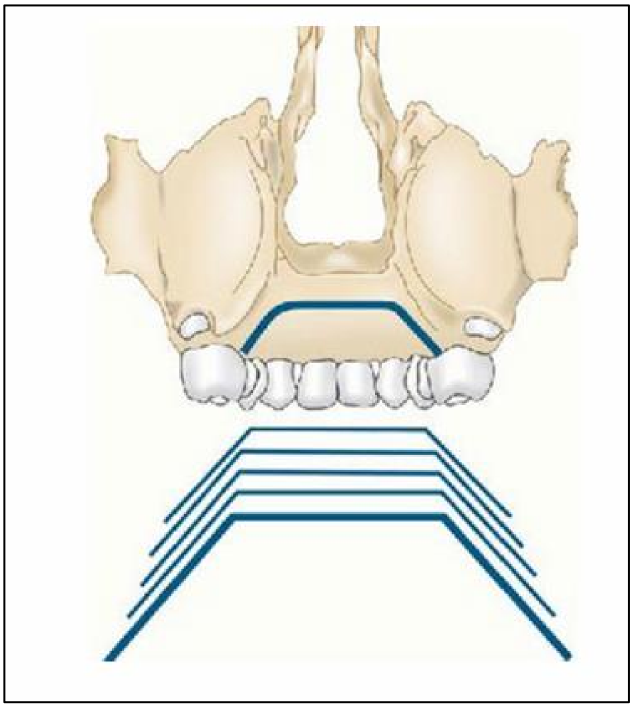


Figure 11: Palate undergoes V-shaped expansion and downward growth as a result of deposition at the palatal roof. Adapted from (Sridhar Premkumar, 2011).

The combination of resorption from the labial surface and deposition on the lingual side of the premaxilla results in a prevailing downward growing trend, accompanied by a minor posterior displacement of the region (Figure 5A). In succession, the premaxillary alveolar bone (incisor area) undergoes a progressive extension, moving down and also drifting slightly posteriorly (a slight “recession” of the incisor area), a situation as well exists in the human mandible. This relocation of the incisor area comes simultaneously as the alveolar process elongates and increases in depth by new bone additions at its free margin.

#### 4.2.1.3 The Maxillary Arch

The maxillary arch represents the example site engaging two growth principles, “area relocation” and the “principle of the V”. In fact, the compound's resorption from the labial side and subsequent deposition on the lingual surface of the arch observed, results in a progressive backward growth where multiple anterior parts of the maxillary arch (incisor areas) constantly shift (relocate) towards more medial positions along the midline. During postnatal growth, the incisor area of the mandible undergoes a growth remodeling process that involves a lingual movement. The overall development of the maxilla requires continuous structural adaptation, as the ongoing displacement of its different components leads to subsequent growth movements.

Therefore, it is necessary to have a supplementary procedure for the rearrangement of teeth. Indeed, the migration of teeth through bone seems to be a physiological mechanism that is adapted to maintain constant relationships between teeth and specific areas of growing, moving bone, as well as to maintain contact between neighboring teeth. When the entire maxilla is shifted towards the front, these teeth are situated in a parallel trajectory. The prevailing consensus is that teeth undergo a process of "drift" within the cortical bone, which is characterized by high mobility and stability. As bone deposition continues along the lateral surface of the maxillary tuberosity, the width of the dental arch likewise increases in size. It is evident that these bone additions simultaneously promote growth in the same directions.

As previously stated, the posterior expansion of the postnatal maxilla elongates the dental arch at its free ends, resulting in an increased number of teeth and so creating greater space for the eruption of all molars. There is a suggestion that the diverse range of distinct remodeling mechanisms linked to the growth of the mandible and maxilla plays a role in the distinctive alterations observed in the overall facial appearance of individuals as they age.

### 4.2.2 The Orbit

The orientation of the orbital surface of the maxillary bone can be grouped into three primary orientations: lateral, anterior, and superior. Deposition of bone on this surface results in an enlargement and a proportional growth in each of these orientations. The lateral rim of the orbit is resorptive and exhibits posterior growth. The medial walls of the right and left orbits develop laterally during the process of growing; consequently, this leads to an expansion of the nasal bridge and the nasal cavities beneath it. Simultaneously, the gradient of the surface facing anteriorly will result in a minor growth displacement in the anterior direction, as well as a certain level of vertical or superior displacement. Consequently, this contributes to the intricate forward propulsion of the posteriorly developing maxillary body. However, it is important to note that the incorporation of bone to the inner lateral-sloping floor of the orbital cavity does not decrease in the overall size of the cavity. Instead, these movements are causing the complete displacement of the orbital cavity in both anterior and lateral orientations.

Hence, the overall patterns of growth in the combined superior, lateral, and anterior orientations substantially resemble those observed in the neighboring nasal region (Figure 12). The orbital rim undergoes anterior displacement throughout the process of facial growth in individuals aged between their third and eighth decades of life. The absolute distance from the Sella to the Orbital exhibits an increase when the SNA angle gets more obtuse in males, but it remains relatively constant in females.

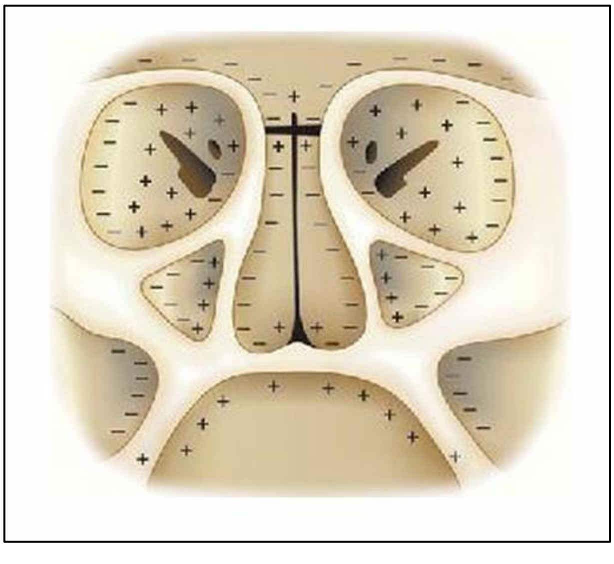


Figure 12: Remodeling of orbit and nasal cavity Adapted from (Sridhar Premkumar, 2011).

A thin cortex bounding the superior limit of the maxillary sinus constitutes the orbital surface of the maxilla (floor of the orbit) with a characteristically resorptive endosteal surface (on the various “outer” surfaces) and a depository periosteal side (the inside cortical lining of the sinus); which actually approves a generalized process of sinus enlargement during maxillary growth. The observation reveals that the floor of the orbit, along with many other maxillary regions, does not exhibit a “downward and forward” trajectory (Maddux & Butaric, 2017).

## 4.3 Mandible

Although the maxilla experiences early growth, the mandible exhibits a greater capacity for growth modification and completes growth at a later stage. There is a need for clinicians to enhance their understanding of early mandibular growth, as extensive research on the mandible in older age has demonstrated its role in determining occlusion type, facial expression, and speech. During early life, the mandible, which is the least developed structure in the craniofacial complex, exhibits the highest growth potential and demonstrates more significant growth rates compared to later childhood or adolescence. Nevertheless, the extent of mandibular growth during infancy and early childhood (ages 0 to 5) is restricted and occasionally indeterminate.

The relative growth, expressed as a percentage of the adult size, serves as an indirect indicator of response potential. The investigation of the relative growth of the mandible throughout the initial five years of life has received less attention, despite its potential utility in assessing reaction potential, surpassing the significance of absolute growth disparities or absolute size changes. Indeed, the comparison between minor growth changes in small structures and small changes in large structures is not applicable. However, it is possible to directly compare relative growth differences between structures, irrespective of their size (Liu et al., 2010).

### 4.3.1 Absolute Mandibular Growth

Several studies have documented the existence of significant attributes of the mandible during infancy. The mandible, which is still developing from birth to 2 years old, exhibits a significantly wide gonial angle of 175 degrees. It also has thin cortices, tooth buds, a tiny ramus, a low-set mental foramen between the deciduous canine and first molar and a small condyle.

However, the data gathered by Izard (Upadhyay et al., 2012) regarding the gonial angle during the initial 2 years after birth indicates that the most significant reduction (10 degrees) occurs within the first 5 months of age. Subsequently, the angle undergoes a considerably smaller change (4 degrees) during the following 19 months. At birth, the angle decreases from 141 degrees to 126 degrees when the main dentition emerged. At the age of 2, the gonial angle experiences an average decline of 15 degrees. This angle continues to decrease until the twelve-year-old molars emerge, reaching a maximum of 120 degrees. This allows for the growth of permanent teeth.

There has been a suggestion that the establishment of muscle and ligament action occurs around the age of 5 months. Hence, the observed alterations in the gonial angle can be linked to functional factors, as they manifest during the period of infants' feeding pattern development and acquisition of mandibular excursive movements. Across all instances, research has confirmed that during the period from early infancy to late infancy (from birth to 2 years of age), the ramus has greater vertical growth compared to the rise in length of the mandibular body, the reason why the angle becomes more acute (Figure13). The magnitude of the gonial angle depends on the ratio between the length of the body and the height of the ramus; If the ramus is shorter, the angle becomes more obtuse.

There was twice as much posterior remodeling as superior remodeling in the gonial region. Nevertheless, in the latter stages of childhood and adolescence, there is a notable disparity in the proportions of horizontal and vertical growth. The researchers observed that the gonion underwent a comparable or slightly greater level of remodeling superiorly compared to posteriorly across the period lasting from 6 to 15 years of age. This observation once more highlights a significant disparity in the remodeling patterns observed in older and younger children, a phenomenon that has not been previously documented (Liu et al., 2010).

Furthermore, there is a notable increase in the size of the ramus and corpus, as well as a more resilient osseous structure in the mandible, observed throughout the corresponding timeframe. The initial theory of corpus lengthening proposed that there is resorption occurring at the front edge of the ramus and deposition occurring at the back edge, resulting in the ramus being pushed towards a more posterior position and the corpus being lengthened. The ramus has a rotational pattern like an arc (Sridhar Premkumar, 2011). Although this process of ramus remodeling, the mandibular foramen remains in its current location, specifically positioned at the medial surface of the ramus. It undergoes posterior displacement due to resorption in the posterior rim and bone deposition in the anterior rim (Figure 14).

The implant study conducted by Björk (De Oliveira Ruellas et al., 2016) demonstrated a high level of stability in the anterior portion of the chin. During the period of childhood and adolescence, there is a rise in both the height and thickness of the symphysis.

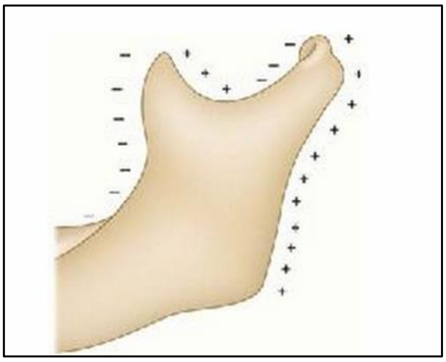


Figure 13: Remodeling of the ramus. Adapted from (Sridhar Premkumar, 2011).

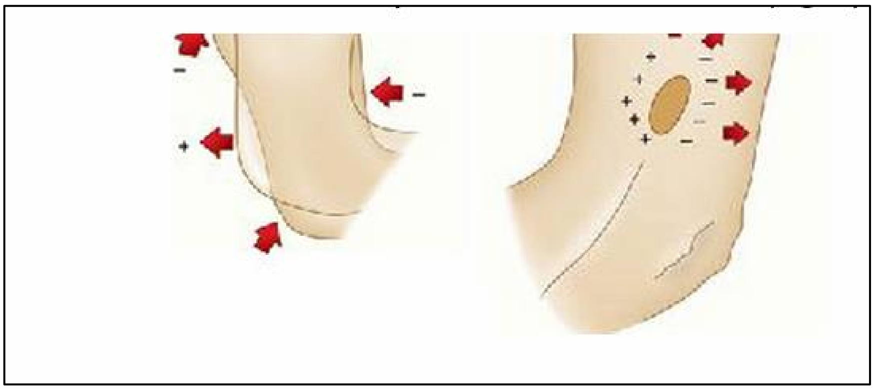


Figure 14: Ramus: Vertical growth and direction of rotation (left); Mandibular foramen moves posteriorly to preserve its position in the ramus (right). Adapted from (Gurkeerat Singh, 2015)

The coronoid processes undergo growth movements characterized by the continuous apposition of periosteal bone superiorly and lingually on the lingual surfaces. This apposition leads to simultaneous movement of the coronoid processes in both directions. The mandibular body acquires lengthening through direct conversion and the relocation of the basal portion of the ramus under lingual growth into the lingual tuberosity of the body.

Additional research (Upadhyay et al., 2012) revealed that there is a notable decline in the growth rate of ramus height during the period spanning from 1 to 5 years of age. The length of the corpus exhibited a decline throughout the period from 3 to 5 years of age, and comparable patterns were observed in the growth of the midfacial and lower facial regions between the ages of 4 and 8. These findings appear to contradict previous studies conducted on girls aged 3 to 16, which indicate that the growth of the body of the mandible and the ramus at 5 or 6 years old is believed to proceed primarily independently of changes in the midface. Yet, exists evidence supporting the notion that the expansion of the ramus occurs in an anteroposterior direction, exhibiting an anterior projection that aligns with the growth of the middle cranial fossa and pharynx. Conversely, the height of the mandibular ramus and particularly the length of the corpus reveal their most rapid growth rate before the age of 5 (Figure 15). In fact, many studies have indicated that the height of the ramus only reaches 38-42% of its full adult size by the age of 0.4 years. Given its relatively lower level of maturity, it is reasonable to anticipate that ramus height would exhibit a more pronounced reaction to epigenetic and environmental stress compared to both mandibular and corpus lengths.

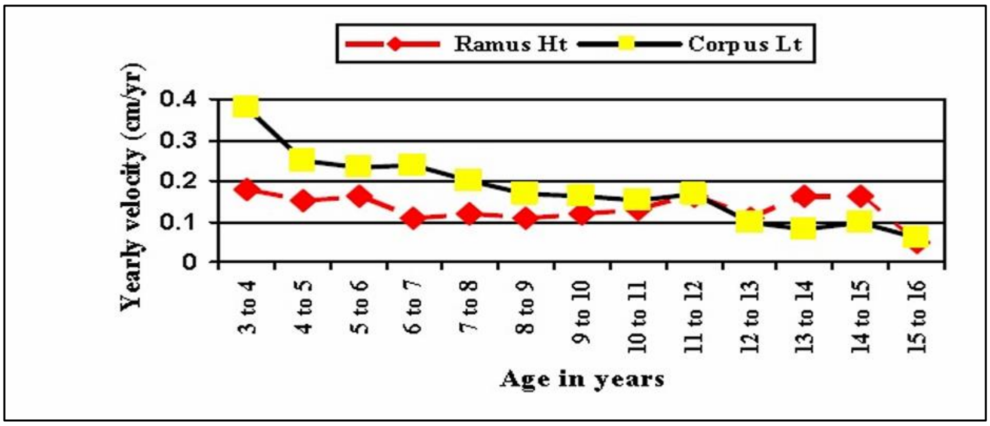



Figure 15: Mandibular growth of girls 3-16. Adapted from (Liu et al., 2010).

According to Smartt et al., it was observed that the condyles of newborns have a nearly linear relationship with the corpus of the mandible (Liu et al., 2010). Research conducted on mandibles aged 4 to 12 years has shown that the most significant growth is observed in the width of the mandibular bicondylar bone during the initial 3 years of life. This rise coincides with the rapid growth of the lateral cranial base.

The condylion and posterior ramus underwent superior remodeling, with a somewhat greater extent of remodeling compared to posterior remodeling. This pattern is significantly distinct from what is observed in older children and teenagers. The implant tests conducted by Björk (Bjork, 1963) on children aged 5 to 22 years often demonstrate a higher degree of vertical condylar growth compared to posterior condylar growth. Further studies (Knigge et al., 2021) examined patients aged 8.5 to 15.5 who had metallic implants in their mandibles, revealed that, unlike the gonial region, the condylar region had nearly ten times greater vertical development (superiorly) compared to horizontal growth (posteriorly). This observation suggests a clear shift in the direction of condylar growth during the later stages of childhood and adolescence, potentially associated with the shift from primary to permanent dentitions.

Due to the observed growth movements in the mandible structures, the mandibular canal is positioned slightly above the mylohyoid line, the inferior alveolar nerve experiences considerable superior displacement, and the mental foramen gradually moves towards the posterior region. Nevertheless, the mandibular canal remains unaltered, and its curvature is indicative of the mandible's previous morphology. The posterior growth of the ramus is accompanied by a parallel backward migration of the zygomatic bone of the maxilla, which is likewise parallel to the coronoid process of the expanding mandible (Figure16).

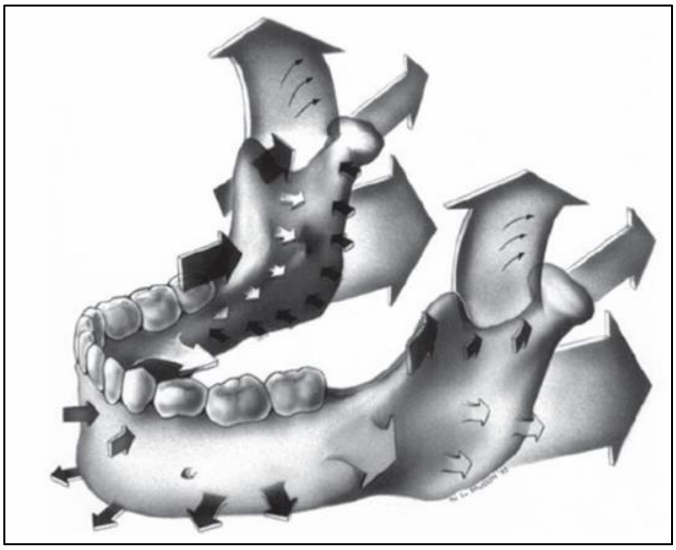


Figure 16: Mandible grows downward and forward if cranial base is taken as reference and Vital studies have shown that the mandible grows backwards and upwards. Adapted from (Andriani et al., 2021).

### 4.3.2 Mandibular Growth and Tooth Eruption

Facial growth (normal and aberrant) and tooth eruption, are significant subjects in various dental disciplines, including pedodontics, orthodontics, and maxillofacial and oral surgery. The contemporary paradigm of superimposition technique is exemplified by the works of Björk (1969) and Björk & Skieller (1983) (Davidovitch et al., 2016).

Through their comprehensive research, they have verified the feasibility of overlaying cephalometric films or drawings onto natural stable anatomical reference structures in longitudinal examinations of individual children. The structures observed in the mandible include: (1) the anterior contour of the chin; (2) the inner contour of the cortical plate located at the lower border of the symphysis menti; (3) any identifiable trabecular structure within the symphysis menti; (4) the contour of the mandibular canal; and (5) the lower contour of mineralized tooth germs prior to the initiation of root development (Figure 17). Nevertheless, the previously mentioned studies relied on two-dimensional analysis (Roentgen-cephalometric).

Krarup et al (Krarup et al., 2005) conducted a 3D analysis of normal tooth eruption and mandibular growth using computer tomography (CT) scans. They expanded the concept of mandibular superimposition on "stable, natural, anatomical reference structures" from two to three dimensions, thus examining the stability of these structures. According to Krarup et al, the age range of the participants varied from 1 week to 14.5 years, while the number of scans per patient ranged from 3 to 7 .

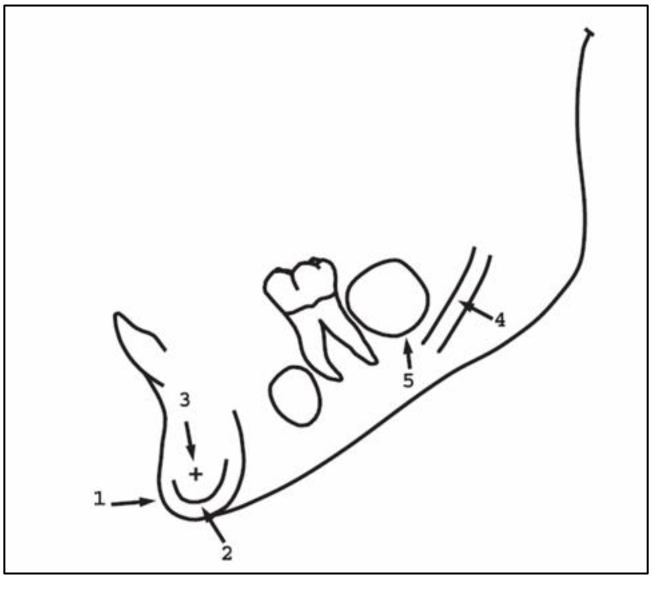



Figure 17: Anatomical reference structures. Adapted from (Krarup et al., 2005).

The utilization of the 3D approach appears to provide novel perspectives on the processes of jaw growth and tooth eruption. The longitudinal series involved superimposition of the mandibles using the mandibular canals and the symphysis menti, as proposed by Björk (Bjork, 1963). This finding aligns with the two-dimensional observations of Björk & Skieller (Love et al., 1990), which demonstrated that the symphysis menti widened in the antero-posterior direction as bone deposits formed in the posterior region. The mandibular canals exhibited a consistent curvature over time when viewed from a lateral angle. However, a lateral displacement of the mandibular canals was detected during growing in the frontal plane, which has not been previously documented in the literature.

According to Björk (Bjork, 1963), the symphysis menti undergoes fusion within the initial year of life. Nevertheless, according to Krarup (Krarup et al., 2005), it is likely that there is an increase in the width of the mandible at the location of the symphysis menti between birth and one year of age. The observed lateral shift in the mandible may be attributed to either a remodeling process or a manifestation of dynamic changes in its structure, however, when considering the profile view, the study appears to support the paradigm of stability of the mandibular canals and the symphysis menti, as suggested by Krarup et al (Krarup et al., 2005). There have been quite few previous attempts to investigate tooth eruption in 3D, and most research have been restricted to a single case. Research has demonstrated that the positioning of tooth buds in the mandible remains constant until the initiation of root formation. In addition, the eruption routes of premolars and canines appear to be vertical, while the mandibular molars erupt in a lingually inclined direction. This observation is likely associated with the tooth inclination within the mandible (Krarup et al., 2005).

## 4.4 Temporo-Mandibular Joint (TMJ)

The condylar cartilage undergoes adaptive remodeling, which can lead to mandibular growth even after puberty. This contrasts with epiphyseal cartilages, where growth stops with cartilage ossification.

The condylar surface is composed of four distinct zones: (1) the Articular zone, (2) Proliferative zone, (3) Hypertrophic zone, (4) Zone of Endochondral Ossification. These zones, along with the flat articular disc, exhibit a high degree of vascularity and cellularity throughout the early stages of development in newborns. With age, there is a noticeable decrease in the supply of blood. Collagen fibers undergo a process of becoming rough and compact, resulting in a fibrous disk. The central region of the disk becomes thinner, while the anterior and posterior regions become thicker. The zone of hypertrophy exhibits active cellular proliferation until the age of 13 to 15 years. Subsequently, the cells undergo mineralization, resulting in their replacement by bone, and a reduction in their mitotic index. The articular eminence and glenoid fossa typically exhibit anatomical features resembling the head of the condyle throughout the neonatal period. At birth, the articular layer is vascular and gradually transforms into a fibrous structure.

Research has shown that in the early years of life the Condylar cartilage has rapid growth. However, during the pubertal period there is a noticeable increase in cell proliferation in the fossa and the articular eminence. This finding contradicts the widely held belief that condyle growth occurs rapidly throughout puberty.

At the age of 20, cartilage islands can be observed in the anterior and superior areas of the condyle, as well as in the posterior region of the articular eminence. The Condylar cartilage remains in the superior and anterior half of the condyle, as well as the posteroinferior part of the eminence, after a period of 20 years.

The most plausible explanation for this observation is the phenomenon of adaptation to functional stress. The biological distinctiveness of mandibular condylar cartilage lies in its ability to undergo adaptive remodeling in response to changes and external stimuli in the microenvironment, either during or after natural growth. Therefore, it may be concluded that condylar cartilage does not function as an active growth center, but rather serves as a place of rapid growth during the early stages.

As individuals age, the temporomandibular joint (TMJ) assumes the responsibility of resisting pressure and stress. The development of the articular eminence is also functional. Eminence is not present at birth. This arrangement facilitates the progression of the mandible during the process of suckling. As the process of dentition progresses and occlusion, specifically overbite, sets in, the eminence expands to support the establishment of the condyle's movement pathway (Santander et al., 2020; Sridhar Premkumar, 2011).

## 4.5 Facial Growth and Changes in Facial Dimensions

The growth of different components of the dentofacial complex does not adhere the same rate or pattern. Specifically, the middle and lower anterior regions of the face exhibit a growth pattern that aligns with the overall bodily growth. However, during the period between 10 and 20 years, the remaining growth occurs at a rate of 4% in the cranium and 35% in the middle and upper regions of the face. Research has demonstrated that the development of the brain is nearly finished by the age of 6, while the face remains typically infantile. Consequently, it may be argued that the development of the face is mostly impacted by external factors. Even following the attainment of biological maturity, the arrangement, form, and dimensions of craniofacial soft and hard tissues undergo modifications.

Peterson et al. (Rajbhoj et al., 2023) demonstrated that the alterations in facial dimensions and the correlation between different facial parameters among individuals aged 5 (childhood) and 25.5 years (adulthood) vary in terms of timing and magnitude within the same growth interval, among both boys and females. Typically, most of these variations in females happened within the developmental phase from 5 to 15 years, a timeframe that precedes those of males, who exhibited a more dispersed pattern of growth modifications across a span of 5 to 25.5 years. Indeed, several mandibular parameters exhibited notable variations in males. Specifically, there was a substantial augmentation observed in mandibular depth (Ar-Pog), as well as in mandibular relationship (SNB and SNPog). These findings are particularly intriguing, as they reveal a disparity of 2.1 degrees (equivalent to approximately 30% of the increment) in males and 1.6 degrees in females. Nevertheless, males exhibited a comparatively minor expansion in the maxilla, with a slight rise in maxillary depth (A-Ptm) and only 11% increase in SNA. The relationship between the maxilla and mandible diminished to about one third. The ratio of anterior to posterior face heights (S-Go/N-Me) indicated a decrease of 50% as a result of the more pronounced increase in posterior facial height compared to anterior height. There was a significant decrease in the convexity of the soft-tissue profile, except the tip of the nose. In contrast, females presented a meaningful reduction in maxillary depth and the ratio of anterior face heights (N-Ans'/N-Me) (Rajbhoj et al., 2023; Sridhar Premkumar, 2011).

Björk (Bjork, 1963) reported that there was a persistent increase in mandibular length (Ar-Pog) among individuals aged 20 and above. The controversy surrounding the impact of "early" orthognathic surgery on residual mandibular or/and maxillary growth, as well as its potential effects on orthodontic and surgical treatment outcomes, is heightened by the notable modifications observed in the relationship or/and size of certain facial parameters following the age of fifteen. Thus, it is imperative to undertake further research about the comprehensive alterations in facial dimensions and interconnections across various age groups (Sridhar Premkumar, 2011).

## 4.6 Maturation of Orofacial Functions and their Influence on Craniofacial Growth

Physiologic orofacial functions, such as respiration, swallowing, mastication, and speaking, undergo a front to back maturation process. In neonates, the oral cavity serves as the sole means of contact with the external environment, wherein the lips exhibit maturity and engage in energetic activities. Remarkably, the sensory development within the oral cavity surpasses that of the immature posterior structures and other regions of the body. The mouth and throat work together as a coordinated system from early infancy to facilitate the development of orofacial functions (Sridhar Premkumar, 2011).

### 4.6.1 The Importance of Masticatory Muscles Function in Dentofacial Growth

According to Moss's functional matrix theory, the muscles of the face have a crucial part in the process of bone development. The cells involved in bone formation are influenced by the surrounding muscle environment, which determines their morphology, orientation, and spatial relationship. Also, additional tissues, known as embryonic functional matrices, play a role in guiding the differentiation process at specific times and locations.

Hypothetically, it can be argued that the occurrence of muscle dysfunction and reduced activity would have an impact on the growth of the craniofacial region and the local development surrounding insertion sites and muscle attachment. Consequently, the etiology and treatment of jaw deformities and malocclusions can primarily be attributed to the significant involvement of facial muscles in preserving the stability of dental treatment. Sutural growth is a crucial factor in determining the changes in craniofacial dimensions in response to changes in masticatory function during postnatal bone growth. In general, tension promotes sutural growth while compression retards it. The growth of sutural strains is significantly influenced by the orientation and attachment of the muscles, as well as the positioning of the masticatory muscles in respect to the rest of the teeth and the skull. In addition, modifying the diet's consistency in experimental animals leads to variations in masticatory behavior, and activity and biting force level. Consequently, these changes have an impact on the diameter and composition of the fiber types in the masticatory muscles of the animal. Nevertheless, the modifications in masticatory function do not elicit comparable alterations in humans as they do in animals due to the presence of distinct masticatory systems. These conditions are believed to occur either because deciduous teeth are lost prematurely due to caries or because the masticatory muscles become less effective due to changes in the diet, which reduces the pressures applied to the jaws (Kiliaridis, 2006; Tsai et al., 2010).

An alternative approach to examining the correlation between facial morphology and masticatory muscle function was assessing the capability of the participants' masticatory apparatus in relation to their facial morphology.

All these studies generally agree that individuals with robust or substantial mandibular elevator muscles exhibit wider transverse head dimensions. It has been demonstrated in previous research that certain individuals in the present era have advanced levels of dental wear, characterized by robust masticatory muscles mostly attributed to bruxism.

The aforementioned individuals also have a propensity for parallelism in the alignment of jaw bases and between mandibular and occlusal lines. They also display a low occurrence of malocclusions, a relatively uniform short face, lower inter-maxillary angles, and reduced gonial angles (Figure 18). Wrestlers exhibit comparable phenotypes, characterized by heightened muscle activity, a more rectangular facial structure, and well-developed dental arches. On the other hand, individuals who have weak masticatory muscles exhibit significant variance in their facial structures.

The findings of this study suggest that a specific degree of masticatory muscle strength may be an adequate requirement for the effective growth of the craniofacial region. However, it is crucial to note that masticatory muscle strength is not an essential or prerequisite condition for this process (Kiliaridis, 2006; Tsai et al., 2010).

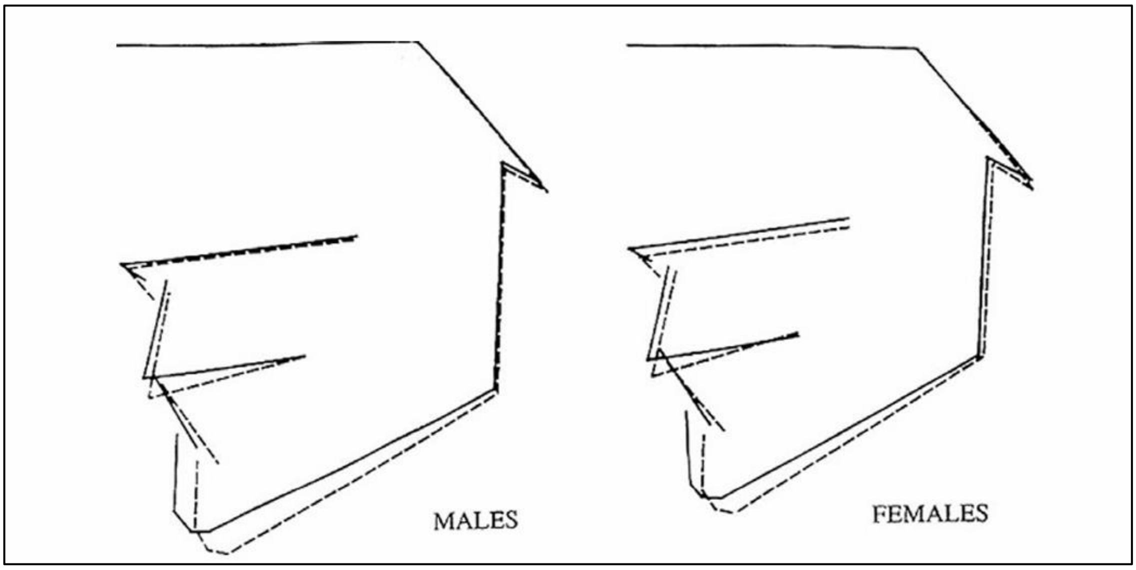



Figure 18: Male and female mean facial diagrams in an advanced dental wear sample compared to a mean cephalometric diagram representing healthy norms. Adapted from (Kiliaridis, 2006).

The chewing pattern shown by children differs from that of adults (Figure 19). The learning process of mastication in a child necessitates the exploration and acquisition of novel sensory motor patterns.

The child's chewing pattern becomes stable once the primary dentition is fully erupted (chewing only occurs after teeth eruption). In the maturation of mastication, the sensory aspect of tooth eruption is the most crucial factor. It is only when the mandibular and maxillary incisors establish contact that the jaw muscles start to learn the process of mastication. The typical chewing pattern observed in children involves the initial lateral movement of the jaw on opening, followed by the execution of the masticatory cycle. In an adult, the chewing pattern involves a sequential process: initially, the adult opens their mouth vertically, followed by lateral movement of the jaw, and finally, contacting their teeth. The transition to adult chewing pattern takes place when permanent canines emerge, often around the age of 12.

The masticatory envelope is formed by the synchronization of three distinct functional systems, specifically bone, teeth, and muscle. It is commonly characterized as a "tear-drop shaped" structure, exhibiting a minor displacement during the initial phase of opening. This suggests that the initial movement rarely exhibits a linear descent. Typically, it tends to deviate towards the chewing side.

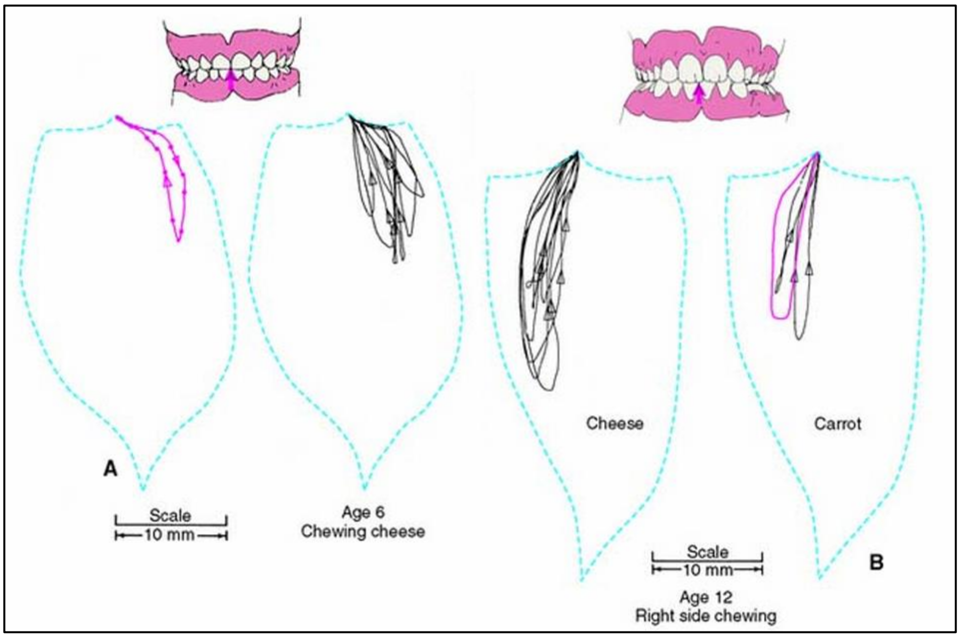



Figure 19: Comparison of chewing movement in adults and children. Adapted from (Yamashita et al., 1999)

In the figure (A), a child's mandible initially exhibits lateral movement on opening, followed by a reduction in lateral movement during closing. In the figure (B) , in an adult, the opening occurs in a vertical downward direction, followed by a lateral movement.

Experimental animal studies reveal that the observed variations in muscle fiber distribution during growth may be attributed to changes in the functional state of individuals during this period. These alterations have been partially explained by biting force recordings in growing individuals. Nevertheless, there is a lack of research on the motor function features of the masticatory system and the potential changes in these variables over the growing period in children.

According to the study done by Kiliaridis et al. (Kiliaridis et al., 1991), a group of 90 individuals with angle Class I occlusal relation and no apparent orthodontic issues was examined. Various age groups were analyzed in this study, including children aged 9-10 years (to investigate a pre-puberty group with late mixed dentition, wherein the second deciduous molars were still in occlusion alongside the first permanent molars, thus permitting adequate chewing capacity). Additionally, adolescents aged 13 to 15 years and adults were included in the analysis to ascertain whether alterations in oral masticatory function (indicated by mandibular displacement and velocity) occurred during typical development and growth. To reduce the variability across individuals, efforts were made to standardize aspects like volume of the bolus, adhesiveness, food hardness and occlusion. It has been demonstrated that these factors affect the chewing pattern.

No notable disparity was detected in the duration of the masticatory cycle, or the frequency of chewing, between young and older persons with dentition. This suggests that the fundamental rhythmic pattern is formed at an early stage of development and remains “constant” throughout one's lifetime, as long as no other factors, such as prosthesis rehabilitation, muscle or central nervous system weariness, impact the process of chewing. Nevertheless, the decline in both peripheral and central mechanisms in senior adults (with an average age of 80 years) compared to younger individuals who are not growing may explain the correlation between aging and a decrease in velocity. In contrast, Vignon et al. (Van Der Heijden et al., 2008) have documented that elevator muscles in adults show a higher prevalence of type H fibers, primarily fast-twitch fibers, in comparison to those observed in children aged 10-13 years. Consequently, the variations in masticatory cycle velocities may be attributed to disparities in muscle fiber types. The disparities observed in motor characteristics may be attributed to variations in craniofacial morphology among different age groups within the population.

In older people, there appears to be a tendency towards a decrease in mandibular vertical displacement. Research findings indicate that there is a higher frequency of vertical mandibular displacement among younger individuals (mean age, 28 years) compared to older persons (mean age, 80 years).

Nevertheless, the etiology may be influenced by multiple factors and could be attributed to anatomical variations in facial structure between children and adults, rather than changes in the mode of mastication. However, it is challenging to make any deductions from the results that have previously been reported. The observed changes can be attributed to either functional adaptations resulting from changes in dentition and skeletal growth, or to the physiological development of the masticatory system due to peripheral and central modifications. Further researches are required in this field due to the absence of longitudinal studies related to the function and development of the masticatory muscles (Kiliaridis, 2006; Sridhar Premkumar, 2011).

#### 4.6.1.1 The Effect of the Masticatory Hypofunction on the Craniofacial Growth and Development

There exist a limited number of experiments in the literature that study the impacts of masticatory hypofunction. It was revealed that the masticatory hypofunction didn't have a statistically significant impact on cranial development and growth, nor on cranial bone weight. However, it did have an impact on the development and growth of the maxillofacial skeleton.

Experiments showed that the mandibular bone weight, the thickness of the mandibular corpus (the appositional development of gonial angle), ramus mandibular height, maxillary width and premaxillary length were all reduced in soft diet experimental group in comparison with the control group; except for the foramen incisivum which increased in width. Despite the initial appearance of a contradictory result, it is reasonable to assume that in the group with normal masticatory function, the foramen incisivum has become narrower due to the continuous appositions surrounding it. Conversely, in the hypofunction group, reduced bone apposition resulting from decreased functional stimuli led to a larger foramen incisivum. A study by Engstorm et al (Varrela, 2006) was conducted on rats, which were fed a soft diet, showed that masticatory hypofunction alters and decreases the overall apposition pattern (specifically in cortical bone and sutures).

In line with the discoveries of Kiliaridis et al., Ulgen et al. (Karamani et al., 2022) reported that a soft diet can cause notable changes in the vertical direction and that the hypofunction group's total skull length and total anterior face height were considerably lower than those of the control group. A different study (Tsai et al., 2010) examined the impact of masticatory muscles after receiving local injections of Botulinum Neurotoxin (BoNT/A). This substance was used to temporarily inhibit nerve endings without disrupting the normal development and growth of the animals in the study.

Injecting BoNT/A causes a reversible paralysis of the temporalis and masseter muscles, leading to alterations in the morphology of the craniofacial bone at the areas where these muscles are attached. As a result of the relaxation of their jaws, the examined animals in this study had a long ramus height and mandibular length (which is indicative of a dolichofacial pattern). Additionally, open-bite or clockwise-rotation of the mandible was seen. Consequently, the measurement of the anterior face height showed an increase. The insertion locations of the temporalis muscles are commonly known to be located at the medial surface and the rostral border of the coronoid process. This suggests that a gain in upper anterior facial height is mostly impacted by the temporalis muscles. And regarding the insertion of the superficial masseter muscles into the lateral surface and the lower borders of the mandible, the injection of BoNT/A on these muscles resulted in the most pronounced bicoronoidal and bigonial widths, lower and total anterior facial height. These results validate site-specific effects on the face, both upper and lower, after injection of BoNT/A into the temporalis and masseter muscles (Karamani et al., 2022; Tsai et al., 2010).

#### 4.6.1.2 Masticatory Function and Malocclusion

An examination of malocclusion and masticatory function may seem to have a little impact on orthodontics at first. Nevertheless, the occurrence of malocclusions seems to have risen as modern human populations have been exposed to industrialized civilization and embraced a modern way of life, particularly a processed and high-calorie diet that has led to a significant decrease in the intensity and duration of mastication. Consequently, the occlusal abnormalities seen in modern man are caused by this inadequate development of the jaws. This aligns with the evidence that intense masticating required in a hard diet not only activates the muscles involved in mastication, but also influences various aspects of facial bone development, particularly the transversal growth of the mandible and maxilla (affecting bone dimensions and density). Masticatory activity seems to regulate both sutural and appositional bone development. Similar to how the genome functions, epigenetic factors can be used to turn on or off genomic processes. Developmental or phenotypic plasticity is the capacity of organisms to respond to external factors, helping them to adapt to their environment during their ontogeny, thereby improving their chances of survival. Malocclusions can be regarded as abnormalities or developmental disorders of the alignment of teeth that occur after birth due to external factors. These factors may disturb normal development or prevent the necessary stimuli for proper development. However, it is possible that genetic factors may also contribute to the observed variance in occlusion that we see today (Kiliaridis, 2006; Varrela, 2006).

### 4.6.2 Influence of the Respiratory Function on Craniofacial Growth

Respiration begins at the 25th week of intrauterine development. Neonates are biologically expected to breathe through their nose, and if their nasal airway is obstructed, their ability to survive is compromised. A child can't breathe through their mouth till later in life.

During respiration, the pharynx and the dorsal region of the mouth share the role of positional stabilization. The tongue, hyoid, and larynx are arranged in a column that is kept forward throughout postnatal life to preserve the patency of the airway in the pharynx and the laryngeal vestibule. The column is raised, with the tongue positioned close to the palate, enabling the airway to connect with the nose instead of the mouth. The soft palate is involved in this approximation, creating a separation between the throat and the mouth (Figure 20B). The vertical array of the mandible, hyoid, and pharynx lengthens after birth, causing changes in the structure of the anterior wall of the larynx. This is due to the tongue appearing between the palate and the epiglottis (Figure 20A). More than ever, we now understand the importance of regular nasal breathing and nocturnal respiration, particularly in young infants. According to the functional matrix theory, the growth of orofacial bones is influenced by the development of respiratory spaces and the maintenance of the airway space in the mouth and throat.

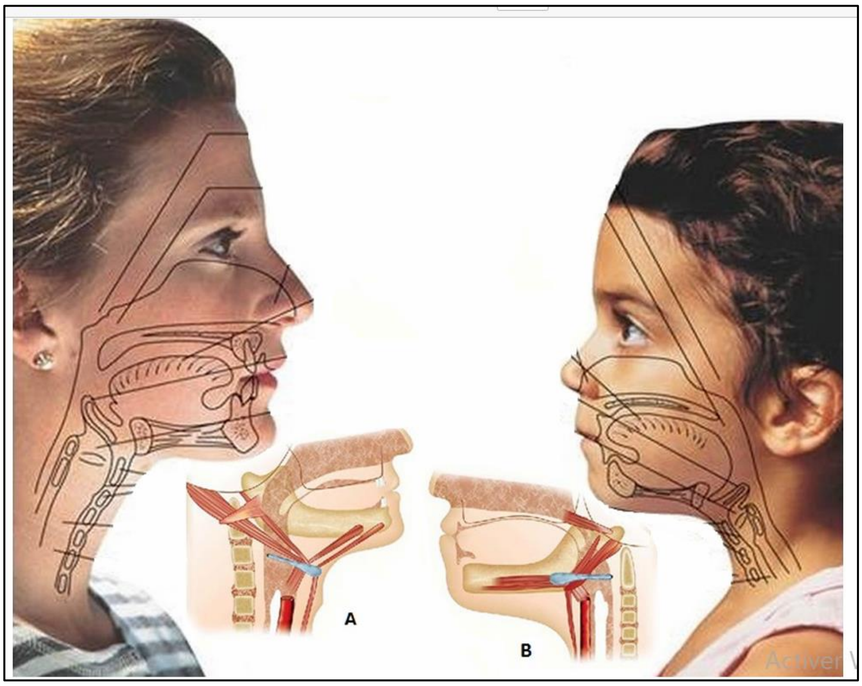



Figure 20: Pattern of the pharynx, mouth, and hyoid suspensory muscles' spatial orientation in an adult (A) and in an infant (B). Adapted from(Sridhar Premkumar, 2011).

Oral respiration in mouth-breathing individuals creates airflow through the mouth, which disrupts the normal airflow patterns and pressures in the nasal and oral cavities. This disruption impacts the proper development of these structures and obstructs the normal downward growth of the palate, resulting in the formation of a deep palatal vault. The classic clinical illustration of the potential correlation between airway obstruction and abnormal craniofacial development is the patient characterized as having "adenoid facies". Mouth-breathers are thought to position their tongues more downward and forward, which doesn't put enough buccal pressure on the maxilla to offset the forces from the lips and cheeks pressing inward.

These patients have been classically described as often short in stature for their age, with a long and narrow face and usually present a mouth open posture, small and poorly developed nostrils and a narrow nose, a narrow, V-shaped maxillary arch, a class II occlusal relationship, short upper lip, proclination upper incisors, a pouting lower lip and a vacant facial expression. On the other hand, patients with a condition of upper airway obstruction usually exhibit a vertical pattern of facial growth, even with a normal anteroposterior relation between the mandible and maxilla. The augmentation of anterior facial height and the subsequent posterior displacement of the maxillary complex result in a more retrognathic facial appearance (a retrusive anteroposterior skeletal relationship). Many other manifestations are inevitable as changes in the mandibular posture and the function of related muscles, a reason behind undesirable changes in facial growth. Patients can also suffer from otitis media, tonsillitis, experience hearing loss as well as a hypo nasal speech.

Some studies (Z. Zhao et al., 2021) examined the impact of removing the causal obstruction in children who had undergone adenoidectomies. The spectrum of dental and skeletal configurations correlated with upper airway obstruction underwent dramatic alterations, demonstrating a strong correlation between form and function, specifically between abnormal facial development and obstruction.

The following postoperative results can illustrate this relationship:

- A marked difference between the dentition and facial skeleton of the operated children (children who had switched postoperatively from oral to nasal breathing) and control ones.
- The greatest changes occurred in the dentition and in the sagittal depth of the nasopharynx during the first postoperative year.

- Spontaneous closure of the open bite and a normalization of the dimensions between the maxilla and the mandible and a lessening of the severe vertical growth pattern seen in initial radiographs.
- There's also a correlation between increased nasal resistance and an increase in the mandibular plane. In fact, the steep mandibular plane seen in mouth-breathing individuals undergoes a dramatic closure of the mandibular plane angle that can go down to 4 degrees in a very short period.
- Aside from the improvement in skeletal and dental relationships, hearing can be restored as well as the quality of speech can be improved.

Nonetheless, an analysis of the initial lateral radiograph of several mouth breathers with an average age of 7 years old showed that some patients had mandibular plane angle that fell within the normal range. The emphasis on the "adenoid facies" patient in the literature has been unfortunate in one sense, because it implies that all patients having these facial characteristics are mouth breathers and that all mouth breathers have these facial characteristics. This is not always the case.

In a subjective evaluation of 1,033 children, Humphrey and Leighton (Hani F. Ounsi, 2009) found that nearly half of those children who breathed with an open mouth did so nasally. Gwynne-Evans and Ballard (Tarkar et al., 2016) conducted a subjective evaluation of the correlation between breathing conditions and facial morphology for a duration of 15 years. According to their findings, orofacial morphology does not change during growing, regardless of breathing methods. In addition, they asserted that mouth breathing did not lead to malocclusions or jaw abnormalities, nor does it cause the development of the adenoidal facies.

Howard (Hani F. Ounsi, 2009) confirmed in his study of 500 patients that 59% of mouth breathers present a normal occlusion and only 14% have a class II malocclusion. The relationship between dentofacial morphology and nasorespiratory function is still unclear, despite numerous proposed theories. Clinical studies have shown that the craniofacial relationship associated with mouth breathing varies and can be observed in patients with different facial types (Sridhar Premkumar, 2011; Z. Zhao et al., 2021).

### 4.6.3 Swallowing or Deglutition

Infantile Swallow (Fig. 21, (1))

The main features of a physiological infantile swallow are:

- Jaws are apart with the tongue thrust and interposition between the gum pads or primary teeth.
- The interposed tongue and the contraction of facial expression muscles stabilize the mandible.
- The process of swallowing is directed and regulated by the sensory interchange between the tongue and lips

Mature Swallow

Infantile swallowing ends with the emergence of permanent incisors (7 to 8 years). Once the permanent incisors have fully emerged, the tongue is no longer positioned between the incisors or gum pads. Instead, it currently fills the gap between the toothless regions of the upper and lower gum pads. This leads to a more developed somatic swallow, as shown in Figure 21 (2). During a mature swallow, the lips do not contract. The teeth are held together, and the incisors briefly come into contact. The tongue tip is simultaneously retracted and placed behind the incisive foramen. Typically, children exhibit the fully developed swallowing pattern by the time they reach 7 to 8 years of age.

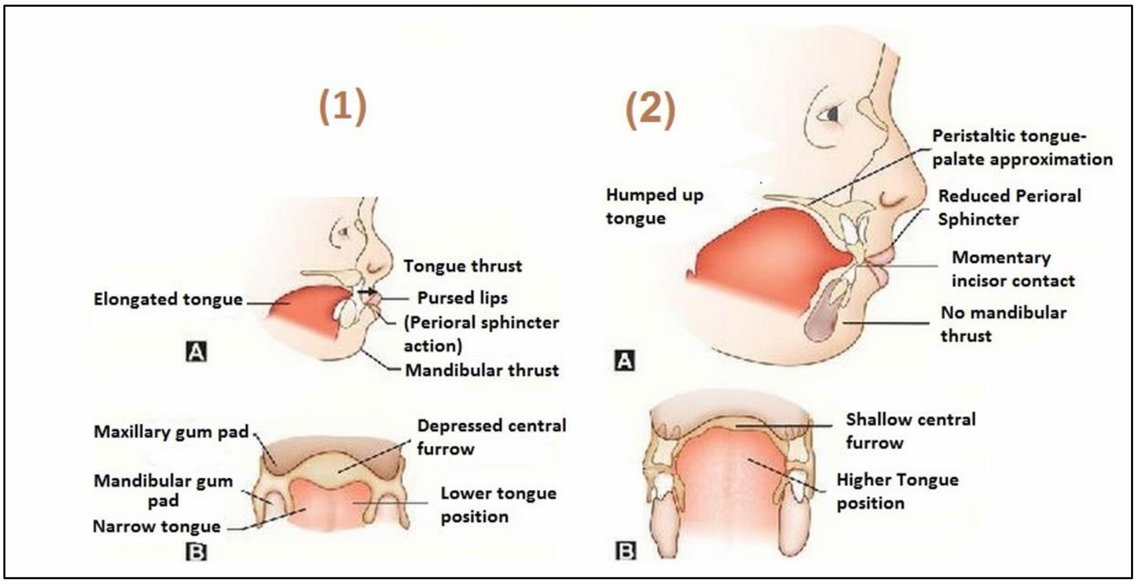



Figure 21: Immature swallowing mechanism (1) Vs Mature swallowing mechanism (2). Adapted from (Sridhar Premkumar, 2011).

Nursing often involves a plunger-like motion. Nursing cheek pads flow between posterior gum pads without resistance from tongue margins. The tongue-thrust is accompanied by the forward posture of the lower jaw. The condyle can be palpated moving smoothly and regularly in a forward and backward motion during the nursing process.

During deglutition, the dorsum is less concave and fits closer to the palate. The anterior part of the tongue is positioned behind the incisors, whereas the outside parts of the tongue move between the opposing posterior segments. The anterior mandibular thrust is no longer present.

## 5 Development of Human Dentition, Supporting Structures and Occlusion

### 5.1 Development of Occlusion

Occlusion undergoes continuous changes throughout the process of growth, maturation, and aging, and is influenced by several factors such as genetics, environment, and muscular forces. Concepts of occlusion differs among different dental specialties (Sridhar Premkumar, 2011).

#### 5.1.1 Mouth of the Neonate/ Gum Pads/ Predental Stage (0-6 Months)

Gum pads refer to the alveolar arches present at birth. At first, they have a firm and smooth texture, but later become divided into segments that align with the locations where teeth are emerging. The fundamental structure of the arches is established during prenatal formation; however, additional factors like as genetic factors, the size of growing primary teeth, and birth weight all contribute to the size of gum pads.

The maxillary arch has a horseshoe configuration, with complete overlap of the maxillary gum pads in both the transverse and anteroposterior dimensions, which are wider than the gum pads of the mandible. The maxillary gum pads extend more in the labio-buccal direction compared to those of the mandible. They also extend in the lingual direction and are separated by the dental groove. The mandibular gum pads have a U shape and are anteriorly everted.

Every primary tooth has tooth buds that are present at birth, but at varying stages of development. At this stage, a line drawn along the occlusal surface crosses with the condyle (Figure 22). Virtual location of primary growing tooth buds is on the same occlusally orientated plane (Figure 23). The relationship between gum pads in the neonatal jaws is arbitrary because there is no clear jaw relationship or bite. Multiple authors have claimed that the relationship between lower and upper gum pads shows significant variability, and that the arrangement of these pads in newborns cannot serve as a criterion for diagnosing or predicting future occlusion of the primary teeth. The top lip seems shortened when the tongue is positioned between the lips (Sridhar Premkumar, 2011).

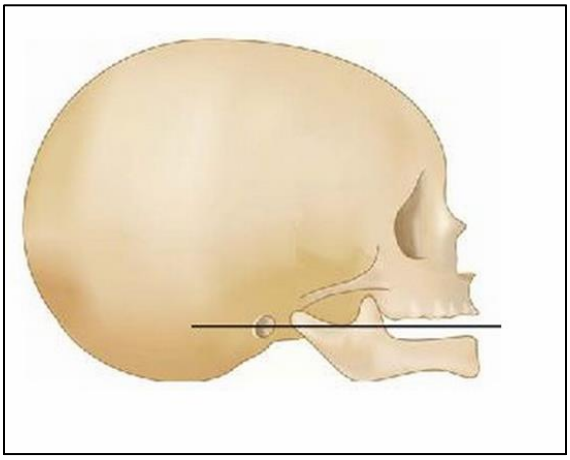


Figure 22: The occlusal plane passes through the underdeveloped condyle in an infant. Adapted from (Sridhar Premkumar, 2011).

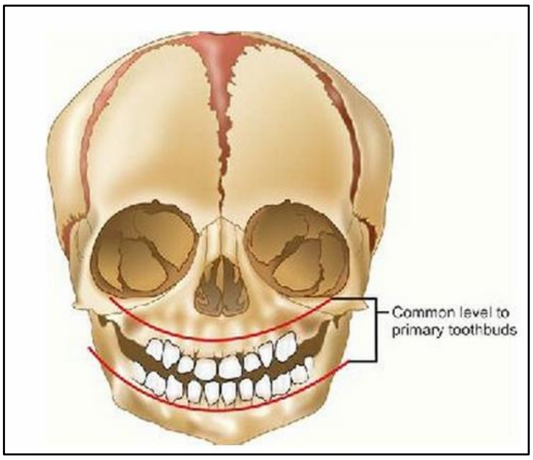



Figure 23: Tooth buds' position in an infant. Adapted from (Sridhar Premkumar, 2011).

### 5.1.2 Primary Dentition Stage (6 Months to 6 Years)

The stage of primary dentition may be analyzed using three categories:

#### 5.1.2.1 Development of the Primary Teeth

Infante (1974) demonstrated a strong correlation between the growth of teeth and the height, weight, and head circumference of individuals. Key characteristics of a primary tooth (Siécola et al., 2017):

- Generally, boys have larger primary teeth compared to girls.
- Primary teeth have a lower incidence of size and shape irregularities when compared to permanent teeth.
- Primary teeth have a higher probability of experiencing ankylosis than permanent teeth. A tooth that has become ankylosed is referred to as a "submerged tooth". Ankylosis becomes apparent throughout the later stages of primary and mixed dentition.

#### 5.1.2.2 Development of Primary Occlusion

Characteristics of deciduous dental occlusion and arches:

- The term "open dentition" or "spaced dentition" refers to the existence of gaps or spaces between the teeth. Having gaps between teeth is advantageous in children since it significantly reduces the possibility of overcrowding in their permanent dentition. Spacing can be categorized into two distinct types: physiologic spacing and primate spaces. The anteroposterior growth of the jaws is responsible for the presence of developmental gaps in the primary dentition, measuring 4 mm in the maxillary arch and 3 mm in the mandibular arch. Primate Spaces, also known as Simian space or Anthropoid space, are located in the maxillary arch between the deciduous lateral incisor and canine. In the mandibular arch, they are utilized during the early mesial shift and are found between the primary first molar and primary canine.

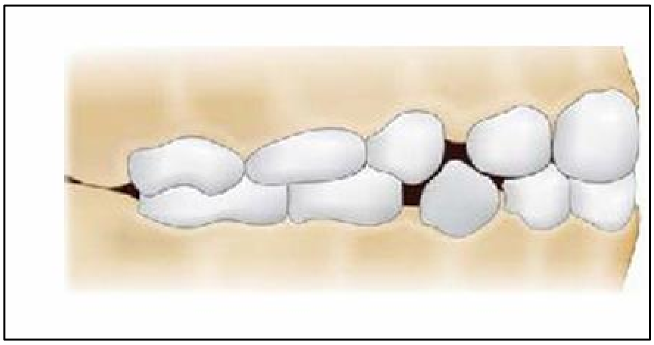
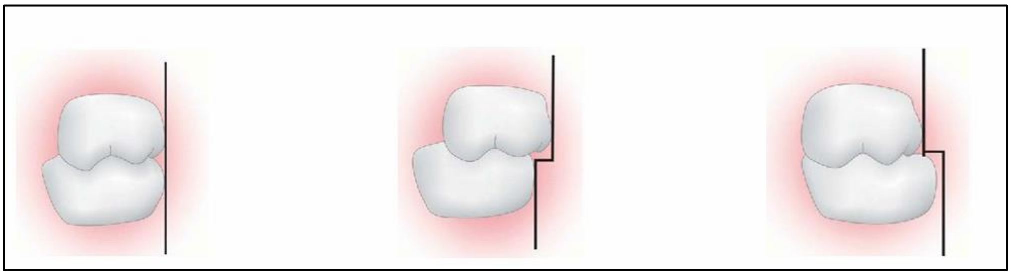


Figure 24: Primate space seen in maxillary and mandibular arch. Adapted from (Sridhar Premkumar, 2011).

- The presence of a deep bite in primary incisors is likely caused by their vertical inclination. As the primary molars emerge and the rapid attrition of incisors, the deep overbite gradually decreases. By the age of six, there could potentially be an edge-to-edge relationship;
- Initially, there is an increase in overjet during the primary dentition stage, which then diminishes as the entire dental arch moves forward anteriorly. This drop is typically around 1 to 2 millimeters;
- Vertical or straight inclination of incisors; Absence of crowding and flat curve of spee; Shallow intercuspal contact;

- Baume classified the relationship between primary teeth into three groups (Figure 25A to C) based on a line drawn along the distal surface of the mandibular and maxillary second primary molars, which determines the "terminal plane relationships" (Sridhar Premkumar, 2011) :



(A) Flush terminal plane (76%) (B) Mesial step relation (14%) (C) Distal step relation (10%)

Figure 25: Baume's classification of primary teeth. Adapted from (Sridhar Premkumar, 2011)

- Neuromuscular considerations: Once the incisors have emerged, the muscles adapt to perform the required functional movements of the teeth when more teeth emerge. The functional matrix of the muscles actively directs the teeth into their occlusal position during the formation of the face skeleton. Once the main teeth have fully erupted, the occlusal plane is positioned beneath the condyle (Figure 26)(Sridhar Premkumar, 2011).

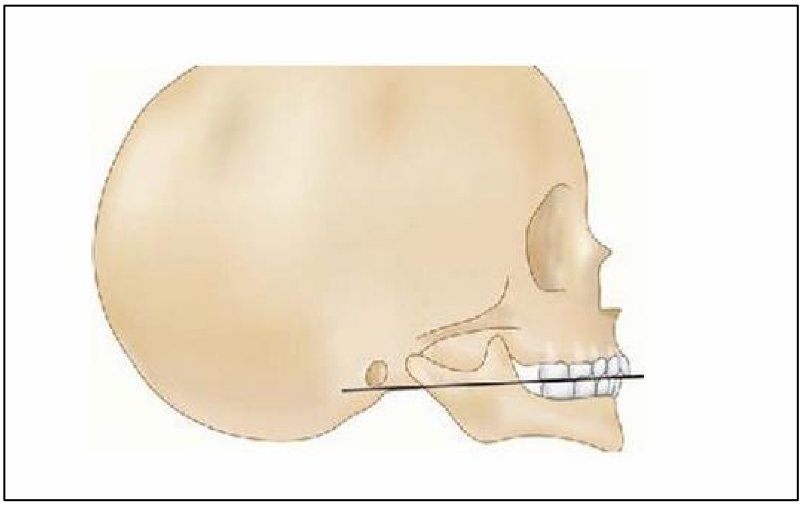


Figure 26: In a child with entire primary teeth, the occlusal plane is located below the condyle. Adapted from (Sridhar Premkumar, 2011)

### 5.1.3 Mixed Dentition Stage: The Transitional Years (6-12 Years of Age)

During the early stages of transitioning from primary dentition to permanent dentition, most children undergo the eruption of permanent mandibular central incisors and the eruption of the four initial permanent molars. The term refers to the period in which both deciduous and permanent teeth coexist in the oral cavity (Sridhar Premkumar, 2011).

Normal occlusion characteristics in permanent dentition include:

- Overlap: In a characteristically occluding dentition, maxillary teeth are buccal or labial to mandibular teeth;
- The average overjet of 1 to 3 mm and the normal overbite in adult dentition is 2-3mm (30% or third the clinical crown);
- Occlusion: Except for the maxillary third molars and the mandibular central incisors, each permanent tooth comes into contact with two other teeth;
- Dimensional changes in the dental arch during growth: It is essential for the basal and alveolar arches to be in proportion, and there is a strong relationship between the vertical growth of the alveolar process and the increase in width of the maxillary arch; this occurs because of the divergence of the maxillary alveolar process during vertical growth. In contrast to the mandibular process, which grows in a parallel direction. The expansion of the arch width is also influenced by the growth and eruption of teeth. The mandibular intercanine width reaches its full development at 10 years of age in boys and 9 years of age in girls. This development is finished by 12 years of age in girls and 18 years of age in boys in the maxilla. According to certain writers (Siécola et al., 2017), The growth delay in the width of the maxillary intercanine arch serves as a protective mechanism for the rapid growth of the mandible during puberty. The circumference of the mandibular arch decreases considerably with age in comparison to the maxilla for many reasons (Sridhar Premkumar, 2011);
- The first permanent molars undergo a mesial shift to compensate for the leeway space;
- Lingual positioning of the mandibular incisors;
- A lifelong tendency for mesial migration of the posterior teeth;
- Tipped position of molars and incisors. The reduction in arch circumference is contributed by distally tipped incisors and mesially tipped molars;

- Interproximal wear of the teeth;
- Third molar function is still up for debate and discussion.

The circumference of the maxillary arch, on the other hand, expands due to the labial inclination of the permanent maxillary incisors compared to the primary incisors (Sridhar Premkumar, 2011) (Figure 27).

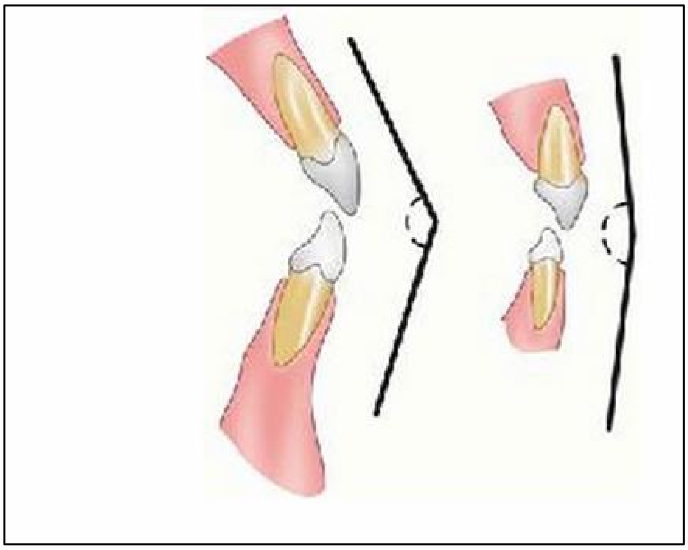


Figure 27: Comparison of the labial angulation of primary and permanent incisors. Adapted from (Sridhar Premkumar, 2011).

## 5.2 Occlusal Forces in Normal Children and Adults

When comparing adults with a vertical dysplasia of the long-face type and adults with normal vertical dentofacial proportions, Profitt et al. (Knigge et al., 2021) Indicated that persons with long faces exhibit a notably reduced occlusal force while engaging in simulated chewing. Still, they noticed comparable occlusal forces in kids with normal and long faces. The results presented in Figure 28 provide a graphical representation of the occlusal forces during simulated chewing, maximum biting force (MBF) and swallowing for both normal and long-face children. It is evident from the graph that both groups of children had values approximately half of those observed in normal adults. Adults with long faces have forces that are similar to those encountered by both normal and long-faced children.

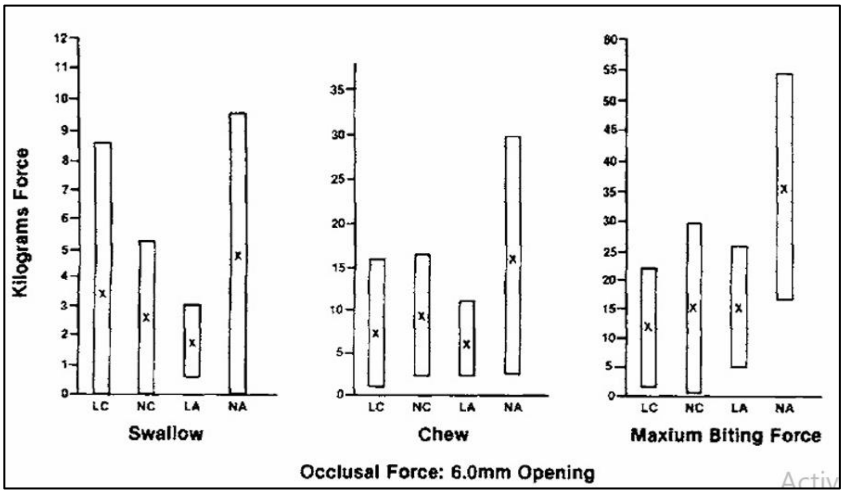



Figure 28: Comparison of occlusal forces in long-face and normal adults and children at 6-mm jaw separation. Adapted from (Upadhyay et al., 2012).

NC=normal child; LC=long-face child; LA=long-face adult; NA=normal adult. Values for normal adults are significantly different from those for the other groups ($p < 0.01$)

While not all persons who will develop a long-face as adults exhibit this facial pattern before reaching puberty, children who do have this pattern almost never outgrow it. Indeed, when comparing patients with long-face morphology to persons with flat mandibular plane and a square gonial angle, it is shown that the same amount of muscle contraction would result in less force applied on the molars in long-face adults. This observation can be attributed to the fact that when the mandibular plane angle is steep and the gonial angle is obtuse, the elevator muscles have a mechanical disadvantage. However, the reduced occlusal forces that are shown in adults with long faces do not appear to be present in children with long faces, despite both groups having the same mechanical disadvantage. This suggests that the mechanical disadvantage alone is not a sufficient explanation for the long-face pattern. Thus, it is further validated that when children with long faces have a mechanical disadvantage, they almost completely surpass it.

For children with short faces, there is insufficient data, but it is also possible that the facial pattern can be identified before differences in occlusal forces manifest. The duration and amplitude of occlusal force possibly have a crucial role in the relationship between occlusal forces that counteract tooth eruption. However, the relationship between occlusal forces and dentofacial growth is still unclear, and prospective research should be done to learn more about this subject (Knigge et al., 2021).

## 6 Growth of Soft Tissues

Subtelny, Burstone, and Björk were the leaders in the field of soft tissue growth and behavior researches (Sridhar Premkumar, 2011).

In 1944, Tweed gave particular attention to esthetics and asserted that "a thorough concept of the normal growth pattern of the child's face or any face is as important to orthodontists". Prior to that moment, it is crucial to acknowledge that the majority of the investigations focused on skeletal analysis. The configuration of the soft tissue profile was considered to be principally associated with the underlying skeletal configuration. Subtelny and Burstone argued that there may not be a strong correlation between the underlying skeletal pattern and the soft tissue profile. The reason behind this is the wide variation in the thickness of the soft tissue that covers the skeletal face, and not all parts of the soft tissue profile align directly with the underlying skeletal structures (Sharma et al., 2014). Ferrario (Schmitz et al., 2011) also noted that changes in face morphology due to aging affect both the size and form. An appropriate assessment should differentiate between size variations and shape adjustments, as they can interact with each other and perhaps obscure each other's effects. While both sexes experience variations in shape, men tend to exhibit more noticeable alterations in size compared to women.

### 6.1 Soft Tissue Changes due to Growth

Orthodontic therapy has traditionally aimed to achieve both functional occlusion and harmonious facial esthetics. For orthodontists, a comprehensive grasp of the science of occlusion is crucial, as is a deep understanding of the typical growth pattern of the child's face, or any face for that matter (Abdullah et al., 2006).

#### 6.1.1 Nose

Measurements of both female and male patients consistently indicate a period of increased development and growth. However, girls tend to exhibit more advanced progress despite being generally smaller in size compared to boys. The nose undergoes continuous morphological changes, with males exhibiting an observable rise in nasal size until reaching adulthood. The nasal volume in males at 9 years of age was slightly over half the size of an adult's nasal volume. The highest increase in nasal volume occurred between the ages of 13 and 14. In girls of the same age, the nasal volume was 60% of an adult's size, with the largest increase occurring between 9 and 10 years of age. Men exhibit a higher nose projection compared to women, as men continue to experience growth even after females have ceased growing. Boys experienced the greatest increases in the anterior growth of the nasal tip and in lower nasal width. This is most likely related to the increasing breathing demands during the development and use of the muscles, which is a crucial aspect of the teenage growth spurt.

The main cause of profile modifications in late adolescence and adulthood is the fluctuation in the depth of the nose. Subtelny determined that the nose tip grows by around 1 mm every year between the ages of 9 and 15.

A morphologic feature of particular interest in orthodontic diagnostic procedures and treatment planning is the increasing prominence of the nose in the midline soft-tissue profile of the face in boys during and after orthodontic treatment. Furthermore, the late growth changes that occur in the nose may have an impact on the midline profile after orthodontic treatment (Hallgrimsson et al., 2015; Sridhar Premkumar, 2011; Van Der Heijden et al., 2008)

The nasolabial angle, which is initially larger in females than in boys, declines more in females than in boys as they age, then, by 16 years of age, noses in girls become considerably narrower when the two widths are compared with the relevant nasal heights. These slight increases suggest that the nose has become longer due to vertical expansion (Hallgrimsson et al., 2015). The growth in width is approximately 0.5 mm per year. Nose length increases about 1 to 1.5 mm per year and while the nose almost ceased to grow in girls, it continues to growth in males even after 17 years of age, also contributes majorly to the increase in overall facial length. Male nasal height reached adult value at 18 years, while females at 15 years.

Obviously, nose size increases horizontally and vertically, but the anteroposterior dimension distinguishes gender (Sridhar Premkumar, 2011).

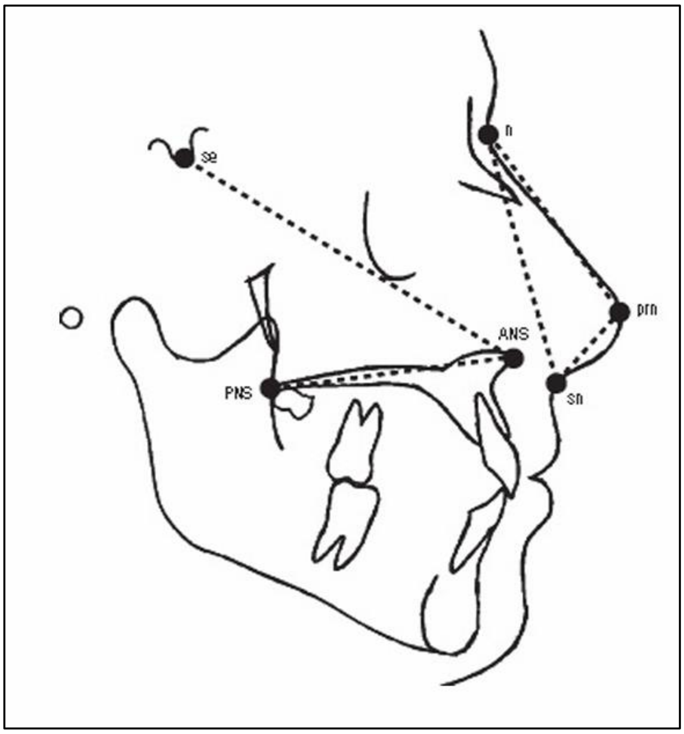



Figure 29: The five measures relevant in observing nasal growth. Adapted from (Van Der Heijden et al., 2008).

From this last figure, we can deduce some measures to know: (A) nasal bridge length from nasion (n) to pronasal (prn); (B) nasal protrusion from subnasal (sn) to prn; (C) nasal height from n to sn; (D) palatal length from anterior nasal spine (ANS) to posterior nasal spine (PNS); and (F) midfacial protrusion from sella (se) to ANS.

### 6.1.2 Lips

The thickness of soft tissue varies markedly throughout the body; it is highly adherent to cartilaginous structures (nose and ear) and thick in other areas (lips). In addition to the fact that facial soft tissue does not expand uniformly, its growth is highly autonomous and does not correspond to the development of the underlying hard tissue. Instead, it is the growth of the hard tissue that is dependent on the growth of the soft tissue (Sridhar Premkumar, 2011).

Ferrario et al. (Ferrario et al., 2003; FERRARIO et al., 2000; Rostovtseva et al., 2021) employed a three-Dimensional Facial Morphometry (3DFM), a noninvasive landmark-based method in three dimensions, to solve the limitations of cephalograms analysis. Their objective was to establish reference data for specific lip dimensions (such as vermilion area, ratios and linear distances, and volume) in a larger sample of healthy individuals from the age of 6 years old to young adulthood.

Typically, the growth patterns of the various measurements exhibit sex-specific features. Usually, girls have earlier, and more rapid growth compared to boys, reaching adult size around 2 to 5 years earlier. Indeed, the achievement of the appropriate adult value was reported to be 95% in girls between the ages of 13 and 14, with faster growth observed in the upper lip. However, in boys, the upper lip areas, linear distances, and volumes were significantly larger than those of girls, with some exceptions at the ages of 6 to 8. Boys reached the adult values only by the ages of 15 to 18. Despite the fact that the value of certain dimensions nearly came to double (such as total lip volume, which went from 3 to 6 cm in boys and from 2±7 to 4±5 cm in girls, as well as vermilion area and lower lip volume), other dimensions only saw an increase of one third (such as total vermilion area and upper lip volume), and the remaining dimensions only saw an increase of one fifth (such as upper vermilion area, mouth width, total vermilion height, and total and upper lip heights)(FERRARIO et al., 2000).

### 6.1.3 Chin

The thickness of the soft tissue chin can be evaluated by measuring the distance between the pogonion and the pogonion of the soft tissue (Pg-Pg'). In contrast to other soft tissue structures, the prominence of the soft tissue chin is determined by the underlying skeletal chin. The chin is a crucial component of the facial profile, contributing to its straightening and exhibiting a growth rate of 0.2 to 0.7 mm per year. The value indicates a little disparity favoring males, thus making it more pronounced in males compared to females and having a bigger impact on the facial profile of males than girls. Singh (Dimaggio et al., 2007) found that the thickness of soft tissue in the chin changes depending on the individual's facial type. Dolichofacial patients see a greater increase in soft tissue thickness after therapy compared to brachyfacial individuals. Nevertheless, there was no modification in the thickness of the chin among female over a period of 15 years (Sridhar Premkumar, 2011).

### 6.1.4 Tongue

At birth, the mandible is undersized, and it seems like there is insufficient space in the mouth to accommodate the tongue. The latter is so large that the infant is frequently observed protruding it from its mouth. As the tongue grows, it balances the muscle pressure from inside and promotes the development of the jaws, leading to an increase in the volume inside the mouth. Eventually, the tongue begins to retract into the oral cavity (Sridhar Premkumar, 2011).

### 6.1.5 Early and Late Profile Changes

Several research have evaluated the relationships between soft tissues in order to determine standard values and achieve treatment objective (Poosti et al., 2012). Bishara et al. (Rajbhoj et al., 2023) conducted a longitudinal study using a sample of individuals aged 5 to 45 years to determine the changes in profiles that occur as a consequence of growth and treatment. The soft-tissue profiles showed age-related modifications, with comparable changes observed in both males and females. Nevertheless, there were no statistically significant disparities observed between the sexes at any of the time points (5, 10, 15, 25, 45 years) (Halazonetis, 2007).

Esthetic evaluation in children is typically more challenging than in adults due to the impact of skeletal growth on the development of the soft-tissue profile. However, facial esthetics becomes a significant concern as early as 6 years old. Children between the ages of 6 and 7 are in a distinct stage of face development. The loss of deciduous teeth starts, while permanent incisors and molars emerge, potentially resulting in noticeable changes to their visual aspect.

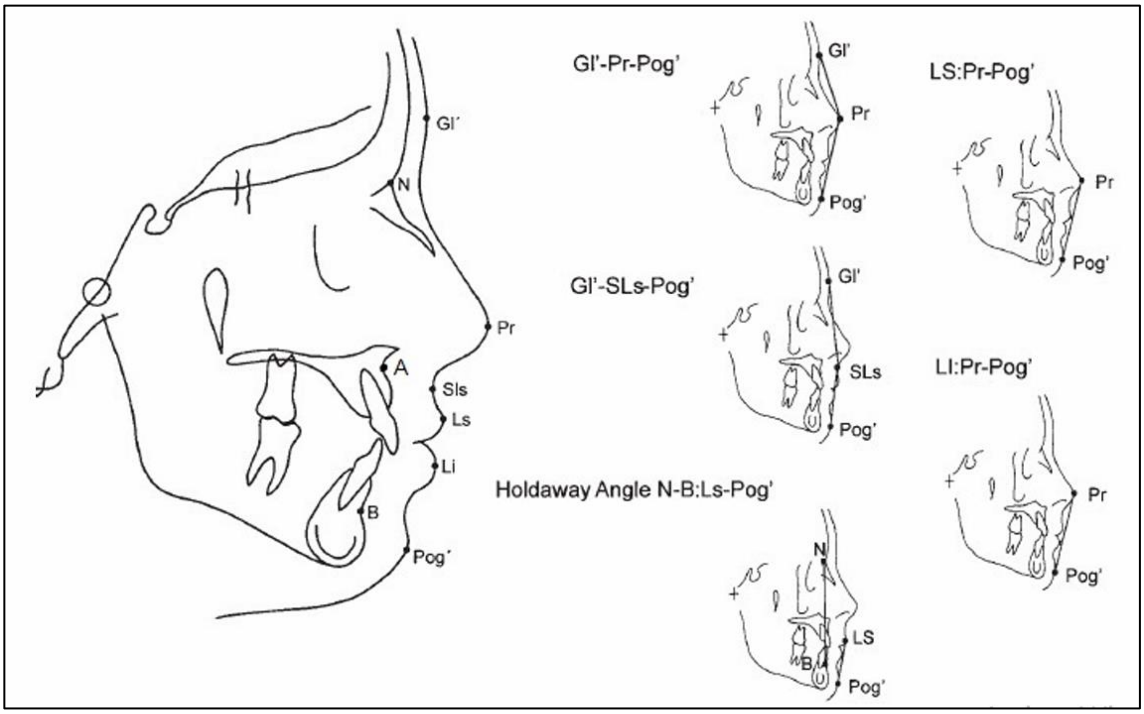



Figure 30: Landmarks and measurements. Adapted from (Samir E. Bishara, 1998).

From this last figure, we can deduce some landmarks and measurements to know: A point (A), B point (B), nasion (N), soft tissue gladbella (G1'), soft tissue pogonion (Pog'), superior labial sulcus (SLs), labrale superious (Ls) labrale inferius (Li), pronasale (Pr). Angle of facial convexity excluding the nose (Gl'-SLs-Pog'), Angle of total facial convexity including the nose (Gl'-Pr-Pog'), Holdaway's soft tissue angle (Ls-Pog':NB), Lower lip to Ricketts esthetic line in mms (Li:Pr-Pog'), Upper lip to Ricketts esthetic line in mm (Ls:Pr-Pog').

#### 6.1.5.1 Changes in the Soft Tissue Profile with Age

Children who have dental Class I exhibit stable soft-tissue face dimensions in relation to their hard-tissue counterparts (Siécola et al., 2017). However, Behrents suggested that after the age of 25, small number of parameters continue to change and declared that individuals in their twenties experience vertical growth instead of maintaining the growth pattern observed in earlier years(Sharma et al., 2014). Orthodontists selected five regularly used measurements to assess changes in the soft tissue profile during diagnosis and treatment planning (Samir E. Bishara, 1998) (Figure 30):

- Face convexity: Within the age range of 5 to 45 years, there is an average minor shift in the angle of soft tissue convexity that does not include the nose. The mean difference was 1.2° in boys and -0.5° in females, indicating a level of consistency in this angle, as previously seen in longitudinal studies that demonstrated a relative stability in face convexity after the age of 6.
- Total face convexity: Behrents (Samir E. Bishara, 1998) noted that the nose tip moved more vertically forward and downward than the upper lip, subnasale, or point A combined. The nose seemed more prominent in comparison to the rest of the soft tissue profile during growing because of this differential movement. The primary cause for the increase in total face convexity from age five years to early adulthood in both male and female individuals is the greater growth of nasal prominence. During the later stages of adulthood, there was a noticeable increase of 2.6° and 2.8° in the angle of the nose in females and males, respectively. This suggests that there was either a more vertical growth of the tip of the nose or a greater forward movement of the soft tissue pogonion. Facial convexity decreased on average over the age range of 25 to 45 years (Samir E. Bishara, 1998).

By the age of 6 to 7 years, females have nearly reached their adult nasal prominence (Sn-N-Pn) values, whereas boys have only achieved roughly 86% of their adult values. Based on the research conducted by Romana et al (Dimaggio et al., 2007), the measurement of nasal protrusion (Pn-Sn) has reached 86% of its adult size in girls and 82% in boys. The remaining growth primarily concerns nasal length (N-Pn), which accounts for 67% in girls and 64% in boys.

- Holdaway's soft tissue angle: is a profile line that is used to assess the face. It starts from the chin, goes through the top lip, and intersects the nose about ten mm behind its tip. Research has shown that this angle is a measurement that varies with age and steadily decreases from 5 to 45 years old (Sridhar Premkumar, 2011).
- Position of the lower and upper lips in relation to the esthetic line: while boys and girls showed a consistent more protrusive upper lip relationship from ages 5 to 15 years, the adult values in the study by Bishara et al. (Samir E. Bishara, 1998) were much in line with those provided by Ricketts (Rajbhoj et al., 2023) who suggests that the upper lip should ideally be slightly more retruded in males and 4.0 mm posterior to this line in adult females. After the age of 25, the upper lip undergoes a downward movement, rather than moving forward, which contributes to the vertical expansion of the face. This phenomenon is also observed in the nasal tip. The lower lip, like the upper lip, becomes increasingly less prominent in respect to the esthetic line from the ages of 15 to 25 in both males and girls. Similar patterns persisted from ages 25 to 45 (Samir E. Bishara, 1998). It is important to mention that by the age of 7, the growth of the nose and lips is already 80% to 90% completed. Evaluating children in this range of ages can offer valuable insights for their orthodontic treatment (Siécola et al., 2017).

## 6.2 Growth and Aging of Facial Soft Tissues: 3D Mesh Diagram Methodology

Growth is a three-dimensional process and should be analyzed in all directions in order not to lose essential information and provide details of allometric proportionality (Ferrario et al., 1998). In dentistry, the mesh diagram analysis, along with its modern computerized applications, is commonly used to analyze two-dimensional data of the hard and soft tissues. This data is typically obtained from lateral cephalometric radiographs. However, a more recent version of the method has been applied to three-dimensional soft tissue data obtained from noninvasive infrared systems, utilizing both its qualitative illustration and its fast quantitative evaluation of a patient's facial status (Rostovtseva et al., 2021).

Ferrario et al. (Ferrario et al., 1998) used in their investigation, a non-invasive system for the spatial digitalization of body landmarks for the quantitative analysis of development and growth of the face through volume changes. The sexual differences observed pertained to both facial size and shape. They suggested that this linear growth patterns in females could arbitrarily be divided into three periods: 6-11, 11-15, where the rate of linear growth decreased from the first growth period to the second, and 15 years to adulthood where practically no further growth was observed. While the growth velocity of the upper face height reduces at a relatively early age in girls, their total face height increases after puberty, which may be explained mostly by the development of their lower jaw and alveolar process. This is not the case for males' linear growth. As growth continues from 6 years to adulthood, it can't be as easily divided into the same periods as in females.

Ferrario et al have also conducted extensive research on the typical growth and development of facial soft tissues (Ferrario et al., 2003; Rostovtseva et al., 2021; Wen et al., 2015) in healthy individuals of different age groups and genders, specifically white males and females in childhood, adolescence, young adulthood, and middle age. They utilized a 3D computerized mesh diagram analysis called the Morphometry Method (3DFM) and established reference meshes based on age and gender (Figure 31). The mesh diagram method necessitates the overlay of the reference lattice onto the patient's lattice (Figure 32). In his research, Ferrario did superimpositions of male and female lattices within a specific age group, as well as child and adult lattices within a particular gender. By the utilization of the Mesh diagram, he conducted a comprehensive examination of facial soft tissues over a 40-year period. This timeframe covered late childhood, prepubertal and pubertal development spurts, adolescence, early maturity (patients ranging from 6 years old to young adulthood), and the initial stages of aging. individuals with entirely deciduous dentition to those with a fully permanent dentition were clearly included in the study's sample.

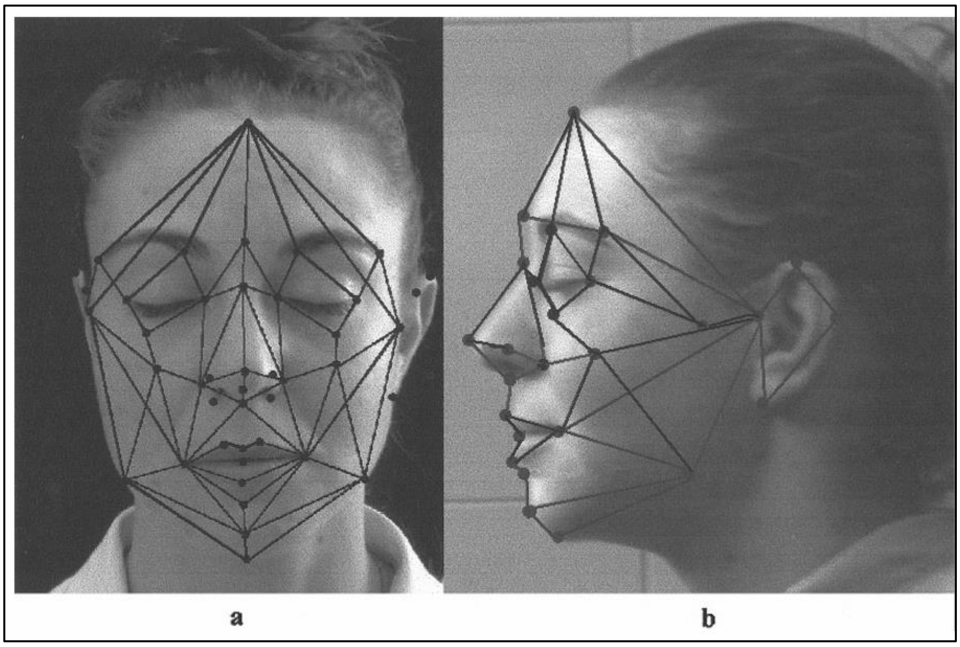



Figure 31: 3D grid superimposed on subject's face (a) frontal view; (b) lateral view. Adapted from (FERRARIO et al., 2000).

The analysis of children in contrast to young adults revealed that the most significant differences in children were observed in the soft tissue profile. The facial shape showed an increase in both the horizontal and antero-posterior dimensions, with notable variations observed in the chin, nose, and forehead. Compared to adults, girls and boys in the initial age groups (6 to 12 years) had less developed soft tissue facial profiles.

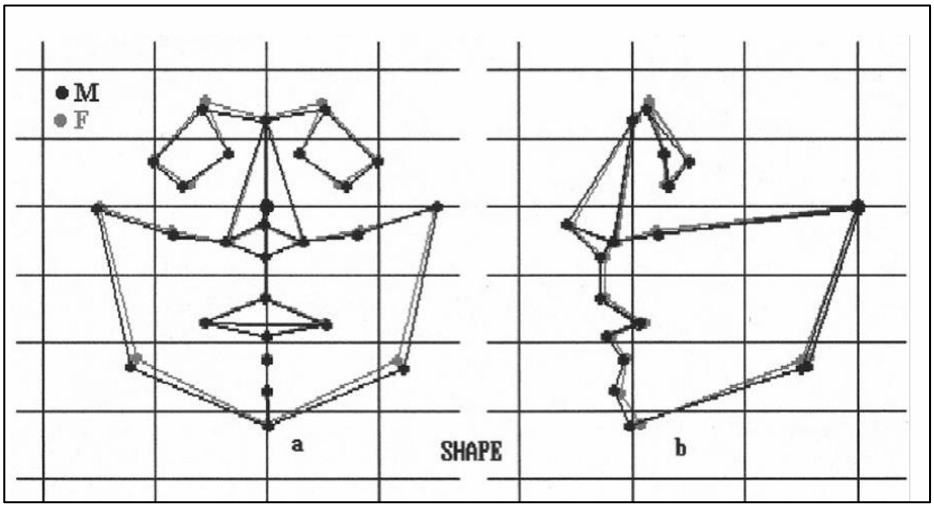



Figure 32: Three-dimensional mesh analysis; facial middle and lower thirds in female and male comparison: Frontal (a) and lateral (b) views of the size-normalized mean young adult female (gray lines) and male (black lines) faces, and female reference mesh. Adapted from (FERRARIO et al., 2000).

Young children have a relatively larger cranial base and central nervous system compared to their nasal and oral cavities (Figure 33). Like the soft-tissue facial profile, the dimensions of soft tissues in the face appear to reach adult proportions after the age of 11 in females who have gone through their growth spurt during adolescence (around 12 to 13 years old). This is accompanied by a noticeable increase in the vertical dimensions of the face and signifies the completion of soft tissue craniofacial growth in relation to young adults. On the other hand, males demonstrated continuous development and aging beyond the age of 30. Based on linear measures, men had a facial volume that is 1.2 times larger than women (FERRARIO et al., 2000). Male faces, on average, had a greater forehead size, a longer and more vertically oriented nose, more pronounced and posteriorly positioned gonia, less prominent lips, and a larger mouth compared to female faces of the same age (Rostovtseva et al., 2021). In 6-year-old children, the vertical dimension, namely the upper facial height, experienced the greatest and most significant rise compared to the adult reference. Between children and young adults of the same sex, the middle and lower facial profiles (subnasale, pronasale, pogonion, and upper and lower lip) varied mostly in their relative global (shape + size) positions, which saw a relative inferior and anterior expansion. Based on the analysis of the lifespan, it can be inferred that the soft tissue profile had a forward and downward expansion, which aligns with prior studies on anthropometry and cephalometry. It is important to note that separating the differences in size and shape allows for a beneficial assessment of the patient's facial characteristics, especially during childhood and adolescence when individuals may experience varying patterns of maturation timing (Ferrario et al., 2003; Rostovtseva et al., 2021).

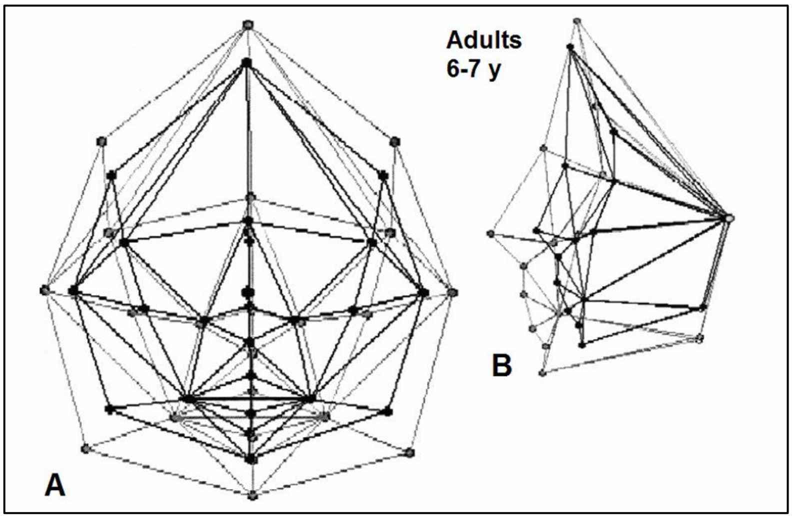



Figure 33: Three-dimensional mesh analysis,boys/men comparison, frontal (A) and lateral (B) views of the mean young adult male (gray circles) and 6- to 7-year-old child (black circles) faces (original size) superimposed. Adapted from (Rostovtseva et al., 2021).

## 7 Adolescence and Craniofacial Growth

Adolescence, also known as puberty, is the period of growth when the differences between males and females become more noticeable in various body systems, and the reproductive organs start to operate (DeGraaff V., 2001). Adolescence is the transitional phase of life characterized by significant physiological and psychological transformations that ultimately lead to adulthood (Sridhar Premkumar, 2011).

### 7.1 Facial Growth during Puberty

Jaw growth typically corresponds with changes in body height and puberty. During the pubertal development spurt, the cranial base experiences rapid expansion. The cephalocaudal growth gradient becomes significantly apparent throughout puberty. During the late phases of the pubertal growth spurt, there is a disparity in the growth of the maxilla and the mandible in the face. Specifically, the lower jaw experiences more growth compared to the upper jaw. It has been reported in the literature (Siécola et al., 2017) that a rise in facial growth occurs nine months ahead of the peak height velocity. Taking this into consideration, we can use the acceleration of body height growth to predict the beginning of adolescent growth spurt in the face. However, other studies (Dimaggio et al., 2007) argued that the maximum height velocity coincided with the maximum facial growth.

### 7.1.1 Growth of Cranial Base during Puberty

During puberty, there are also noticeable development increments in the cranial base. Typically, the maximal height velocity occurs before the growth spurt during puberty in the cranial base. Girls experience an earlier increase in cranial base length compared to males, but boys have a greater increase in cranial base length compared to girls. Hunter (Dimaggio et al., 2007) conducted the initial research on the adolescent development spurt in the cranial base. According to him, the Ba-S distance begins to accelerate around age 12.5, while the S-N length begins to expand between the ages of 8 and 15. Subsequently, it was observed that there was an increase in the rate of growth of the lengths Ba-N, Ba-S, S-N during puberty in boys (Sridhar Premkumar, 2011).

### 7.1.2 Growth of Maxilla during Puberty

During puberty, the maxilla grows slightly, mostly through remodeling and displacement. It was observed that the timing of the greatest increase in maxillary length did not differ significantly in terms of the quantity of growth before or after menarche, the start of epiphyseal-diaphyseal fusion, or the summit of height development. The duration and magnitude of growth were not determined by the maximum size of the maxilla at its peak growth (Sridhar Premkumar, 2011).

### 7.1.3 Pubertal Growth of the Mandible

The mandible develops in synchrony with the body height and the cephalocaudal gradient of growth. Björk (De Oliveira Ruellas et al., 2016) performed a study on the development of the condyles in individuals aged 7 to 21 years. The results showed a noticeable but not significant increase in mandibular growth throughout puberty. With a range of 12 to 15 years, the mean age at which the spurt occurred was 14 years. The Bolton growth investigations and Michigan growth studies revealed a progressive increase in the size of the mandible over time but didn’t show any major growth spike during puberty.

Further investigations have demonstrated that males exhibit much higher vertical growth rates compared to females, particularly in the upper half of the symphysis. Puberty exhibited higher rates of vertical growth compared to childhood. The majority of symphyseal markers moved lingually, as shown by the variations in horizontal growth. Male mandibular incisors remained horizontal during the development of the labial sulcus, but female mandibular incisors migrated lingually during puberty.

Planning a treatment after waiting for a mandibular growth spurt to occur was concluded from the studies mentioned earlier to be unwise. This is not to say that there aren't any such spurts; rather, we should be aware that they don't happen consistently or evenly. During adolescence, there is an important growth of the mandible that occurs over an extended period. But even though knowing who has the spurt and how long and how much of it lasts could be very helpful to doctors, we are still unable to pinpoint an exact moment for early or late treatment because there are a lot of other factors that determine when to start treatment (Sridhar Premkumar, 2011).

## 7.2 Craniofacial Growth and Skeletal Maturation

Arat et al. (Mirzen Arat, 2001) followed the development of 78 subjects (around 10 to almost 17 years of age) with normal facial patterns for a period of 4 to 7 years. No disparities were detected in the relationship between the jaws. During pubertal growth, the sagittal relationship between the jaws generally shown a tendency to remain steady. Figure 34 illustrates reference points, reference lines, and projectional measurements.

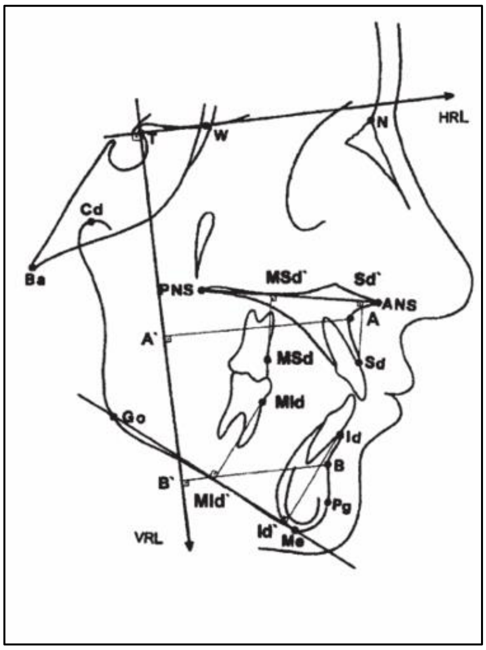



Figure 34: Anatomical reference points. Adapted from (Mirzen Arat, 2001).

Reference lines and projectional measurements employed in the research. Anatomical reference points: T, tuberculum sella; N, nasion; A, point A; W, the point where the sphenoid bone's ala major intersects the middle cranial fossa; PNS, posterior nasal spine; ANS, anterior nasal spine; Pg, pogonion; B, point B; Go, gonion; Me, menton.

Reference lines: ANS–PNS, maxillary plane; Go–Me, mandibular plane; HRL, Horizontal Reference Line (from T to W). Projection points: B', projection point of point-B to Vertical Reference Line; A' is the projection point of point-A to Vertical Reference Line. Projectional measurements: AA' and BB', used as alternatives to SNA, SNB.

The study participants were categorized into groups based on their skeletal maturity, rather than their chronological age. The study found that the length of the mid cranial base (T-W) stayed consistent over all stages of pubertal development. Previous research indicates that the mid-cranial base matures early, finishing at the age of ten. This discovery demonstrates that the T W line in cephalometric superimpositions is reliable. The posterior cranial base, on the other hand, showed considerable growth across the examined age range. Based on prior research, the growth of the posterior cranial base speeds up throughout puberty and is strongly linked to skeletal age. The study also demonstrated that both the mandibular and maxillary basal dimensions, specifically the Go-Pg and ANS-PNS measurements, increased across all three periods. Mandibular growth outpaced maxillary growth as the measurement of the mandibular basal arches (BB') increased between the ages of 15 and 17 (Love et al., 1990). It can be inferred that the growth of the mandibular base is directly related to skeletal maturity, although no such relationship was observed for the maxilla. The facial heights (N–Me, T–Go) saw significant expansion. This growth is influenced by skeletal maturation, somatic growth, respiratory function, mandibular remodeling, and alveolar development, all of which lead to the increase in anterior facial height. Despite the fact that growth begins early, the total posterior and anterior alveolar height increases significantly during puberty and, in subjects between the ages of 12 and nearly 15, was found to be highly correlated with growth potential. However, alveolar growth continued independently of skeletal maturation. This finding shows a flexibility of the alveolar area. This 'dentoalveolar compensatory mechanism' spontaneously does not only mask skeletal deviations as the alveolar bone tries to create and maintain occlusal relationships, but it also changes with skeletal maturation all the same and plays a crucial role in regulating jaw development (Mirzen Arat, 2001).

## 7.3 Gender Differences in Growth Studies

Except for the 10- to 12-year-old age group, gender was found to have an influence on shape in all other age groups. Boys had more pronounced changes in shape across different age groups compared to girls.

### 7.3.1 Soft Tissue Changes during Adolescence

By the age of 16, the establishment of soft tissue contours between the pogonion and ANS suggests that any further projection of the soft tissue profile in different directions between ages 16 and 20 is primarily due to skeletal growth rather than an augmentation in soft tissue thickness. Gender disparities in the soft tissue profile become apparent around the age of 9, as girls experience a quick increase in the size of their soft tissue structures compared to boys, who continue to grow at a slower pace. By the age of 12, both genders attain a similar rate of growth, as indicated by the overlapping velocity curves. After reaching this age, the velocity curve showed an increase in boys and a decrease in girls.

Evidently, females experience earlier maturation compared to males, which may result in varying stages of facial development. Boys have significant growth even after reaching the age of 17 (Halazonetis, 2007), with a greater rise in size of these structures compared to girls. Adult females reached adult size in most measurements by the age of 15, whereas males continued to show a linear rise until the last measurements at 18 years of age (J. Zhao et al., 2023). Therefore, the results are not applicable to adults. In an extensive investigation conducted by Ferrario et al.(Ferrario et al., 1998), it was found that the growth of the face was nearly complete in females by the age of 14, which represented 93% of its total volume. However, in males, there was still a significant increase in growth to occur, which represented only 16% of the total volume. This suggests that the facial volumes are generally greater in males in comparison to girls (Ferrario et al., 1998).

Continuous skeletal and soft tissue movements during the 14–20-year age range can have a considerable clinical impact on the preservation of the post-treatment profile and the requirements for post-treatment occlusal retention. Darwis et al. (J. Zhao et al., 2023) made an investigation on changes in profiles by comparing measurements of landmarks at different ages (7 to 8 years and 17 to 18 years). The study confirmed that the nose, lips, and chin were the facial areas most affected by sexual maturity, which is of significant interest to clinicians. The soft-tissue profile outline exhibits form variability primarily in terms of the protrusion of the chin and nose in relation to lip protrusion, the facial convexity, and the form of the lower lip. Indeed, as individuals mature, both females and males experience an increase in the protrusion of their nose and chin. This growth continues in boys, resulting in greater mandibular and nasal protrusion. Consequently, the adult facial forms of both sexes become more similar and may even approach virtual identicalness. Conversely, girls seem to have shallower labial sulci and more prominent chins and noses. Very slight and imperceptible form changes were discovered between the ages of 12 and later. This could explain why other researchers failed to identify shape dimorphism (Halazonetis, 2007).

The underlying skeleton has no effect on the sagittal growth of the soft tissue of the nose; it persists after the skeletal growth is finished. The study discovered that the horizontal development increments of the nose throughout adolescence at Pr were greater than those observed during childhood (Sridhar Premkumar, 2011). An adolescent development spurt was observed in a more recent investigation(J. Zhao et al., 2023), with a greater manifestation in anterior nasal growth than nasal width and height, which were more influenced by total face growth. The growth spurt in males typically takes place between the ages of 13 and 14, whereas in females it occurs between the ages of 9 and 10.

The growth of nasal tip soft tissue is the most significant parameter observed quantitatively throughout the entire age range. Given that the nasal septum and the ANS support the tip of the nose, and that the ANS advances with age, the nasolabial angle grows greater in females than in males, and it progressively diminishes as a person age more in women than in men. Research on modifications in the facial profile (Halazonetis, 2007; Sridhar Premkumar, 2011; J. Zhao et al., 2023) has proven that overall facial convexity increases in both sexes from five years old to maturity.

Although the development pace lowers in girls during puberty, the thickness of the top lip grows as they age. However, the top lip thickness in males is bigger than in girls, and it has minimal vertical growth, particularly in females, as the A point appears to migrate somewhat distal with age. Girls have a greater distance between the lowest point of their top lip and the tip of their incisor compared to boys. This distance exhibits a greater increase in girls compared to boys. Additionally, as the incisor erupts, it is expected that the distance from the ANS to the tip of the incisor increases in both sexes with age. The position of the top lip in relation to the upper incisor is higher in females than in males, and these data support the idea that females typically exhibit a more elevated lip line compared to males.

Significant statistical differences were seen in the positioning of the lips in relation to the Ricketts E-plane. The most notable disparities were found in the upper lip. According to previous research (Sridhar Premkumar, 2011), male lips exhibited more retrusion compared to female lips. Sexual dimorphism in the top lip was primarily observed in the vertical dimension, while gender-related differences in the lower lip were predominantly identified in the horizontal direction. There appeared to be a lot of variation in the lower lip amongst subjects, most likely due to the combined influence of the location of the mandibular incisor, the maxillary incisor, and postural variables. In orthognathic surgery, it is also well recognized that the lower lip is the hardest to predict (Halazonetis, 2007).

The facial profile is influenced by changes in the lips and might be a crucial factor in predicting stability following orthodontic treatment. The optimal time to employ functional or orthopedic appliances in growth modification therapy is during the pubertal growth spurt. This data can be used to aid in treatment planning, anticipate changes due to growth, and predict outcomes after therapy. Hence, it is crucial for the orthodontist to possess a comprehensive knowledge and comprehension of the alterations that occur in soft tissue throughout the process of growth (Halazonetis, 2007; Sridhar Premkumar, 2011; J. Zhao et al., 2023).

### 7.3.2 Sexual Dimorphism in Mandibular Growth

It is widely recognized that there are very few research that have investigated the differences between females and males in mandibular growth during the early years of life, despite the widespread consensus that these differences are insignificant before puberty. Nevertheless, there have been studies indicating disparities in craniofacial development between sexes during infancy and early childhood growth. Several authors aimed to ascertain whether morphological characteristics could be used to distinguish between sexes. They discovered that prior to the age of six, the distinctions between female and male subjects were quite subtle. However, these differences could still be discerned by examining the contour of the mandible body and the shape of the lower border of the symphysis. This observation remains applicable until the age of 19.

The chin had an adult shape by the age of six. Studies have shown that girls' mandibular growth spurts are less evident and happen about 1.6 years earlier (1.5 to 2 years), while boys' spurts are larger. The greatest rate of Co-Pog length has been seen to occur at an average age of approximately 13.5 years. The craniofacial growth maturity gradient for individuals aged 4 to 16 indicates that girls consistently exhibit greater maturity than males across all age groups. The increase in ramus height during adolescence is significant, with males experiencing a growth rate of roughly 7% per year and females experiencing a growth rate of approximately 7.5% per year. Consequently, this applies to the development of the lower jaw, where the length of the corpus (Go-Gn) exhibits the most significant variations between sexes in terms of maturity. It is worth noting that although males have more growth increments (larger) in their mandibles compared to females (Liu et al., 2010).

### 7.3.3 Facial Growth in Males

Research has demonstrated that skeletal and dental relationships undergo profound changes during post-pubertal development. Björk (De Oliveira Ruellas et al., 2016) conducted a study on mandibular growth and found that the development rate is around 3 mm per year from 16 to 17 years old. However, there is no growth observed between the ages of 21 and 22 years old. Behrents (Love et al., 1990) discovered that mandibular growth remains considerable beyond the age of 35 years. Similarly, Lewis and Roche (Yoon & Chung, 2015) demonstrated that growth in the cranial base and mandible persists into the 3rd decade. Love, Murray, and Mamandras (Love et al., 1990) conducted a study on the dental and skeletal changes in males with Class I dental and skeletal patterns after puberty. The study revealed that there are notable changes in the craniofacial skeleton after the age of 16, as seen by the comparison of mandibular and maxillary growth. There was a notable increase in the length of the mandible between the ages of 16 and 18, compared to the development between 18 and 20. However, the growth of the upper jaw remained relatively consistent across both age periods. Subsequently, a slightly different image was observed. The growth of the mandible remained consistent, whereas the growth of the maxilla accelerated from the age of 16 to 18 and continued to expand from the age of 18 to 20. Overall, mandibular growth exceeded maxillary growth at every age interval, as determined by either of two methods (with a ratio of around 2:1; mandibular growth was twice as much as maxillary growth).

Between 16 and 20 years old, there was a substantial decrease (closed 1.6°) in the mandibular plane angle, suggesting a growth pattern characterized by upward and forward rotation. This decrease seems to be primarily caused by the contrasting growth rates of the posterior (Co-Go) and anterior face (ANS-Me) heights. Both jaws exhibit considerable development after the age of 16 and may require evaluation in orthodontic treatment planning (Love et al., 1990).

### 7.3.4 Facial Growth in females

Significant mandibular and facial development does occur in girls in late adolescence, according to Foley's (Yoon & Chung, 2015), post-pubertal maxillary and mandibular facial growth in Class I females, but the growth increment values were lower than those previously documented in boys. The cessation of active pubertal growth in girls typically happens approximately 2 years prior than boys, and it is generally believed to occur at about 14 years of age.

The level of mandibular incremental growth (Co-Gn) in females between the ages of 14 and 16 is twice as high as the growth observed between the ages of 16 and 20. Similarly, in males, the mandible grows twice as much between the ages of 16 and 18 compared to the growth observed between 18 and 20 years of age.

Nevertheless, the observed increase in growth only constituted approximately two-thirds of the similar increase in boys aged 16 to 20 years (3 mm). The mandibular plane angle in females decreased by 1.1° between the ages of 14 and 20, indicating a tendency for the mandible to rotate in a closing motion. Due to the smaller amount of development change in females, the degree of mandibular rotation would be less obvious in post pubertal males compared to post pubertal females. between 14–20 years of age, Mandibular incisor to MPIA increased by nearly 1.4° of proclination; however, the angulation remained constant from 14–16 years of age. No link was detected between the observed change in position of the lower incisor and the growth of the mandible. This indicates that factors other than late adolescent growth are involved in the positioning of mandibular incisors.

It should be mentioned that maxillary growth in females is independent of mandible growth; yet, between the ages of 14 and 20, the mean mandibular growth was nearly double that of the maxilla (Yoon & Chung, 2015). Study results on the upper incisors were mixed; some authors found no change in their position with respect to S-N, while others found that their alignment improved with age (Yoon & Chung, 2015).

According to earlier postpubertal research, there is a little incremental rise in posterior vertical height over anterior vertical height, with an average opening of 0.4° from 14 to 20 years and a virtually steady facial axis.

The growth potential beyond puberty is more than previously estimated. Studies have shown that the growth that occurs throughout late adolescence can cause changes in the alignment of the bones and teeth in individuals who have previously undergone orthodontic treatment. The unpredictable nature of growth in the mandible serves as a prime example, since we currently lack the ability to precisely predict how it will develop beyond puberty. Consequently, the clinician may have challenges in accurately forecasting how growth may impact post-treatment stability in a specific case. Therefore, it is important to consider the impact of post-treatment growth on the stability or relapse of corrected occlusions in orthodontic patients treated during the pre-pubertal or pubertal age periods. This should be given significant attention during the treatment planning process (Yoon & Chung, 2015).

## 8 Treatment Options Concerning Craniofacial Growth Particularities in Children

To comprehend the development and treatment of craniofacial aberrations, it is necessary to possess a comprehensive understanding of the diverse regulatory systems that govern craniofacial growth (Sridhar Premkumar, 2011).

### 8.1 Dynamics and Clinical Aspects of Facial Growth: What is the Right Treatment Management of Skeletal Problems?

Without an understanding of the mechanics of growth in orthodontics, the study of growth and development cannot be considered complete. Growth can be separated into body growth and dental development. The following concepts of growth that are essential for clinical success and must be monitored throughout orthodontic treatments include:

Pattern, Variability, Timing AND Differential Growth.

Among the many patterns of human growth is cephalocaudal gradient of growth. The term "cephalocaudal gradient" is defined by Proffit as "there is an increasing axis of growth from the head to the feet" (Dimaggio et al., 2007).

The variation in cranial size in relation to body size during human development illustrates this trend. Like parts closer to the head, the maxilla grows and matures earlier than the mandible, which appears to take its time and completes its growth late. Therefore, mandibular surge is not surprising in teenagers, but the growth of the maxilla is not obvious after eleven to twelve years old. Utilizing this element of mandibular growth is beneficial for treating patients who have skeletal malocclusion that affects the mandible. According to the cephalocaudal gradient of growth, it is important to consider that there may be continued expansion of the mandible following the pubertal growth spurt while treating a child with skeletal class III and mandibular prognathism. Nevertheless, employing the pubertal growth spurt in individuals with class II skeletal structure and mandibular retrognathism who are undergoing treatment with functional appliances may effectively resolve the class II skeletal condition, given that these patients are still in the stage of active growth (Sridhar Premkumar, 2011).

An additional aspect of pattern is the Scammon's growth curve, which aims to offer an overview of the growth pattern of various tissues in the body. The mandible does not follow the neural growth curve as closely as the maxillary curve does. Considering the fact that neural tissue experiences rapid growth in the early stages of life (with about 95% of growth occurring by the age of 8), and that growth rate further increases throughout puberty, it becomes clear why maxillary growth is finished at a relatively young age. Therefore, orthopedic appliance therapy (facial mask) should be initiated in deciduous or mixed dentition in order to effectively repair maxillary insufficiency. Simply put, the purpose of having an expansion screw in the maxillary orthopedic protraction appliance is to not only expand the maxilla, but also to loosen the sutures around the maxilla so that they may easily respond to the force applied during protraction. Once the circum-maxillary sutures are interlocked during adolescence, it becomes difficult to repair maxillary retrognathism.

The timing of growth differs among individuals and is also influenced by gender. The pubertal growth spurt is important in orthodontic treatment, but it can be challenging to detect, particularly in early growing girls who may not show obvious signs of it. Some authors have raised doubts about the timing of the mandibular growth spurt, questioning whether it occurs simultaneously with other skeletal structures or at a later stage. The studies conducted by Bacetti et al. (Sridhar Premkumar, 2011) on the use of Frankel and Twin Block appliances for treating skeletal class II malocclusion were highly conclusive.

The results obtained were excellent, particularly when the treatment was administered during the circumpubertal period for individuals with class II malocclusion caused by mandibular retrognathism. This is due to the fact that the circumpubertal group produced twice the amount of mandible growth as the pre-pubertal group. The transverse correction of the maxilla through skeletal expansion faces comparable limitations as the maxillary protraction. In youngsters between the ages of 6 and 8, the intermaxillary suture is both smooth and open. However, during late adolescence, specifically between the ages of 14 and 16, the sutures become fused. Not all children experience growth at the same rate or at the same time. Therefore, it is important to consider the timing of therapy while doing growth modification techniques.

The assessment of Variability in growth increments requires graphing growth within a defined time frame (Sridhar Premkumar, 2011). The face undergoes growth in a sequential manner, starting with an increase in width, followed by an increase in depth (anteroposterior dimension), and finally an increase in height.

Teeth erupting, the alveolar bone expanding, and the jaws separating during displacement all contribute to the growth in height. The mandibular intercanine width is initially determined at 9 years of age in girls and 10 years of age in boys. Unlike males, who had a progressive rise in the maxillary intercanine dimension until the age of 18, girls did not exhibit any further growth in the maxilla after the age of 12 to 13. Therefore, the efforts to expand the intercanine width using expansion treatments in cases of crowding will not only be unsuccessful in achieving a stable increase, but it will also disrupt the balance in the muscles, worsening the condition. During puberty, the growth direction is a crucial factor in growth that must be considered. The variability in growth direction influences the selection of functional treatment, the decision to extract or not, the duration of healing (closure) of the extraction site, the outcome of alternative orthopedic treatments like expansion, the process by which teeth move mesially toward the extraction site, the treatment duration, and the prediction of the response to a specific treatment.

A temporary deep bite occurs during dentition development. It may be corrected in certain situations by changing the axial inclination of the permanent teeth upon erupting (primary teeth are more upright). In rare circumstances, physiological bite raisers may even be necessary. The narrow intercanine width of the mandible can be exacerbated by the existence of a class II skeletal basis and increased overjet. This issue can be easily resolved by providing a bite plane, which will relieve the bite and promote the anterior growth of the mandible. Understanding dental development, growth-related changes, the extent of remaining growth, and the relative rate of postnatal growth in different facial regions is crucial for orthodontic treatment planning, particularly during childhood and adolescence (Liu et al., 2010; Sridhar Premkumar, 2011).

**Orthopedic and Soft Tissue Treatment Considerations:**

When it comes to the optimal timing of orthopedic therapy, which involves the correction of skeletal and dentoalveolar structures during development, growth and development can be considered as a form of energy that determines the appropriate procedure. The fundamental concepts of orthopedic treatment are the prevention and management of unwanted growth-related alterations while promoting desirable ones. When treatment procedures are most effective is a crucial but mostly unanswered question. Arat et al. (Mirzen Arat, 2001) proposed the following:

- The period of intensive craniofacial growth coinciding with MP3cap and DP3u stages may be considered appropriate for the correction of skeletal anomalies. (Between around 11.5 to 15 years);
- Though craniofacial changes from 15 to 17 years of age are minimal, they're significant and constitute an advantage when treating adolescents. However, it is never advisable to wait until this growth stage to correct skeletal deviation (Mirzen Arat, 2001).

Varrela (Varrela, 2006) and other writers have suggested that initiating orthodontic treatment during early childhood could be crucial for effectively managing growth and development and achieving therapeutic control. Varrela (Varrela, 2006) states that the primary obstacle is to acquire the ability to imitate the external regulation of occlusal development through orthodontic correction methods, in order to regulate the genomic processes responsible for the development and growth of the jaws. This is because therapeutic actions during orthodontic treatment can only influence the environmental aspect of development, not the genetic aspect. This has the potential to facilitate the proactive promotion of a balanced growth of the facial soft tissues, the jaws and occlusion, as opposed to the current practice of allowing problems to occur before initiating treatment. Once we have a complete understanding of how the genetics and environment interact during early occlusal development, it should be feasible to avoid malocclusions through primary prevention.

It is not recommended that orthodontists manage the growth of adolescents in accordance with adult standards, as subsequent modifications may have a negative impact on the profile (Sharma et al., 2014).

On top of that, research shows that lower incisors in males typically retrocline as they get older. The level of tipping wasn't consistently linked to either mandibular or maxillary growth, nor with the discrepancy between the two. Nevertheless, it was suggested that for people who received orthodontic treatment, retention should last for a long time, maybe even until they are 20 years old or older in male patients (Love et al., 1990).

## 8.2 Other Treatment Considerations

### 8.2.1 Endodontic Considerations

Vital pulp therapy techniques are performed to deal with reversible pulpal damage caused by caries, restorative procedures, or trauma. Nevertheless, direct pulp treatment techniques have a high probability of being unsuccessful, even when dealing with a small opening in the pulp that is protected by a rubber dam, which prevents oral pollutants from reaching the tooth. Typically, teeth like this should be treated with either pulpotomy or pulpectomy. Factors such as overall health, age, and the cooperation of the young patient and their parents should be taken into account before deciding on a treatment procedure. The decision between pulpectomy and pulpotomy is typically determined by the severity of the symptoms noticed during clinical examination or/and through radiographic imaging. Compared to pulpotomy of the deciduous tooth, which is a reasonably simple procedure with favorable outcomes, pulpectomy is a more challenging therapy for children due to anatomical complexity that are absent in permanent teeth. Unlike permanent teeth, ultrasonic shaping instruments should be avoided for relatively thin root canal walls. Similarly, the use of Gates-Glidden drills is restricted due to the increased risk of stripping. The estimated length of the root canal is determined by analyzing a preliminary radiograph, as it is crucial to maintain the integrity of the apical region. It is best to reduce the working length of the root canal by 1 to 2 mm in order to prevent over-instrumentation and overfilling, especially since teeth frequently exhibit apical resorption phenomena. Apex locators are worthless because deciduous teeth's electrical and morphophysiological properties prevent an electronic working length estimation. Unlike permanent teeth, it is necessary to utilize resorbable filling and root canal sealing material for deciduous teeth. This is done to ensure that these materials are eliminated during the natural process of root resorption and do not obstruct the emergence of the permanent tooth (Hani F. Ounsi, 2009).

### 8.2.2 Maxillofacial Trauma

When treating fractures and facial injuries in children, it is necessary to have a thorough comprehension of the developing pediatric facial anatomy and the anatomical variations in the pediatric craniofacial skeleton. The most notable disparity between the adult, juvenile, and newborn facial skeletons is in the comparative ratios of the skull and face in individuals of varying ages. Due to their lower body mass, children experience a higher force per unit of body area following a traumatic incident. The pediatric skeleton, especially the facial bones, possesses several active growth zones that render it more flexible due to incomplete calcification. Consequently, fractures in children are less prevalent compared to adults.

During the early stages of life, the midface bones are relatively shielded. Midface fractures are uncommon in infants and early children because to the region's increased elasticity caused by a higher cancellous to cortical bone ratio, the developing dentition inside the facial skeleton and the lack of sinus pneumatization. On the other hand, damage to the mandible can happen to anyone at any age. Fractures of the mandible in infants and young children typically happen in vulnerable areas, such as the mandibular condyle. This section of the jaw has a thick and short neck, as well as a high proportion of cancellous (spongy) to cortical (dense) bone. As growth occurs, the neck of the condyle becomes longer. Compression fractures are more commonly linked to the condylar neck rather than fractures of the condylar head. Fractures in the forehead and upper orbital regions, as well as brain injury and dural tears with cerebrospinal fluid leakage, are common in children under the age of 5 when they receive major trauma to the front of the head and face. In cases of such accidents, reduction and fixation are essential when fractures are displaced. However, it is more common for these fractures to be non-displaced. Frontal sinus fractures have a higher incidence in older children and teenagers than in very young children because the maturation of the frontal sinus occurs later in development. Before the age of seven, injuries to the central cranio-orbital region are uncommon because the ethmoidal sinuses are not fully developed. However, when they do occur, they are strongly linked to naso-orbital-ethmoid fractures. Because of the way forces are distributed in the developing orbit, children are more likely than adults to suffer from supraorbital rim and orbital roof fractures. Surgery is not necessary for treating non-displaced orbital roof fractures that do not cause muscular entrapment. However, fractures that have functional repercussions or involve tears in the dura are often treated with surgery. A neurosurgical consultation is necessary.

Soft-tissue injuries are typically the result of facial fractures and need to be properly cleansed and closed as soon as practical. Following sufficient irrigation, debris clearance, and excision of necrotic tissue, primary closure is typically recommended, even if there is a considerable delay in treatment, due to the abundant vascular supply in the neck and head region of a kid. It is preferable to choose suture material that is absorbed quickly. Cyanoacrylate tissue glue can be employed to wounds with low or no tension, which are not near to mucosal membranes such as the eyes or mouth (Kellman & Tatum, 2014).

### 8.2.3 Pharmacological Management of the Pediatric Dental Patient

The Main Principles in Pediatric Pharmacological Therapy:

- Toxicity in children increases with low plasma protein content and weak protein binding capacity;
- Most children need more dose per unit body weight than adults.
- Children are more susceptible to neurotoxicity due to skin and blood-brain barrier permeability, which increases topical medication absorption and CNS distribution;
- Infants may excrete drugs more slowly than adults, increasing the risk of drug accumulation within the body;
- Pediatric patients require precise dosing due to their immature physiological responses, which fail to adequately compensate for potential drug errors.

Tetracycline and Teeth Discoloration in Children:

Several years ago, there were reports of tooth discoloration in kids who underwent long- or short-term therapy with tetracycline. The degree of tetracycline dyschromia varies depending on the dosage of the medication (Enabulele et al., 2020). The severity of enamel discoloration is directly proportional to the dose of medication given in relation to body weight. Furthermore, it has been documented that administering tetracyclines to pregnant patients can result in tooth discoloration in their kids. Pigmentation of the deciduous anterior teeth can occur from midpregnancy until about 4 to 6 months after birth, before the first set of teeth appear. However, the most significant risk to the permanent anterior teeth occurs when the drug is administered between the ages of 2 months and 5 years. This is when the crowns of the teeth are forming and the teeth are undergoing calcification (Enabulele et al., 2020). Tetracycline pigment deposition occurs during the rapid development of the tooth bud, which is why permanent teeth are unlikely to be damaged by tetracycline given during the birth period or later in infancy. In technical terms, the younger the infant is, the higher the likelihood of tetracycline accumulation in developing teeth and bones. However, it is uncertain whether the low glomerular filtration rate of the underdeveloped kidney in premature infants leads to elevated blood levels of tetracycline and subsequently increased tissue penetration (Enabulele et al., 2020).

Conscious Sedation in Children:

The pharmacological treatment of pediatric dentistry patients can be categorized into two main groups: (1) sedation; and (2) general anesthesia (GA). Dental specialists resort to general anesthesia (GA) when patients exhibit severe phobia and distress during unpleasant treatments or upon seeing sharp tools. In the field of dentistry, the use of immobilization techniques for uncooperative youngsters leads to worsened treatment outcomes, which is not the case in other medical specialties. Additionally, it is important to note that such treatments may pose a safety risk. In light of this fact, sedation appears to be a viable substitute for general anesthesia, given the necessary guidelines. While it's true that children's bodies are more complex and that their dosage requirements are different from those of adults, the lack of proper training among some medical professionals can increase the risk to otherwise healthy children (Dr. Wilson, 2004). It is important to customize the dosage of drugs for children based on the specific needs of each patient (Vinay Kumar Srivastava, 2011).

The Effectiveness of Mandibular Infiltration and Risks Associated with Mandibular Block Anesthesia in Treating Primary Molars:

Due to the bone's greater density, infiltration anesthesia is not sufficient for treating mandibular molars as the anesthetic does not spread enough, as in the case of maxillary teeth. According to the other authors (jerry swee, 2013), it was determined that infiltration anesthesia was successful in all cases. This suggests that mandibular infiltration is a reliable and effective technique for local anesthesia when performing a class I or II amalgam or a Stainless-Steel-Crown (SSC) restoration in a primary molar, regardless of whether it is in the deciduous or mixed dentition. However, it is not a dependable method for performing pulpotomy in a primary molar, regardless of whether it is in the main or mixed dentition. In addition, it was noted that youngsters exhibited a higher level of tolerance towards the infiltration approach during the injection, as compared to the block. It is worth noting that the amount of anesthetic given during the infiltration can be decreased without impacting the level of anesthesia (Chopra et al., 2016).

A recent discovery validates that nearly 40% of children who lack third molars exhibit agenesis of only one tooth. Limited research has been undertaken to investigate the cause of this abnormally high occurrence of unilateral agenesis. A study conducted by Swee et al.(jerry swee, 2013) has demonstrated a potential link between the administration of local anesthetic to children during an inferior alveolar nerve block (IANB) and the absence of the third molar. This suggests that there is a possibility that the development of the third molar may be harmed because of this procedure.

The developing tooth bud of the third molar is located beneath the surface of the soft tissues in a young kid, very close to where the needle enters during normal IANB administration (less than 1 centimeter between the bud and the internal oblique ridge). During a properly executed conventional inferior alveolar nerve block (IANB), the needle is pointed towards the middle of the internal oblique ridge, which is a bony structure. However, the majority of the hard-tissue markers are hidden by flexible soft tissue, making it difficult to accurately position the needle, especially in juvenile patients who tend to move often. Therefore, if the needle used for the IANB injection in young children is accidentally misdirected even slightly to the side, it can directly hit the vulnerable third-molar tooth bud. This can easily damage the developing molar bud and the immature tooth formative tissues, leading to a greater prevalence of asymmetrical third-molar agenesis observed by clinicians (Chopra et al., 2016; jerry swee, 2013).

Whereas dental local anesthetics often have acidic pH levels as low as 3.5. Due to the elevated acidity levels, which are characteristic of lemon juice, local anesthetics have been demonstrated to be harmful to the tissues responsible for tooth formation. In the event of an unintentional needle penetration, these solutions may be delivered in high concentrations in close proximity to developing tooth buds, particularly during the initial stages of development, when the tooth bud is unlikely to be larger in diameter than the needle. Animals have shown that even in the later phases of tooth development, a single needle penetration can cause severe lasting morphological damage and limit the formation of teeth. However, further investigations are necessary to address this issue (jerry swee, 2013).

## III Conclusion

There has been a lack of systematic research on the subject of relative growth and development during infancy and early childhood, and this topic continues to be poorly understood. There is some evidence that craniofacial growth is noticeable during the early years after birth. This growth is closely related to overall body growth, which tends to have larger increments throughout the first 5 years of life compared to later periods after birth. Enlow states that "all parts, regardless of regional remodeling directions, become displaced in the anterior inferior direction". Therefore, as the cheekbone moves posteriorly, the maxilla shifts inferiorly, and the orbit undergoes remodeling to enhance its vertical size.

The study also determined that there was no linear correlation between soft and hard tissue changes, indicating that they should be evaluated separately. The loss of soft tissue volume and location reveals the underlying skeletal outlines, leading to the typical alterations associated with aging. Hence, it is crucial to acquire a greater awareness of the total alterations that happen in the facial structure throughout the process of development. Having such comprehension will assist orthodontists and other clinicians in establishing the most optimal treatment for their patients. Furthermore, it is crucial to acknowledge that the primary requirement of patients receiving orthodontic treatment is an improvement of their aesthetic appearance. When it comes to the description of human morphology, as well as in the clinical analysis of patients undergoing orthodontic, maxillofacial, and plastic surgery, the dimensions of the facial soft-tissue structures (nose, lips, and chin), as well as their reciprocal spatial positions and relative proportions, are essential components. In order to effectively assess the impact of orthodontic therapy on skeletal structures and soft tissue profile, it is important for improvements in craniofacial studies to thoroughly investigate changes in both shape and size across all dimensions during growth and development. Further research in various populations, including children with craniofacial abnormalities, should incorporate a combination of recently developed methods applicable to longitudinal studies, such as three-dimensional facial morphometry and Fourier analysis. This will allow for a more thorough understanding of the growth and development of the craniofacial structures and even assist in establishing standards or norms for clinicians to compare individuals, ensure harmonious facial esthetics and optimal functional occlusion, which are the main goals of orthodontic treatment, and improve the prediction of clinical outcomes.

Ultimately, the process of maturing does not appear to be limited to a certain age, as ongoing transformations in the upper and lower lips can still be detected in adults, leading to further alterations in the facial profile. However, our understanding of face growth in adults is limited. The shift in focus towards studying growth in adults highlights the common belief that craniofacial growth stops at the end of adolescence.

The present trajectory of future research concerning the development and growth of the face, teeth, and jaw is to accommodate the unique characteristics of each individual. This is because longitudinal studies, which quantify growth time on a quasi-percentage basis, are essential for comprehending the organic reality of sexual maturity and the attainment of adulthood.

## IV References


Abdullah, N., Naing, L., Mastura Ismail, N., & Rashid Ismail, A. (2006). A CROSS-SECTIONAL STUDY OF SOFT TISSUE FACIAL MORPHOMETRY IN CHILDREN AND ADOLESCENTS. In *Malaysian Journal of Medical Sciences* (Vol. 13, Issue 1).

Anas, I. Y., Bamgbose, B. O., & Nuhu, S. (2019). A comparison between 2D and 3D methods of quantifying facial morphology. *Heliyon*, *5*(6). https://doi.org/10.1016/j.heliyon.2019.e01880

Andriani, A. T., Zahra, P. K., & Auerkari, E. I. (2021). Genetic contributions to craniofacial growth: A review. *Journal of Physics: Conference Series*, *1943*(1). https://doi.org/10.1088/1742-6596/1943/1/012095

Bishara, S. E., Ortho, D., Peterson, L. C., & Bishara, E. C. (1984). *Changes in facial dimensions and relationships between the ages of 5 and 25 years*.

Bjork, A. (1963). *Variations in the Growth Pattern of the Human Mandible: Longitudinal Radiographic Study by the Implant Method*.

Chopra, R., Marwaha, M., Bansal, K., & Mittal, M. (2016). Evaluation of Buccal Infiltration with Articaine and Inferior Alveolar Nerve Block with Lignocaine for Pulp Therapy in Mandibular Primary Molars. In *Pulp Therapy in Mandibular Primary Molars The Journal of Clinical Pediatric Dentistry* (Vol. 40, Issue 4). http://meridian.allenpress.com/jcpd/article-pdf/40/4/301/1745678/1053-4628-40_4_301.pdf

Davidovitch, M., Eleftheriadi, I., Kostaki, A., & Shpack, N. (2016). The use of Bjork's indications of growth for evaluation of extremes of skeletal morphology. *European Journal of Orthodontics*, *38*(6), 555–562. https://doi.org/10.1093/ejo/cjv084

De Oliveira Ruellas, A. C., Yatabe, M. S., Souki, B. Q., Benavides, E., Nguyen, T., Luiz, R. R., Franchi, L., & Cevidanes, L. H. S. (2016). 3D mandibular superimposition: Comparison of regions of reference for voxel-based registration. *PLoS ONE*, *11*(6). https://doi.org/10.1371/journal.pone.0157625

DeGraaff V. (2001). Human Anatomy. *6th Edition. Portland: The McGraw−Hill Companies*.

Dellavia, C., Catti, F., Sforza, C., Tommasi, D. G., & Ferrario, V. F. (2010). Craniofacial growth in ectodermal dysplasia: An 8 year longitudinal evaluation of Italian subjects. *Angle Orthodontist*, *80*(4), 733–739. https://doi.org/10.2319/101909-584.1

Dimaggio, F. R., Ciusa, V., Sforza, C., & Ferrario, V. F. (2007). Photographic soft-tissue profile analysis in children at 6 years of age. *American Journal of Orthodontics and Dentofacial Orthopedics*, *132*(4), 475–480. https://doi.org/10.1016/j.ajodo.2005.10.029

Dr. Wilson. (2004). *Pharmacological management of the pediatric dental patient pediatric*.

Enabulele, J. E., Chukwumah, N. M., & Enabulele, O. (2020). Tetracycline use in children and knowledge of its oral implications among nursing mothers. *Pediatric Dental Journal*, *30*(3), 224–230. https://doi.org/10.1016/j.pdj.2020.08.003

Enlow, D. H., & Hans, M. G. (2008). *Essentials of facial growth*. Distributed by Needham Press.

Ferrario, V. F., Sforza, C., Poggio, C. E., & Schmitz, J. H. (1998). Facial volume changes during normal human growth and development. In *Anatomical Record* (Vol. 250, Issue 4). https://doi.org/10.1002/(SICI)1097-0185(199804)250:4<480::AID-AR12>3.0.CO;2-K

FERRARIO, V. F., SFORZA, C., SCHMITZ, J. H., CIUSA, V., & COLOMBO, A. (2000). Normal growth and development of the lips: a 3-dimensional study from 6 years to adulthood using a geometric model. *Journal of Anatomy*, *196*(3), 415–423. https://doi.org/10.1046/j.1469-7580.2000.19630415.x

Ferrario, V. F., Sforza, C., Schmitz, J. H., & Santoro, F. (1999). *Three-dimensional facial morphometric assessment of soft tissue changes after orthognathic surgery*.

Ferrario, V. F., Sforza, C., Serrao, G., Ciusa, V., & Dellavia, C. (2003). Growth and aging of facial soft tissues: A computerized three-dimensional mesh diagram analysis. *Clinical Anatomy*, *16*(5), 420–433. https://doi.org/10.1002/ca.10154

Garib, D., Natsumeda, G. M., Massaro, C., Miranda, F., Naveda, R., & Janson, G. (2021).

Cephalometric changes during aging in subjects with normal occlusion. *Journal of Applied Oral Science*, *29*. https://doi.org/10.1590/1678-7757-2021-0199

Goldstein, M. (1936). Wth Age ’. *East*, *XXII*(1).

Gurkeerat Singh. (2015). *Textbook of orthodontics* (Gurkeerat Singh (ed.); THIRD EDITION).

Halazonetis, D. J. (2007). Morphometric evaluation of soft-tissue profile shape. *American Journal of Orthodontics and Dentofacial Orthopedics*, *131*(4), 481–489. https://doi.org/10.1016/j.ajodo.2005.06.031

Hallgrimsson, B., Percival, C. J., Green, R., Young, N. M., Mio, W., & Marcucio, R. (2015). Morphometrics, 3D Imaging, and Craniofacial Development. In *Current Topics in Developmental Biology* (Vol. 115, pp. 561–597). Academic Press Inc. https://doi.org/10.1016/bs.ctdb.2015.09.003

Häner, S. T., Kanavakis, G., Matthey, F., & Gkantidis, N. (2021). Valid 3D surface superimposition references to assess facial changes during growth. *Scientific Reports*, *11*(1). https://doi.org/10.1038/s41598-021-95942-3

Hani F. Ounsi. (2009). *Figure 1: Pre and postoperative bite-wing and periapical radiographs of a pulpotomy procedure, following which a stainless-steel crown and band and loop were placed on tooth #85. Notice the extent of the cameral filling that reaches into the entrance of the root canals*.

Hellman, M. (1927). Changes in the human face brought about by development. *International Journal of Orthodontia, Oral Surgery and Radiography*, *13*(6), 475–516. https://doi.org/10.1016/S0099-6963(27)90222-1

jerry swee. (2013). *Inferior alveolar nerve block*.

Karamani, I. I., Tsolakis, I. A., Makrygiannakis, M. A., Georgaki, M., & Tsolakis, A. I. (2022). Impact of Diet Consistency on the Mandibular Morphology: A Systematic Review of Studies on Rat Models. In *International Journal of Environmental Research and Public Health* (Vol. 19, Issue 5). MDPI. https://doi.org/10.3390/ijerph19052706

Katsube, M., Yamada, S., Utsunomiya, N., Yamaguchi, Y., Takakuwa, T., Yamamoto, A., Imai, H., Saito, A., Vora, S. R., & Morimoto, N. (2021). A 3D analysis of growth trajectory and integration during early human prenatal facial growth. *Scientific Reports*, *11*(1). https://doi.org/10.1038/s41598-021-85543-5

Kellman, R. M., & Tatum, S. A. (2014). Pediatric craniomaxillofacial trauma. In *Facial Plastic Surgery Clinics of North America* (Vol. 22, Issue 4, pp. 559–572). W.B. Saunders. https://doi.org/10.1016/j.fsc.2014.07.009

Kiliaridis, S. (2006). The Importance of Masticatory Muscle Function in Dentofacial Growth. *Seminars in Orthodontics*, *12*(2), 110–119. https://doi.org/10.1053/j.sodo.2006.01.004

Kiliaridis, S., Karlsson1, S., & Kjellberg, H. (1991). Characteristics of Masticatory Mandibular Movements and Velocity in Growing Individuals and Young Adults. In *J Dent Res* (Vol. 70, Issue 10).

Knigge, R. P., McNulty, K. P., Oh, H., Hardin, A. M., Leary, E. V., Duren, D. L., Valiathan, M., & Sherwood, R. J. (2021). Geometric morphometric analysis of growth patterns among facial types. *American Journal of Orthodontics and Dentofacial Orthopedics*, *160*(3), 430–441. https://doi.org/10.1016/j.ajodo.2020.04.038

Koudelová, J., Hoffmannová, E., Dupej, J., & Velemínská, J. (2019). Simulation of facial growth based on longitudinal data: Age progression and age regression between 7 and 17 years of age using 3D surface data. *PLoS ONE*, *14*(2). https://doi.org/10.1371/journal.pone.0212618

Krarup, S., Darvann, T. A., Larsen, P., Marsh, J. L., & Kreiborg, S. (2005). Three-dimensional analysis of mandibular growth and tooth eruption. In *Journal of Anatomy* (Vol. 207, Issue 5, pp. 669–682). Blackwell Publishing Ltd. https://doi.org/10.1111/j.1469-7580.2005.00479.x

Lacruz, R. S., Bromage, T. G., O'Higgins, P., Arsuaga, J. L., Stringer, C., Godinho, R. M., Warshaw, J., Martínez, I., Gracia-Tellez, A., De Castro, J. M. B., & Carbonell, E. (2015). Ontogeny of the maxilla in Neanderthals and their ancestors. *Nature Communications*, *6*. https://doi.org/10.1038/ncomms9996

Levine, R. A., Garza, J. R., Wang, P. T. H., Hurst, C. L., & Dev, V. R. (2003). Adult Facial Growth: Applications to Aesthetic Surgery. *Aesthetic Plastic Surgery*, *27*(4), 265–268. https://doi.org/10.1007/s00266-003-2112-4

Liu, Y.-P., Behrents, R. G., Peter, ;, & Buschang, H. (2010). *Mandibular Growth, Remodeling, and Maturation During Infancy and Early Childhood*. https://doi.org/10.2139/020309-67.1

Love, R. J., Murray, J. M., & Mamandras, A. H. (1990). *Facial growth in males 16 to 20 years of age*.

Maddux, S. D., & Butaric, L. N. (2017). Zygomaticomaxillary Morphology and Maxillary Sinus Form and Function: How Spatial Constraints Influence Pneumatization Patterns among Modern Humans. *Anatomical Record*, *300*(1), 209–225. https://doi.org/10.1002/ar.23447

Mirzen Arat. (2001). *craniofacial growth and skeletal maturation: a mixed longitudinal study*.

Mulharrem Akguner. (1998). Adolescent Growth Patterns of The Bony and Cartilaginous Framework of the Nose a Cephalometric Study. *Annals of Plastic Surgery*, *41*, 1.

Poosti, M., Jahanbin, A., Rashed, R., Sharifi, V., & Bozorgnia, Y. (2012). ORIGINAL REPORT Evaluation of Nasomaxillary Growth of Adolescent Boys in Northeastern Iran. In *Acta Medica Iranica* (Vol. 50, Issue 10).

Rajbhoj, A. A., Stroo, M., Begnoni, G., Willems, G., & de Llano-Pérula, M. C. (2023). Skeletal and soft-tissue changes in humans with untreated normal occlusion throughout lifetime: a systematic review. In *Odontology* (Vol. 111, Issue 2, pp. 263–309). Springer. https://doi.org/10.1007/s10266-022-00757-x

Rostovtseva, V. V., Mezentseva, A. A., Windhager, S., & Butovskaya, M. L. (2021). Sexual dimorphism in facial shape of modern Buryats of Southern Siberia. *American Journal of Human Biology*, *33*(2). https://doi.org/10.1002/ajhb.23458

Samir E. Bishara. (1998). *Soft tissue profile changes from 5 to 45 years of age*.

Santander, P., Quast, A., Olbrisch, C., Rose, M., Moser, N., Schliephake, H., & Meyer-Marcotty, P. (2020). Comprehensive 3D analysis of condylar morphology in adults with different skeletal patterns – a cross-sectional study. *Head and Face Medicine*, *16*(1). https://doi.org/10.1186/s13005-020-00245-z

Savoldi, F., Massetti, F., Tsoi, J. K. H., Matinlinna, J. P., Yeung, A. W. K., Tanaka, R., Paganelli, C., & Bornstein, M. M. (2021). Anteroposterior length of the maxillary complex and its relationship with the anterior cranial base: A study on human dry skulls using cone beam computed tomography. *Angle Orthodontist*, *91*(1), 88–97. https://doi.org/10.2319/020520-82.1

Schmitz, J. H., Assistant, R., & Ferrario, V. F. (2011). *Chiarella Sforza, MD Professor of Human Anatomy Claudia Dellavia, DDS Postgraduate Student Harmonic analysis of facial profiles: A 10-year evaluation*.

Sharma, P., Arora, A., & Valiathan, A. (2014). Age changes of jaws and soft tissue profile. In *Scientific World Journal* (Vol. 2014). Hindawi Publishing Corporation. https://doi.org/10.1155/2014/301501

Siécola, G. S., Capelozza Filho, L., Lorenzoni, D. C., Janson, G., & Henriques, J. F. C. (2017). Subjective facial analysis and its correlation with dental relationships. *Dental Press Journal of Orthodontics*, *22*(2), 87–94. https://doi.org/10.1590/2177-6709.22.2.087-094.oar

Sridhar Premkumar. (2011). *Textbook of Craniofacial Growth*.

Tarkar, J. S., Parashar, S., Gupta, G., Bharadwaj, P., Maurya, R. K., Singh, A., & Singh, P. (2016). An evaluation of upper and lower pharyngeal airway width, tongue posture and hyoid bone position in subjects with different growth patterns. *Journal of Clinical and Diagnostic Research*, *10*(1), ZC79–ZC83. https://doi.org/10.7860/JCDR/2016/16746.7158

Tsai, C. Y., Yang, L. Y., Chen, K. T., & Chiu, W. C. (2010). The influence of masticatory hypofunction on developing rat craniofacial structure. *International Journal of Oral and Maxillofacial Surgery*, *39*(6), 593–598. https://doi.org/10.1016/j.ijom.2010.02.011

Upadhyay, R., Upadhyay, J., Agrawal, P., & Rao, N. (2012). Analysis of gonial angle in relation to age, gender, and dentition status by radiological and anthropometric methods. *Journal of Forensic Dental Sciences*, *4*(1), 29. https://doi.org/10.4103/0975-1475.99160

Van Der Heijden, P., Korsten-Meijer, A. G., Bernard, ;, Van Der Laan, F., Hero, ;, Wit, P., Sieneke, ;, & Goorhuis-Brouwer, M. (2008). Nasal Growth and Maturation Age in Adolescents A Systematic Review. In *Arch Otolaryngol Head Neck Surg* (Vol. 134, Issue 12).

Varrela, J. (2006). Masticatory Function and Malocclusion: A Clinical Perspective. *Seminars in Orthodontics*, *12*(2), 102–109. https://doi.org/10.1053/j.sodo.2006.01.003

Vinay Kumar Srivastava. (2011). *Modern Pediatric Dentistry*.

Wen, Y. F., Wong, H. M., & Mcgrath, C. P. (2015). Longitudinal Photogrammetric Analysis of Soft Tissue Facial Changes: A Systematic Review of the Literature and a Summary of Recommendations. In *Journal of Craniofacial Surgery* (Vol. 26, Issue 6, pp. 1830–1834). Lippincott Williams and Wilkins. https://doi.org/10.1097/SCS.0000000000001909

Wen, Y. F., Wong, H. M., & McGrath, C. P. (2017). A longitudinal study of facial growth of Southern Chinese in Hong Kong: Comprehensive photogrammetric analyses. *PLoS ONE*, *12*(10). https://doi.org/10.1371/journal.pone.0186598

Yamashita, S., Hatch, J. P., & Rugh, J. D. (1999). Does chewing performance depend upon a specific masticatory pattern? *Journal of Oral Rehabilitation*, *26*(7), 547–553. https://doi.org/10.1046/j.1365-2842.1999.00446.x

Yoon, S. S., & Chung, C. H. (2015). Comparison of craniofacial growth of untreated Class i and Class II girls from ages 9 to 18 years: A longitudinal study. *American Journal of Orthodontics and Dentofacial Orthopedics*, *147*(2), 190–196. https://doi.org/10.1016/j.ajodo.2014.10.023

Zhao, J., Xu, Y., Wang, J., Lu, Z., & Qi, K. (2023). 3-dimensional analysis of hard- and soft-tissue symmetry in a Chinese population. *BMC Oral Health*, *23*(1). https://doi.org/10.1186/s12903-023-03163-z

Zhao, Z., Zheng, L., Huang, X., Li, C., Liu, J., & Hu, Y. (2021). Effects of mouth breathing on facial skeletal development in children: a systematic review and meta-analysis. *BMC Oral Health*, *21*(1). https://doi.org/10.1186/s12903-021-01458-7