DIMENSIONAL RELATIONSHIP BETWEEN MAXILLARY SINUSES, FRONTAL SINUSES, AND CRANIOFACIAL PARAMETERS USING CT SCAN IN HOSPITAL UNIVERSITI SAINS MALAYSIA

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BY

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CT	-	Computed Tomography
RMW	-	Right Maxillary Width
LMW	-	Left Maxillary Width
RMH	-	Right Maxillary Height
LMH	-	Left Maxillary Height
RML	-	Right Maxillary Length
LML	-	Left Maxillary length
RFW	-	Right Frontal Width
LFW	-	Left Frontal Width
RFH	-	Right Frontal Height
LFH	-	Left Frontal Height
RFL	-	Right Frontal Length
LFL	-	Left Frontal length
Zyg-zyg	-	maximum facial width
NW	-	Nasal Width
Zm-zm	-	maxillary width
N-S	-	anterior cranial base length
Ba-ns	-	midfacial length
N-ns	-	nasal height
ns-pr	-	alveolomaxillary height

HUBUNGAN DIMENSI ANTARA SINUS MAKSILARI, SINUS FRONTAL DAN PARAMETER KRANIOFASIAL MENGGUNAKAN PENGIMEJAN CT DI HOSPITAL UNIVERSITI SAINS MALAYSIA

Abstrak

Sinus paranasal adalah penting kerana ia mempunyai hubungan yang rapat dengan organ yang penting seperti otak, mata, hidung dan mulut. Ia membesar di sebalik kerangka muka dan memainkan beberapa peranan seperti meningkatkan resonans untuk suara dan membantu mengurangkan kecederaan muka semasa trauma. Pada masa kini, pangkalan data imej perubatan canggih seperti pengimejan CT membantu kajian sinus paranasal dan hubungan mereka dengan struktur lain. Tujuan kajian ini adalah untuk mengkaji hubungan antara dimensi sinus maksilari, dimensi sinus frontal dan parameter kraniofasial dalam CT scan dan untuk mengenal pasti perbezaan antara jantina dengan meggunakan imej struktur tersebut.

Kajian ini dilakukan dengan menggunakan pemeriksaan imej CT kepala secara retrospektif daripada pangkalan data dari Hospital Universiti Sains Malaysia. Jumlah subjek adalah seramai 120 pesakit yang terdiri daripada 60 lelaki dan 60 perempuan. Subjek tersebut dibahagikan kepada tiga kumpulan; kumpulan pertama dengan umur 5 hingga 10 tahun, kumpulan kedua 11 hingga 20 tahun dan kumpulan ketiga adalah antara 21 hingga 40 tahun. Pengukuran dimensi sinus maksilari, dimensi sinus frontal dan parameter kraniofasial pada imej CT dijalankan dengan menggunakan perisian komputer.

Dapatan kajian ini menunjukkan korelasi yang signifikan secara statistik antara dimensi maksilari dengan semua parameter kraniofasial dalam subjek berumur antara 5 hingga 10 tahun. Hubungan ini berterusan sehingga umur 20 tahun tetapi menjadi lemah antara umur 21 hingga 40 tahun. Selain itu, terdapat hubungan yang signifikan antara struktur midfasial dengan dimensi sinus frontal. Hubungan ini lebih signifikan dengan

struktur hidung. Hubungan antara dimensi sinus maksilari dan sinus frontal adalah tidak signifikan. Walau bagaimanapun, kajian berdasarkan jantina menunjukkan hasil yang signifikan antara struktur sinus maksilari, sinus frontal dan struktur midfascial.

Kesimpulannya, terdapat hubungan dimensi di antara sinus maksilari dan frontal dengan parameter kraniofasial. Hubungan ini berubah secara berterusan dengan pertambahan usia. Kajian ini juga menunjukkan perbezaan yang signifikan antara lelaki dan wanita dalam parameter sinus maksilari, sinus frontal dan midfasial.

DIMENSIONAL RELATIONSHIP BETWEEN MAXILLARY SINUSES, FRONTAL SINUSES, AND CRANIOFACIAL PARAMETERS USING CT SCAN IN HOSPITAL UNIVERSITI SAINS MALAYSIA

Abstract

The importance of paranasal sinuses cannot be denied as they have close relationships with vital organs such as the brain, eye, nose, and mouth. They grow deep within several facial skeletons and play many functions, such as increasing the voice resonance and acting as a crumpling zone in case of facial trauma skeletons. Nowadays, the advanced medical images database, such as the CT scan database facilitates the study of the paranasal sinuses and their relationships with other structures. Therefore, this study aimed to investigate the correlation between the maxillary and frontal sinuses dimensions and craniofacial parameters in CT scan and to identify the differences between gender in these structures.

This was performed by using the head CT scan images, retrospectively analyzed from the database accessible in the Hospital Universiti Sains Malaysia. There were 120 subjects, which consisted of 60 males and 60 females. These subjects were divided into three groups; the first group with age between 5 to 10 years old, the second group, between 11 to 20 years old and the third group, between 21 till 40 years old. The measurements of maxillary sinus dimensions, frontal sinus dimensions and craniofacial parameters on the CT images were obtained by using computer software.

The result of this study showed a statistically significant correlation between maxillary dimensions with all craniofacial parameters observed within the age of 5 to 10 years old. This correlation lasted till age 20 but became weak between age 21 till 40 years

old. Also, there was a significant correlation between midfacial parameters with frontal sinuses dimensions. This correlation was more significant with the nasal structure. The correlation between maxillary and frontal sinuses dimensions was not significant. On the other hand, gender determination showed significant results towards the maxillary sinus, frontal sinus and midfacial structures.

In conclusion, dimensional correlations exist between the maxillary and frontal sinuses with craniomaxillofacial parameters. These correlations constantly change with ageing. Also, this study showed significant variations between males and females in the maxillary sinus, frontal sinus and midfacial parameters.

CHAPTER 1

INTRODUCTION

1.1. Introduction

It is known that the growth and development of the skull is a very complex process, as it develops in parallel with the brain (Weickenmeier *et al.*,2017). As a result, studying this process entirely can be challenging; therefore, most researchers tried to investigate the skull growth through an evaluation of its parts separately. This approach allows them to investigate the growth of different parts of skull bones independently. At the same time, they would also understand the process of the neurocranium and facial skeleton development and the interactions among different skull bones. From the literature, the study of skull bones development has led to multiple hypotheses and theories with regards to the development of skull bones, including the paranasal sinuses.

1.2. Problem statements and rationale study

There have been many works of literature on anthropometric measurements of paranasal sinuses anatomy and anatomical variations of paranasal sinuses (Bhushan *et al.*,2016; Dkhar *et al.*,2017; Przystanska *et al.*,2018). However, most of these studies have limitations, either due to the small sample size (Halpern, 2010) or a limited age range (Przystanska *et al.*,2018). Furthermore, there are still many measurements of the frontal and maxillary sinuses that have not been investigated. Also, there are very limited data available on the relationships between these sinuses with the surrounding structure, especially the craniofacial parameters.

A few researchers have studied the growth of paranasal sinuses (Adibelli *et al.*,2011; Przystanska *et al.*,2018; Spaeth *et al.*,1997). However, the pattern of development of paranasal sinuses and their first radiological appearances either in plain radiography or CT scan is still controversial. It has been found that initial signs of pneumatization in radiographical images were noted at birth for the maxillary and ethmoid sinuses, at nine months old for sphenoid sinus, and after the age of five years old for the frontal sinus (Adibelli *et al.*,2011). In contrast, in another study, it has been mentioned that frontal sinuses were visible only in 10.7% of four-year-olds and 50 % of eight-year-olds. Finally, they were found to be visible in more than 90% after the age of 15 (Spaeth *et al.*,1997). In another study, it has been suggested that frontal sinuses continue to expand until age 40 (Tatlisumak *et al.*,2008; McLaughlin *et al.*,2001). Nevertheless, other studies mentioned that they stop growing by the age of 20 (Wolf *et al.*,1993; Adibelli *et al.*,2011).

Regarding the pattern of growth maxillary sinus, it has been found that it grows in an inferior and lateral direction (Leclerc, J. E., & Leclerc, J. T. 2009). However, another study concluded that it expands like a balloon style in all directions (Halpern, 2010). There is a possibility that these patterns of growth are closely related to the different craniofacial parameters, which need to be further investigated.

Therefore, the present study will attempt to correlate the sizes of the frontal sinus, maxillary sinuses with craniofacial parameters. There is a possibility that if the changes of dimensions of sinuses and the craniofacial parameters are measured at any specific timeline, it might increase the understanding of the pattern of paranasal sinuses developments and relationships between sinuses and anatomical facial features regarding age and gender.

1.3. Justification of the study

Despite all studies of dimensions and volume of the maxillary sinuses and frontal sinuses, there is limited literature on development and correlation between those sinuses. More studies in the dimensions of the craniofacial and paranasal complex will increase our knowledge and help us in various clinical areas such as preoperative staging of complex craniofacial abnormality, osteochondrodysplasic, craniomaxillofacial tumors by maxillofacial surgeons and neurosurgeons. Also, in plastic surgery, the expanded role of the importance of knowing normal values of these parameters and incorporated in the management plan of craniomaxillofacial trauma is just one example of how this research would have a significant impact. The knowledge of these parameters would also help maxillofacial surgeons and neurosurgeons to find the best plan treatment for those patients who are suffering from chronic paranasal pathology.

Moreover, it is an opportunity to discover new anatomical variations in the paranasal and craniofacial features. There was an article which states the discovery of a new anatomical foramen in the lower jaw, proving that the human body is not entirely discovered, and by using current technology such as CT scan, new unidentified structures might be discovered (Subhan, 2018).

In this study, the lower age limit of the inclusion criteria is five years old. This is based on findings by (Adibelli *et al.*,2011), which stated that initial signs of pneumatization of frontal sinus in radiographical images were first noted at five years old. Even though the maxillary sinus is visible at birth, the current study is focussing on the growth relationship between two sinuses, which are maxillary and frontal sinuses. Therefore, it is more appropriate to select one age limit, where both sinuses are simultaneously visible and measurable.

The upper age limit of the cases selected is 40 years old. This age limit was selected because it has been found that the craniofacial complex is still growing in the age range of between 25 and 40 years old. It reaches maturity and stops growing at the age of 40 years old (Jacobson, 1996). Therefore, measurement of the craniofacial parameters are expected to be still showing significant results up to this age limit.

It is hoped that with the aim of the current study which is to investigate the correlation between the maxillary sinus and frontal sinus dimensions with the parameters of the craniofacial in related age-change and gender, this would assist maxillofacial surgeons and neurosurgeons in finding best plan treatment for those patients who are suffering from chronic paranasal pathology.

1.4. Values of the current study

Even though there are disagreements about the significant results in previous studies, several important points are noticed. Firstly, if the change of dimensions of paranasal sinuses is referred to an appropriate midface parameter, it might guide us to comprehend more about the paranasal sinuses' development and their pathologies. Secondly, most of the previous studies used either a small sample size or a shortage range. Therefore, a larger sample size used in the current study would have produced a more reliable result. Finally, even with the advance of endoscopic sinus instrumentation, surgeons have faced the complexity of endoscopic sinus procedures due to the complex anatomical structures of paranasal sinuses, the limited information on sinus development and the relationships with other structures. It is the aim of the current study to create primary data for related studies on Malaysian populations and to increase the knowledge about paranasal sinuses growth in the Malaysian population.

1.5. Study Objectives

1.5.1. General:

This study aims to investigate the correlation between the maxillary sinus and frontal sinus dimensions with craniofacial parameters in related age-change and gender using computed tomography analysis.

1.5.2. Specific:

The specific objectives of the study are:

1. To determine the correlation between maxillary sinuses dimensions and craniofacial parameters at different stages of development.
2. To determine the correlation between frontal sinuses dimensions and craniofacial parameters at different stages of development.
3. To determine the correlation between dimensions of the frontal sinus and maxillary sinus at different stages of development.
4. To determine the potential difference in maxillary sinuses, frontal sinuses, and craniofacial parameters according to gender.

1.6. Research Questions :

1. Is there any correlation between the Maxillary sinus and craniofacial parameters at different stages of development?
2. Is there any correlation between the Frontal sinus and craniofacial parameters at different stages of development?
3. Is there any correlation between the frontal sinus and maxillary sinus parameters at different stages of development?
4. Are there any relationships between all measurements of different genders?

1.7. Hypothesis:

1.10.1. Alternate Hypotheses (HI)

1. There is a statistically significant association between maxillary sinus dimensions and craniofacial parameters.

2. There is a statistically significant relationship between frontal sinus dimensions and craniofacial parameters.

3. There is a statistically significant association between the maxillary sinus dimensions and frontal sinus dimensions.

4. There is a significant difference in the frontal sinus, maxillary sinus dimensions, and craniofacial parameters according to gender.

CHAPTER 2

LITERATURE REVIEW

2.1 Anatomy of paranasal sinus

Paranasal sinuses refer to four sinuses that are named according to their locations in the skull bones. The largest sinus located inferior to the eye socket in the maxillary bone is called maxillary sinus. The sinus located superior to the eye socket within the frontal bone is called a frontal sinus. The third is ethmoid sinus, which consists of many air cells and is in the ethmoid bone, lateral to the nasal cavity. The fourth sinus, sphenoid sinus, lies in the body of the sphenoid bone (Figure2.1 & 2.2) (Sobiesk, & Munakomi, 2019).

Sobiesk, & Munakomi., (2019) described that anatomist divides the paranasal sinuses into different groups according to their sites of drainage. The anterior group contains maxillary sinus, frontal sinus, and anterior ethmoidal air cells open into the middle meatus. The posterior group consists of sphenoidal sinus and posterior ethmoidal air cells, open into the sphenoethmoidal recess and superior meatus, respectively (Figure2.2).

According to Cappello ZJ *et al.*, (2020), the functions of paranasal sinuses are still inconclusive. However, it has been found that there have been several known functions. They have been found to add resonance to voice, serve as crumpling zone in facial trauma, lighten the weight of the skull, aid in cleaning and moistening the nasal cavity and humidifying and heating of the inspired air.

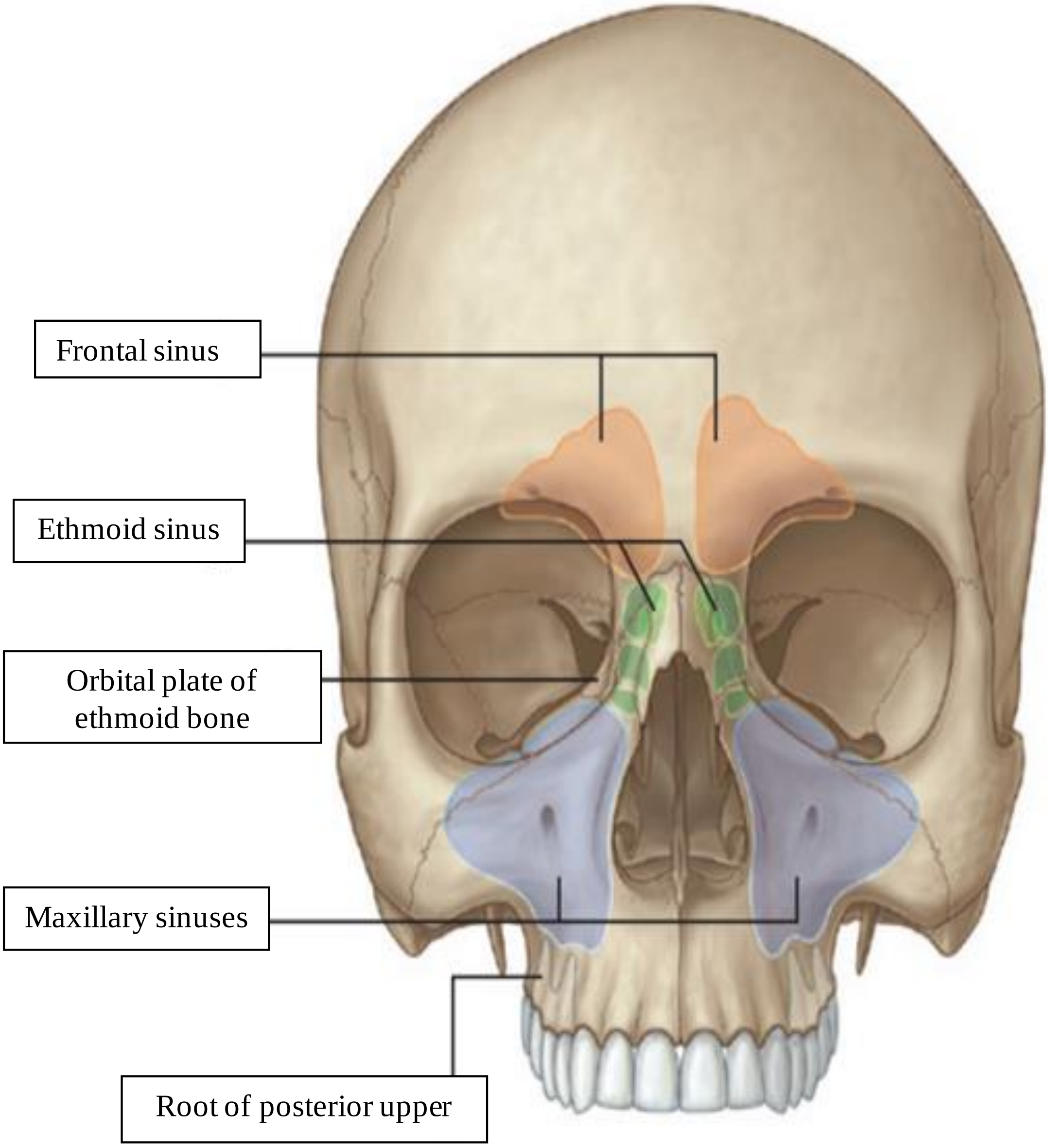

Figure 2.1. Paranasal sinuses and related structures (adapted f*rom* Gray's Anatomy for Students, *3rd edition, pp. 1074).*

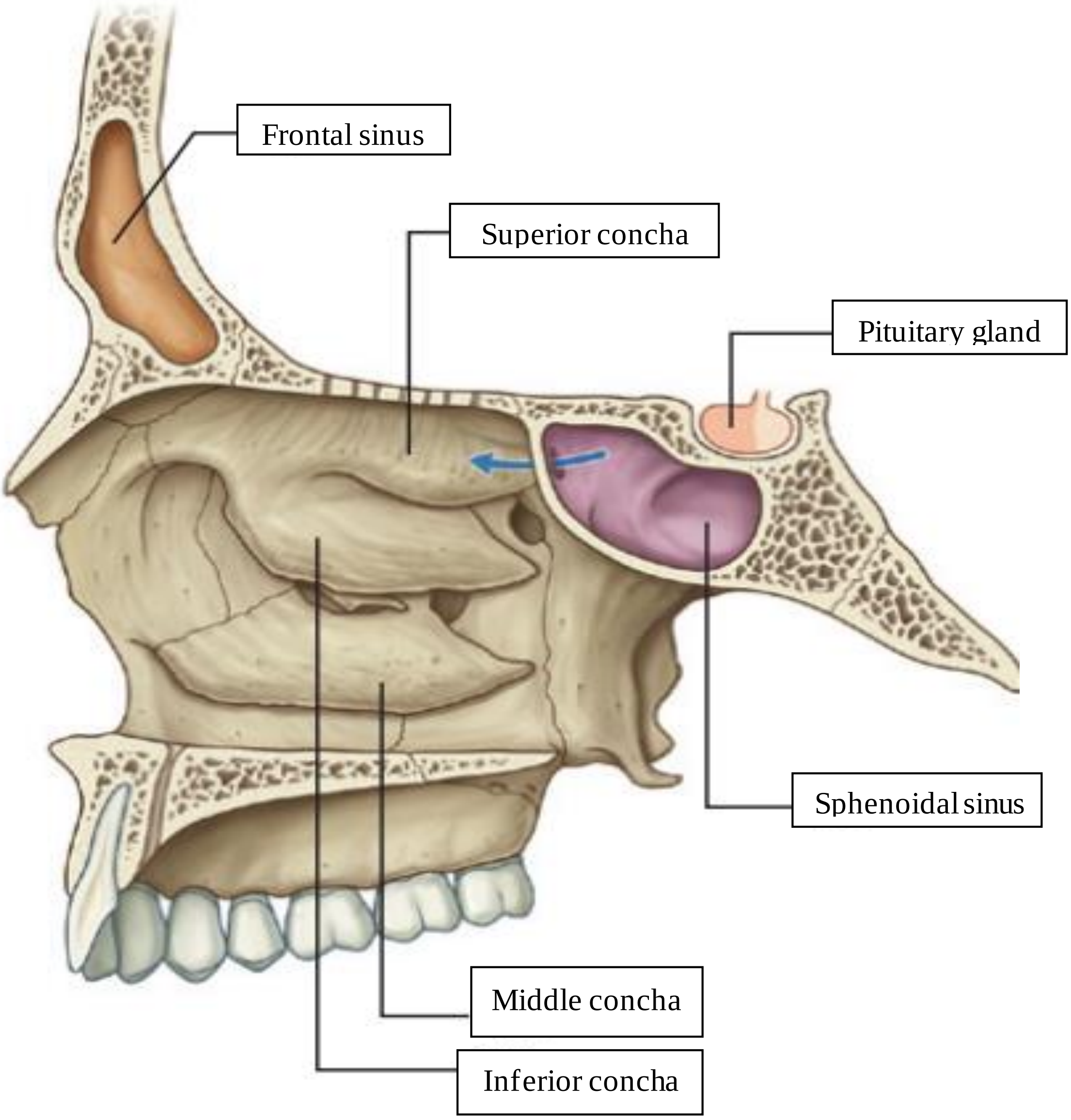

Figure 2.2 Paranasal sinuses and related structures (adapted f*rom* Gray's Anatomy for Students, *3rd edition, pp. 1075).*

2.2 Anatomy of the facial skeleton

The human skull is divided into two parts, which are the cranial vault (neurocranium/brain box) and the facial skeleton. The cranial vault forms the case for the brain and cranial meninges, proximal parts of the cranial nerves and blood vessels of the brain. The facial skeleton or called viscerocranium surrounds the three cavities, which are the oral cavity, nasal cavities, and orbits. Both parts influence facial appearance. The brain box influences the frontal and temporal region, whereas the facial skeleton contributes to the appearance of orbital, nasal, oral, cheeks regions and neck.

According to Moore *et al.* 2013 the following 14 bones: mandible, vomer, paired lacrimal bones, paired nasal bones, paired palatine bones, paired inferior nasal concha, paired maxillary bones, and paired zygomatic bones are considered as the facial skeleton. They play a massive role in facial ageing and external appearance (Figure 2.3).

The two zygomatic bones lie at the upper and lateral parts of the face on both sides. It has a diamond shape and articulates with frontal, temporal, and maxilla through processes. High cheekbones that are a result of zygomatic convexity are considered as an attractive facial appearance in women (Moore *et al.* 2013).

The upper jawbone, called in Latin as maxilla has a body and four processes that articulate with zygomatic, nasal, lacrimal, and palatine bones. Both sides are merged in the midline by intermaxillary suture, forming a bed for upper teeth. Maxilla contains maxillary sinus inside its cavity (Moore *et al.*, 2013).

The nasal bone, which is located on midface, consists of two small, slender, and symmetrical bones. It forms a bridge of the nose superiorly and gives attachment to nasal cartilages inferiorly. Each bone has an external surface that is concave curving outward and covered by nasalis and procerus muscles. Its internal surface curves inward and travels downward and contains a groove for a branch of the nasociliary nerve. Nasal bones are related to the cranium by the frontal and ethmoid bone and facial skeleton by opposite nasal and maxillary bones (Moore *et al*. 2013).

Inside the nasal cavity, a spongy bone, inverted upon itself like a spiral called inferior nasal concha, helps to enlarge the surface area of the nasal cavity. It has two surfaces, a convex medial and a concave lateral surface. Anteriorly, it articulates with the frontal process of maxilla, anteromedially with lacrimal and ethmoid bones, and posteromedial with the perpendicular plate of the palatine bones (Moore *et al*. 2013).

At the back of the nasal cavity, a paired thin L- shaped bones contain two plates: a horizontal plate that forms the roof of the mouth (posterior portion of the hard palate) and perpendicular plate that forms the posterior aspect of the lateral wall of the nasal cavity. This bone is named palatine bones. Each bone articulates with six bones: sphenoid, ethmoid, maxilla, inferior nasal concha, vomer, and the contralateral palatine bone (Moore *et al.*,2013).

The smallest paired bones in the face are lacrimal bones that form the anterior part of the medial wall of the orbit. It articulates with the frontal, ethmoid, maxilla, and inferior nasal concha. It has two surfaces (internal and external) and four borders, each one connected to the related bone that has been mentioned earlier (Yung*, & Logan*. 1999)

The vomer is a singular, thin, midline bone forming the inferior posterior aspect of the nasal septum, along with a perpendicular plate of the ethmoid bone. It is also attached to the body of the sphenoid and both maxillary bones (Moore *et al.*,2013).

The jawbone, also called the mandible, is the largest and strongest bone of the facial skeleton. It has a horseshoe shape, forming the only non-sutured joint the cranium (temporomandibular joint). It consists of a horizontal part called the body, and two vertical portions called rami, which fused with the body at the angle of the mandible. The upper border of the body forms a socket of upper teeth, known as the alveolar process. Its lower border is called the base of mandible and contains a small depression called digastric fossa. The ramus of mandible has two processes, the condylar processes that project from the posterosuperior part, consisting of head and neck. They form an articular surface of the temporomandibular joint. A triangular projection from the anterosuperior part is called the coronoid process. (Moore *et al.*,2013)

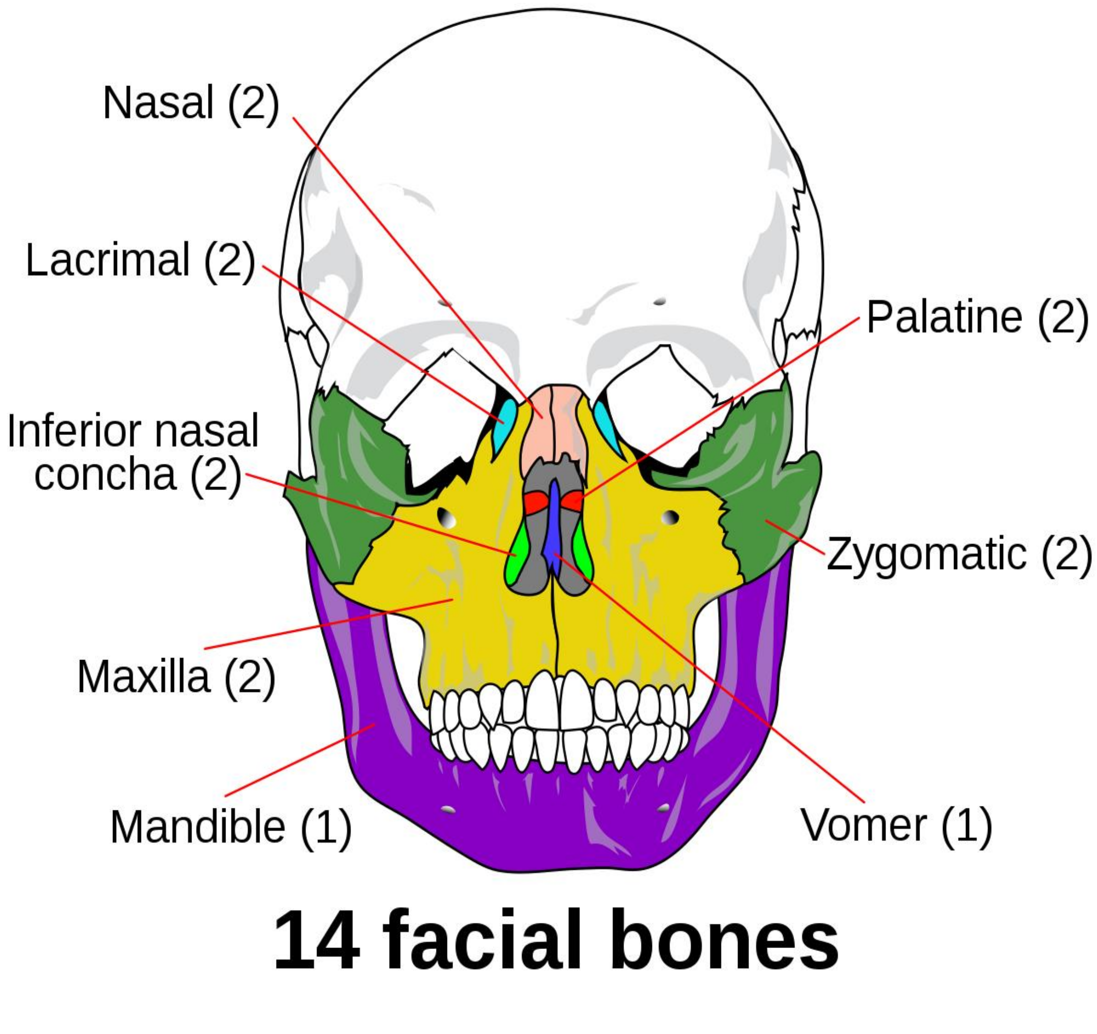

Figure 2.3. Facial bones: Most of them paired like maxilla and nasal bone. Only vomer and mandible are singular (reprinted from Wikipedia).

2.3. Development of the facial region

Knowledge about the embryology of the facial region is essential for understanding the occurrence of normal variations in facial structure and congenital anomalies. During the fourth to eighth weeks of gestation, most embryological development of facial region occurs via several coordinated and overlapped events (Som *et al.*,2013). The first site of the future face is an oropharyngeal membrane located between primitive heart and brain. It starts to break down in the fourth week to form the oral cavity (stomodeum or primitive mouth) and the foregut (Schoenowolf *et al.*, 2015). Around the oropharyngeal membrane, two sources forming the external face. First, frontonasal process tissues derive from neural crest cells, and the second source is a tissue of the mandibular arch, which is derived from mesoderm and neural crest cells. The frontonasal region further gives rise to a pair of the lateral nasal process that develops as a result of the migration of midbrain neural crest cells between the area of the future lens placode and the optic cup while forebrain neural crest cell migration will form a pair of the medial nasal process (Som *et al.*,2013).

As been shown in figure 2.4. The frontonasal process forms the forehead, the nasal root to the tip, and the nasal bones. The most anteroinferior part of the nasal septum, medial cleft of the upper lip, the perpendicular plate of the ethmoid bone, the vomer, the cribriform plates, and the primary palate are developed from the medial nasal process. At the same time, the alae of the nose and its sides develop from the lateral nasal. The maxillary processes which develop from the first pharyngeal arch are responsible for forming most of the upper lip, the maxilla, zygoma, upper cheek region, and secondary palate whereas mandibular processes that also rise from the first pharyngeal arch will form the chin, lower lip, lower cheek regions, and the mandible (Schoenowolf *et al.*, 2015).

The initial facial skeleton is cartilaginous by eight to nine weeks. It consists of the nasal capsule at the upper face while Meckel cartilage in the lower face. Around 12 weeks of development, ossification starts within membranous bones and endochondral ethmoidal bones. In the first year of life, the metopic suture unites, and soon after, the mandibular symphysis unites. Then the greater sphenoid wings unite with the sphenoid body. These changes close the midline sagittal suture system, and it ceases to be a growth site. Between 17 – 20 weeks (late fetal period) and until the first postnatal year, the width growth of the craniofacial skeleton occurs at the midsagittal suture system. The principal cause for this development is the continuous brain expansion and cartilage development between the body and the greater wings of the sphenoid bone.

Later after birth, several sites in the skull start to fuse. These include metopic suture, mandibular symphysis, and greater wings and body of the sphenoid bone. These become growth sites that allow developing continually and remodelling of facial bones, which later give variations in facial morphology (Som *et al.*,2014).

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Figure 2.4. Diagram of an anterior oblique aspect of the late fatal face, including the contributions of the numerous facial processes. Green colour shows the frontonasal process; in yellow, the lateral nasal processes; while purple, is the medial nasal processes; the maxillary processes coloured by orange; and the mandibular processes by blue. (Adapted from Som *et al.*,2013)

2.4. Development of paranasal sinuses

At birth, the ratio of the volume of the facial skeleton to skullcap is around 1:7. During the growth period, this ratio steadily decreases due to the formation of teeth, viscerocranium, together with the growth of four pairs of paranasal sinuses: maxillary, ethmoid, sphenoid, and frontal sinuses (Schoenowolf *et al.*,2015).

Nose and paranasal sinuses start to form around the fourth week of gestation from a combination of ectoderm, mesoderm, and neural crest cells (figure 2.5). The ectoderm gives rise to the outer layer and covering of the face. The mesoderm forms the precursors for the facial muscles, and the neural crest cells grow into the vessels and nerves (Zalzal *et al.*,2018).

Inside the nasal cavity, numerous out pouches appear during the development of paranasal sinuses. The maxillary, ethmoid, and frontal sinuses grow from invaginations of the nasal cavity that extend into the bones, while the sphenoid sinus forms by the closure of the sphenoethmoidal recess (Schoenowolf *et al.*,2015).

The maxillary sinus is the largest of the paranasal sinuses. It is located inferior to the orbital cavity within a maxillary bone, above the teeth, and on the sides of the nose. It arises during the third to fourth gestational month as invaginations of the nasal sac that slowly enlarge within the maxillary bones. At birth, they are like pea-size but continue to inflate throughout childhood. The early invagination of the sinus is called primary pneumatization, whereas the dilation is known as secondary pneumatization (Schoenowolf *et al.*,2015).

The frontal sinuses lie above the orbital cavity within frontal bone. Initial development occurs around the fourth or fifth week of gestation and continues in the postnatal period through puberty and even early adulthood (Al-Bar *et al.*,2016). The frontal sinuses are absent radiographically until the fifth or sixth postnatal year (Adibelli *et al.*,2011). Each frontal sinus consists of two independent spaces that develop from different sources. One space form by the expansion of the ethmoid sinus into the frontal bone and the other develops from an independent invagination of the middle meatus of the nasal passage (the space underlying the middle nasal concha). Because these cavities never coalesce, they drain independently.

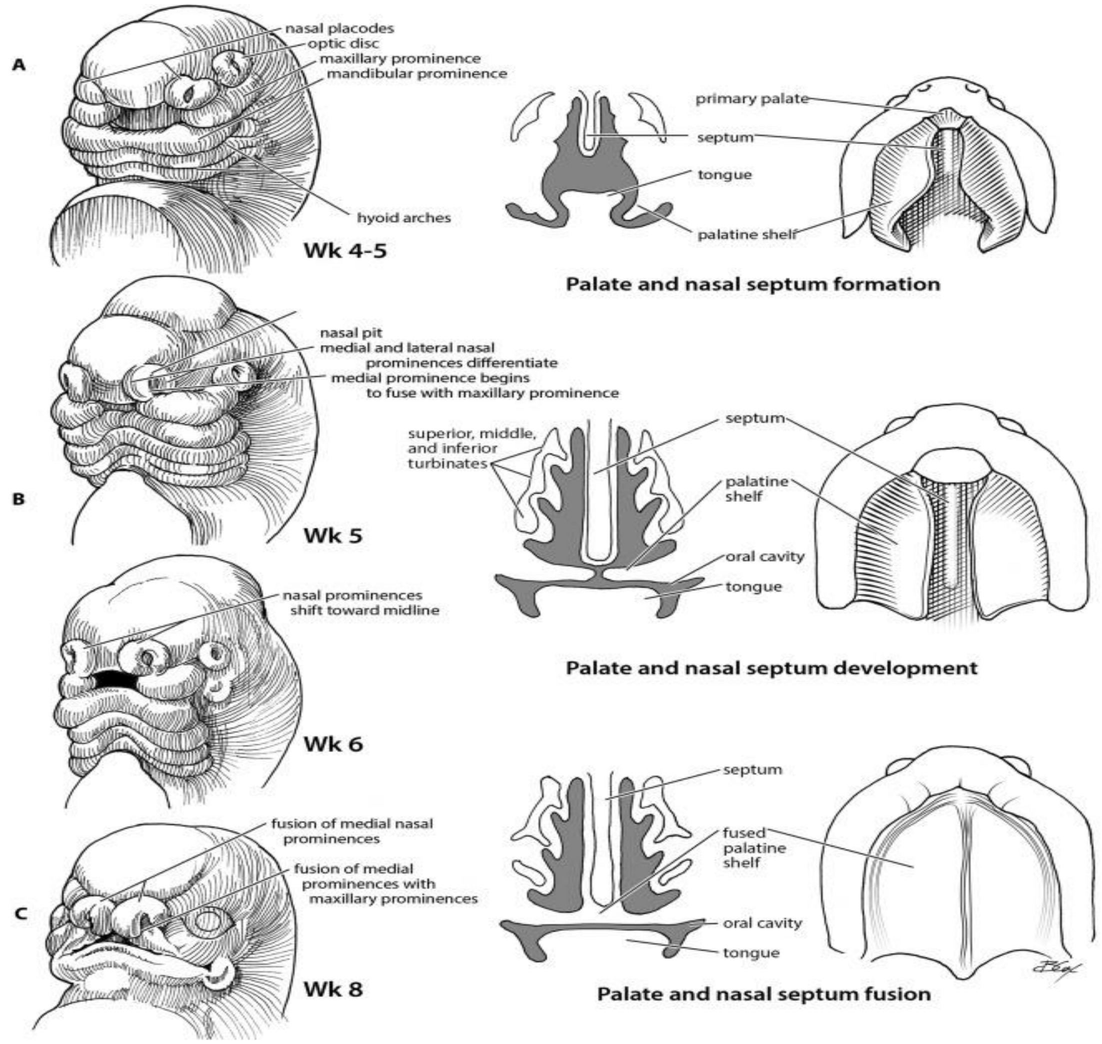

Figure 2.5. Nose and midface structure embryology. (A) Nose and midfacial start grow at week 4-5. On the outward view, the frontonasal, maxillary and mandible prominences are visible. While nasal septum formation can be defined with the palate openings internally. (B) The frontonasal region further gives rise to a pair of medial and lateral nasal processes during weeks 5 to 6, which will become the nasal philtrum and lateral alae, respectively. (C) Between the sixth week to week 8, the paired maxillary processes grow medially and fusion with the paired nasomedial. (Reprinted from Zalzal et al.,2018).

2.5. The use of computed tomography (CT) scan in the skull growth study

Computed tomography is the heart of modern medical imaging to diagnose certain diseases. On many occasions, the CT scan is the gold standard procedure for clinical diagnosis. For example, in oral and maxillofacial investigations, plain radiography could only provide some shreds of evidence. While, in the CT, the images generated in the axial or transverse plane, perpendicular to the long axis of body human, which allows for modern scanner to reformatted in various planes or even as volumetric (3D) representations of structures. Therefore, a CT scan is needed in clinical practice to provide more detailed radiological data required for further management. It has been reported that the use of medical CT imaging is increasing at an estimated annual rate of 15–20%, mainly due to its effectiveness and affordability (Vannier, 2003). Since its introduction in the mid-1970s, CT scan has technologically advanced every decade. Principally, this is due to consequent perfections in instrumentation that have improved the functions in speed and image quality. At the beginning of the 1990s, a spiral or helical CT scan became the gold standard radiological investigation for many diseases.

CT scanning has been used since its invention for craniofacial imaging. However, it was not widespread until high resolution' scanners with slice thicknesses of 2 mm (in comparison with the old version, that provided 1 cm slice thicknesses) in the early 1980s. In the later 1990s, craniofacial cone-beam CT scanners were developed and later transformed into commercial products.The Elscint CT Twin was launched in 1992 as the first multiple slice generation scanner. Since recent multislice CT was developed, it became the main advancement of Spiral CT (Vannier, 2003). He concluded that the low price of craniofacial CT scanners is significantly different from general-purpose medical CT scanners, with concessions in technical performance. Regardless of their limitations, these devices are remarkably valuable for their planned application field and are expected to become more advance and improve in performance parallel with the advancement in computer applications.

Computed tomography scan has been proven to be accurate in measuring craniofacial parameters. This is evidenced in a study by Waitzman *et al.* (1992), where they tried to evaluate whether CT measurements of the upper craniofacial skeleton accurately represent the bony regions imaged. In their study, eight measurements were performed on five dry skulls from three adults, over 18 years of age, one four-year-old and one six-month-old skulls, both directly on the dry skulls, and indirectly by axial CT scan. The result showed a significant agreement between the direct (dry skull) and indirect (CT) measurements. In addition to that, the effect of head tilt on the accuracy of these measurements was examined. The error was within clinically acceptable limits (less than 5 percent) if the angle was no more than + 4° from baseline (0°) (Waitzman *et al.* 1992). This study concluded that craniofacial measurements obtained from CT scans are accurate and reproducible. Computed tomography scan, therefore, can be used as an objective tool to assist with diagnosis and guide presurgical planning. The use of CT should facilitate the normalisation of skeleton deformities in patients and assist in follow-up evaluation. Computed tomography has also been widely used as a reliable radiological tool to study the measurements of paranasal sinuses. For example, Dhakr *et al.* (2018) investigated the normal upper and lower limit values of different dimensions of maxillary and frontal sinuses by using CT scans. It has been found that the CT scan is a very reliable and ideal method for obtaining the measurement for different dimensions of paranasal sinuses (Dhakr *et al.*,2018).

2.6. Midface growth and their defects

Recently, there is an increasing need for the availability of craniofacial development data. This is since many clinicians, such as plastic and maxillofacial surgeons, face challenges in their decision making on their patients' surgical management. They need to know in detail how the midface constantly changes from birth to adulthood. As cited by Thilander, (2017), a thorough understanding of growth and development in 'normal' cases is crucial in diagnosing different types of malocclusion. Growth and development of the different parts of the skull (cranial base, nasomaxillary complex, and mandible) form the fundamental for a detailed diagnosis and the treatment plan for any patient with any type of malocclusion (Thilander, 2017).

Development of face is often described as a simple growth process anteriorly and inferiorly (Enlow, & Hans. 1990; Lieberman, 2011). Embryologically, the bone formation has two models of development, either by endochondral ossification with a cartilage model or by a direct intramembranous formation. Even though the beginning of the processes is different, once completed, bones of both origins are modelled and remodelled in the same way. The fact that the facial skeleton consists of fourteen intramembranous bone, which leads to creating several ossification centres, helps to understand the postnatal ontogeny of the face by examining the separate midface modules (Wheat, 2015). However, the growth of craniofacial complex bone is influenced by genetic, epigenetic, and environmental factors (Przystanska *et al.*,2018). These factors lead to craniofacial anomalies, which have increased in the past decade. A study on mice treated with a high dosage of ethanol during pregnancy shown an anterior neural plate deficiency and cleft lip with increased cell death (Sulik, 2005).

Furthermore, a study in the early 1980s suggested that the mode of breathing influences midface growth has created a considerable controversy (McNamara JR, 1981; Harari *et al.*, 2010). In a more recent study, the researcher examined the effect of mouth breathing during childhood on craniofacial and dentofacial development compared to nasal breathing in malocclusion patients (Harari *et al.*, 2010). In this retrospective study, 116 pediatric patients who had undergone orthodontic treatment were examined. Fifty-five pediatric patients complained from symptoms and signs of nasal airway obstruction, which means they are mouth breathers while 61 patients were normal nose breathers. Radiographic cephalometric analysis was made on the standardized lateral head plates to compare the parameters that might be influenced by the different modes of breathing in the two groups. The result of this study showed a significant difference between the mouth breathers and control groups in the horizontal, vertical, and lateral cephalometric dimensions. Moreover, this study concluded that nasal obstruction with mouth breathing during critical growth periods in children has a higher tendency for clockwise rotation of the developing mandible, with an unequal increase in anterior lower vertical face height and decreased posterior facial height.

Despite the fact that several studies have shown the effect of environmental risk factors in craniofacial parameters such as smoking during pregnancy, maternal alcohol consumption and abnormal diets of pregnant, there is still need for more studies and collaborations to elucidate better the issues surrounding the management of midface defects and the development of the craniofacial skeleton.

2.7. Paranasal sinuses growth and their relationship to the midface

Anatomical structures of the paranasal sinuses have been identified since the beginning of the twentieth century (Vaid, S., & Vaid, N., 2015). However, In the literature, there is little information on sinus growth. A few scholars investigated the formation of paranasal sinuses; nevertheless, most of these studies used small sample sizes and included few age cohorts (Adibelli *et al.* 2011).

The development of paranasal sinuses starts from nasal placodes that differentiate from the frontonasal prominence and later grow into the nasal cavity and choana. Around the seventh month of gestation, the ethmoid bone is a central structure in the forming skull base. It starts to be developed from the folding of the cartilaginous olfactory capsule. As a result, the first sinus that develop during childbirth is ethmoid sinuses. In contrast, the other sinuses (frontal, maxillary, and sphenoid) develop due to pneumatization beyond the confines of the olfactory capsule. Therefore, the ethmoid sinus is totally unlike the other air-containing paranasal sinuses phylogenetically, anatomically, embryologically. Functionally Each group of sinuses has a pneumatic pattern and the frequent shifts in the size of sinuses and its aeration as a child continuously grows up, has a significant influence on the treatment plan of sinus pathology in the pediatric age group (McKinney *et al.* 2018). Table 2.1 outlines showed each growth pattern of the sinus group and the ostiometal complex with the resultant clinical implications.