j

Sudan University of Science and Technology

College of Graduate Studies

Volumetric Analysis of the Paranasal Sinuses Using CT Among Chronic Sinusitis Patients

التحليل الحجمي للجيوب الأنفية باستخدام الأشعة المقطعية لدى الأشخاص المصابين بالتهاب الجيوب الأنفية المزمن

A Thesis Submitted for the Requirements of the fulfillment of the Award

Ph.D. Degree in Diagnostic Radiological Technology

By:

Abbas Omer Hussein Ahmed

(M.Sc. in Diagnostic Radiological Technology, Al-Ribat National University, 2014)

Supervisor:

Dr. Mohamed Mohamed Omer Yousef

Associate Professor

Co – Supervisor:

Dr. Mohammed Ahmed Ali Omer

Associate Professor

2021

الآيـة

﴿قَالَ عِفْرِيتٌ مِّنَ الْجِنِّ أَنَا آتِيكَ بِهِ قَبْلَ أَن تَقُومَ مِن مَّقَامِكَ ۖ وَإِنِّي عَلَيْهِ لَقَوِيٌّ أَمِينٌ * قَالَ الَّذِي عِندَهُ عِلْمٌ مِّنَ الْكِتَابِ أَنَا آتِيكَ بِهِ قَبْلَ أَن يَرْتَدَّ إِلَيْكَ طَرْفُكَ ۚ فَلَمَّا رَآهُ مُسْتَقِرًّا عِندَهُ قَالَ هَٰذَا مِن فَضْلِ رَبِّي لِيَبْلُوَنِي أَأَشْكُرُ أَمْ أَكْفُرُ ۖ وَمَن شَكَرَ فَإِنَّمَا يَشْكُرُ لِنَفْسِهِ ۖ وَمَن كَفَرَ فَإِنَّ رَبِّي غَنِيٌّ كَرِيمٌ﴾

صدق الله العظيم

سورة النمل: الآية (٣٩-٤٠)

Dedication

To the soul of my mother and my father Omer who have been glistering as a diamonds to lit my way and have been sincerely encourage and fostering me throughout my study-hood, I dedicate the benefits of this humble work.

To my wife and daughter and son for their patience, understanding and encouragement

Acknowledgment

Thanks with supplications and prayers to Allah the most compassionate and merciful.

Then my sincere acknowledgement and indebted thanks to my supervisors Dr. MOHAMMED YOUSEF And Dr. MOHAMMED ALI OMER

*For their contact supervision, inexhaustible patience, constant encouragement, and for giving me a valuable times, guidance, criticism and corrections to this thesis from beginning up to end ****

ABSTRACT

Volumetric of air sinuses contributes in diagnosis of sinus pathologies, and applied in forensic field. The aim of the study was to estimate the volumes of paranasal sinuses in Saudi Arabia Qassim region relative to right, left, gender and age in normal patients and to compare paranasal sinus volumes of chronic rhinosinusitis (CRS) patients to unaffected controls.

This study is retrospective based on CT images for a sample consisted of 50 normal controls (24 males, 26 females) and101 patients with chronic sinusitis (47 males, 54 females) ranging from 1 to 83 years. The volumes obtained by axial manual segmentation of the air sinuses using 3D Slicer Program.

Normal sample group divided into six age groups**;** 1-5; 6-10; 11-15; 16-20; 20-25 and more than 25 years old. The results showed that: the volume of the maxillary air sinus was the largest and the sphenoid and frontal air sinuses were the smallest, and the mean volumes of maxillary, ethmoid, frontal and sphenoid were 13.1, 4.6, 3.4 and 3.4 cm respectively. When we compared the growth of the air sinuses with age groups, the results showed that; the air sinuses have significant proportional correlation with aging and the data revealed that; the maximum volume reached by maxillary, ethmoid, frontal and sphenoid were at age groups 21-25,16-20,16-20 and 21-25 years respectively. While the growth of ethmoid and sphenoid sinuses decreased after reaching the maximum volume; the maxillary and frontal sinuses followed by a plateau thereafter.

The data revealed that the growth rates of the two sides were symmetrical for all sinuses except for the frontal air sinuses in which the left air sinus appears to grow at a faster rate than the right side in the period from16 to 20 years old. Male sinuses volumes were greater than female in different age groups for all sinuses except both sphenoid sinuses.

Chronic sinusitis group divided into two age groups: more than 20years old (n=82) and less than 20 years (n=19) to compare with normal unaffected group; more than 20years (n=26) and less than20 years (n=24). The results showed that; the commonly involved gender with sinuses pathologies was the female, with a 53.5% relative to male. The chronic sinusitis infected older ages (more than 20years old) with a percent of 81.18% more than the younger one (less than 20 years old) with a percent of 18.81%.The study revealed that the common involved sinuses were the maxillary sinuses followed by ethmoid sinuses , the mean of bilateral maxillary and ethmoid sinus volumes in the chronic sinusitis patients were smaller than that in the normal or control group, the mean bilateral frontal and sphenoid sinus volumes in the chronic sinusitis patients were similar to the normal or control group.

مستخلص البحث

يساهم القياس الحجمي للجيوب الهوائية في تشخيص أمراض الجيوب الأنفية ، ويتم تطبيقه في مجال الطب الشرعي. كان الهدف من الدراسة هو تقدير حجم الجيوب الأنفية في منطقة القصيم في المملكة العربية السعودية بالنسبة إلى موقع الجيب الانفي (اليمين واليسار) والجنس والعمر في الأشخاص السليمين ومقارنة أحجام الجيوب الأنفية لمرضى التهاب الجيوب الأنفية المزمن باحجام الجيوب الأنفية للأشخاص السليمين. تعرف منهجية الدراسة كدراسة بأثر رجعي تعتمد على صور التصوير المقطعي المحوسب لعينة من ٥٠ ضابطًا عاديًا (شخص سليم) و ١٠١ مريضًا مصابًا بالتهاب الجيوب الأنفية الأحجام مشتقة من تجميع مناطق الجيوب الأنفية وضربها في سماكة الشريحة في المستوى المحوري للصورة المقطعية التي تعتمد على برنامج التقطيع ثلاثي الأبعاد. تكونت مجموعة العينة الطبيعية(الأشخاص السليمين) من ٢٤ ذكر و٢٦ أنثى. تم تقسيمهم إلى ستة فئات عمرية ؛ ١-٥ ؛ ٦-١٠ ؛ ١١-١٥ ؛ ١٦-٢٠؛٢٥-٢٠؛ واكبر من ٢٥سنة. أظهرت النتائج أن: حجم الجيوب الفكية هو الأكبر ، والجيوب الجبهية والوتدية هي الأصغر ، ومتوسط أحجام الجيوب الفكية ، الغربالية ، الجبهية والوتدية كان كالأتي : ١٣.١ ، ٤.٦ ، ٣.٤ و ٣.٤ سم مكعب على التوالي. وعندما قارنا نمو الجيوب الهوائية مع الفئات العمرية أظهرت النتائج أن للجيوب الهوائية ارتباط نسبي كبير مع تقدم العمر وقد كشفت البيانات الاتي ؛ كان الحجم الأقصى الذي بلغته الجيوب الفكية ، الغربالية ، الجبهية والوتدية في الفئات العمرية ٢١-٢٥ ، ١٦-٢٠ ، ١٦-٢٠ ، ٢١-٢٥ سنة على التوالي بعد الوصول إلى الحجم الأقصى انخفض نمو الجيوب الغربالية والجيوب الوتدية بينما لم يحدث تغيير في الجيوب الفكية والجبهية وكشفت البيانات أن معدلات نمو الجانبين للجيوب الهوائية(اليمين واليسار) كانت متماثلة لجميع الجيوب الأنفية باستثناء الجيوب الجبهية حيث يبدو أن الجيب الجبهي الأيسر ينمو بمعدل أسرع من الجانب الأيمن في الفترة من ١٦ إلى ٢٠ عامًا. كانت أحجام الجيوب الأنفية للذكور أكبر من الإناث في مختلف الفئات العمرية لجميع الجيوب ما عدا الجيوب الوتدية . تتكون مجموعة المرضى بالتهاب الجيوب الأنفية المزمن من ٤٧ ذكر و ٥٤ أنثى. تم تقسيمهم إلى فئتين عمريتين أصغر من ٢٠سنة (عدد = ١٩) وأكبر من ٢٠ سنة (عدد = ٨٢) لمقارنتها مع المجموعة السليمة غير المتأثرة أظهرت النتائج الاتي؛ كان الجنس الشائع مع أمراض الجيوب الأنفية هو الأنثى بنسبة ٥٣.٥ ٪ مقارنة بالذكور. أصاب التهاب الجيوب الأنفية المزمن كبار السن (أكبر من ٢٠ سنة) بنسبة ٨١.١٨٪ أكثر من الأصغر سنا (أقل من ٢٠ سنة) بنسبة ١٨.٨١٪ .

أوضحت الدراسة أن الجيوب الأنفية الأكثر أصابة كانت الجيوب الأنفية الفكية تليها الجيوب الغربالية ، وكان متوسط أحجام الجيوب الأنفية الفكية والغربالية في مرضى التهاب الجيوب الأنفية المزمن أصغر من تلك الموجودة في المجموعة السليمة أو المجموعة الضابطة ومتوسط أحجام الجيوب الأنفية الأمامية والجيوب الوتدية الثنائية. في مرضى التهاب الجيوب الأنفية المزمن كانوا مشابهين للمجموعة السليمة أو مجموعة التحكم.

Table of Contents

Lists of Tables

Lists of figures

List of Abbreviation

CT	Computed Tomography
PAS	Paranasal sinuses
3D	Three dimension
CRS	Chronic Rhinosinusitis
CF	Cystic Fibrosis
RS	Rhinosinusitis
ARS	Acute Rhinosinusitis
AIFRS	Acute Invasive Fungal Rhinosinusitis
HIV	Human Immunodeficiency Virus
EPOS	European Position Paper On Rhinosinusitis
CrswNP	Chronic Rhinosinusitis With Nasal Polyps
CRSsNP	Chronic Rhinosinusitis Without Nasal Polyps
RT-PCR	Real-Time Polymerase Chain Reaction
TLR	Toll-Like Receptors
NP	Nasal Polyps
AFRS	Allergic Fungal Rhinosinusitis
ENT	Ear, Nose and Throat
MRI	Magnetic Resonance Imaging
FESS	Functional Endoscopic Sinus Surgery
MDCT	Multidetector Computed Tomography
HU	Hounsfield Unit
FOV	Field Of View
DICOM	Digital Imaging and Communications in Medicine

Chapter One
Introduction

1.1 Introduction

The paranasal sinuses are hollow, air-filled spaces located within the bones of the face and base of the skull surrounding the nasal cavity. There are four pairs of sinuses, each connected to the nasal cavity by small canal. They include the frontal, ethmoidal, maxillary and sphenoid sinuses (Sobiesk and Munakomi, 2020).

The paranasal sinuses are found by three essentially components; thin normal mucus secretions, normally functioning hair-like cilia that move the mucus out of the sinuses and open sinus drainage openings (called sinus ostium). These components allow continuous clearance of secretions. Interference with any of these three components of the normal sinuses may predispose to sinusitis. Conditions that interfere with drainage of a sinus like inflammation or foreign bodies also predispose to infection. If the ostium of a sinus is blocked, the secretions or exudates accumulate behind the obstruction (Alho, 2004).

The function of the sinuses are; decreasing the relative weight of the front of the skull, increasing resonance of the voice, providing a buffer against blows to the face, insulating sensitive structures like dental roots and eyes from rapid temperature fluctuations in the nasal cavity and humidifying and heating of inhaled air because of slow air turnover in this region(Stamm, Draf, 2012).

They develop as diverticulae of the nasal cavity at the end of the third intrauterine month, maintaining communication with it via patent ostia (Chang et al, 2014). These out pouchings expand into the maxillary, sphenoid, frontal and ethmoid bones by growth of the mucous membrane sacs. This may be regarded as primary pneumatization (Scuderi et al, 1993).

Computed tomography (CT) is currently the modality of choice in the evaluation of the paranasal sinuses and adjacent structures. Its ability to optimally display bone, soft tissue, and air provides an accurate depiction of both the anatomy and the extent of disease in and around the paranasal sinuses. In contrast to standard radiographs; CT clearly shows the fine bony anatomy of the ostiomeatal channels. With the use of double spiral scanners or multidetector technology, the slice thickness can be reduced to 0.5 mm or less. For the pediatric, elderly, and debilitated patients who may not be able to remain still for prolonged periods of time, this technique offers the best opportunity to acquire a motion-free, high-quality study(Zinreich et al, 2003).

There have been several studies focus on the volume of the paranasal sinuses and the literature reviewed reveals that the volume of the air sinuses is the most important parameter that can establish its size and these normal values may be useful in the diagnosis of sinus pathologies (Emirzeoglu et al, 2007), and in forensic identification of sex and ancestry (Fernandes, 2004). Therefore, evaluating volume and morphology in 3D of the PAS would theoretically be more accurate than closest estimates, offering values that are the best fit to their natural measurements(Apuhan et al, 2011) .

Various methods have been utilized in the literature to measure the volume of the paranasal sinuses. In the latest studies, volume rendering techniques and three dimensional (3D) reconstruction models have been developed(Jun et al, 2005; Park et al, 2010; Apuhan et al, 2011).Currently, CT imaging is the radiological technique of choice for analyzing the paranasal sinuses, as the distinction between bone, mucosa and other soft tissue can be clearly defined (Apuhan et al, 2011). According to (Lee et al, 2012) 3D reconstructions from these CT images are able to yield a more precise form or 3D morphology of the paranasal sinuses.

Chronic rhinosinusitis is an inflammatory disease of the paranasal sinuses that occurs in 1% to 5% of the U.S. population. It may significantly decrease quality of life. Chronic rhinosinusitis is defined by the presence of at least two out of four cardinal symptoms (i.e., facial pain/pressure, hyposmia/anosmia, nasal drainage, and nasal obstruction) for at least 12 consecutive weeks, in addition to objective evidence. Objective evidence of chronic rhinosinusitis may be obtained on physical examination (anterior rhinoscopy, endoscopy) or radiography, preferably from sinus computed tomography (Sedaghat, 2018).

The cause for these differences and their impact on sinonasal disease is unclear (Wine et al, 1991; Eggesbø et al, 2003; Chang et al, 2012), and is frequently associated with chronic sinus disease (Wine et al, 1991). This raises the relevant question of whether the relationship between sinus pneumatization and mucosal disease can apply as a generalization. This remains incompletely resolved because paranasal sinus pneumatization has been difficult to quantify (Wine et al, 1991).

This study aimed to calculate volume of normal growth of the PAS from ages 1 to 83 years, and its relationship to age, sex, laterality and to compares paranasal sinus volumes of chronic rhino sinusitis patients to unaffected controls within a Saudi Arabia population using Computerized tomography.

1.2 Problem of the study:

The problem of this study that the wide variation in paranasal sinus volumes, but the cause for these differences and their impact on sinonasal disease is unclear, and is frequently associated with chronic sinus disease. There is lack of studies in this entity to study the volumes of Para nasal sinus (PNS) and this remains incompletely resolved because paranasal sinus pneumatization has been difficult to quantify.

1.3 Objectives of the study:

1.3.1 general objective

The purpose of this study is to study the relation of age, gender and pathological issues in the sinuses volumes.

1.3.2 Specific objectives:

- To generate the average volumes of paranasal sinuses in Saudi samples
- To compare between the air sinuses' growth according to ages
- To compare between the air sinuses' growth according to sides
- To compare between the air sinuses' growth according to gender
- To detect the common involved gender with sinuses pathologies
- To determine the common involved sinuses with pathologies,
- To classify the most age groups affecting by sinuses pathologies
- To compare between means volume of paranasal sinuses in control group and chronic sinusitis group related to age g and gender and side.

1.4 Overview of this study:

This study consists of five chapters, chapter one consist of an introduction; introduce briefly this thesis and it was containing general introduction about CT scan of Para nasal sinuses, problem of the study, general and specific objectives in addition to the over view of the study. Chapter two was the literature review which contains the general theoretical background and previous study about detection of these diseases during CT scan for PNS. Chapter three describe the methodology (material and method) that used in this study. Chapter four was including result of presentation of the final finding of the study. Chapter five was including discussion, conclusion and recommendations for future scope in addition to references and appendices.

Chapter Two
Literature Review

2.1 Anatomy

The paranasal sinuses are connected system of hollow air field cavities in the skull which communicate with the nasal cavity and lined by ciliated mucous membrane. They develop as out Pouching from the nasal passages and are sufficiently will developed to be demonstrable in radiographs at four or five years of age and do not stop growing until age 18 years old (Sobiesk and Munakomi, 2020)

In all, there are eight sinuses they are divided into two groups; the anterior and posterior groups the anterior group consist of the two maxillary sinuses (antra), the two frontal sinuses and the two anterior and middle ethmoidal sinuses. The posterior group comprises the two posterior ethmoidal sinuses and the two sphenoidal sinuses (Figure2.1) (Sobiesk and Munakomi, 2020).

The anterior group drainage into middle meatus which is bordered by the middle turbinate bone and the posterior group drainage into superior meatus (which is a space defined by superior turbinate bone) and the sphenoethmoidal recess (Figure2.1) (Sobiesk and Munakomi, 2020).Although in a minority of patients some of the sinuses do not fully form. These hypo plastic (incompletely formed) or a plastic sinus (completely unformed) are often an incidental finding, usually not associated with any increased sinus problems, although in some instances they should be addressed (Sobiesk and Munakomi, 2020).

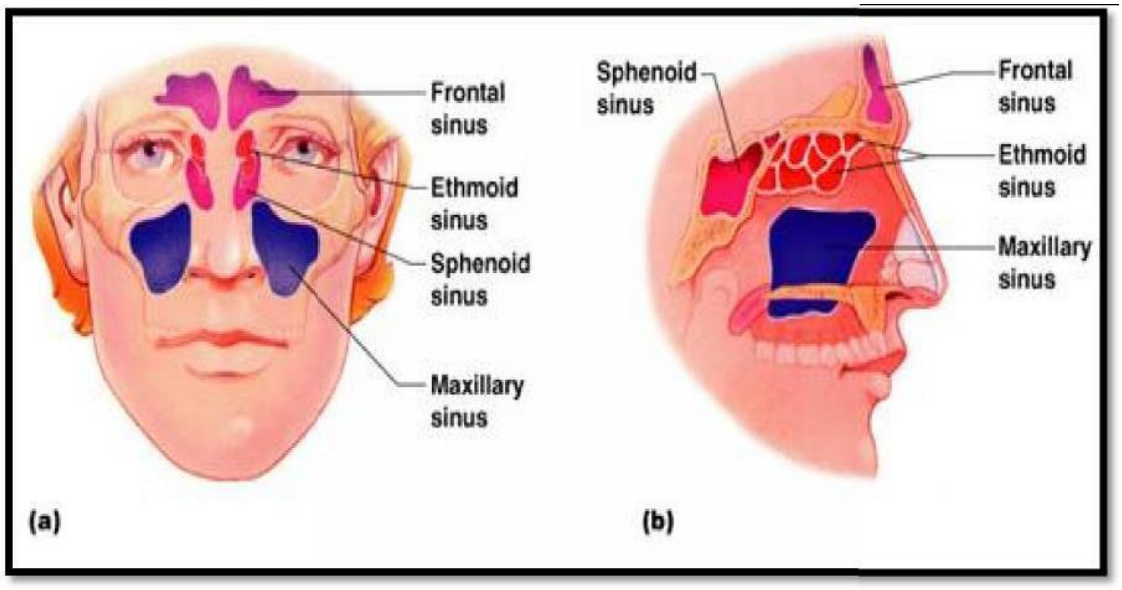


Figure (2.1): Anatomy of paranasalsinuses: (a) anterior view (b) side view (Marieb, 1998)

2.1.1 The Maxillary Sinus

The maxillary sinus (antrum of Highmore) is the first to develop. These structures are usually fluid-filled at birth. The growth of these sinuses is biphasic with growth during years 0-3 and 7-12. During the later phase pneumatization spreads more inferiorly as the permanent Teeth take their place. Pneumatization can be so extensive as to expose tooth roots with only a thin layer of soft tissue covering them (Sobiesk and Munakomi, 2020).

The three molar teeth are directly related to the floor of the sinus and related to pre-molars less frequently. The ostium of the maxillary sinus is located superiorly on the sinus's antero-medial wall and opens via the ethmoidal infundibulum in the middle meatus. The orbital floor is formed predominantly from the roof of the maxillary sinus. Between the roof of the maxillary sinus and the floor of the orbit lies the infraorbital canal through which runs the infraorbital artery and nerve. The maxillary sinus itself is lined by ciliated columnar epithelium, which is directly

related to its physiological function. The facial, maxillary, infraorbital and greater palatine arteries and veins supply and drain the maxilla. As this study is performed on dry crania this aspect of the anatomy and physiology will not be detailed further(Lund, 1997).

2.1.2The ethmoid sinuses and related anatomy

This bone is comprised of the following parts; two ethmoidal labyrinths attached to a perpendicular plate, Perpendicular plate forming superior portion of nasal septum, Cribriform plate and The crista gallia superior midline extension of the perpendicular plate of the ethmoid. The bone is cruciate in form and exhibits anatomical variation between individuals (Lund, 1997).

The perpendicular plate articulates with the nasal spine of the frontal bone and nasal bones. It also articulates posteriorly with the sphenoid and the vomer.

The crista exhibits variations in length with a mean length of 21.6 mm (Lund, 1997). The crista may be pneumatised to varying degrees although this is rare.

The nasal cavity and the anterior cranial cavity are separated by the presence of the cribriform plates(Lund, 1997).

The ethmoid sinuses essentially consist of a number of air cells divided into anterior and posterior air cells. The number of air cells varies between individuals. The middle turbinate is a shelf of bone protruding into the nasal cavity which attaches anteriorly to the agger nasi and to the nasal process of the maxilla and posteriorly, it attaches horizontally to the inferior portion of the lamina papyracea. In between is an oblique plate of bone attached to the lamina papyracea called the basal lamella, which is part of the middle turbinate and serves to divide the ethmoidal labyrinth into the anterior and posterior ethmoid cells(Lund, 1997).

The most posterior ethmoid cell may extend laterally to the sphenoid and be closely applied to the optic nerve and is referred to as an Onodi cell. The optic nerve is

particularly vulnerable to injury in these cells. There is noted race variation in the incidence with which Onodi cells are found (Lund, 1997). Haller cells are described when ethmoidal cells pneumatise the floor of the orbit. This study will take the presence of these two types of cells into account and assess any race or sex variation that may be present(Lund, 1997).

The bony roof of the ethmoid is provided primarily by the frontal bone. The ethmoid bone is open superiorly over its anterior two thirds. The "roof" for these open cells and ethmoidal clefts is provided by the frontal bone. Because the roof of the ethmoid exhibits much anatomical variation, it is essential that the surgeon have a thorough knowledge of the anatomy of the area prior to performing surgery(Stammberger and Posawetz 1990).

2.1.2.1The aggar nasi

The aggar nasi is an anterior bulge on the lateral wall just anterior to the attachment of the middle turbinate. Anatomical variations exist in the amount of pneumatisation although is only occasionally pneumatised. In animals with a snout, the agger nasi forms a separate turbinate system(Lund, 1997).

2.1.2.2 Hiatus semilunaris

The hiatus semilunaris can be described as the "foyer"; the space from which leads the path to the frontal, maxillary and ethmoid sinuses. The space lies between the posterior edge of the uncinate process and the anterior surface of the ethmoidal bulla(Lund, 1997).

2.1.2.3 Ethmoidal infundibulum

This area is the key to endoscopic sinus surgery and its anatomy is of keen interest to endoscopic sinus surgeons primarily because obstruction at this level is the main cause of sinus disease(Lund, 1997).

The ethmoidal infundibulum can be reached from the middle meatus by going through the hiatus semilunaris. It is funnel-like and connects the natural ostium of the maxillary sinus to the middle meatus, via the hiatus semilunaris. The natural ostium of the maxillary sinus lies in the floor of the ethmoidal infundibulum (Lund, 1997).

Its landmarks are: medial: uncinate process and hiatus semilunaris, lateral: lamina papyracea, anterior: an acute angled blind recess where the uncinate process meets the lamina papyracea, posterior: anterior face of the ethmoidal bulla, superior: varies according to uncinate process attachment(Lund, 1997).

2.1.2.4 The frontal recess

This is a region into which the frontal sinus drains via the ostium, into the middle meatus. It is located anterosuperiorly in the middle meatus. "Depending on the position of the uncinate process, the frontal recess opens into the middle meatus, medial to the uncinate process and between this structure and the middle turbinate, or directly into the ethmoidal infundibulum" (Stammberger and Posawetz 1990).

2.1.2.5 The ethmoidal bulla

This is the largest air cell in the anterior ethmoid. It may be poorly aerated or completely unpneumatised in 8% of patients(Stammberger and Posawetz 1990).

The lateral sinus is a cleft that may be found between the posterior wall of the bulla and the basal lamella of the middle turbinate(Lund, 1997) .

Anatomical variations are plentiful in this region and authors such as Zinreich et al (1988) have related anatomical variations and sinus infection. This study will closely examine race and sex variations in the context of forensic human identification and where relevant, clinical applications of any variation found(Lund, 1997).

2.1.3 The sphenoid sinuses

The sphenoid bone is the largest bone in the skull base dividing the anterior from the middle cranial fossa. The sphenoid bone has a body, two wings- the greater and lesser wings and two inferior plates- the medial and lateral pterygoid plates. The jugum on the anterior surface of the body of the sphenoid articulates with the cribriform plate. The body of the sphenoid sinus is pneumatised to a variable extent (Lund, 1997). The anterior face of the body bears a grest, which articulates with the perpendicular plate of the ethmoid. On either side of the crest lie the ostia of the sinuses and these are partially overlapped by the superior turbinate and form the sphenoethmoidal recess. The sinus cavities are variable in size and shape and pneumatisation can be extensive(Lund, 1997).

The sphenoid sinuses are divided by a septum, which is often paramedian but is variable and sometimes incomplete. The inferior surface of the body of the sphenoid has the rostrum, which articulates with the vomer. The greater wings contribute to the middle cranial fossa and to the lateral orbital wall. The superior orbital fissure separates it from the lesser wing on each side and the inferior border contributes to the inferior orbital fissure (Lund, 1997).

The sphenoid bone contains the foramen rotundum through which the maxillary nerve runs, the foramen ovale through which the mandibular nerve, the accessory meningeal artery and sometimes the lesser petrosal nerve travel and the foramen

spinosum through which the middle meningeal artery and a meningeal branch of the mandibular nerve pass(Lund, 1997).

A paired structure located predominantly in the sphenoid bone. Asymmetry in size and shape is most frequently present. The walls of the sinus are irregular. Bony septae partially separate recesses, producing incomplete compartmentalisation of the sinus. There may be dehiscences in the thin bony sinus wall, especially laterally and superiorly. Such dehiscences may result in direct contacts between the sinus mucosa and the overlying dura(Lund, 1997).

The sphenoid sinus is surrounded by several important anatomic structures. Superior to the sinus lie the cerebral hypophysis, olfactory tract, frontal lobes of the brain, and an often extensive intercavernous venous network. Anterosuperiorly, the optic chiasm is present. Anteriorly, the anterior margin of the sphenoid bone forms a small segment of the posterior orbital wall. Inferiorly, the nasopharynx is present, as are the blood vessels and the nerve of the pterygoid canal, which run anteroposteriorly immediately below the sinus floor. These structures may be surrounded completely by the bony wall of the pterygoid canal, or they may lie directly underneath the mucosa of the sinus floor(Lund, 1997).

Posteriorly, a thick, bony wall separates the sinus from the basilar artery and the pons. Anteriorly, an incomplete bony wall separates the sinus mucosa from the nasal mucosa and from the posterior ethmoid sinuses. If the sphenoid sinus is larger, it may extend over the pterygopalatine fossa with its contents, and it may be located directly posterior to the maxillary sinus. Laterally, a thin, bony wall with occasional dehiscences separates the sphenoid sinus from Meckels's cave, the cavernous sinus, and the internal carotid artery; and, along the lower border of the sinus, the maxillary division of the trigeminal nerve(Lund, 1997).

The ostium of the sphenoid sinus is located high on the anterior sinus wall approximately 1/3 to 1⁄2 up the face of the sinus. It is crucial to this study to

differentiate posterior ethmoidal air cells from the sphenoid sinus and special care will be taken to successfully delineate the two regions(Lund, 1997).

2.1.4 The frontal sinuses.

The frontal bone is pneumatised to a varying degree between individuals. The frontal bone forms the forehead and orbital roof and the roof of the ethmoidal sinuses. The frontal sinus develops from one of the anterior ethmoidal cells but does not start to pneumatise until the first or second year of life(Schuller et al, 1994).The frontal sinus is only significant after approximately age 9. It is the last sinus to complete its growth in early adulthood and its configuration is highly variable(Schuller et al, 1994).

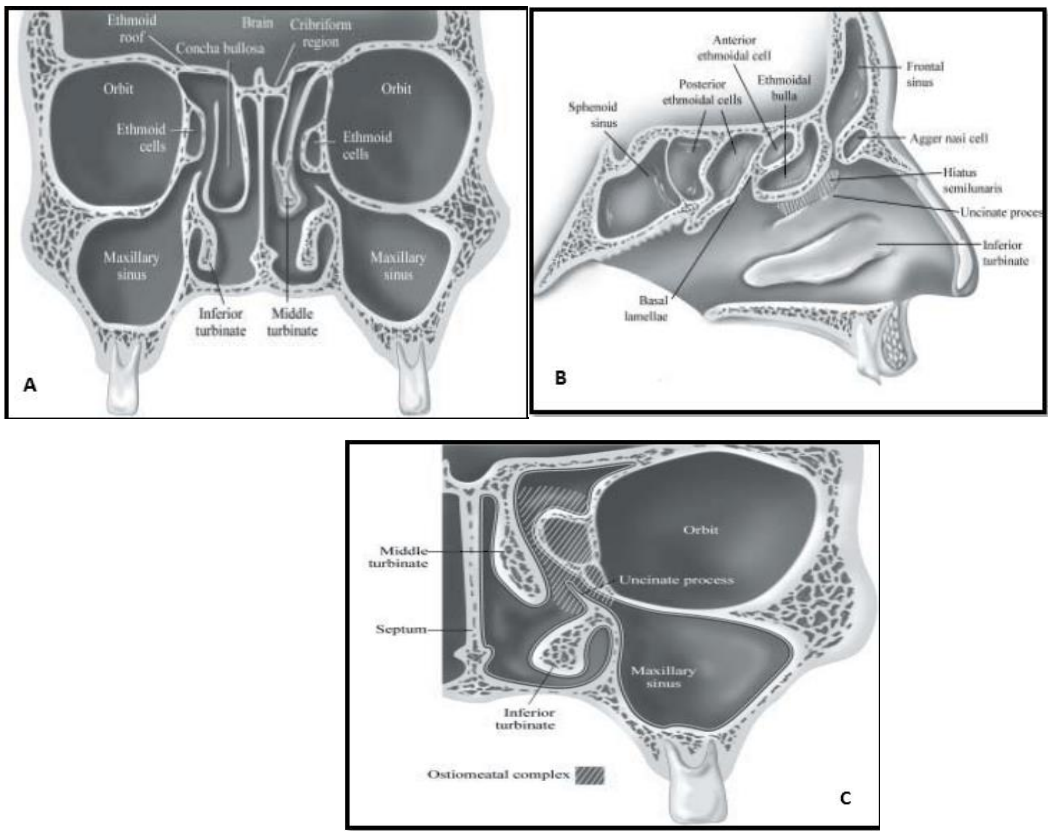


Figure (2.2): Anatomy of the paranasal sinuses: A, B: Coronal and sagittal views into the paranasal sinuses. C: The maxillary, frontal, and ethmoid sinuses drain into the middle meatus, which is bordered by the middle turbinate bone (Stamm and Draf 2012).

2.2 Physiology

2.2.1 Physiology of the maxillary sinus

Normal physiological function of the paranasal sinuses is dependent on drainage and ventilation. This study is concerned with anatomical variation and volumetric differences of the sinuses. The physiology of the sinuses is relevant because surgery is directed at restoring the normal function of the sinuses(Stammberger and Posawetz 1990).

The maxillary sinus is lined by ciliated, columnar epithelium containing a high number of goblet cells. Messer linger, in his studies on cadaver heads, identified the pathways of secretion transport in the paranasal sinuses(Stammberger and Posawetz 1990).

In the maxillary sinus mucus transport begins in the floor of the sinus. The mucus is transported along the anterior, lateral, posterior and medial walls and along the roof of the sinus(Stammberger and Posawetz 1990). The natural ostium of the maxillary sinus is the point where all the secretion routes converge. The secretions subsequently pass into the ethmoidal infundibulum and then into the middle meatus, via the hiatus semilunaris. All current surgery is directed at opening the natural ostium to allow ventilation and drainage of the sinus to occur in a normal manner. The volumetric aspect of the study may give surgeons information about ease of anatomical access. Blood supply to the maxillary sinus is via branches of the facial, infraorbital, maxillary and greater palatine arteries and veins(Stammberger and Posawetz 1990).

Nerve supply is from the maxillary division of the trigeminal nerve, which supplies sensation via the infraorbital, superior alveolar and greater palatine nerves(Lund, 1997). The anterior superior alveolar nerve supplies the anterior wall of the maxillary sinus. The posterior superior alveolar nerves supply the adjacent mucosa and molar teeth. The middle superior alveolar nerve supplies the lateral wall of the

sinus and the greater palatine nerve supplies the posteriomedial wall of the sinus, whilst branches of the infraorbital nerve supply the roof. Lymphatic drainage is into the pterygopalatine fossa and submandibular nodes(Stammberger and Posawetz 1990).

2.2.2 Physiology of the ethmoid sinuses

Thin ciliated columnar respiratory epithelium lines the ethmoidal sinuses. The density of goblet cells is lower than that found in the maxillary sinus with a mean of 6500 / mm2 (Lund, 1997). The mucosa of the ethmoids has several tubuloalveolar seromucinous glands within it. Mucus transport is through the infundibulum into the nasal cavity beneath the middle turbinate and then posteriorly to the postnasal space. Blood supply to the ethmoid sinuses is via the anterior and posterior ethmoidal arteries and sphenopalatine arteries. The ethmoidal arteries arise from the ophthalmic artery, which is a branch of the anterior cerebral branch of the internal carotid. The anterior ethmoidal artery supplies the anterior ethmoid and frontal sinus. This artery passes through the anterior ethmoidal canal, located on the medial wall of the orbit, it then traverses the roof of the ethmoid and passes through the vertical attachment of the middle turbinate and supplies the upper nasal septum and lateral nasal wall. The posterior ethmoidal artery traverses a canal in the medial wall of the orbit to supply the posterior ethmoidal air cells, the posterior part of the nasal septum and the posterior part of the lateral nasal wall and it anastomoses with the sphenopalatine artery(Lund, 1997).

Of significance to endoscopic sinus surgeons is the relationship of the anterior ethmoidal artery to the roof of the ethmoid and to the middle turbinate where it can be easily damaged. The ethmoidal sinuses are innervated by the anterior and posterior ethmoidal nerves and orbital branches of the pterygopalatine ganglion.

Lymphatic drainage is to the submandibular nodes and retropharyngeal nodes in the neck(Lund, 1997).

2.2.3 Physiology of the sphenoid sinuses

The sphenoid sinuses are lined with ciliated columnar epithelium, which contains goblet cells and seromucinous glands. The sinus drains into the posterior most portion of the sphenoethmoid recess, above the level of the superior turbinate. Blood supply is from the posterior ethmoidal vessels and nerves. Additional supply is from the orbital branches of the pterygopalatine ganglion. Lymphatic drainage is to the retropharyngeal nodes(Lund, 1997).

2.2.4 Physiology of the Frontal Sinuses

The frontal sinus is lined with ciliated columnar epithelium with mucus secreting goblet cells. Drainage is inferiorly via the nasofrontal duct into the frontal recess, which is situated in the anterior part of the hiatus semilunaris in the middle meatus. The arterial supply is from the ophthalmic artery, which is a branch of the anterior cerebral artery. Branches of the ophthalmic artery feeding the frontal sinus are the anterior ethmoidal artery interiorly and the supraorbital and supratrochlear arteries externally. The venous drainage is intracranial to the superior sagittal sinus, which ends blindly at the foramen caecum at the crista galli. Drainage also via the orbital veins to the cavernous sinus. Nerve supply is derived from the supraorbital nerve. Lymphatics drain to the submandibular gland. It is extremely difficult to differentiate posterior wall of frontal sinus from anterior fronto-ethmoidal air cells and special care will be taken in this study to delineate correctly(Lund, 1997).

2.3 Pathology:

Rhinosinusitis (RS) is defined as inflammation of the nose and paranasal sinuses. Multiple etiologies contribute to the presence of this condition (**table2-1)**, including viral or bacterial infection, allergy, and, occasionally, anatomical variations or obstruction. Rhinosinusitis is a serious health problem that has been reported to affect up to 1 in 7 adults(Pleis and Coles 2009). Much like rhinitis, it can have detrimental impact on quality of life, school and workplace productivity, and health-care costs (Anand, 2004).

Host factors	Environmental
Genetic/congenital • **Cystic fibrosis** • **Ciliary dyskinesia**	**Infectious** • Viral • Bacterial • Fungal
Allergic/ immune	**Trauma**
Anatomic	**Noxious chemicals**
Systemic disease • **Endocrine** • **Autoimmune**	**Iatrogenic** • Medications • Surgery

Table (2.1) : Etiology of Rhinosinusitis(Pleis and Coles 2009)

2.2.1 Acute Rhinosinusitis

Acute rhinosinusitis is a condition whereby nasal and sinus inflammation occurs and lasts for up to 4 weeks. Patients can describe a variety of symptoms, but its cardinal diagnostic features are (1) mucopurulent/purulent nasal or postnasal drainage, and either (2) nasal obstruction or (3) facial pressure/pain. Objective evidence for the diagnosis of acute rhinosinusitis includes: (1) visualized

nasal/sinus passage purulent or mucopurulent discharge, (2) posterior pharyngeal purulence, or (3) radiographic evidence of sinus soft tissue swelling/inflammation (plain film or CT imaging)(Meltzer et al, 2004).

2.2.2 Chronic Rhinosinusitis

As defined by the European position paper on rhinosinusitis and nasal polyps 2012 (EPOS 2012), chronic rhinosinusitis is a multifactorial complex disorder involving inflammation of the nose and paranasal sinuses lasting at least 12 weeks (Fokkens et al, 2012). CRS is most often classified into chronic rhinosinusitis with nasal polyps and without. Controversy still remains about classification of CRS into new endophenotypes, with potentially different pathogenetic mechanisms and/or therapeutic responsiveness. CRS can also be classified according to histologic evidence of chronic hyperplastic eosinophilic sinusitis (increased sinonasal tissue eosinophilia) or chronic inflammatory sinusitis. Under this classification system, nasal polyps may be associated to either chronic hyperplastic eosinophilic sinusitis or chronic inflammatory sinusitis(Fokkens et al, 2012).

2.2.2.1 Epidemiology of chronic rhinosinusitis

The first European population-based study on CRS found a prevalence of 10.9% (Tomassen et al, 2011). In Korea, a population-based survey came to a prevalence of only 1% in 1991, which rose to 7%, when results were reported again in 2011(Min, Jung et al. 1996). CrswNP affects 1-4% of the population (Settipane, Peters et al. 2013). Both CRSsNP and CRSwNP tend to affect adult populations. Their prevalence increases with age until 60 years. CRSsNP affects women more than men, whereas CRSwNP affects more likely men than women. NPs are extremely uncommon in patients under the age of 20 (Fokkens et al, 2012).

2.2.2.2 Etiologic Factors in Chronic Rhinosinusitis

Chronic rhinosinusitis (CRS) is an inflammatory disorder involving the mucosa of the nose and paranasal sinuses. Although not necessary for clinical diagnosis, CRS is often accompanied by the presence of infectious processes of viral, fungal, or bacterial origin. These and other environmental influences combine with host factors to produce persistent sinonasal inflammation. The precise etiologic contributors to CRS are difficult to clearly separate and identify(Fokkens et al, 2012).

Certain factors can be easily associated with ongoing CRS, but often cannot be proven as direct etiologies of the disease process itself. It has become increasingly suggested in the clinical and research communities that CRS is driven by an abnormal host immune response against environmental agents. In many ways, this is not surprising(Fokkens et al, 2012).

The nasal cavity is often the first point of contact between the airway mucosa and the external world. Multiple immune mechanisms exist at this critical interface to defend against a myriad of microbial and nonmicrobial elements(Fokkens et al, 2012). Thus, although diverse initiating events may ultimately contribute to the development and persistence of CRS, it is likely that a derangement of host immunity ultimately underlies the recalcitrant mucosal inflammation that characterizes the most severe forms of the disease(Fokkens et al, 2012).

2.2.2.3 Classification of chronic rhinosinusitis:

2.2.2.3.1 Chronicrhinosinusitis Without Nasal Polyps (CRSsNP).

CRSsNP is the most common form of CRS, accounting for 60–65 % of cases(Hamilos 2007). CRSsNP describes the presence of CRS without the other characteristic features that defi ne the other two syndromes (e.g., nasal polyposis or allergic mucin containing fungal hyphae), although the distinction between

subtypes is sometimes hazy. CRSsNP is heterogeneous and may include patients with allergic and nonallergic rhinitis, structural abnormalities, and mucociliary defects (e.g., immotile cilia syndrome); patients with gastroesophageal reflux-associated CRS; and patients with immunodeficiency(Hamilos 2007).

Sinus ostial obstruction is the well-accepted cause of persistent symptoms and sinus inflammation and is found in the majority of cases(Messerklinger, 1987). Underlying conditions, such as allergic rhinitis or immunodeficiency, are important contributive factors to the pathogenesis. CRSsNP is characterized by sinus opacification or sinus ostial obstruction with nonpolypoid mucosal thickening of the associated sinus cavity (Figure 2.3).

Biopsy of mucosal tissue characteristically shows an infiltration of mixed mononuclear cells and neutrophils, with an increase in submucosal glands (Malekzadeh et al, 2002) and stromal fibrosis(Watelet et al, 2004). Epithelial goblet cell hyperplasia may be present. Eosinophils may be present but generally represent <10 % of the infiltrating inflammatory cells(Jankowski, Bouchoua et al. 2002) which is another distinguishing feature in comparison to CRSwNP and AFRS. Chronic infection and biofilm formation are likely important components in the pathogenesis of CRSsNP (Adibelli, Songu et al. 2011).

The characteristic presentation of CRSsNP is that of persistent symptoms with periodic exacerbations characterized by increased facial pain/pressure and/or increased anterior or posterior drainage. Fatigue is a frequent accompanying symptom. Fever is usually absent or low grade. A subset of patients has recurrent acute rhinosinusitis symptoms, which respond well to antibiotic treatment. These patients have been described as having “recurrent acute rhinosinusitis” or “chronic recurrent rhinosinusitis” (Tomassen et al, 2011).

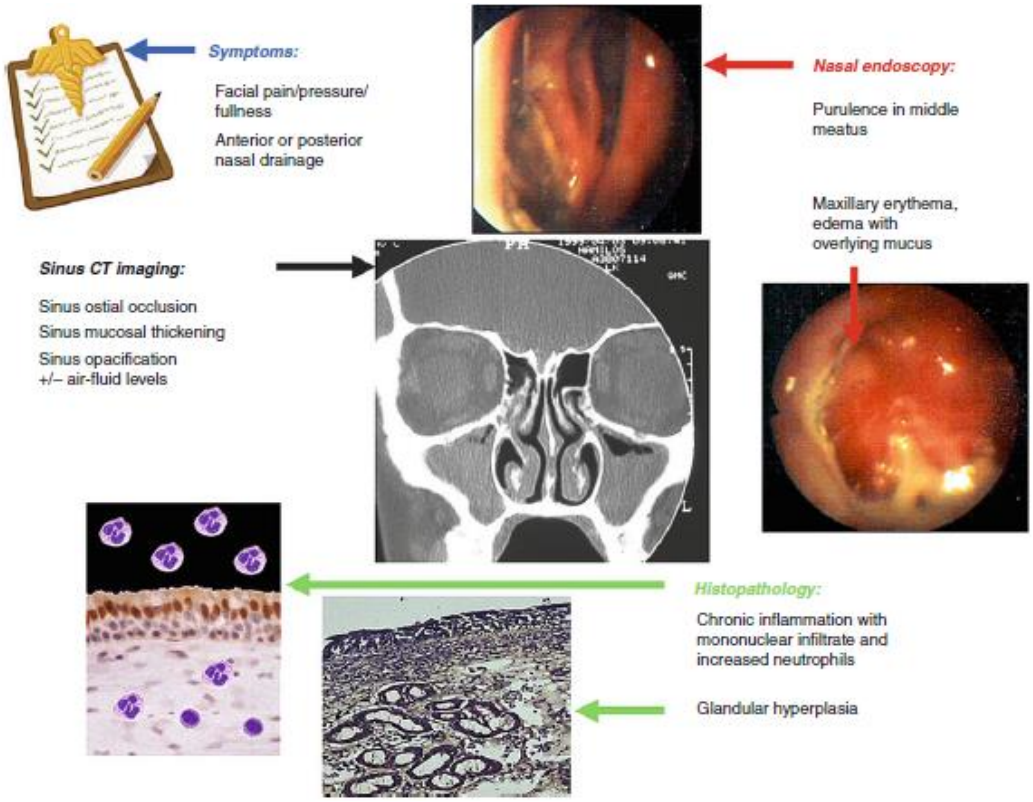


Figure (2.3): Summary of characteristic features of chronic rhinosinusitis without nasal polyposis (CRSsNP)(Ponikau et al, 2005).

2.2.2.3.2 Chronicrhinosinusitis with Nasal Polyps (CRSwNP).

CRSwNP is characterized by the presence of nasal polyps. Nasal polyps are translucent, yellowish-gray to white, glistening masses filled with gelatinous inflammatory material, which may form in the nasal cavity or paranasal sinuses (Figure 2.4). The gray-white color is due to the relatively avascular nature of the polyp tissue. The nasal polyps are characteristically bilateral. Nasal polyps generally begin to form around the ostiomeatal complex, although they may be found through the nasal cavities and sinuses(Larsen and Tos 2004).

The initial trigger for their development is probably variable, but experimental evidence in animal models suggests that underlying allergic inflammation and

bacterial infection may contribute to their formation(Kim et al, 2011). Polyp tissue typically contains a predominance of eosinophils, high levels of the Th2 cytokines interleukin (IL)-5 and IL-13, and high levels of histamine (Drake-Lee and McLaughlan 1982).

In CRSwNP, there is evidence for localized allergic hyperresponsiveness to colonizing Staphylococcus aureus, as evidenced by the local production of specific IgE antibodies against staphylococcal enterotoxins (Bernstein et al, 2011). These antibodies can be measured in sinus tissues, although levels in the blood may be undetectable. The enterotoxins act as superantigens and broadly activate T lymphocytes. In contrast, patients with CRSsNP do not appear to produce IgE to staphylococcal enterotoxins. A role for eosinophilic Th2 fungal sensitization has also been suggested, as in CRSsNP(Van Zele et al, 2004).

The characteristic presentation of CRS with NP is gradually worsening nasal congestion/obstruction, sinus fullness and pressure, fatigue, posterior nasal drainage, and hyposmia or anosmia. Fever and severe facial pain are uncommon(Van Zele et al, 2004).

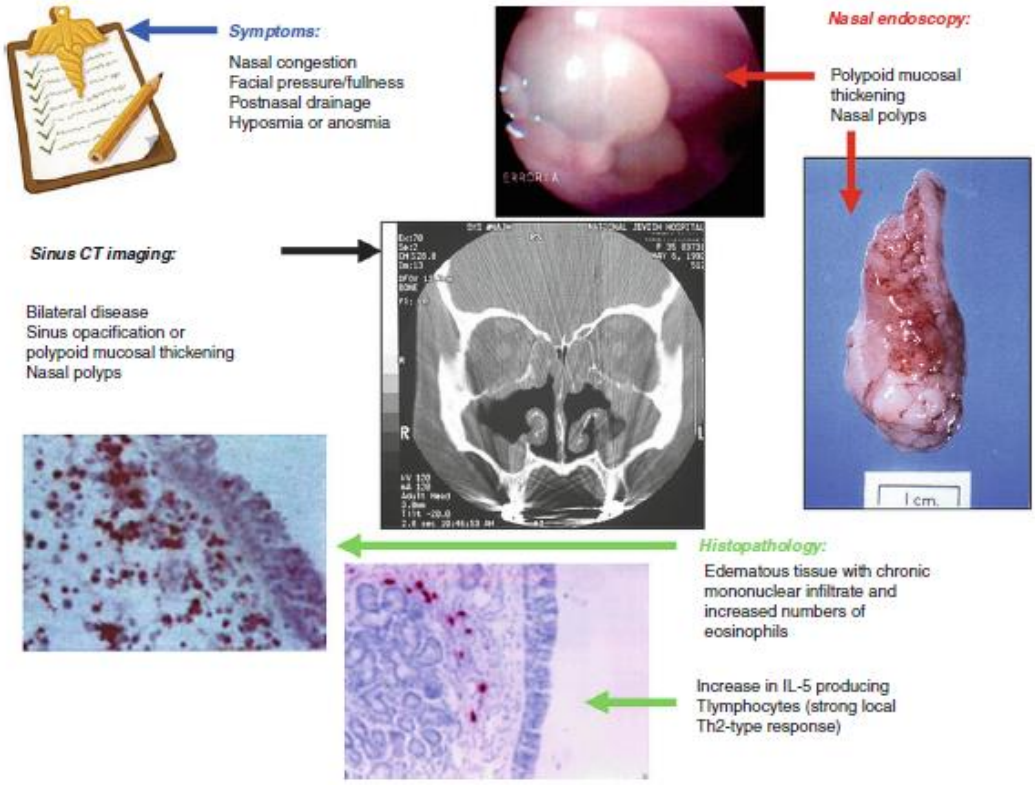


Figure (2.4): Summary of characteristic features of chronic rhinosinusitis with nasal polyposis (CRSwNP)(Ponikau, Sherris et al. 2005).

2.2.2.3.3 Allergic fungal rhinosinusitis (AFRS):

AFRS refers to CRS that is accompanied by sinus opacification with "allergic mucin" or thick, inspissated mucus that ranges in color from light tan to brown to dark green and which contains degranulating eosinophils Figure 2.6) Allergic mucin is generally identified at the time of surgery. Fungal hyphae are demonstrable within the allergic mucin, which suggests fungal colonization rather than invasive fungal disease. In invasive fungal sinusitis, fungal hyphae can be shown histologically to penetrate the underlying mucosa (Taylor et al, 2002).

Over time, patients with AFRS may develop sinus cavity opacification and sometimes local pressure effects on bone. Bony demineralization of the sinus wall may ensue, resulting in expansion of the sinus and possibly mucocele formation.

True bone erosion is less common, occurring in 20 % of cases(Nussenbaum, Marple et al. 2001). Patients with AFRS usually have nasal polyposis and are immunocompetent, similar to patients with CRSwNP. However, AFRS patients have evidence of fungal-specifc IgE by skin tests or IgE immunoassays (commonly called RAST tests). Thus, AFRS is distinguished from CRSsNP and CRSwNP by the presence of allergic mucin containing viable fungal hyphae (as demonstrated by fungal staining or culture) and evidence of IgE-mediated allergy to one or more fungi (Hutcheson et al,2010).

Pathophysiology: The pathophysiology of allergic fungal rhinosinusitis (AFRS) is most consistent with chronic, intense allergic inflammation directed against colonizing fungi. Histologically, allergic mucin demonstrates intense eosinophilic degranulation, mucostasis, and inspissation (Bent III and Kuhn 1994).

AFRS usually presents subtly, with symptoms similar to CRS with NP. Patients may describe semisolid nasal crusts that are similar in appearance to allergic mucin. Fever is uncommon. In occasional patients, AFRS presents dramatically with complete nasal obstruction, gross distortion of facial features, and/or visual changes(Meltzer et al, 2004).

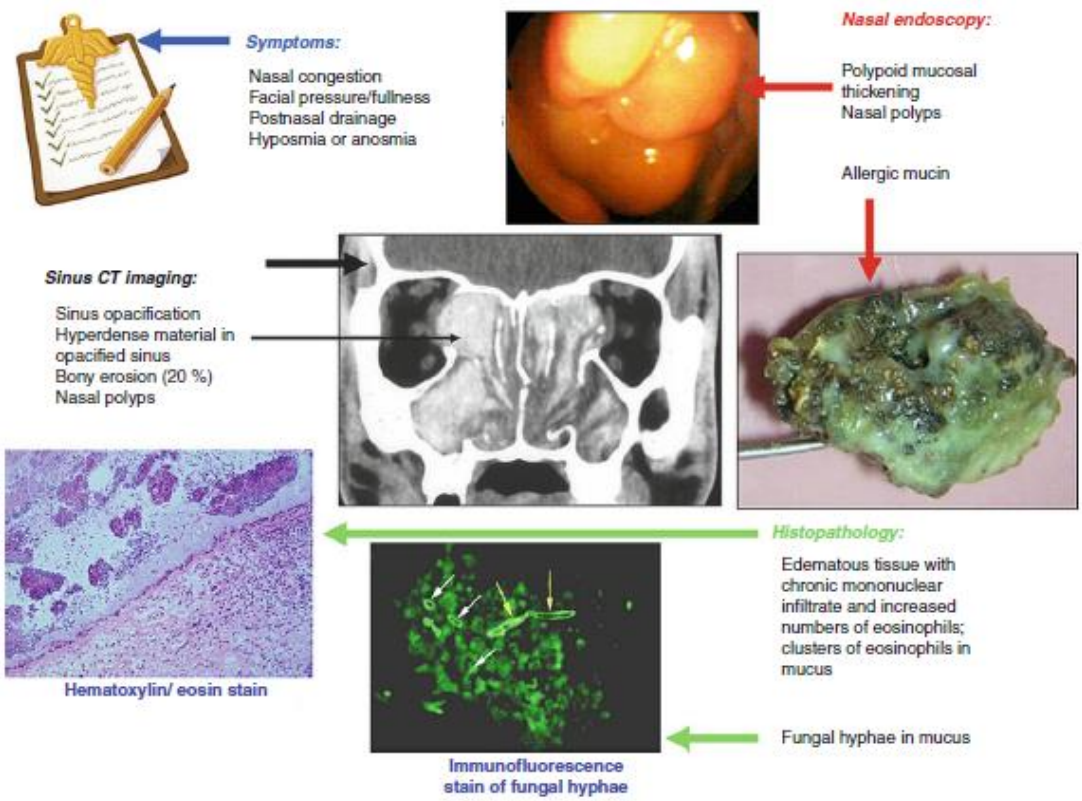


Figure (2.5): Summary of characteristic features of allergic fungal rhinosinusitis (AFRS) (Ponikau et al, 2005).

2.4 Diagnostic Testing of paranasal sinus:

2.4.1 Clinical diagnosis

Clinical judgment combined with history and physical examination is usually sufficient to diagnose sinusitis in most cases of uncomplicated acute and subacuterhinosinusitis. The diagnosis of rhinosinusitis is based on clinical grounds. The emphasis on obtaining a patient history and performing a limited physical examination is based on the fact that most patients can be effectively treated (medically and cost-wise) without the necessity of nasal endoscopy, radiographic studies or bacterial cultures.(Osguthorpe, 2001).

2.4.2 Anterior rhinoscopy:

Anterior rhinoscopy can be performed using a light or otoscope to inspect the anterior nasal cavity. Both the inferior and middle turbinates can be visualised by using an otoscope and the middle meatus can be assessed for the presence of polyposis. A purulent nasal discharge or postnasal drip supports the diagnosis of rhinosinusitis. Nasal turbinate congestion could indicate a viral a etiology, allergic or irritative rhinitis or rhinitis medicamentosa due to decongestant abuse. Small ethmoidal polyps can be missed during anterior rhinoscopy and if the patient's symptoms persist after adequate medical treatment, a referral to an ENT surgeon for nasal endoscopy is required(Lubbe, 2009).

2.4.3 Radiologic Imaging:

The standard plain film sinus series usually consists of four views: lateral, Caldwell, Waters and Submentovertex. Plain films serve as a survey evaluation of the transparency, size, and wall integrity of the sinuses. The overlapping structures and the limited resolution of the fine body outlines provided by plain films hamper this modality in the evaluation of the sphenoid and particularly in the evaluation of the ethmoid sinuses The radiographic signs of PNS disease include variable degrees of opacification, mucosal thickening, air-fluid levels, bony erosion, mass lesion (solid or cystic), foreign body, calcification, and fracture. Meaningful interpretation of these roentgen findings rests on correlation with the clinical signs and symptoms(Mafee et al, 2014).

Although the standard radiographs may be accurate in showing air fluid levels, the degree of chronic inflammatory disease is consistently and significantly underestimated. Furthermore, the superimposition of structures precludes the accurate evaluation of the anatomy of the osteomeatal channels with which the

modern surgeon needs to be familiar. Although a plain-film sinus series can be of value in acute rhinosinusitis and for the initial evaluation of chronic rhinosinusitis and other sinonasal diseases, significant discrepancies are often noted between a sinus series and a CT scan. CT scanning remains the study of choice for the imaging evaluation of acute and chronic inflammatory disease of sinonasal cavities(Mafee et al, 2014).

2.4.4 Magnetic Resonance Imaging

MRI has become increasingly important in assessing patients with neoplasms of the sinonasal cavity, aggressive infections, and developmental lesions, such as meningoencephaloceles(Branstetter and Weissman 2005).

A combination of sagittal, axial, and coronal imaging provides excellent anatomic information regarding the extent of sinonasal pathology Multiple different image sequences are obtained, includingT1- weighted, T2-weighted, as well as contrast-enhanced multiplanar imaging. Excellent anatomic resolution may be acquired from an MRI examination performed in a standard head coil. On occasion, imaging of the sinonasal cavity may be performed with a surface coil positioned over the face(Loevner et al. 1995).

MRI of sinonasal tumors and aggressive infections must include high-resolution unenhanced and enhanced thin section (3 mm) images not only of the sinonasal cavity, but also the orbits, skull base, and the adjacent intracranial compartment(Eisen et al, 2000).

Tumor extension into these structures is frequently not evident on clinical assessment/endoscopy. Images should be acquired in both axial and coronal planes. Contrast-enhanced imaging is essential to assess the extent of local disease, as well as the presence of perineural spread and intracranial extension.

MRI allows discrimination of inflammation and inspissated secretions from neoplasms and other non-neoplastic masses (i.e., encephalocele), and is valuable in assessing for an extension of disease outside the sinonasal cavity into the intracranial compartment, the eye, and the base of the skull(Hermans et al, 1999).

2.4.5 Functional Endoscopic Sinus Surgery

Functional endoscopic sinus surgery (FESS) is a minimally invasive technique in which sinus air cells and sinus ostia are opened under direct visualization. The goal of this procedure is to restore sinus ventilation and normal function (Stammberger and Posawetz 1990).

The ability to treat paranasal sinus disease has been revolutionized by fiberoptic endoscopes and computed tomographic (CT) scanning. Fiberoptic endoscopes have made it possible to examine the nose thoroughly from the anterior nares to the postnasal space. The endoscopic procedure requires local anesthetic and may be performed in the office. The specific features that must be identified and assessed during the examination are the middle turbinate and the middle meatus (osteomeatal complex), anatomic obstruction, mucopus and nasal polyps(Stammberger and Posawetz 1990).

CT scanning identifies the anatomic relationships of the key structures (orbital contents, optic nerve and carotid artery) to the diseased areas, a process that is vital for surgical planning. CT also defines the extent of disease in any individual sinus, as well as any underlying anatomic abnormalities that may predispose a patient to sinusitis(Stammberger and Posawetz 1990).

The reasoning and concepts supporting the use of FESS have recently become widely accepted. (The term "functional" was introduced to distinguish this type

of endoscopic surgery from nonendoscopic, "conventional" procedures. The goal of FESS is to return the mucociliary drainage of the sinuses to normal function. The paranasal sinuses are maintained in a healthy state by ventilation through the individual ostia and by a mucociliary transport mechanism that keeps a continuous protective layer of mucus flowing out of the sinuses(Kennedy et al, 1985).

2.4.6 Computer Tomography and PNS:

The introduction of head and neck CT imaging and the current wider use of this modality have undoubtedly helped the clinician. CT has become a useful diagnostic modality in the evaluation of the paranasal sinuses and an integral part of surgical planning. It is also used to create intraoperative road maps. Today, CT is the radiologic examination of choice in evaluating the paranasal sinuses of a patient with sinusitis (John, 2014).

The use of CT scanning combined with functional endoscopic sinus surgery (FESS) has empowered the modern sinus surgeon to treat patients more effectively, facilitating reduced morbidity and complications. Physicians who are interested in treating patients with sinus disease must be able to read and interpret sinus CT scans. Mastery of sinus anatomy and its variant features forms the basis from which radiologic interpretation begins. Familiarization with the radiologic landmarks and cross-sectional anatomy on patient CT scans, along with clinical correlation, can further enhance the reader's ability to understand sinus CT findings (John, 2014).

With experience, CT findings can be accurately correlated with the anatomic and clinical realities of the particular patient. As in all radiologic surveys, sinus CT scans must be read with a systematic approach. In addition to reviewing the scan to determine the presence of disease, CT scans of the sinuses can also be

reviewed to evaluate potential areas of occlusion and variations of the patient's sinus anatomy in the setting of surgical planning (John, 2014).

CT scans typically obtained for visualizing the paranasal sinus should include coronal and axial (3-mm) cross sections. Soft tissue and bony windows facilitate evaluation of disease processes and the bony architecture. The use of intravenous contrast material just prior to scanning can help define soft tissue lesions and delineate vascularized structures, such as vascular tumors. Contrast-enhanced CT is particularly useful in evaluating neoplastic, chronic, and inflammatory processes (Yousem, 1993).

However, for most patients with sinusitis, noncontrast CT of the paranasal sinuses generally suffices. For patients who may not tolerate the prone position required for coronal cuts, computer-generated reconstructed coronal views can be generated from thin axial sections. If sufficiently thin axial sections (1-2 mm) are available, sagittal reconstructions can also be helpful for teaching purposes and further delineating anatomic structures(Yousem, 1993).

Proper positioning of the patient's head is important to obtain CT images. For axial views, the patient's hard palate is placed perpendicular to the CT scanner table. The images must be captured such that the external auditory canal is in line with the inferior orbital rim. The coronal images are taken so that the gantry is perpendicular to the patient's hard palate. Misalignment or rotation can lead to distortion of the true anatomy on the films(Yousem, 1993).

Sinus CT is used in correlation with clinical examination procedures, including nasal endoscopy. Combined, the information gathered determines the extent of disease and forms the basis of the treatment plan. The timing of CT scanning can have a significant impact on the correlation of CT findings with actual disease state. The diagnostic yield of the scan for detecting irreversible (surgically treatable) disease processes, such as chronic disease or structural problems, is

increased once acute or reversible problems are treated. As such, CT scans should be obtained only after acute sinusitis episodes have been adequately treated. Changes from acute infections can last several weeks; waiting for at least 6 weeks before obtaining a scan is recommended to determine the patient's baseline disease status(Yousem, 1993).

Patients with chronic inflammatory disease, such as strong allergies and/or sinonasal polyposis disease should receive maximized medical therapy for a few weeks before undergoing CT scanning. Depending on the patient's problems, this therapy may include antihistamines, nasal steroid sprays, antibiotics, or a brief course of oral steroids(Yousem, 1993).

Some patients may be referred for evaluation after the discovery of radiologic disease on a screening CT scan. These screening sinus CT scans often only include thicker (5-10 mm) axial cross sections of the paranasal sinuses. They can help to establish disease diagnosis in a more cost-effective manner. One may argue against these so-called screening CT scans because of the superior diagnostic yield of properly obtained axial and coronal sections and the eventual need for coronal sections before surgery in some patients. Moreover, because the cost of CT scanning today is significantly reduced compared to that even a decade ago, complete CT is perhaps a more cost-effective test than screening CT, with a one-time order of a complete CT scan providing much more diagnostic and surgical usefulness(Yousem, 1993).

With experience, CT findings can be accurately correlated with anatomic and clinical realities of the particular patient. As for all radiologic surveys, sinus CT scans must be read with a systematic approach. After the primary survey of the CT scan is completed, including patient name, indications for the CT scan, type of scan, cross-sectional view being discussed, and major radiologic findings, particular attention is directed toward potential "bottle-neck" areas, where

normal passages may be occluded by disease states or variant anatomy(Yousem, 1993).

A systematic approach is helpful when interpreting CT scans. Reading the CT scan from anterior to posterior (on coronal views) or from top to bottom (on axial sections) can help organize one's approach in analyzing structures to be interpreted(Jones et al, 1997) .

2.5 Diagnostic criteria of chronic rhinosinusitis

Chronic rhinosinusitis is defined clinically based on consensus guidelines incorporating both subjective and objective criteria. Guidelines by the American Academy of Otolaryngology—Head and Neck Surgery, as shown in Table 2.2, recommend at least 12 consecutive weeks of symptoms including at least two of the following four major symptoms of CRS (nasal obstruction, drainage, facial pain/pressure, and hyposmia/ anosmia), in addition to objective evidence of sinusitis on nasal endoscopy or sinus computed tomography (CT)(Rosenfeld, Piccirillo et al. 2015).

Very similar diagnostic guideline criteria have been adopted throughout the world(Khan et al, 2019). Because CRS is defined clinically, there are likely many different pathophysiologic processes that converge upon the final clinical phenotype defined by consensus diagnostic criteria. In fact, multiple inflammatory mechanisms are believed to contribute to the development and persistence of CRS (Orlandi et al, 2016).

The characteristic features in CT images of both chronic and acute sinusitis include air fluid levels, mucosal thickening, Sclerotic, thickened bone in the sinus walls is characteristic of chronic sinusitis, although this feature is not seen

in every case. In chronic sinusitis, the ethmoid sinus is commonly involved. Findings include mucosal thickening, complete opacification, bone remodeling and thickening due to osteitis, and polyposis. The appearance of the mucosa is nonspecific and the extent of inflammatory disease does not always correlate with the severity of symptoms or their effects on the quality of life. Therefore, mucosal thickening should be interpreted in the context of clinical examination or nasal endoscopy or both(Momeni et al, 2007).

In general, non-enhanced CT scans suffice in cases of uncomplicated sinusitis. Multidetector CT (MDCT) seems to have the potential to replace primary coronal CT of the paranasal sinuses without any loss of image quality, and it may even improve the overall diagnostic value. İt allows objective assessment of the patency of intercommunicating passages and shows how anatomic variants, inflammatory disease, or both may affect patency anatomic variants that may predispose to chronic disease include septal deviation, concha bullosa, Haller cells, hypoplasia of the maxillary sinus, and narrowing or obstruction of the osteomeatal complex(Ah-See and Evans 2007).

MDCT can show anatomic structures that are not visible by physical examination or nasal endoscopy and is, therefore, the study of choice for the surgeon who is considering or planning functional endoscopic sinus surgery. MDCT allows the reconstruction of data set. When a low radiation- dose protocol is used coronal and sagittal images from a single imaging, the radiation dose from CT is comparable to the standard four-view plain radiographic series. Coronal reconstructions provide views similar to those seen by endoscopy. Axial and sagittal reconstructions are especially useful in delineating certain anatomic abnormalities, such as an Onodi cell, or extra sinus abnormalities. These findings are important to recognize prior to sinus surgery(Ah-See and Evans 2007).

Allergic fungal sinusitis can involve complete opacification of multiple paranasal sinuses, unilateral or bilateral; sinus expansion and erosion of a wall of the involved sinus; and high attenuating areas scattered amid mucosal thickening on nonenhanced scans. With fungal sinusitis, the maxillary and ethmoid sinuses are most commonly involved. These areas are due to inspissated secretions or heavy metals, such as iron, manganese, and calcium Dense opacification or opacification with inhomogeneous "hyperdensities" is suggestive of thick, inspissated mucus and is a feature of "allergic fungal sinusitis" a condition associated with type I IgE-mediated hypersensitivity to one or more fungi. This condition accounts for less than 10% of chronic sinusitis cases but is associated with severe persistent disease. Invasive fungal disease is rare unless the patient is immune compromised or has poorly controlled diabetes(Shah, 2003).

CT can also play an important role in excluding the presence of aggressive infections or neoplastic disease. Characteristics that are suggestive of malignancy include osseous destruction, extra-sinus extension, and local invasion. If these findings are noted, MR imaging should be performed to differentiate between benign obstructed secretions and tumor and to assess for intracranial spread(Mafee et al, 2006).

CT findings should not be interpreted in isolation, and scans should always be read in conjunction with clinical and endoscopic findings because of high rates of false-positive results. Up to 40% of asymptomatic adults have abnormalities on sinus CT scans, as do more than 80% of those with minor upper respiratory tract infections. In immunocompromised patients with invasive sinusitis, CT findings may be negative in the early stages. In advanced cases, differentiating this condition from malignancy may be difficult on the basis of imaging alone. Thus, the clinician cannot rely solely on CT imaging and must maintain a high

index of suspicion when evaluating immunocompromised patients to establish a prompt diagnosis. Early nasal endoscopy, along with biopsy and the initiation of appropriate therapy, is necessary to improve the patient's prognosis(Mafee et al, 2006).

The disadvantages of CT include use of ionizing radiation, higher cost compared to direct radiography and limited a vailiabity in small facilities or rural areas. Also the soft tissue resolution of CT is not as high as that of MRI. Although CT scanning provides an excellent anatomic display, it generally does not help in predicting the histologic nature of the pathologic process. On CT scans, it is difficult or impossible to differentiate tumor tissue from retained fluid in sinuses, where the drainage of a sinus is blocked by obstruction from the tumor(Mafee et al, 2006).

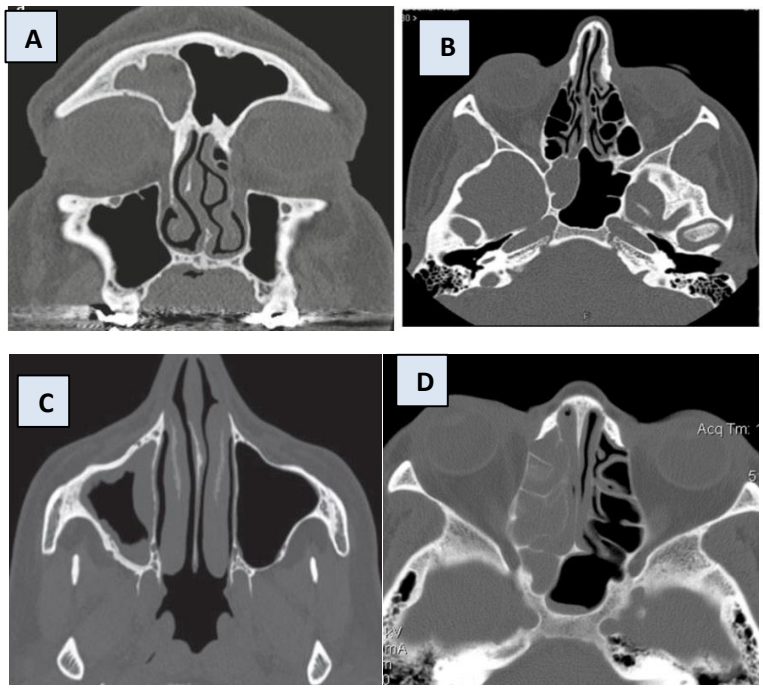


Figure (2.6): Axial CT image shows Chronic sinusitis in A/ Rt. Frontal sinus B/ Rt. sphenoid sinus C/ Rt. Maxillary sinus D/ Rt.ethmoid sinus (Cuenca, Valentín et al. 2020).(Mafee, Farid et al. 2014)

2.6 Previous Studies:

In the latest studies, volume rendering techniques and three-dimensional (3D) reconstruction models have been developed. Currently, CT imaging is the radiological technique of choice for analyzing the paranasal sinuses, as the distinction between bone, mucosa and other soft tissue can be clearly defined(Apuhan et al, 2011)

According to (Lee et al, 2012), 3D reconstructions from these CT images are able to yield a more precise form or 3D morphology of the PAS.

The literature reviewed reveals that the volume of the air sinuses is the most important parameter that can establish its size and these normal values may be useful in the diagnosis of sinus pathologies (Emirzeoglu et al, 2007; Adibelli et al, 2011), and in forensic identification of sex and ancestry (Fernandes, 2004). Therefore, evaluating volume and morphology in 3D of the PAS would theoretically be more accurate than closest estimates, offering values that are the best fit to their natural measurements (Apuhan et al, 2011).

This first step of deriving norms of the volumes for the PAS in populations, followed by determining the actual morphological types or categories, would enable comparison with existing types in comparable populations according to age, sex and population.

Although there are studies from the early 1990s to the present that have estimated the volumes of the developing PAS, most of these studies have limitations.

Some studies calculated the volume of the air sinuses by assuming the shape of the air sinus being ellipsoid, deriving an estimated volume, using the formula:

V=1/2·A·B·C (where A, B, C equal to ellipsoid diameters) from a few parameters (length, width and height)(Barghouth et al 2002; Adibelli et al, 2011).

This posed a problem as the air sinus shape and size are variable at different axial levels. Therefore, the estimated volumes overestimated the actual volume of the air sinuses by 4.7%(Adibelli et al, 2011).

Studies by Sanchez et al (2000), Karakas et al. (2005), Emirzeoglu et al. (2007), Amusa et al. (2011), Apuhan et al. (2011) and Lee et al. (2012) reviewed a relatively small sample of CTs within this period. For example, the study by Karakas et al (2005) analysed the volumes of the PAS in 91 scans of patients from 5 to 55 years of age. Some studies were not able to conclusively evaluate all the sinuses, for example, (Spaeth et al, 1997) study consisting of 5600 CTs, was unable to comprehensively analyze the maxillary sinus, whilst, Karakas et al. (2005); Apuhan et al. (2011) and Lee et al. (2012) did not review the ethmoid air sinus development.

According to Shah et al (2003) separating the age cohort is advantageous. However, some studies have analyzed a few age categories that are too large, for example, Wolf et al.'s (1993) study divided their sample into four year age groups (1-4yrs; 4-8 yrs; 8-12yrs), Karakas et al (2005) into five year age groups (1-5yrs; 6-10 yrs; 11-15yrs; 16-20 yrs) and Sanchez Fernandez et al. (2000) into two large age cohorts (≤20yrs and >20yrs). Further, the development of the PAS for these studies have been limited to a maximum of 12 years (Wolf et al, 1993), 16 to 18 years (Bargouth et al., 2002; Apuhan et al., 2011; Adibelli et al., 2011) or up to 25 years of age (Spaeth et al., 1997; Park et al., 2010). According to Adibelli et al. (2011) "normal paranasal air sinus development may continue into early adulthood". Furthermore, early adulthood according to anatomical textbooks is defined as 21 to 25 years of age, when all ossification and growth is complete (Moore et al., 2016). In addition, Park et al. (2010) further explain that few studies have illustrated the

growth of the air sinuses for all age periods, particularly the growing period of 1 to 25 years.

Karakas et al. (2005) and Emirzeoglu et al. (2007) evaluated the volumes of the air sinuses in childhood, but, calculating the volumes using CTs with slice thicknesses of 3-5 mm. These estimates posed a problem, as the frontonasal complex is extremely difficult to analyse at that thickness, and the methods are not clearly elaborated on nor are they comprehensively shown. Most of the studies (Kim et al., 2010; Park et al., 2010; Apuhan et al., 2011) were conducted in Asian population groups, making generalizations difficult.

Chapter three

Materials and methods

3.1 Tools and equipment:

3.1.1 Place and time of the study:

A comparative retrospective Study was done in Buryidah Central Hospital in Saudi populations; Data were collected in the period between June 2017 and January 2021.

3.1.2 Study population:

The data was consisted of 151 patients divided to:

3.1.2.1 Control group:

A sample size of 50 (24 males, 26 females) and their ages were ranged from 1 to 83 years old.

The inclusion criteria were the following:

a) Images without observable signs of abnormal pathological processes of the paranasal air sinuses

b) Slice thickness <1.25mm

c) Non distorted images.

Growth of the air sinuses was compared with age, sex and laterality. The age period was arranged as stipulated in similar studies by Fernandez et al, as following 1-5; 6-10; 11-15; 16-20; 21-25; >25.

In comparison with chronic sinusitis, the samples were divided into two age groups :> 20years and<20 years.

3.1.2.2 Chronic sinusitis group:

The sample consisted of 101 patients with chronic sinusitis (47 males, 54 females). They were divided into two age groups; more than 20years and less than20 years.

The inclusion criteria were the following:

a) Images diagnosed and reported with chronic sinusitis of the paranasal air sinuses.

b) Slice thickness <1.25mm.

c) None distorted images.

3.1.3 Machine used:

All patients were examined on a multislice CT scanner (Toshiba Aquilion 64 CT scanner) according to the following parameters: slice thickness between 0.625 to 1.25mm, 120 kV, 230 - 280 mA, Collimator width 3 - 5 cm, Scan type-Helical full 1.0 sec, FOV: 25.0, Bone window (center 200 HU, width 1500 HU).

3.2 Methods and technique:

CT scans typically obtained for visualizing the paranasal sinuses should include axial and coronal cuts.

Proper positioning of the patients head is important to obtain symmetrical image for both sides.

3.2.1 Axial View:

Patient should be positioned lying supine with the head in axial head holder. Scan should be taken parallel to the orbitomeatal line (0-10) degree gantry tilt; 5mm slice thickness should be taken forward through the entire face till we examined all sinus or area of interest.

3.2.2 Coronal view:

Coronal images are obtained directly, with the patient prone or supine with the neck in hyperextension (hanging head) position. The gantry should be angled perpendicular to the hard palate. Scan should be taken forward 5mm slice thickness until we cover all sinuses. Be reconstructing coronal from axial cuts, we can obtain images in coronal plane.

3.2.3 Method of collection of data:

- The selected patients were subjected to detailed history and relevant clinical examination.
- Each patient underwent CT- PNS examination in both axial and coronal planes.
- Normal patients were diagnosed and reported by radiologist in patients with clear paranasal sinuses images
- Chronic sinusitis patients were diagnosed and reported by radiologist according to presence of two of three major clinical signs (rhinorrhea, postnasal drip, and cough) for at least 3 months and confirmed by sinus CT scan with mucosal thickening, air fluid level, or opacification of sinus.
- The DICOM images of the patients were then transferred and viewed on a personal computer (Lenovo-PC, 64bit, Intel core i3, 4GB RAM).
- The images of each patient were of slice thick-nesses between 0.625 to 1.25mm in the axial plane, and were imported to SLICER 3D (www.slicer.org). SLICER 3D also allowed for viewing of the DICOM images in the three different planes viz. axial, sagittal and coronal.
- The axial view was selected as the most convenient and easiest method to trace axial contours of the sinuses for further analysis.

- Once each sinus was manually segmentally traced (per slice) from the floor to roof, the 3D models of each paranasal air sinus was reconstructed.
- SLICER 3D then calculated the bilateral volumes (right and left sides) of each PAS from these 3D models. Volumes of the PAS were determined and measured in cm^3 according to the SLICER 3D program.
- Data was written in data sheet collection.

3.3 Segmenting the Sinus Cavities

The CT-PNS DICOM images imported to SLICER 3D in three different views (axial, sagittal, coronal). Adjustment of the contrast was made by clicking and dragging to the right and left, and Adjustment of the brightness was made by clicking and dragging up and down, and follow these steps for any sinus's segmentation:

1. choosing any two colors (for left and right side)
2. selected the segmentation traced tool
3. outline the chosen sinus slice by slice from beginning to end
4. pressing on 3D tool to create a 3D model of the sinus
5. The most important note is carefully to traced sinuses from beginning to the end and to determine the start and end point for each sinus as follow:

- For frontal sinuses from a small opening on the forehead to the midline of the eye
- For maxillary sinuses from a small holes appearing within the teeth to near the junction of the ethmoid and sphenoid sinuses
- For ethmoid sinuses from the point where the frontal sinus ends to point where the maxillary sinuses begins
- For sphenoid sinuses the beginning visualized under the large maxillary sinuses and the end at the middle of the ethmoid sinus.

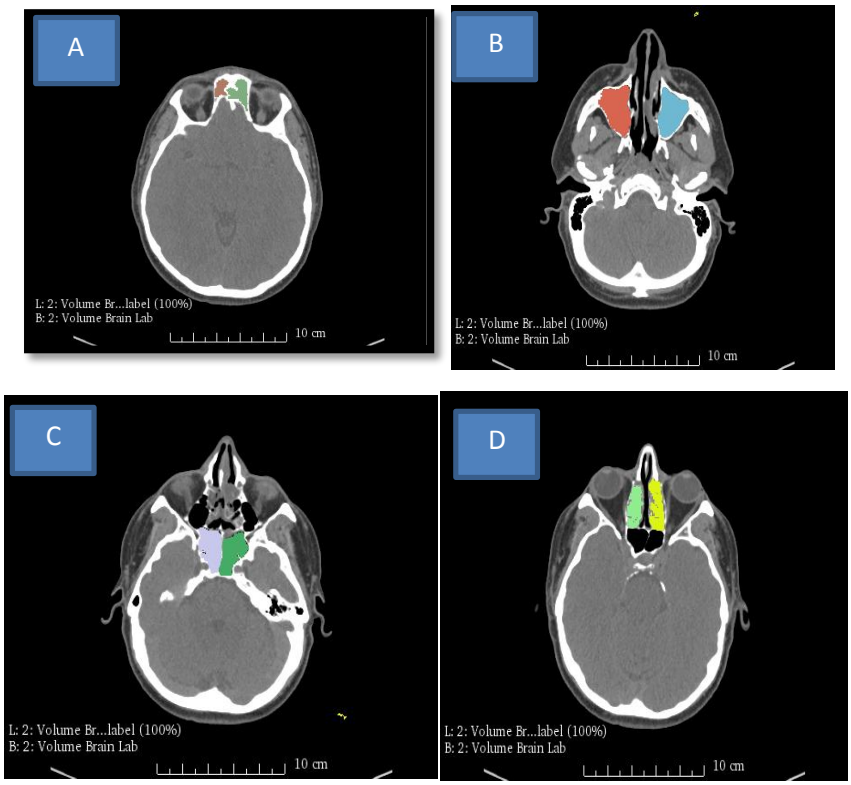


Figure (3.1) A-D: Segmenting the Sinus Cavities A. Frontal sinuses B. Maxillary sinuses C. Sphenoid sinuses D. Ethmoid sinuses (Pradeep k, 2020).

6. After we had finished labeling all of the sinuses, the 3-D model of all of the sinuses can be visualized

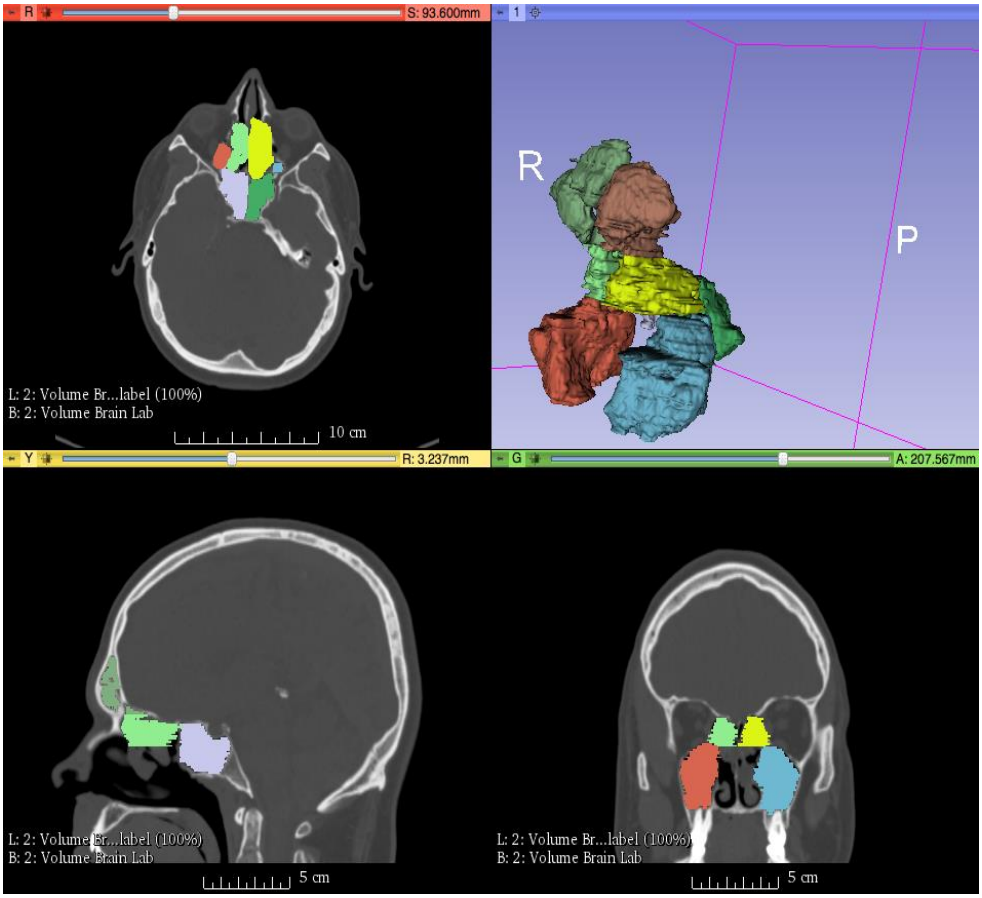


Figure (3.2):3D model of PNS (Pradeep k, 2020).

7. Finally, we pressed on label statistics tools to calculate volume of all of the sinus cavities and Copy the data into an excel workbook (Pradeep k, 2020).

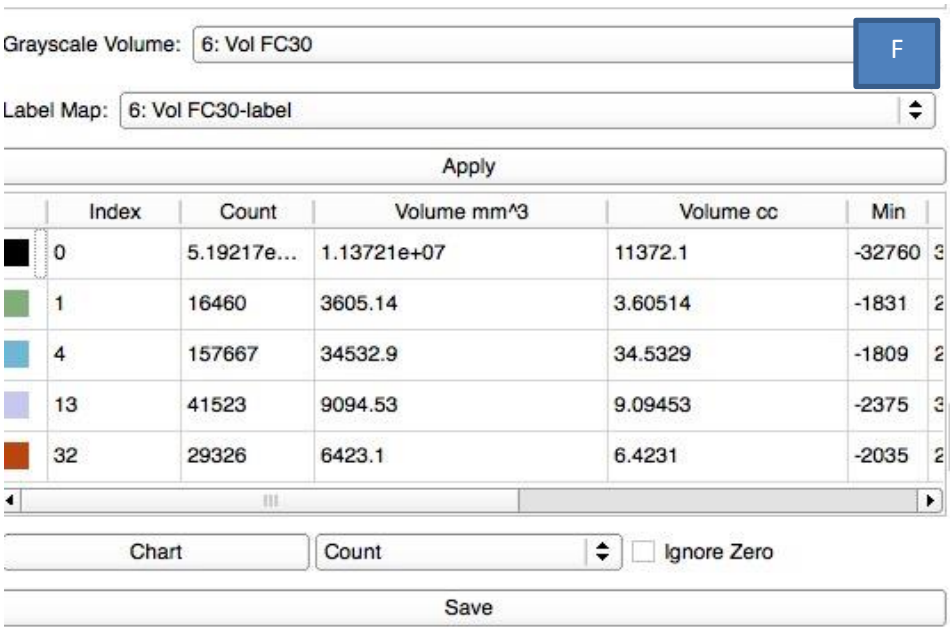


Figure (3.3): calculation volume of PNS (Pradeep k, 2020).

3.4 Ethical consideration:

The research was conducted after receiving the ethical approval from the hospital (head of radiology department).

3.5 image evaluation:

Normal patient's images were diagnosed and reported by radiologist in patients with clear paranasal sinuses images. Chronic sinusitis patient's images were diagnosed and reported by radiologist according to presence of two of three major clinical signs (rhinorrhea, postnasal drip, and cough) for at least 3 months and confirmed by sinus CT scan with mucosal thickening, air fluid level, or opacification of sinus.

3.6 Statistical analysis

Final analysis using excel sheet program.

Chapter Four
Results

Table (4.1): The mean volume in cm^3 for paranasal sinuses (PAS).

Paranasal sinuses	Mean volume in cm3
Frontal sinuses (F.S)	3.4
Ethmoid sinuses(E.S)	4.6
Sphenoid sinuses(S.S)	3.4
Maxillary sinuses (M.S)	13.1

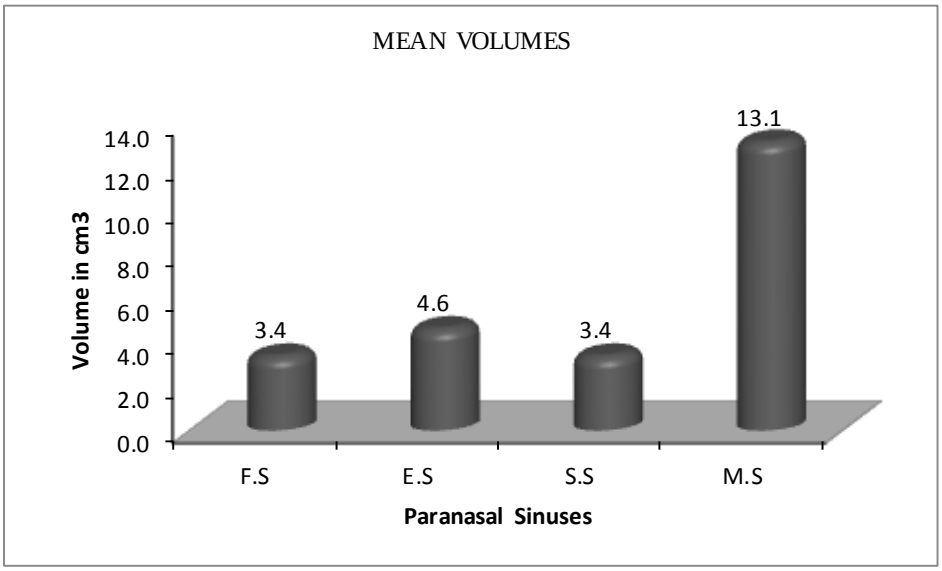


Figure (4.1): Shows the mean volume in cm3 for paranasal sinuses (PAS).

Table (4.2): The comparison of the growth of the paranasal air sinuses according to age groups.

Year	R. FV	L. FV	R. EV	L. E V	R.SV	L. SV	R. MV	L. MV
1-5	0	0	1.785103	1.783586	0	0	3.400147	3.40702
6-10	0.84111	0.817608	2.454715	2.333533	1.537395	1.475105	5.36806	5.33891
11-15	2.046492	2.04311	4.481252	4.482782	2.772788	2.760058	8.0602	8.247374
16-20	3.463973	3.531711	5.127816	5.075285	3.544737	3.831515	9.72748	9.707753
21-25	3.470468	3.611408	4.484243	4.504062	4.652943	4.65368	10.83828	10.83535
>25	3.4844	3.586402	4.344876	4.344703	4.130754	4.198648	11.07761	11.04224

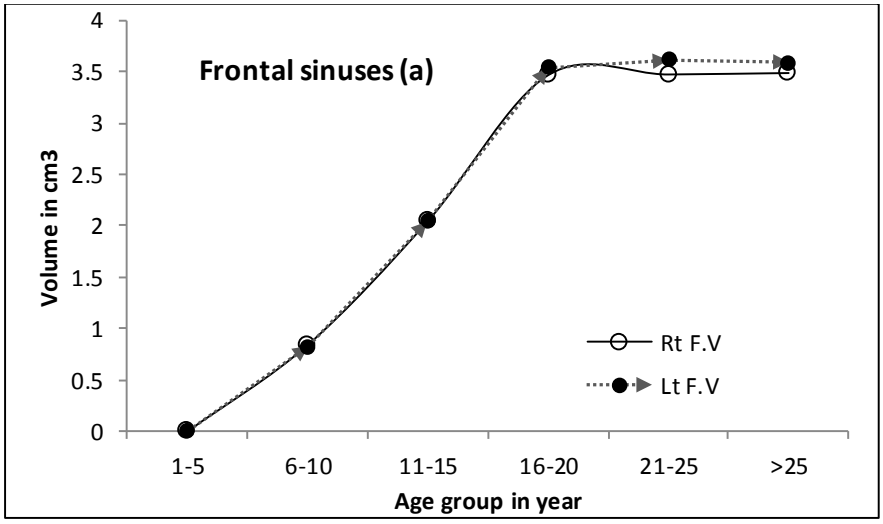


Figure (4.2a): Show the comparison of the growth of the frontal air sinuses according to age groups.

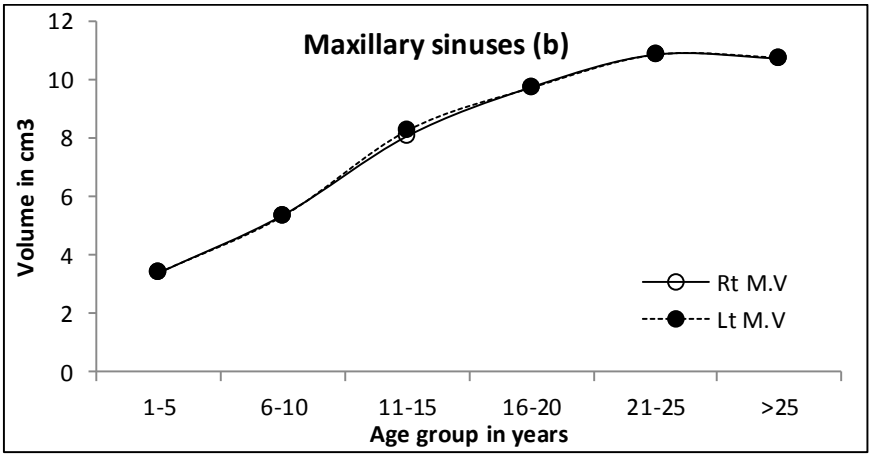


Figure (4.2b): Show the comparison of the growth of the maxillary air sinuses according to age groups.

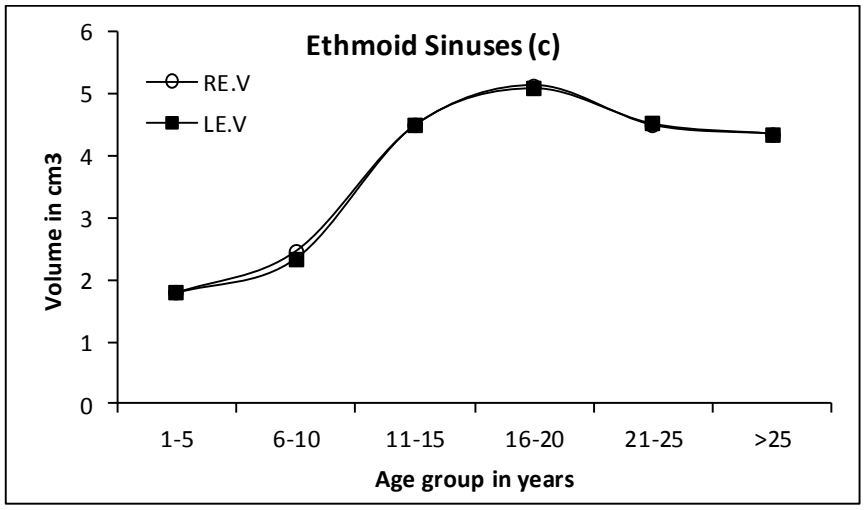


Figure (4.2c): Show the comparison of the growth of the ethmoid air sinuses according to age groups.

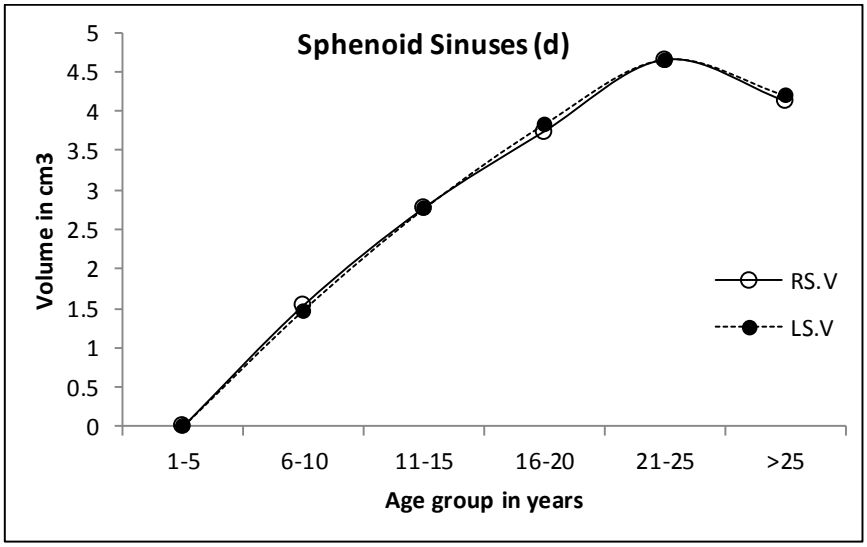


Figure (4.2d): Show the comparison of the growth of the sphenoid air sinuses according to age groups.

Table (4.3a): the growth of the paranasal air sinuses in male

a	Volumes of paranasal sinuses in Male							
Year	Rt F.V(Mal)	Lt F.V(Mal)	Rt E.V(Mal)	Lt E.V(Mal)	Rt S.V(Mal)	Lt S.V(Mal)	Rt M.V(Mal)	Lt M.V(Mal)
1-5	0.00	0.00	1.79	1.78	0.00	0.00	3.50	3.42
6-10	0.84	0.83	2.20	2.32	1.54	1.49	5.40	5.34
11-15	2.05	2.04	4.49	4.49	2.80	2.76	8.21	8.28
16-20	3.51	3.87	5.14	5.13	3.65	3.80	9.74	9.72
21-25	3.48	3.72	4.71	4.65	4.78	4.41	12.00	10.85
>25	3.42	3.67	4.07	3.96	4.36	4.10	11.72	10.75

Table (4.3b): the growth of the paranasal air sinuses in female.

b	Volumes of paranasal sinuses in female							
Year	Rt F.V(Fem)	Lt F.V(Fem)	Rt E.V(Fem)	Lt E.V(Fem)	Rt S.V(Fem)	Lt S.V(Fem)	Rt M.V(Fem)	Lt M.V(Fem)
1-5	0.00	0.00	1.78	1.80	0.00	0.00	3.22	3.31
6-10	0.84	0.81	2.22	2.34	1.53	1.48	5.23	5.13
11-15	2.05	2.04	4.44	4.48	2.76	2.71	7.99	8.03
16-20	3.46	3.78	4.98	5.02	3.63	3.80	9.51	9.40
21-25	3.36	3.62	4.47	4.48	4.70	4.41	11.71	10.58
>25	3.36	3.60	3.79	3.78	4.31	4.11	11.50	10.45

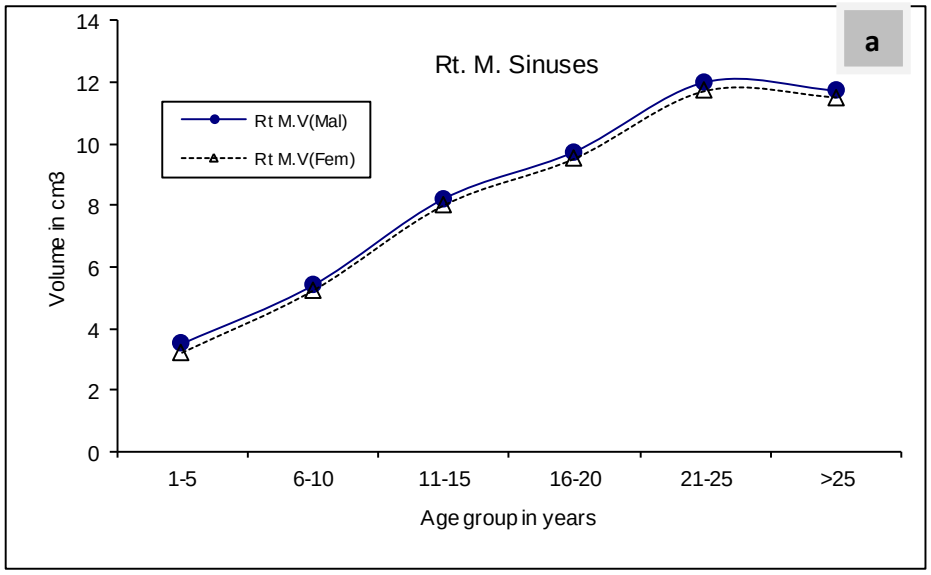


Figure (4.3a): show the comparison of the growth of the right maxillary sinuses according to gender.

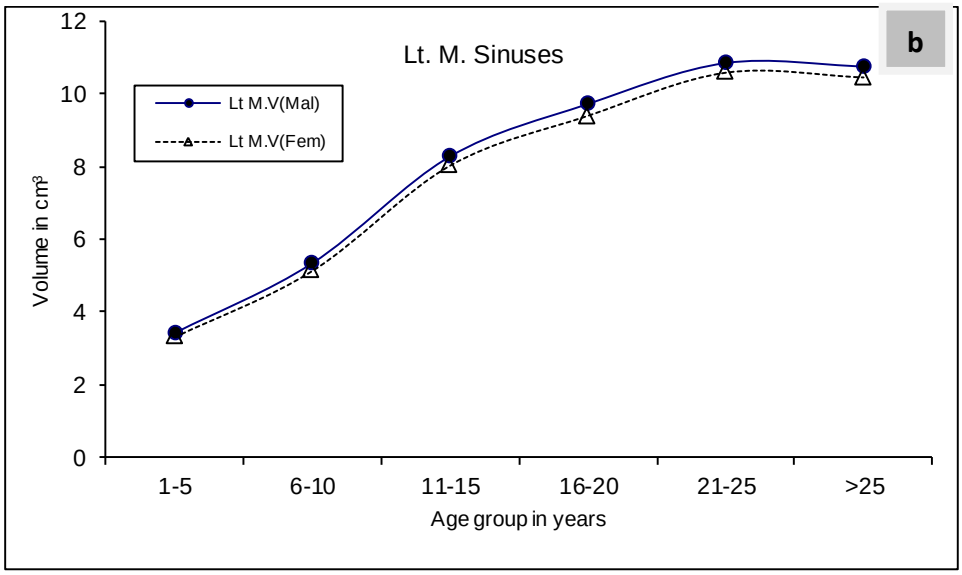


Figure (4.3b): show the comparison of the growth of the left maxillary sinuses according to gender.

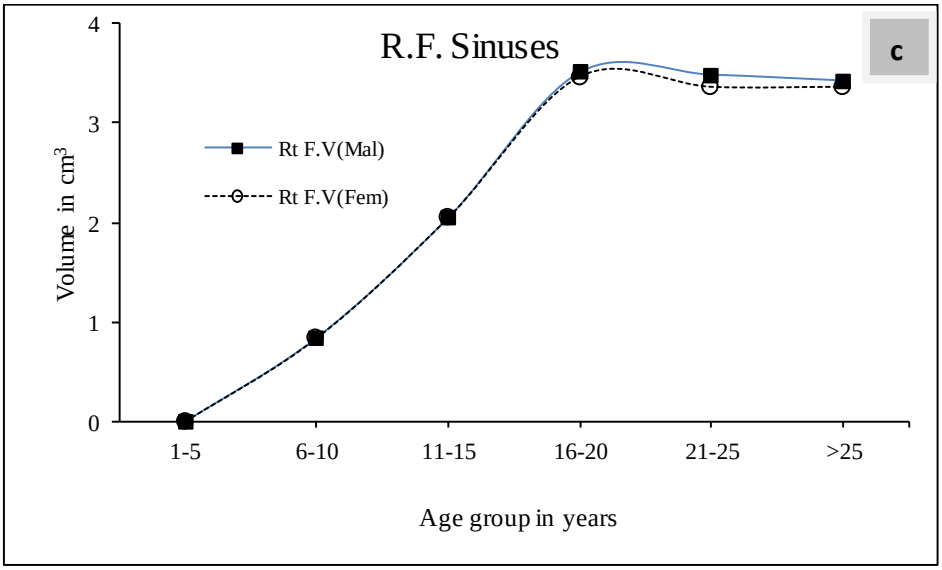


Figure (4.3c): show the comparison of the growth of the right frontal sinuses according to gender.

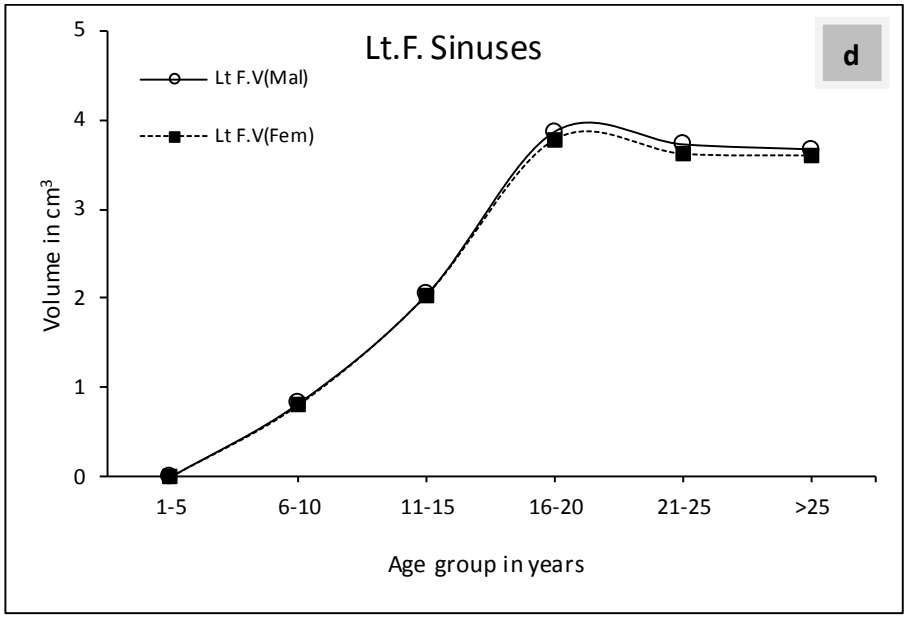


Figure (4.3d): show the comparison of the growth of the left frontal sinuses according to gender.

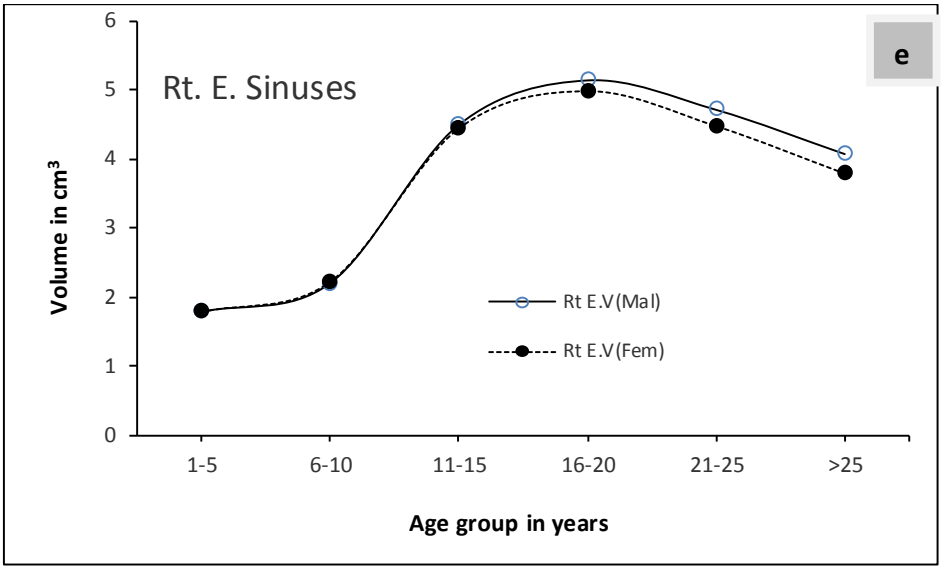


Figure (4.3e): show the comparison of the growth of the right ethmoid sinuses according to gender.

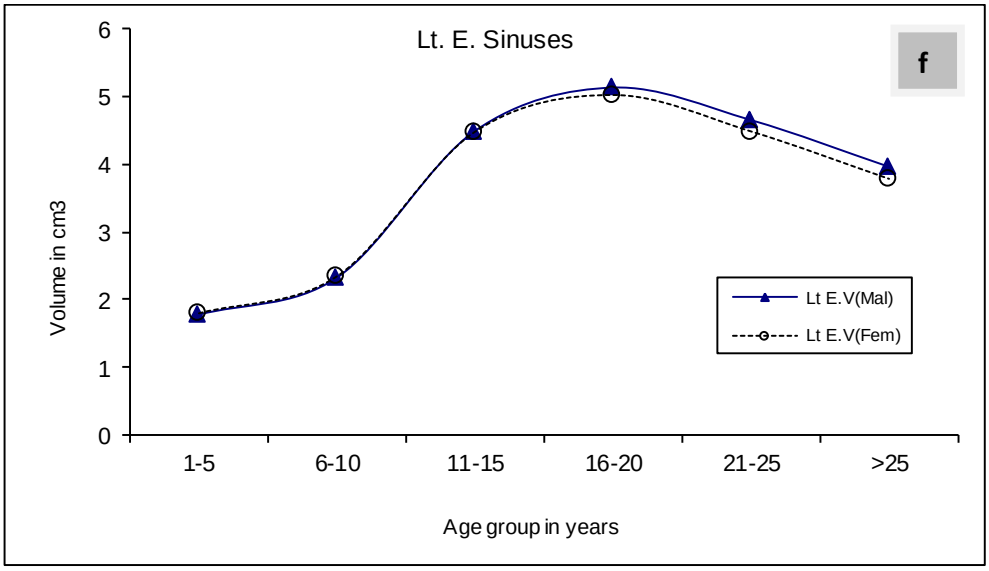


Figure (4.3f): show the comparison of the growth of the left ethmoid sinuses according to gender.

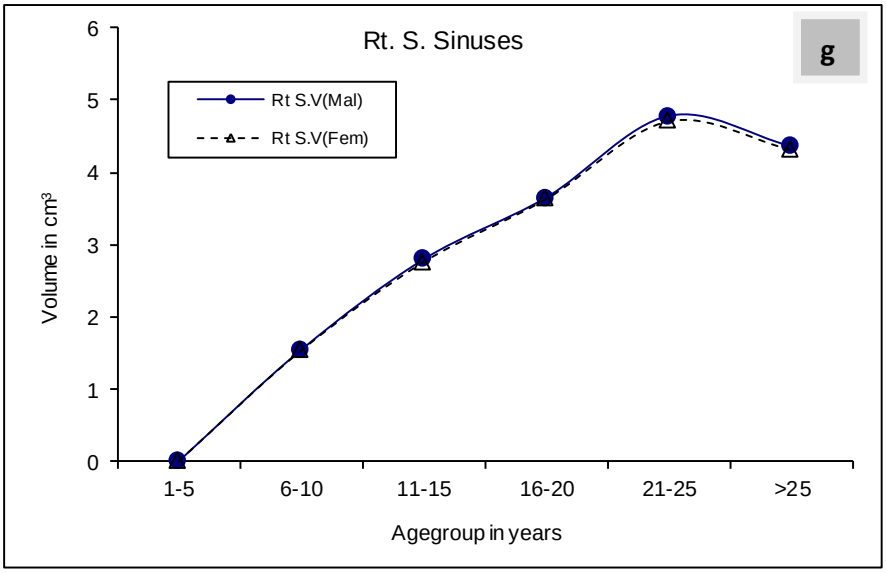


Figure (4.3g): show the comparison of the growth of the right sphenoid sinuses according to gender.

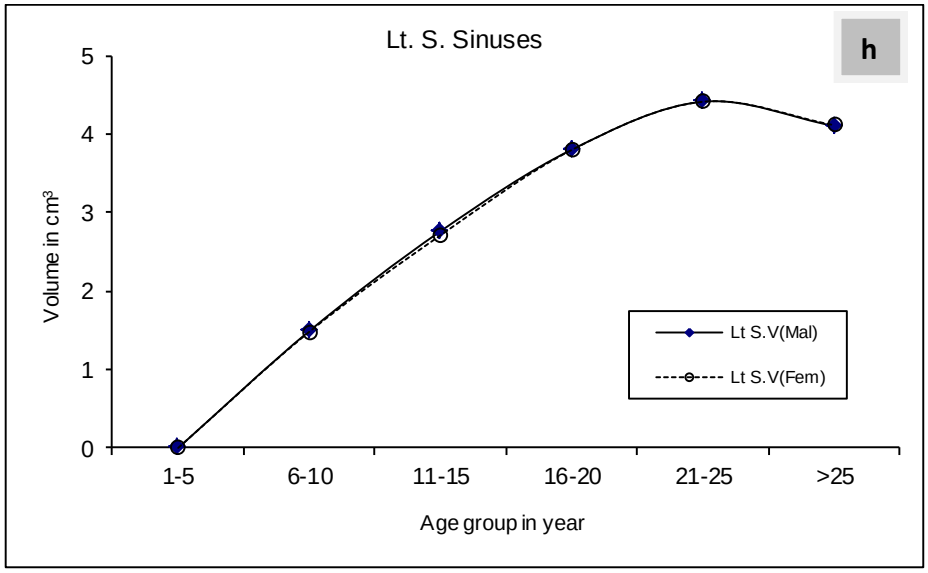


Figure (4.3g): show the comparison of the growth of the left sphenoid sinuses according to gender.

Table (4.4): Distribution of samples according to gender

Gender	Normal		Pathologized	
	frequency	percent	frequency	percent
Male	26	48%	54	53.5%
Female	24	52%	47	64.5%
Total	50	100%	101	100%

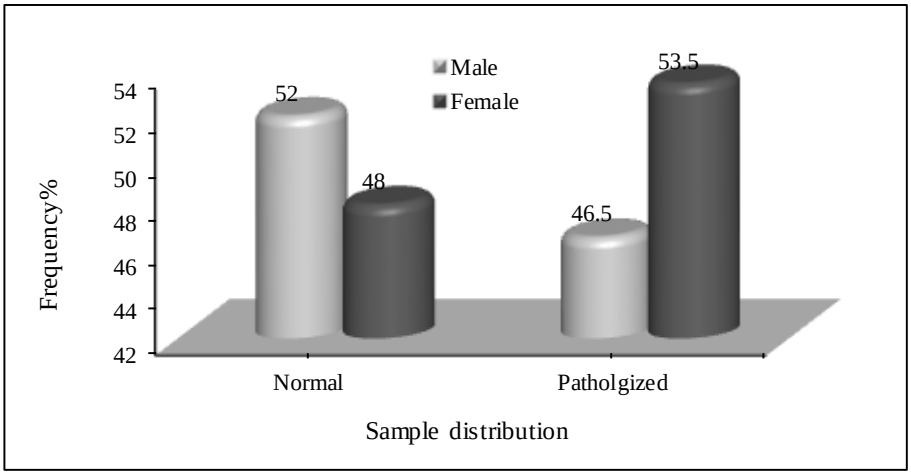


Figure (4.4): Distribution of samples according to gender.

Table (4.5) shows the distribution of chronic sinusitis based on age groups

Pathology	Frequency	Percent
CS < 20	19	18.8%
CS > 20	82	81.2%
Total	101	100%

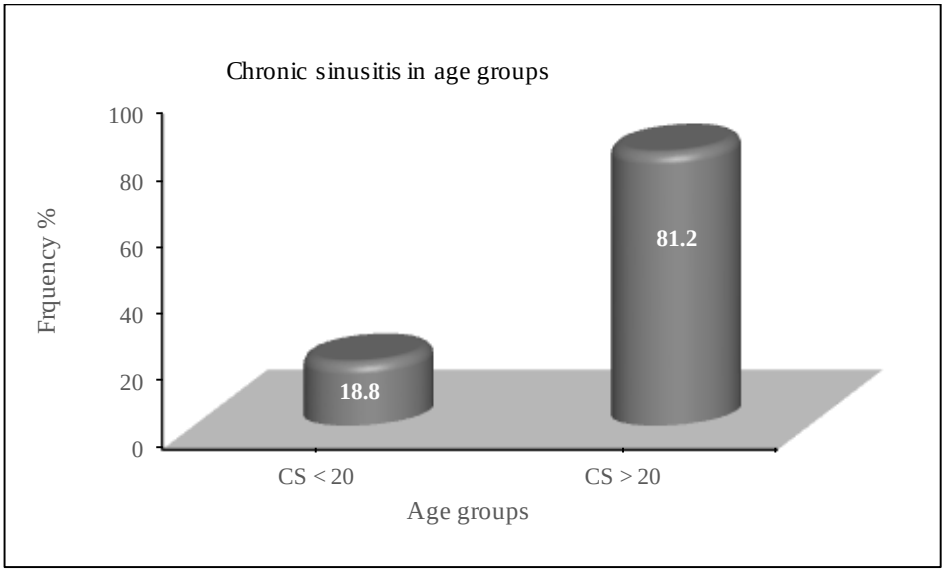


Figure (4.5): shows the distribution of chronic sinusitis based on age groups

Table (4.6): shows the involved paranasal with chronic sinusitis related to age and gender

Gender-age sinuses	CS-M<20		CS-F-<20		CS-M>20		CS-F>20	
	frequency	percent	frequency	percent	frequency	percent	frequency	percent
RF	6	33.3%	7	35	20	26.3	23	26.1
LF	5	27.8%	6	30	17	22.4	19	21.6
RE	10	55.6%	12	60	39	51.3	45	51.1
LE	11	61.1%	12	60	40	52.6	52	59.1
RS	2	11.1%	4	20	10	13.2	16	18.2
LS	3	16.7%	3	15	12	15.8	14	15.9
RM	13	72.2%	15	75	54	71.1	65	73.9
LM	12	66.7%	13	65	53	69.7	64	72.7
total	18	100%	20	100%	76	100%	88	100%

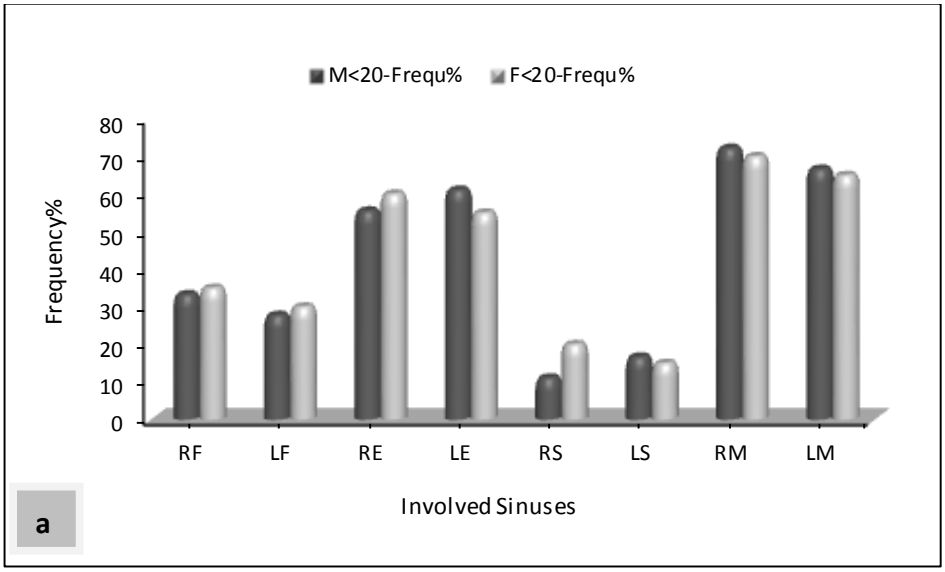


Figure (4.6a): shows the involved paranasal with chronic sinusitis related to age and gender (male)

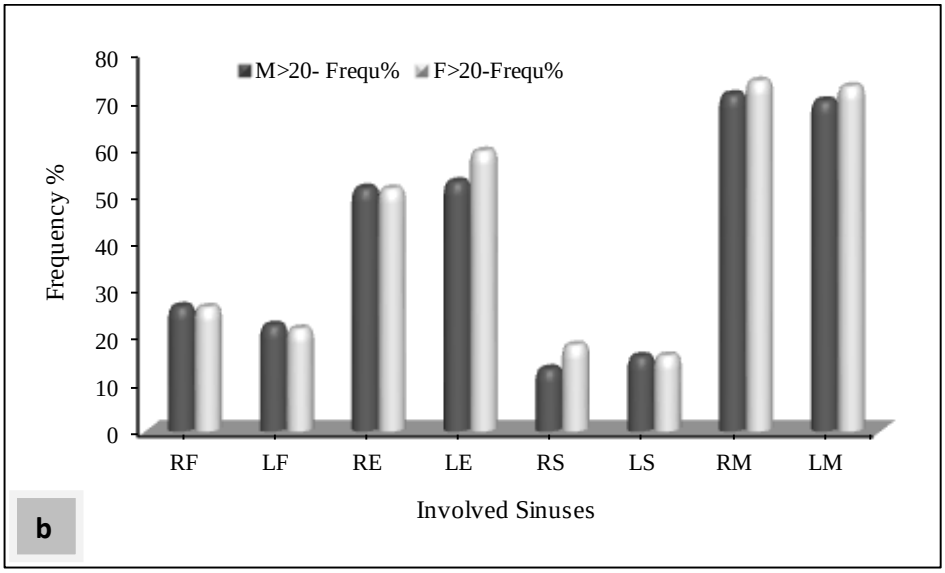


Figure (4.6a): shows the involved paranasal with chronic sinusitis related to age and gender (female)

Table (4.7): shows the comparison between control group and chronic sinusitis group related to age and gender

Sinuses Age-gender(normal/CRS)	RF .V	LF.V	RE.V	LE.V	RS.V	LS.V	RM.V	LM.V
N-M<20	2.11	2.98	4.92	4.97	2.76	2.86	11.71	11.78
Cs-M<20	2.21	2.97	4.31	4.38	2.75	2.78	9.85	9.87
N-F<20	2.10	2.86	4.24	4.23	2.77	2.86	10.07	10.10
Cs-F<20	2.01	2.87	3.06	3.08	2.74	2.79	7.41	7.80
N-M>20	4.1	4.9	5.9	5.8	4.9	4.9	12.9	13.0
Cs-M>20	4.0	4.8	4.1	4.3	4.8	4.8	10.4	10.8
N-F>20	3.9	4.8	5.3	5.4	4.8	4.9	11.5	11.8
Cs-F>20	3.8	4.7	4.0	4.2	4.8	4.7	8.2	8.8

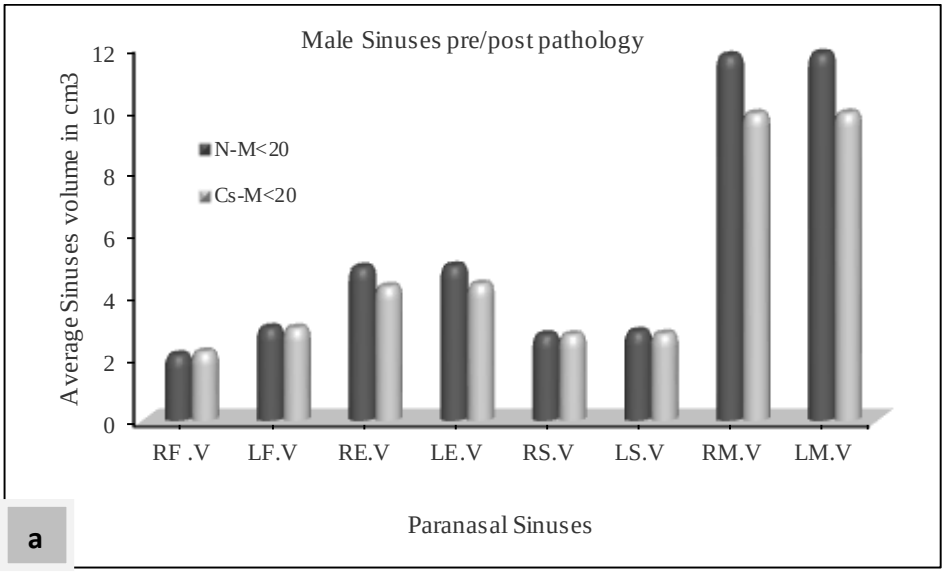


Figure (4.7a): shows the comparison between control group and chronic sinusitis group related to age (<20) and gender (male)

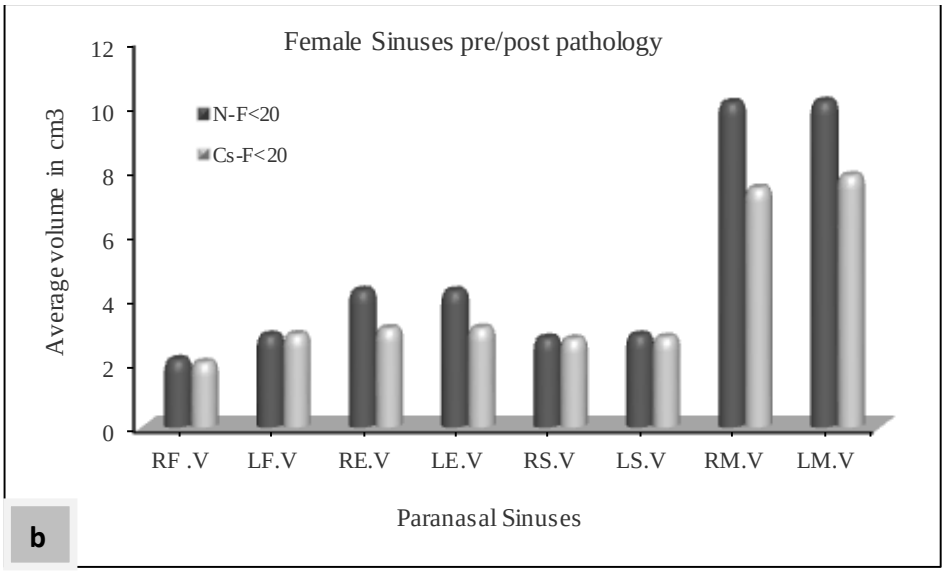


Figure (4.7b): shows the comparison between control group and chronic sinusitis group related to age (<20) and gender (female)

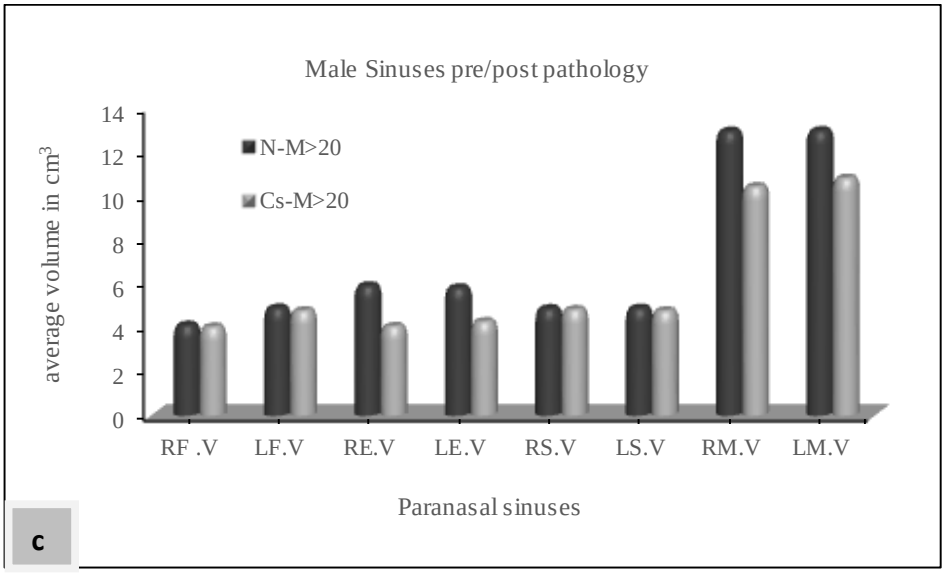


Figure (4.7c): shows the comparison between control group and chronic sinusitis group related to age (>20) and gender (male)

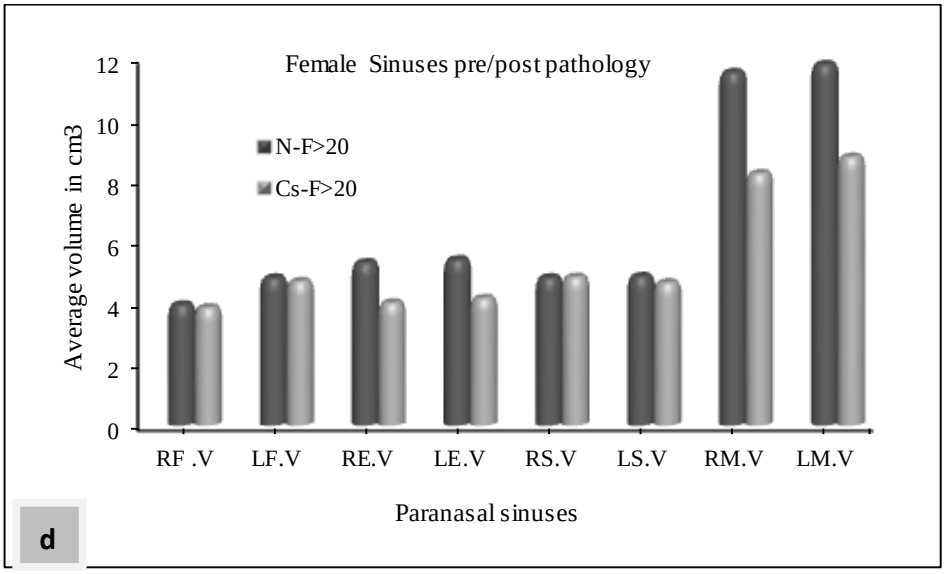


Figure (4.7d): shows the comparison between control group and chronic sinusitis group related to age (>20) and gender (female)

Chapter Five
Discussion, Conclusion and Recommendation

5.1 Discussion

The following chapter will deals with presentation of results related to paranasal sinuses volumes in relation to side, age and gender in normal(control group) and abnormal(chronic sinusitis group) samples by analyzing 3D of axial PAS CT scan images to reveal the average volumes of PAS in Saudi patient, the air sinuses' growth related to ages, the differences between two sides (right and left), the differences between gender PAS volumes, the common involved gender with sinuses pathologies, the common involved sinuses with pathologies, the common involved ages with sinuses pathologies and the comparison between means volume of PAS in control group and chronic sinusitis group related to age g and gender and side .

The obtained results with relevant discussion and analysis have been enumerated as follows:

Figure 4.1 shows the mean volume in cm^3 for paranasal sinuses (PAS). It revealed that: the largest sinuses were the maxillary air sinus (13.1 cm^3) followed by ethmoid air sinuses (4.6 cm^3) and the sphenoid and frontal air sinuses were the smallest. In comparison with previous studies; Park et al. (2010) found same result while Rennie et al, (2017) agreed that maxillary sinuses were the largest but the one was not as the current result. And they ordered as follows: maxillary air sinus [8727.3 mm3 (R); 8849.5 mm3 (L)]; frontal air sinus [3605.0 mm3 (R); 4029.9 mm3 (L)]; ethmoid air sinus [3558.2 mm3 (R); 3512.7 mm3 (L)] and sphenoid air sinus [3243.7 mm3 (R); 3396.0 mm3 (L)], concluded that the mean bilateral volume for the maxillary air sinus was the largest and the sphenoid air sinus was the smallest.

The results in Figures 4.2a-d showing that: the air sinuses' growth has proportional increment correlation with ageing, and varied dependent on age groups.

For frontal sinuses Figure 4.2a, the graph show that frontal sinuses had strong correlation (R^2 = 0.8) with age, showing rapid continues increasing in growth, reaching the maximum by 16-20 years of age followed by a plateau thereafter. Several previous studies agreed with the current result with different maximum volumes as follow ; maximum volume at 19 years of age (Park et al, 2010), over 20 years of age (Fernandez et al, 2000), between 21-25 years of age(Karakas and Kavaklı 2005) and over 25 years of age (Rennie et al, 2017).

For maxillary sinuses Figure 4.2b, the graph showed that: maxillary sinuses gradually increase in growth and reaching a maximum by 21-25 years of age followed by a plateau thereafter. three studies agreed with the current result with different maximum volumes as follow; over 20 years of age Fernandez et al, (2000),between 21-25 years of age Karakas and Kavaklı, (2005) and over 25 years of age Rennie et al, (2017).

In comparison between the current study and the previous studies; we can conclude that, both frontal and maxillary sinuses reaching maximum growth in 20 years old followed by a plateau thereafter, or continuing in growth over 20 years old, and these results supported by Jun et al, (2005) and Tatlisumak et al, (2008).

For ethmoid sinuses Figure 4.2c, the graph showed that: there was gradual increase in growth reaching a maximum by 16 to 20 years old and then decreased. Relative to literature, Rennie et al, (2017) showed that: ethmoid sinuses had strongest correlation with age, and continues rapid increasing in growth reaching a maximum by 16 to 18 years of age followed by a plateau

thereafter. While Fernandez et al, (2000) got same result with a maximum by 11 to 15 years of age, and then decreased.

For sphenoid sinuses Figure 4.2d, show that sphenoid sinuses had strongest correlation with age, and has a rapid continuing increment growth as ageing to reach the maximum by 21 to 25 years old then decreased. Compared with this result; Rennie et al, (2017) agreed that sphenoid sinuses increase gradually with ageing (1-9 years) and peaking at 16 to 18 years old. On the other hand Fernandez et al, (2000) got same results for sphenoid sinuses correlation with ageing but reaching the maximum by 11 to 15 years old, and then decreased. Also, Karakas and Kavaklı, (2005) showed same result related to sphenoid sinuses correlation with ageing however the maximum growth occurred by 21 to 25 years of age and then decreased

In comparison between the current study and the previous ones; the researchers could conclude that: both ethmoid and sphenoid sinuses reaching maximum growth by 15-25 years old and decreased thereafter.

Also, the current study agree with the result obtained by Takahashi, (1984); in view of growth relation with ageing where they ascribed such type of growth to resorption type that develop between osseous walls of both frontal & sphenoid sinuses and however Rennie et al, (2017) disagreed with the above argument and suggestions and further they ascribed the similarity between ethmoid and sphenoid sinuses to their common origin and as well got strengthen by Spaeth et al, (1997).

The result in Figures 4.2 b, c & d showed symmetrical side's growth relative to ageing except for the frontal air sinuses figure 4.2(a), in which the left air sinus appears to grow at a faster rate than the right side in the period from16 to 20 years old. similar result have been noticed by Rennie, et al, (2017) with exception for the frontal and sphenoid air sinuses. However Ariji, et al, (1996)

stated that: no significant differences concerning sides growth. while in this realm Amusa et al, (2011) highlighted a significant difference concerning sides growth where the left and right frontal sinuses develop independently and attributed such phenomena to unequal reabsorption of diploe during sinuses development. Also, for the justification of growth variation in sinuses, Koertvelyessy (1972) ascribed to environmental factors such as coldness.

finally, the result in figures 4.2 a & d, show that both frontal and sphenoid sinuses were not appeared at age group (1-5) or at birth and this scribed to slow development between these periods and paranasal sinus development is linked with facial and dental growth (wolf,1993). Similar result by Rennie et al, (2017) whom their the sample revealed that the ethmoid and maxillary air sinuses were the first to appear, at 1 to 3 years of age (>95% bilaterally). They were present in 100% of the sample by the ages of 4 to 6 years. The frontal air sinuses appeared at 1 to 3 years of age in only 10.3 % on the right and 13.2% on the left, reaching 50% by ages 4 to 6 years, and finally 100% by ages 16 to 18 years. The sphenoid air sinuses were present bilaterally by the ages 1 to 3 years in approximately 55.9% on the right and 54.4% on the left side, appearing in 100% of the sample by ages 13 to 15 years.

The result in figure 4.3a-h shows the comparison of the growth of the paranasal air sinuses according to gender.

for maxillary sinuses (Figure 4.3a&b), show that male have larger sinus volumes than female in all age groups, same result found by (Karakas and Kavaklı 2005) . For frontal and ethmoid sinuses (Figure 4.3c-f), the result show that there was little increase in male sinus volume than female after 16-20 age group for frontal sinuses, and after 11-16 age group for ethmoid sinuses, these findings are similar to(Rennie, Haffajee et al. 2017) which he found that all of

the paranasal sinuses have increase in volume after 16-18 age group. Our study also agree with (Fernandez, Escuredo et al. 2000) and(Apuhan, Yıldırım et al. 2011).Some studies (Emirzeoglu, Sahin et al. 2007),(Sahlstrand-Johnson, Jannert et al. 2011),(Kawarai 1999)],not all [(Fernandes 2004)],reported differences in the maxillary sinus. Differences were noted in the frontal sinus[(Emirzeoglu, Sahin et al. 2007),(Kawarai 1999)].

For sphenoid sinuses (Figure 4.3g&h), the graphs show no differences between male and female sinus volume, and this finding supported by [(Emirzeoglu, Sahin et al. 2007),(Kawarai 1999)].

In study by (Cohen, Warman et al. 2018) demonstrated that men have larger maxillary, sphenoid and frontal sinus volume than females. This was found nearly for all sides of each sinus, the mean volume and the sum. In contrast, volumetric studies of mastoid air cell pneumatization did not find significant difference between genders [(Lee, Jun et al. 2005),(Luntz, Malatskey et al. 2001)]. This might suggests that the difference noted could not be solely explained by general difference in skull size between genders, and that mastoid air cells and the paranasal sinuses are affected by different factors in their pneumatization process. Further studies are needed to evaluate the relation between the volume of the sinuses and total skull volume.

Figure 4.4 shows the common involved gender with sinuses pathologies. It shows that the common involved gender with sinuses pathologies was the female, with a percent of 53.5% relative to male. Such high incidence among female could be ascribed to fact that ; women exposure to dust and smoking from home cleaning and cooking more than men and these lead to allergic rhinitis which is the causative factor in sinusitis. Another causative factor is rhinitis of pregnancy. Recent theories of sinusitis indicate that it often occurs as

part of a spectrum of diseases that affect the respiratory tract and is often linked to asthma thus Women are known to have higher prevalence and severity of asthma (Cruz, 2005).

Same results have been noticed by Timmanagouda, (2008) in which he found that the incidence percent among female was 65.4% relative to male (34.6%)

Figure 4.5 show the distribution of chronic sinusitis based on two age groups. In which it reveals that the chronic sinusitis infected older ages (>20years old) more than younger one (<20 years old). The high incidence among adult age group could be ascribed to more expose to the environment, recurrent upper respiratory tract infections. Same result has been obtained by Ologe and Olatunji, (2003) said that these findings corroborate the findings by earlier workers and scribe the less common incidence in children to wide ostia and some of their sinuses are not fully developed. These factors could reduce the chances of sinus obstruction that could lead to sinusitis. Chan et al, (2004) in a histopathologic study of children with chronic rhinosinusitis (CRS) compared to the sinus mucosa in pediatric and adult CRS concluded that sinus mucosa of young children with CRS has less eosinophilic inflammation, basement membrane thickening, and mucus gland hyperplasia characteristic of adult CRS.

Figure 4.6a&b shows the involved paranasal with chronic sinusitis among age groups. All age groups reveal that the common involved sinuses were the maxillary sinuses followed by ethmoid sinuses. For maxillary sinuses, this result could be scribe to anatomical location of The frontal, ethmoidal and the sphenoidal sinuses are witch anatomically located above the nasal cavities, therefore, their drainage into the nasal cavity is assisted by gravity especially when their openings are not obstructed by disease so that changes or alterations

in the aforementioned paranasal sinuses may initially be subtle and not radiologically evident until it becomes extensive with blockage of sinus openings. On the other hand, poor anatomical position drainage predisposes the maxillary sinus to stagnation of secretions and infection more than any other paranasal sinus (Ahmad and Tahir, 2003). Other investigators in Nigeria have reported 47.5%-80.4% maxillary sinus involvement (Ezeanolue et al., 2000). They all agreed that maxillary sinusitis is much commoner than sinusitis of the other paranasal sinuses. On the other hand, several studies found that; ethmoid sinuses were the common involved sinuses because of the obstruction of the osteomeatal complex, which is located within the ethmoidal sinuses and this obstruction due to mucosal inflammation (Kennedy et al., 1985; Garcia et al., 1994).

Figure 4.7a-d shows the comparison between control group and chronic sinusitis group related to age and gender; It reveals that; the mean bilateral maxillary and ethmoid sinus volumes in the chronic sinusitis patients were smaller than that in the normal or control group, also reveals that the mean bilateral frontal and sphenoid sinus volumes in the chronic sinusitis patients were similar to the normal or control group, this result could be scribe to more inflammatory changes in maxillary and ethmoid sinuses (more involvement to chronic sinusitis, more than 50%) and less inflammatory changes in the frontal and sphenoid sinuses (less involvement to chronic sinusitis, less than 50%) in figure 3a-b. Similar results have been noticed by Kim et al, (2008) in which they found that; the mean volume of the maxillary sinuses was 22.5 ± 4.4 cm3 in the normal group and 20.0 ± 4.1 cm3 in the CRS group in longstanding pediatric chronic rhinosinusitis. Bilal et al, (2019) found that the left-side maxillary sinus, sphenoid sinus and frontal sinus pneumatization in the patients with nasal

polyposis were smaller than those of the control group, and he scribed that to genetic pneumatization and environmental factors. On the other hand Ikeda, (1996) scribed the reduction in volume to the narrowing of ethmoid infundibulum and middle meatus by inflammation of the ostiomeatal complex and by various bony anatomic variations in the nasal cavity, leading to impaired pneumatization of the maxillary sinus.

5.2Conclusion:

The Study concluded that the Saudi sinus morphology is different from other populations mentioned in the previous studies. CT imaging with 3D reconstruction, as conducted in this study, should ensure accurate data capture of both the morphology and morphometry of the PAS. The current study was undertaken to provide normal volumetric parameters for a Saudi Arabia population. The findings highlighted the development of all the air sinuses according to age utilising 3D reconstruction. In particular, the volume of the ethmoid air sinus was documented, which was not fully reported. The data illustrated important morphometric volume growth of the paranasal air sinuses and variation according to age, sex, laterality and pathological conditions.

PSA showing strong correlation growth relative to ageing from 1-5 years up to 11-15 years as superimposed type of graph, then the variation started after the age of 16 years old and as well divided into two anatomical sides as simultaneous right sinuses and simultaneous left sinuses in view of growth correlated with ageing and gender.

CT Volumetric analysis of paranasal sinuses between normal and pathological condition provide us with real action of pathological changes. Chronic sinusitis disease has an effect on the growth of sinus volumes at different ages. Inflammatory changes decrease the sinuses volume rely on the widespread of the disease, so maxillary and ethmoid sinuses were decrease therefore. More research and studies are needed to determine the percentage of the sinus opacification that lead to sinus volume decreasing.

5.2 Recommendation

By the end of the following thesis we would like to recommend the following points:

- The volumes of the PAS are the simplest, most comprehensive means to appreciate the extent and anatomy of these air filled spaces.
- CT imaging is the radiological technique of choice for analysing the PAS, as the distinction between bone, mucosa and other soft tissue can be clearly defined and 3D reconstructions from these CT images are able to yield a more precise form or 3D morphology of the PAS.
- The volume of the air sinuses is the most important parameter that can establish its size and these normal values may be useful in the diagnosis of sinus pathologies, and in forensic identification of sex and ancestry.
- Researches and studies are needed to determine the percentage of the sinus opacification that lead to sinus volume decreasing.

References:

Adibelli, Z. H., M. Songu and H. Adibelli (2011). "Paranasal sinus development in children: A magnetic resonance imaging analysis." American journal of rhinology & allergy 25(1): 30-35.

Ahmad, B. and A. Tahir (2003). "Rhinosinusitis in north-eastern Nigeria: computerized tomographic scan findings." Nigerian Journal of Surgical Research 5(3): 110-113.

Ah-See, K. W. and A. S. Evans (2007). "Sinusitis and its management." Bmj 334(7589): 358-361.

Alho, O.-P. (2004). "Nasal airflow, mucociliary clearance, and sinus functioning during viral colds: effects of allergic rhinitis and susceptibility to recurrent sinusitis." American journal of rhinology 18(6): 349-355.

Amusa, Y., Eziyi, J., Akinlade, O., Famurewa, O., Adewole, S., Nwoha, P., et al. 2011. Volumetric measurements and anatomical variants of paranasal sinuses of Africans (Nigerians) using dry crania. *International journal of medicine and medical sciences,* 3(10):399-03.

Anand, V. K. (2004). "Epidemiology and economic impact of rhinosinusitis." Annals of Otology, Rhinology & Laryngology 113(5_suppl): 3-5.

Apuhan, T., Y. S. Yıldırım and H. Özaslan (2011). "The developmental relation between adenoid tissue and paranasal sinus volumes in 3-dimensional computed tomography assessment." Otolaryngology--Head and Neck Surgery 144(6): 964-971.

Ariji, Y., T. Kuroki, S. Moriguchi, E. Ariji and S. Kanda (1994). "Age changes in the volume of the human maxillary sinus: a study using computed tomography." Dentomaxillofacial radiology 23(3): 163-168.

Barghouth, G., J. Prior, D. Lepori, B. Duvoisin, P. Schnyder and F. Gudinchet (2002). "Paranasal sinuses in children: size evaluation of maxillary, sphenoid, and frontal sinuses by magnetic resonance imaging and proposal of volume index percentile curves." European radiology 12(6): 1451-1458.

Bent III, J. P. and F. A. Kuhn (1994). "Diagnosis of allergic fungal sinusitis." Otolaryngology—Head and Neck Surgery 111(5): 580-588.

Bernstein, J. M., C. Allen, G. Rich, D. Dryja, P. Bina, R. Reiser, M. Ballow and G. E. Wilding (2011). "Further observations on the role of Staphylococcus aureus exotoxins and IgE in the pathogenesis of nasal polyposis." The Laryngoscope 121(3): 647-655.

Bilal, N., N. Yurttutan, B. Kizildag, S. Sarica, S. Sağıroglu, A. Doganer and I. Orhan (2019). "An evaluation of the effect of a change in paranasal sinus volumes on the formation of nasal polyposis and mastoid aeration." JOURNAL OF CLINICAL AND ANALYTICAL MEDICINE 10(2): 177-182.

Branstetter, B. F. and J. L. Weissman (2005). "Role of MR and CT in the paranasal sinuses." Otolaryngologic Clinics of North America 38(6): 1279-1299.

Chan, K. H., M. J. Abzug, L. Coffinet, E. A. Simoes, C. Cool and A. H. Liu (2004). "Chronic rhinosinusitis in young children differs from adults: a histopathology study." The Journal of pediatrics 144(2): 206-212.

Chang, C. C., G. A. Incaudo and M. E. Gershwin (2014). Diseases of the sinuses: a comprehensive textbook of diagnosis and treatment, Springer.
Cruz, A. (2005). "The 'united airways' require an holistic approach to management." Allergy 60(7): 871-874.

Cuenca, J. H. Á., P. N. Valentín, M. A. H. García, J. M. S. Bermejo, C. R. Robles and C. F. Arguelles (2020). Imaging in sinonasal inflammatory disease, European Congress of Radiology 2020.
Eggesbø, H., S. Søvik, S. Dølvik, K. Eiklid and F. Kolmannskog (2003). "Proposal of a CT scoring system of the paranasal sinuses in diagnosing cystic fibrosis." European radiology 13(6): 1451-1460.
Eisen, M. D., D. M. Yousem, L. A. Loevner, E. R. Thaler, W. B. Bilker and A. N. Goldberg (2000). "Preoperative imaging to predict orbital invasion by tumor." Head & Neck: Journal for the Sciences and Specialties of the Head and Neck 22(5): 456-462.
Emirzeoglu, M., B. Sahin, S. Bilgic, M. Celebi and A. Uzun (2007). "Volumetric evaluation of the paranasal sinuses in normal subjects using computer tomography images: a stereological study." Auris Nasus Larynx 34(2): 191-195.
Ezeanolue, B., E. Aneke and D. Nwagbo (2000). "Correlation of plain radiological diagnostic features with antral lavage results in chronic maxillary sinusitis." West African journal of medicine 19(1): 16-18.

Fernandes, C. (2004). "Volumetric analysis of maxillary sinuses of Zulu and European crania by helical, multislice computed tomography." The Journal of laryngology and otology 118(11): 877.
Fernandez, J. S., J. A. Escuredo, A. S. Del Rey and F. S. Montoya (2000). "Morphometric study of the paranasal sinuses in normal and pathological conditions." Acta oto-laryngologica 120(2): 273-278.
Fokkens, W. J., V. J. Lund, J. Mullol, C. Bachert, I. Alobid, F. Baroody, N. Cohen, A. Cervin, R. Douglas and P. Gevaert (2012). "European position paper on rhinosinusitis and nasal polyps 2012." Rhinology. Supplement 23: 3 p preceding table of contents, 1-298.
Hamilos, D. L., D. Y. Leung, R. Wood, L. Cunninghama, D. K. Bean, Z. Yasruelb, E. Schotmanb and Q. Hamid (1995). "Evidence for distinct cytokine expression in allergic versus nonallergic chronic sinusitis." Journal of allergy and clinical immunology 96(4): 537-544.
Hermans, R., S. De Vuysere and G. Marchal (1999). Squamous cell carcinoma of the sinonasal cavities. Seminars in Ultrasound, CT and MRI, Elsevier.
Hutcheson, P. S., M. S. Schubert and R. G. Slavin (2010). "Distinctions between allergic fungal rhinosinusitis and chronic rhinosinusitis." American journal of rhinology & allergy 24(6): 405-408.
Ikeda, A. (1996). "Volumetric measurement of the maxillary sinus by coronal CT scan." Nippon Jibiinkoka Gakkai Kaiho 99(8): 1136-1143, 1155.

Jankowski, R., F. Bouchoua, L. Coffinet and J. Vignaud (2002). "Clinical factors influencing the eosinophil infiltration of nasal polyps." Rhinology 40(4): 173-178.
Jones, N., A. Strobl and I. Holland (1997). "A study of the CT findings in 100 patients with rhinosinusitis and 100 controls." Clinical Otolaryngology & Allied Sciences 22(1): 47-51.

Jun, B.-C., S.-W. Song, C.-S. Park, D.-H. Lee, K.-J. Cho and J.-H. Cho (2005). "The analysis of maxillary sinus aeration according to aging process; volume assessment by 3-dimensional reconstruction by high-resolutional CT scanning." Otolaryngology—Head and Neck Surgery 132(3): 429-434.
Karakas, S. and A. Kavaklı (2005). "Morphometric examination of the paranasal sinuses and mastoid air cells using computed tomography." Annals of Saudi medicine 25(1): 41-45.
Kennedy, D. W., W. E. Bolger and S. J. Zinreich (2001). Diseases of the sinuses: diagnosis and management, PMPH-USA.
Khan, A., G. Vandeplas, M. T. H. Thi, V. N. Joish, L. Mannent, P. Tomassen, T. Van Zele, L. O. Cardell, J. Arebro and H. Olze (2019). "The Global Allergy and Asthma European Network (GALEN) rhinosinusitis cohort: a large European cross-sectional study of chronic rhinosinusitis patients with and without nasal polyps." Rhinology 57(1): 32-42.
Larsen, P. L. and M. Tos (2004). "Origin of nasal polyps: an endoscopic autopsy study." The Laryngoscope 114(4): 710-719.
Lee, D.-H., J.-H. Shin and D.-C. Lee (2012). "Three-dimensional morphometric analysis of paranasal sinuses and mastoid air cell system using computed tomography in pediatric population." International journal of pediatric otorhinolaryngology 76(11): 1642-1646.
Lubbe, D. (2009). "Rhinosinusitis: management guidelines." CME: Your SA Journal of CPD: ENT 27(8): 349-350, 352.
Lund, V. (1997). "Anatomy of the nose and paranasal sinuses." Scott Brown's Otolaryngology: Basic Sciences 6.
Mafee, M. F., N. Farid and W. Y. Lim (2014). Imaging of the paranasal sinuses: plain-film radiography, Computed Tomography, and Magnetic Resonance Imaging. Diseases of the Sinuses, Springer: 295-322.
Malekzadeh, S., M. D. Hamburger, P. J. Whelan, J. F. Biedlingmaier and J. N. Baraniuk (2002). "Density of middle turbinate subepithelial mucous glands in patients with chronic rhinosinusitis." Otolaryngology—Head and Neck Surgery 127(3): 190-195.
Marieb EN. (1998) Human anatomy & physiology 4th ed. Menlo Park, Calif: Addiso Wesley Longman p: 633-634.

Meltzer, E. O., D. L. Hamilos, J. A. Hadley, D. C. Lanza, B. F. Marple, R. A. Nicklas, C. Bachert, J. Baraniuk, F. M. Baroody and M. S. Benninger (2004). "Rhinosinusitis: establishing definitions for clinical research and patient care." Journal of allergy and clinical immunology 114(6): 155-212.
Min, Y.-G., H.-W. Jung, H. Kim, S. Park and K. Yoo (1996). "Prevalence and risk factors of chronic sinusitis in Korea: results of a nationwide survey." European archives of oto-rhino-laryngology 253(7): 435-439.
Momeni, A. K., C. C. Roberts and F. S. Chew (2007). "Imaging of chronic and exotic sinonasal disease." American Journal of Roentgenology 189(6_supplement): S35-S45.
Moore, K. L. and A. F. Dalley (2018). Clinically oriented anatomy, Wolters kluwer india Pvt Ltd.
Ologe, F. and A. Olatunji (2003). "Radiographic pattern of chronic sinusitis in Ilorin, Nigeria." The Nigerian postgraduate medical journal 10(4): 205-207.

Orlandi, R. R., T. T. Kingdom, P. H. Hwang, T. L. Smith, J. A. Alt, F. M. Baroody, P. S. Batra, M. Bernal- Sprekelsen, N. Bhattacharyya and R. K. Chandra (2016). International

consensus statement on allergy and rhinology: rhinosinusitis. International forum of allergy & rhinology, Wiley Online Library.
Osguthorpe, J. D. (2001). "Adult rhinosinusitis: diagnosis and management." American family physician 63(1).
Pansky, B. (1982). Review of medical embryology, Macmillan.
Park, I.-H., J. S. Song, H. Choi, T. H. Kim, S. Hoon, S. H. Lee and H.-M. Lee (2010). "Volumetric study in the development of paranasal sinuses by CT imaging in Asian: a pilot study." International journal of pediatric otorhinolaryngology 74(12): 1347-1350.
Pleis, J. R. and R. Coles (2009). Summary Health Statistics for US Adults: National Health Interview Survey, Department of Health and Human Services, Centers for Disease Control and ….
Ponikau, J. U., D. A. Sherris, G. M. Kephart, E. B. Kern, D. J. Congdon, C. R. Adolphson, M. J. Springett, G. J. Gleich and H. Kita (2005). "Striking deposition of toxic eosinophil major basic protein in mucus: implications for chronic rhinosinusitis." Journal of Allergy and Clinical Immunology 116(2): 362-369.
PradeepK .(2020, Septemper 29). Manual Segmentation of Sinus CT-Scans using Slicer 3D Retrieved from https://changlab.medicine.arizona.edu/sites/changlab-medicine/files/new-slicer-tutorial_.pdf

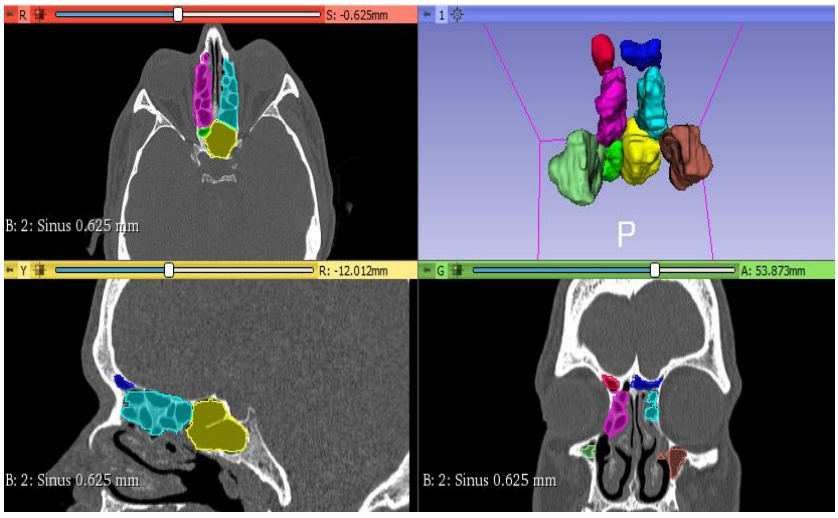
Rennie, C. O., M. R. Haffajee and K. S. Satyapal (2017). "Development of the paranasal air sinuses in a South African Population utilising three dimensional (3D) reconstructed models." Eur. j. anat 21(3): 197-209.
Rosenfeld, R. M., D. Andes, N. Bhattacharyya, D. Cheung, S. Eisenberg, T. G. Ganiats, A. Gelzer, D. Hamilos, R. C. Haydon III and P. A. Hudgins (2007). "Clinical practice guideline: adult sinusitis." Otolaryngology-Head and Neck Surgery 137(3): S1-S31.
Schuller, D. E., A. J. Schleuning, D. D. DeWeese and W. H. Saunders (1994). DeWeese and Saunders' Otolaryngology--head and Neck Surgery, Mosby Incorporated.
Scuderi, A. J., H. R. Harnsberger and R. S. Boyer (1993). "Pneumatization of the paranasal sinuses: normal features of importance to the accurate interpretation of CT scans and MR images." AJR. American journal of roentgenology 160(5): 1101-1104.
Sedaghat, A. R. (2018). Chronic rhinosinusitis. Infections of the Ears, Nose, Throat, and Sinuses, Springer: 155-168.
Settipane, R. A., A. T. Peters and A. G. Chiu (2013). "Nasal polyps." American journal of rhinology & allergy 27(3_suppl): S20-S25.
Shah, A. (2003). "Allergic bronchopulmonary and sinus aspergillosis: the roentgenologic spectrum." Front Biosci 8: e138-e146.
SOBIESK, J. L. & MUNAKOMI, S. 2020. Anatomy, Head and Neck, Nasal Cavity.StatPearls. Treasure Island (FL).

Spaeth, J., U. Krügelstein and G. Schlöndorff (1997). "The paranasal sinuses in CT-imaging: development from birth to age 25." International journal of pediatric otorhinolaryngology 39(1): 25-40.
Stamm, A. C. and W. Draf (2012). Micro-endoscopic surgery of the paranasal sinuses and the skull base, Springer Science & Business Media.
Stammberger, H. and W. Posawetz (1990). "Functional endoscopic sinus surgery." European archives of oto-rhino-laryngology 247(2): 63-76.

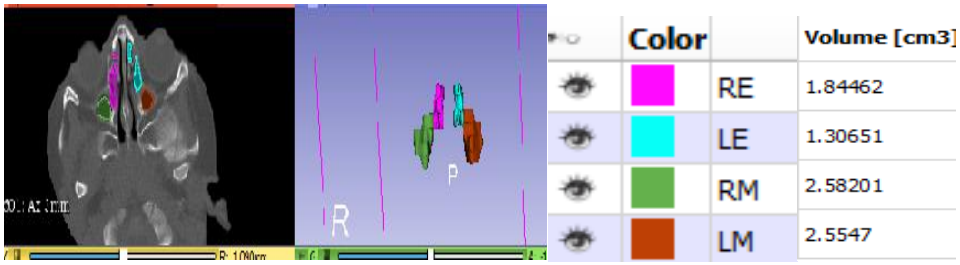
Tatlisumak, E., Ovali, G.Y., Asirdizer, M., Aslan, A., Ozyurt, B., Bayindir, P. et al. 2008. CT study on morphometry of frontal sinus. Clinical Anatomy: The Official Journal of the American Association of Clinical Anatomists and the British Association of Clinical Anatomists, 21(4):287-93.

Taylor, M. J., J. U. Ponikau, D. A. Sherris, E. B. Kern, T. A. Gaffey, G. Kephart and H. Kita (2002). "Detection of fungal organisms in eosinophilic mucin using a fluorescein-labeled chitin-specific binding protein." Otolaryngology—Head and Neck Surgery 127(5): 377-383.
Tomassen, P., T. V. Zele, N. Zhang, C. Perez-Novo, N. V. Bruaene, P. Gevaert and C. Bachert (2011). "Pathophysiology of chronic rhinosinusitis." Proceedings of the American Thoracic Society 8(1): 115-120.
Van Zele, T., P. Gevaert, J.-B. Watelet, G. Claeys, G. Holtappels, C. Claeys, P. van Cauwenberge and C. Bachert (2004). "Staphylococcus aureus colonization and IgE antibody formation to enterotoxins is increased in nasal polyposis." Journal of Allergy and Clinical Immunology 114(4): 981-983.
Watelet, J.-B., Cindy, C. Perez-Novo, P. Gevaert, P. Van Cauwenberge and C. Bachert (2004). "Transforming growth factor β1 in nasal remodeling: differences between chronic rhinosinusitis and nasal polyposis." American journal of rhinology 18(5): 267-272.
Wine, J., V. King and N. Lewiston (1991). "Method for rapid evaluation of topically applied agents to cystic fibrosis airways." American Journal of Physiology-Lung Cellular and Molecular Physiology 261(2): L218-L221.
Wolf, G., W. Anderhuber and F. Kuhn (1993). "Development of the paranasal sinuses in children: implications for paranasal sinus surgery." Annals of Otology, Rhinology & Laryngology 102(9): 705-711.
Yousem, D. M. (1993). "Imaging of sinonasal inflammatory disease." Radiology 188(2): 303-314.
Zinreich, S., D. Kennedy and B. Gayler (1988). "Computed tomography of nasal cavity and paranasal sinuses: an evaluation of anatomy for endoscopic sinus surgery." Clear images 1(2): 10.

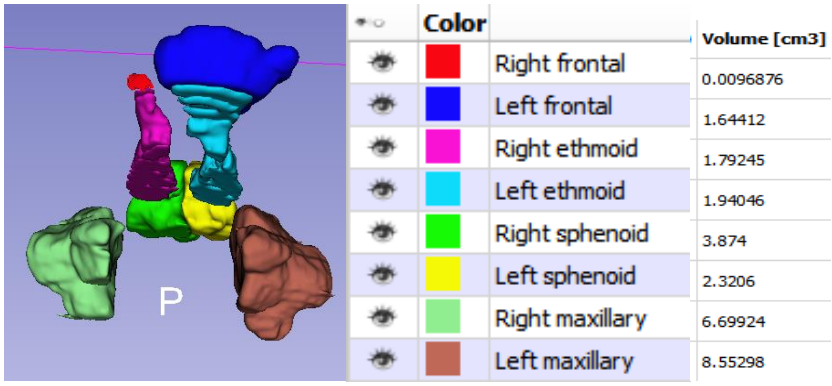
Appendix(1):



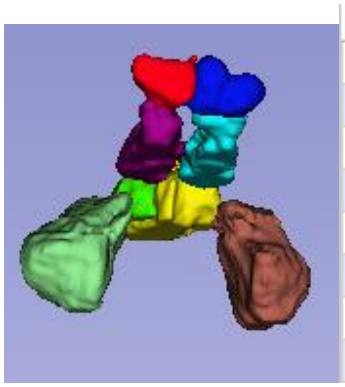
Case 1:3DSLICER program demonstrate axial, sagittal, coronal CT and 3D images in a 41years old man:



Case 2: axial and 3D CT images demonstrate the PAS volume in normal in a one year child. Noticed that only maxillary and ethmoid sinuses were appeared

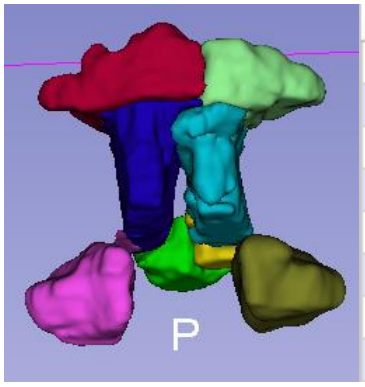


Case 3: 3D CT images demonstrate the PAS volumes in normal in a 8 years old woman.



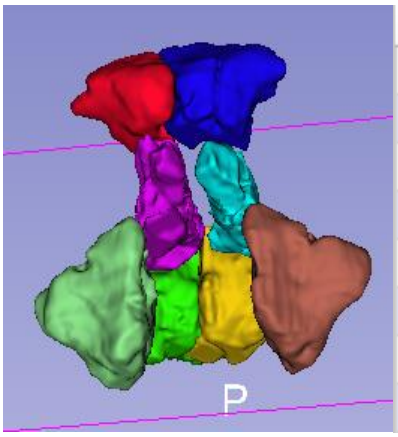
Color		Volume [cm3]
	Right frontal	0.421697
	Left frontal	0.683203
	Right ethmoid	2.31416
	Left ethmoid	2.19311
	Right sphenoid	0.926493
	Left sphenoid	4.18819
	Right maxillary	8.35288
	Left maxillary	7.57369

Case 4: 3D CT images demonstrate the PAS volumes in normal in a 12 years old man.



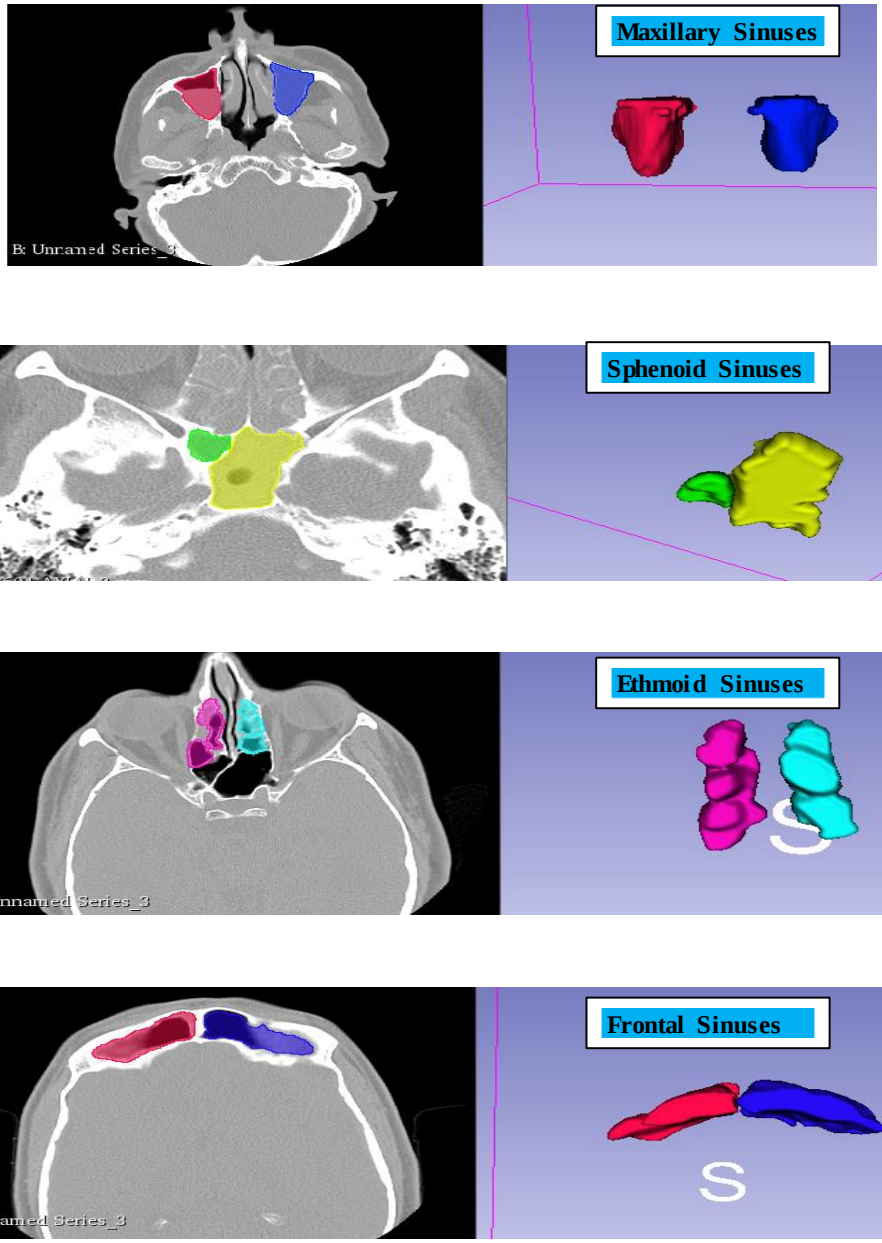
Color		Volume [cm3]
	Rt forantal sinus	1.77177
	Lt forantal sinus	2.24977
	RT ethmoid sinus	4.49638
	Lt ethmoid sinus	4.39277
	Rt sphenoid sinus	4.5089
	Lt sphenoid sinus	4.69478
	Rt maxillary sinus	11.6894
	Lt maxillary sinus	11.2915

Case 5: 3D CT images demonstrate the PAS volumes in normal in a 17 years old woman.



Color		Volume [cm3]
	Right frontal	4.40643
	Left frontal	6.54741
	Right ethmoid	6.54063
	Left ethmoid	4.76508
	Right sphenoid	8.70953
	Left sphenoid	10.7254
	Right maxillary	19.6191
	Left maxillary	20.7181

Case 6: 3D CT images demonstrate the PAS volumes in normal in a 24 years old man.



Case 7: axial and 3D CT images demonstrate chronic sinusitis patient in a 43 years old man in all of the PAS

Appendix (2)

Previous studies analyzing the volume of the paranasal air sinuses.

Author	Sample Size (n)	Age (yrs)	Population	Methodology	Mean Volumes (cm3)			
					Maxillary	Frontal	Sphenoid	Ethmoid
Sanchez Fernandez 2000	100normal controls & 163 patients	1-88	Spanish	Axial, coronal CT images, calculated volume, trapezoi-dal rule	(9.9 R; 9.9 L) M (7.9 R; 8.8 L) F	(1.9 R; 1.9L) M (1.6 R; 2.1 L) F	(2.2 R; 2.4 L) M (3.6 R; 3.3 L) F	(4.0 R; 3.9 L) M (3.3 R; 3.4 L) F
Bargouth 2002	179	1-17	Swedish	MRI, sinus volume index calculated	18.3 (16 years)		2.7 (16 years)	
Karakas 2005	91	5 – 55	Turkish	CTscans, calculat-ed volume based on Cavalieri princi-ple	(15.0 R; 16.0 L) M (11.1 R; 11.5 L) F (>25 years)	8.4 M 3.5 F (>25 years)	8.5 M 7.9 F (>25 years)	
Emirzeoglu 2007	77	18 – 72	Turkish	CTscans, calculat-ed volume, stereo-logical method, Cavalieri principle	19.8 (M) 16.0 (F) 35.9 (B)	7.5 M 4.1 F 11.6 B	7.7 (M) 6.1 (F) 13.6 (B)	6.3 (M) 5.5 (F) 11.8 (B)
Pirner 2009	50	16 – 78	German	Spiral CT scans, manual segmenta-tion	17.4 (R) 17.9 (L)	4.2 R 4.0 L	5.3 R 5.5 L	
Park 2010	260	0-25	Asian	CT scans, 3D reconstruction	14.8	3.5	3.5	4.5
Kim 2010	60	18 – 63	Korean	CT scans, 3D reconstruction	41.6	6.8	13.8	
Adibelli 2011	1452	0-18	Turkish	MRI, sinus volume index	23.7 (15 -18 yrs)	6.3 (15 -18 yrs)	4.96 (15 -18 yrs)	4.6 (15 -18 yrs)
Amusa 2011	24	Adult	Nigerian	Endoscopy, verni-er calipers, volume water displace-ment	26.6	7.8	9.6	9.9
Apuhan 2011	104	3-16	Turkish	Multislice CT, 3D reconstruction	24.5	4.6	7.4	
Lee 2012	62	<18 years	Korean	Multislice CT, 3D reconstruction	8.6 (R) 8.8 (L)	3.6 (R) 3.9 (L)	3.2 (R) 3.3 (L)	3.5 (R) 3.4 (L)

Appendix (2) ***Data collection sheet***

Sudan University of Science and Technology

College of Graduate Studies

VOLUMETRIC ANALYSIS OF THE PARANASAL SINUSES IN NORMAL AND CHRONIC SINUSITIS CONDITIONS

Date: \ \ Reference No: ( )

No	Item	
A	**Normal cases :**	**NO( )**
1	**Age**	
2	**Age groups**	**1-5 ( ) 6-10( )11-15( )16-20( ) 21-25( ) >25( )**
		< 20 ( ) >20( )
3	**Gender**	**Male ( ) female ( )**
4	**PAS volumes**	**RF( )LF( )RE( )LE( ) RS( )LS( )RM( )LM( )**
B	**Chronic sinusitis cases :**	**NO( )**
1	**Age**	
2	**Age groups**	**< 20 ( ) >20( )**
3	**Gender**	**Male ( ) female ( )**
4	**PAS volumes**	**RF( )LF( )RE( )LE( ) RS( )LS( )RM( )LM( )**