ANATOMICAL VARIATIONS OF MAXILLARY SINUS SEPTA AND THEIR RELATIONSHIP TO THE ANTRAL VOLUME IN PATIENTS WITH DIFFERENT SKELETAL PROFILES

NOOR AZWANI MAT NAWI

FACULTY OF DENTISTRY
UNIVERSITY OF MALAYA
KUALA LUMPUR

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NOOR AZWANI MAT NAWI

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ANATOMICAL VARIATIONS OF MAXILLARY SINUS SEPTA AND THEIR RELATIONSHIP TO THE ANTRAL VOLUME IN PATIENTS WITH DIFFERENT SKELETAL PROFILES

ABSTRACT

Maxillary sinus pneumatization may result in the formation of bony ridges (septa) and an increase in antral volume. This CBCT study was conducted to determine the prevalence, height, location, and variations of maxillary sinus septa, at the same time determining their relationship to the antral volume in patients with different skeletal profiles. *Methods:* Two hundred four septa in 137 maxillary sinus segments from 150 patients with different skeletal profiles were studied. Bony projections with a minimum height of 2.5mm were considered as septa. Volumetric analysis of the maxillary sinus was conducted using MIMICS 16.0 software. *Results:* The mean age of the subjects was 41.13 (SD 17.23) years; this includes 48% male and 52% female from three major ethnics. The prevalence of sinus septa was 45.7%. Three quarters of septa (75.9%) was observed in bilateral antrum. Most septa were located in the mid-antral floor (66.7%). There were variations in mean septal height and location depending on the plane of examination. The average volume of maxillary sinus segment was 16.36 (SD 0.50) cm^3 in Class I, 17.96 (SD 0.59) cm^3 in Class II and 16.65 (SD 0.55) cm^3 in Class III patients, unaffected by the side, and patients' gender and ethnicity. Males manifested larger antral volume than female. The skeletal profile did not influence the prevalence of maxillary sinus septa and antral volume. *Conclusion:* This study has provided detailed information of maxillary sinus septa and antral volume, both of which are not significantly affected by the differences in patients' skeletal profile.

Keywords: cone-beam computed tomography; maxillary sinus septa; antral volume; skeletal profile.

VARIASI ANATOMIKAL SEPTA SINUS MAXILLA DAN HUBUNGAN MEREKA DENGAN ISIPADU ANTRAL PADA PESAKIT DENGAN PROFIL RANGKA BERLAINAN

ABSTRAK

Pneumatisasi sinus maxilla boleh menyebabkan pembentukan tulang (septa) dan peningkatan isipadu antral. Kajian CBCT ini dijalankan untuk menentukan prevalens, ketinggian, lokasi, dan variasi sinus maxilla, pada masa yang sama menentukan hubungan mereka dengan isipadu antral pada pesakit dengan profil rangka yang berlainan. *Kaedah:* Dua ratus empat septa dalam 137 segmen sinus maxilla dari 150 pesakit dengan profil rangka berlainan telah dikaji. Unjuran tulang dengan ketinggian minimum 2.5mm dianggap sebagai septa. Analisis volumetrik sinus maxilla dijalankan menggunakan perisian MIMICS 16.0. *Keputusan:* Purata umur subjek ialah 41.13 (SD 17.23) tahun; ini termasuk 48% lelaki dan 52% wanita dari tiga etnik utama. Prevalens sinus septa adalah 45.7%. Tiga suku septa (75.9%) diperhatikan terdapat di dalam kedua-dua antrum. Kebanyakan septa terletak di pertengahan lantai antral (66.7%). Terdapat variasi pada ketinggian dan lokasi septum bergantung kepada satah pemeriksaan. Purata isipadu segmen sinus maxilla adalah 16.36 (SD 0.50) cm^3 dalam Kelas I, 17.96 (SD 0.59) cm^3 dalam Kelas II dan 16.65 (SD 0.55) cm^3 dalam Kelas III, tidak dipengaruhi oleh sisi, jantina dan etnik pesakit. Lelaki menunjukkan isipadu antral yang lebih besar daripada wanita. Profil rangka tidak mempengaruhi prevalens septa sinus maxilla dan isipadu antral. *Kesimpulan*: Kajian ini telah menghasilkan maklumat terperinci mengenai septa sinus dan isipadu antrum, kedua-duanya tidak terjejas dengan ketara akibat perbezaan dalam profil rangka muka pesakit.

Kata kunci: tomografi berkomputer pancaran-kon; septa sinus maxilla; isipadu antral; profil rangka

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LIST OF SYMBOLS AND ABBREVIATIONS

MS	:	Maxillary sinus
CBCT	:	Cone beam computed tomography
MPR	:	Multiplanar reconstruction

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CHAPTER 1: INTRODUCTION

The maxillary sinus (MS) or 'Antrum of Highmore' is the largest pair of paranasal airspace in the face, and drains into the middle meatus through a small opening called ostium. It has a quadrangular pyramidal shape that occupies two-third of the midface, with an average volume of 15ml (Chanavaz, 1990; Garg, 1999).The close relation of the maxillary sinus to the roots of posterior maxillary teeth is considered a clinical challenge once tooth loss occurs, as the alveolar ridge undergoes rapid, severe and irreversible resorption leading to insufficient bone quality and deficient alveolar ridge to support prosthesis (Cawood & Howell, 1988; Chanavaz, 1990; Underwood, 1910; Vinter, Krmpotić-Nemanić, Hat, & Jalsovec, 1993). In addition, progressive floor pneumatization within the maxillary sinus that follows tooth loss leads to increased volume and development of spiny ridges and undercuts formation, known as septa (Vinter et al., 1993). These septa form in addition to the congenital or primary septa (Krennmair, Ulm, Lugmayr, & Solar, 1999) that are present without an obvious cause. The increased incidence of sinus septa has been reported to be associated to pneumatization following age change, and as secondary changes after the loss of posterior teeth. However, the cause and effect of this relationship is a casual one.

The skeletal profiles of patients can be classified by determining the relationship of the mandible to the maxilla. They can be classified as normal (Class I), retrognathic (Class II) or prognathic (Class III). It is unknown if difference in skeletal profiles has any influence on the incidence of sinus septa. In addition, no study has been undertaken to determine if patients of different skeletal profiles have similar or different volume of maxillary sinus, as most emphasis has been given toward understanding changes in volumetric growth. It is known that the maxillary sinus has two periods of rapid growth i.e. after birth until it reaches adult size, and continuous increment in volume through pneumatization and the loss of posterior teeth, as described above. Different gender shows variations in maxillary sinus (antral) volume depending on their growth spurt (Ariji, Kuroki, Moriguchi, Ariji, & Kanda, 1994; Gosau, Rink, Driemel, & Draenert, 2009; Uchida, Goto, Katsuki, & Akiyoshi, 1998). In general, males have larger sinus volume compared to females. There are a few other factors contributing to the difference of maxillary sinus volume, namely breathing pattern (Tikku, Khanna, Sachan, Srivastava, & Munjal, 2013), the presence of space occupying lesion either benign (teeth) (Oz, Oz, El, & Palomo, 2017) or malignant, inflammatory paranasal sinus disease, infection in the maxillary sinus (Casamassimo & Lilly, 1980) and the presence of congenital deformity such as hypoplastic maxilla in cleft patients (Lopes de Rezende Barbosa et al., 2014) or those with craniofacial abnormalities such as cleidocranial dysplasia (Erdur, Ucar, Sekerci, Celikoglu, & Buyuk, 2015; Kulczyk, Przystanska, Rewekant, Turska-Malinska, & Czajka-Jakubowska, 2018).

As dental implants have become an excellent treatment option for replacing missing teeth, the biggest challenges with implant placement in the posterior maxilla are the reduction in alveolar height and the presence of low lying sinus floor (Cawood & Howell, 1988; Maestre-Ferrin, Galan-Gil, Rubio-Serrano, Penarrocha-Diago, & Penarrocha-Oltra, 2010; Pommer et al., 2012; Vinter et al., 1993). For that reason, the placement of short implants can be an alternative in posterior maxilla, but their success is less predictable in the presence of poor bone quality (Boyne & James, 1980). Tatum (1986) previously proposed sinus lifting surgery and maxillary sinus augmentation with bone graft to provide adequate bone for implant installation (Tatum, 1986). In the presence of sinus septa, the risk of sinus membrane perforation is higher during sinus lift procedure (Betts & Miloro, 1994; Krennmair et al., 1999; Tatum, 1986; Ulm, Solar, Krennmair, Matejka, & Watzek, 1995; Underwood, 1910). To overcome this problem, sinus elevation technique can be modified by creating two hinged doors at the lateral wall to elevate the Schneiderian membrane (Boyne & James, 1980) but at the same time avoiding the septa. Therefore, it is crucial to have a good knowledge on the prevalence, location, morphology of sinus septa and their potential variations in deciding the surgical approach to be taken for maxillary sinus augmentation (Betts & Miloro, 1994; Gosau et al., 2009; Krennmair, Ulm, & Lugmayr, 1997; W.-J. Lee, Lee, & Kim, 2010; Zijderveld, van den Bergh, Schulten, & ten Bruggenkate, 2008). In addition, having a good knowledge of the maxillary sinus volume will allow for better estimation of the amount of bone graft material needed for sinus floor augmentation, without encroaching close to the ostium.

Several methods have been used to determine the prevalence, height, location, and variations of maxillary sinus septa, and to analyze the volume of the maxillary sinus. The methods used to study sinus septa include direct observation while performing surgical procedures or on dried-skull, as well as in radiographic analysis using panoramic imaging or computed (CT/CBCT) tomography (Ella et al., 2008; Kasabah, Slezák, Simunek, Krug, & Lecaro, 2002; Kim et al., 2006; Krennmair et al., 1997; Neugebauer et al., 2010; Ulm et al., 1995; Underwood, 1910; Velasquez-Plata, Hovey, Peach, & Alder, 2002). Dental panoramic radiograph is commonly used as preoperative diagnostic imaging prior to implant treatment planning since it provides complete visualization of the maxillary sinus. However, because of the two-dimensional nature of the radiographs, they can only be used to estimate the size and location of septa (Kasabah et al., 2002). In contrast, 3D CT scans are very useful in showing precise 3D image of maxillary sinus septa (Park, Jeon, Shim, Lee, & Moon, 2011). The introduction cone-beam CT (CBCT) recently can be considered as excellent tool to evaluate sinus anatomy in implantology (Shiki et al., 2014; Sukovic, 2003; Tischler, 2008). CBCT generates volumetric images utilizing low dose of radiation but produces high geometric accuracy (Ludlow & Ivanovic, 2008; Shiki et al., 2014). These data can be used to determine the volume of the maxillary sinus.

It is the aims of this study were to determine the prevalence, height, location, and variations of maxillary sinus septa, and to analyze the volume of the maxillary sinus in patients of different skeletal profiles.

The specific objectives include:

i. To determine if the volume of maxillary sinus remains the same in patients with different skeletal profile, and

ii. To determine if the skeletal profiles of patients influence the prevalence of sinus septa.

CHAPTER 2: LITERATURE REVIEW

2.1 Anatomy and development of maxillary sinus

The maxillary sinus (MS) or 'Antrum of Highmore' is the largest paranasal airspace in the face, which drains into the middle meatus through small opening called ostium. It comes with pair at midface region. The 'Antrum of Highmore', comes from the author name Nathaniel Highmore, who is first described about anatomy of maxillary sinus (Wells, 1948). The quadrangular pyramidal shape is obtained from the boundaries that form the maxillary sinus. Among all the paranasal sinus, the maxillary sinus is the first paranasal sinus developed at 11 weeks intrauterine (Koppe, Yamamoto, Tanaka, & Nagai, 1994). It continues the development postnatally until the patient reached their growth spurt. The maxillary sinus expands its size and shape by directly linked to the facial bony boundaries that undergone resorption in all walls except medial wall which form from cartilage. The size of maxillary sinus also associated with the presence of dentition. Sharan & Madjar (2008) proved that progressive maxillary floor pneumatization occur after posterior tooth loss (Sharan & Madjar, 2008).

The process of maxillary sinus expansion is called pneumatization. The expansion occurs in three dimensions which involve vertical, horizontal and antero-posterior direction (Scuderi, Harnsberger, & Boyer, 1993). Along the process of pneumatization, the shape of the maxillary sinus will be affected based on direction of expansion. Wolf et al. (1993) reported the shape of maxillary sinus changed during growth from spherical to quadrangular pyramide (Wolf, Anderhuber, & Kuhn, 1993).

The first rapid expansion occurs after birth in antero-posterior and horizontal direction and continues to increase in size until patient 3 years old. The next expansion accelerates again during primary school age between 6-12 years. It occurs in a downward direction towards the dentition and leaves the ostium in the superior position on the medial wall that is against the gravity for drainage (Wolf et al., 1993). Then, the pneumatization becomes slow between 14-18years of age. The growth of maxillary sinus ends and remains stable when all permanent teeth erupt.

2.2 Anatomical variations of maxillary sinus in different population

Detailed knowledge of the possible maxillary sinus variations such as septa is crucial in determining a surgical approach for sinus surgery and to avoid serious complications. Different methods were applied in order to study the maxillary septa. These include direct observation, percussion, endoscopy, palpation and transillumination as well as panoramic imaging or computed (CT/CBCT) tomography (Borris & Weber, 1998; Gonzalez-Santana, Penarrocha-Diago, Guarinos-Carbo, & Sorni-Broker, 2007; Underwood, 1910).

2.2.1 Maxillary sinus septa

The maxillary sinus septa or also known as Underwood‘s septa is a barriers of cortical bone that arise from the floor or from any walls of the sinus. It was first described by Underwood in 1910 and reported the prevalence of 33% (Underwood, 1910). Ulm et al. (1995) described the minimum septa height of 2.5mm will be considered as real septum or a lath of the sinus floor (Ulm et al., 1995). The presence of septa has been ignored until the implant era becomes the first treatment option to replace missing teeth.

The septa can be presented in a few forms and size based on which angle it was looked. It may incomplete or complete septa which divided the maxillary sinus into multiple compartment or smaller accessory sinuses. The common features is thin and fragile associated with the apices of maxillary posterior teeth (Underwood, 1910). It can also presented as bony exostosis with rounded bony margin (M. Naitoh, Suenaga, Kondo, Gotoh, & Ariji, 2009). It may not be a true septa but were bony projection as a result from progressive floor pneumatization that follows tooth loss (Krennmair et al., 1997). Kim et al. (2006) reported the septa is inverted gothic arch (Kim et al., 2006). It has also been described septa as a part of infraorbital canal which carries vital structures and sometimes hang down in to the sinus cavity (Underwood, 1910). The difference in definition of septa only can be standardized based on Ulm et al. (1995) inclusion criteria.

According to Underwood (1910), the formation of primary septa is related to natural maxillary development and correspond with different period of tooth eruption. It occurs when the sinus floor sinks down as a result following the contour of root formation as tooth erupt (Underwood, 1910). This findings similar to study done by Munetaka NAITOH et al. (2010). The study reported presence of septa or bony projection in dry skulls of children with different age (Munetaka NAITOH et al., 2010). The incidence of sinus septa also has been reported to be associated with pneumatization following age change and secondary changes after the loss of posterior teeth in adulthood. This process leads to spiny ridge formation, known as secondary septa. Based on this fact, Krennmair et al. (1997) categorized septa into primary (as Underwood explanation) and secondary septa (following tooth loss) (Krennmair et al., 1997). Therefore, it can be concluded that septa found in the dentate area is primary (developmental), while if it present at edentulous area may either primary or secondary septa.

The number of septa varies depending on types of edentulism. Several studies revealed the prevalence of septa is higher in fully edentulous than in partially edentulous or dentate maxilla (Kim et al., 2006; Krennmair et al., 1997; Krennmair et al., 1999; Velasquez-

Plata et al., 2002). This finding suggested both primary and secondary septa present in fully edentulous patients. It is expected the number of septum present is correlated with the size of the maxillary sinus.

2.3 Maxillary sinus volume

It is known that the maxillary sinus has two periods of rapid growth after birth until it reaches adult size and continuously increase in sinus volume throughout this process. The average volume of a maxillary sinus in adults is $4.56cm^3$ to $35.21cm^3$. Different gender shows variations in maxillary sinus volume depending on their growth spurt (Ariji et al., 1994; Gosau et al., 2009; Uchida et al., 1998). Therefore, the size and volume of maxillary sinus proportionate to the individual age and whole growth process.

2.3.1 Estimation of maxillary sinus volume

Several methods have been used to determine the prevalence, height, location, variations of maxillary sinus septa as well as analysis of the maxillary sinus volume of previous studies. The direct estimation using cadaver heads was done by Gosau et al. (2009) by measuring the amount of water filled the maxillary sinus that represent the actual volume of sinus (Gosau et al., 2009). This direct technique is difficult to apply on the living object. Hence, it is rarely use currently.

In recent years, indirect method has become more popular in measuring the maxillary sinus volume using either magnetic resonance imaging or conventional computed tomography as well as cone beam computed tomography. The biggest challenge with this modern imaging technology is, the presence of automatic advanced software calculation which is more complex and time consuming. For that reason, it requires an experienced researcher to understand the complexity and specificity of radiological method (Sahlstrand-Johnson, Jannert, Strombeck, & Abul-Kasim, 2011).

Alternatively, Przystanska et al. (2018) recommended manual calculation of maxillary sinus volume using simple mathematical formulas which the result is precise and resemblance to automatically estimate volume (Przystańska et al., 2018). It can be applied when access to CT is not feasible. For this method, it is still not recognized for research purposes. Therefore, the simple and standardized method is preferable.

2.3.2 Factors affecting maxillary sinus volume

The volume of the maxillary sinus is not continuously constant. There are a few factors contributing to the changes of maxillary sinus volume. Males have larger sinus volume compared to females. It is due to wider maxillary sinus size as a result of physiological changes of nasomaxillary complex to compensate the increase in oxygen demand for massive muscle and body organ (Sharma, Jehan, & Kumar, 2014).

The maxillary sinus is known to increase in size throughout the infancy and adolescence, hence the antral volume also is significant higher in adult. In addition, increase pneumatisation following tooth extraction also affect the antral volume (Ariji et al., 1994). Therefore, large antral volume can be seen at edentulous area. It has been reported that the cleft patient has a smaller maxillary antral volume than in normal groups due to the hypoplstic maxilla (Erdur et al., 2015; Lopes de Rezende Barbosa et al., 2014). Kulczyk et al. (2018) found diminished maxillary sinus volume in patients with craniofacial abnormalities (i.e. Cleidocranial dysplasia) as the result of hypoplastic maxilla or undeveloped maxilla (Kulczyk et al., 2018).

Breathing pattern also has an impact on maxillary sinus development. In certain circumstances, the mouth will take over of nose function as a primary route for breathing in mouth breather. The study of volume changes in the different breathing pattern revealed that mouth breather has a lesser maxillary antral volume due to loss of nose function in addition to the presence of sinus pathology, but the exact mechanism remains unclear (Tikku et al., 2013).

The impacted or ectopic teeth in close relation to maxillary sinus may alter the volume if it occupies the sinus. Study by Oz et al. (2017) reported a significant increase in volumetric changes, after the impacted tooth within the maxillary sinus erupted into the dental arch by orthodontic treatment (Oz et al., 2017). The orthodontic traction by moving posterior maxillary teeth through the sinus, may cause remodelling of sinus wall due to new bone formation. Depending on the type and rate of tooth movement, the significant changes in the size, shape together with antral volume can be observed (Oh et al., 2014).

The position of the maxilla during orthognathic surgery may influence the antral volume depending on the direction of jaw movement. Panou et al. (2013) found a significant decrease in the total volume of the maxillary sinuses after maxilla impaction and vice versa in maxillary down graft (Panou, Motro, Ates, Acar, & Erverdi, 2013). Presence of space occupying lesion either benign or malignant, inflammatory paranasal sinus disease and infection in the maxillary sinus can influence the antral volume depending on size and severity of disease. Based on (Casamassimo & Lilly, 1980) study, it shows decrease in antral volume in the presence of sinus disease.

2.4 Clinical Implications of maxillary sinus

The maxillary sinus is a complex structure among individual and has a strong relation to dental treatment planning due to presence of anatomical variation. It is lined by the mucous lining called Schneiderian membrane which very thin and easy to tear during sinus lifting. Although the true function of maxillary sinus is still unknown, Negus and Street (1954) found the biological roles of sinuses include air humidification, as resonators and amplifier in vocal function, insulator, lighten the skull as well as absorber against blows to face (Negus & Street, 1954).

2.4.1 Implant placement and sinus augmentation

More recently, the use of dental implants has increased dramatically as a treatment option for the replacement of missing teeth providing both conservative and aesthetic alternatives. In the oral cavity, the alveolar ridge undergoes rapid, severe and irreversible resorption, leading to insufficient bone quality and deficient alveolar ridge following tooth loss at the posterior maxilla (Van der Weijden, Dell'Acqua, & Slot, 2009). The minimum bone height 10mm is required for standard implant length based on previous study using Branemark implant system (S.-A. Lee, Lee, Fu, Elmisalati, & Chuang, 2014).

The biggest challenge with implant placement on the posterior maxilla are the reduction in alveolar height and the presence of the low lying sinus floor as stated above. For that reason, the placement of short implants was considered or performing sinus lift together with sinus augmentation using bone graft to support normal length implant fixtures (Boyne & James, 1980). Depending on the amount of posterior bone height, Ali et al. (2014) also reported in specific condition the modified implant designs with modified surgical technique can be applied for implant placement in atrophic maxilla (Ali, Karthigeyan, Deivanai, & Kumar, 2014). Tatum (1986) previously proposed sinus lifting surgery and maxillary sinus augmentation with bone graft using modified Caldwell Luc to provide adequate bone for implant installation. This direct technique is performed by creating a hinge door in the lateral maxillary sinus wall and rotated inward and upward (Tatum, 1986). The indirect sinus grafting was developed by Summers (1994) by performing internal sinus lift through alveolar crest using osteotome to fracture the sinus floor (Summers, 1994). This technique is more conservative and limited for sinus augmentation up to 5mm.

In the presence of sinus septa, the risk of sinus membrane perforation is higher during the sinus lift procedure as well as could interfere with the rotation of trap door into the sinus and may require modification of the procedure. To avoid this problem, the sinus lifting technique was modified by creating two hinged doors or follow the inner contour by making a W-shape when a lateral window sinus lift is performed (Boyne & James, 1980; van den Bergh, ten Bruggenkate, Disch, & Tuinzing, 2000). Likewise extra force is required to elevate the sinus floor through transcrestal approach when a septum is present superiorly (Greenstein, 2017). In addition, Dragan et al. (2015) suggested to make use of septa by inserting the implant if the height and width of the septa is enough (Dragan, Guillaume, Haba, & Olszewski, 2015). Therefore provide alternative implant site without sinus grafting.

2.4.2 Endoscopic sinus surgery

The presence of low lying sinus floor in the maxillary posterior teeth region contributes to the incidence of root has been displaced to the antrum while attempting extraction. It is mostly associated with first molar which the palatal and mesiobuccal root are most often displaced. This statement corresponding with study done by (Osman, Mohamed, Robertson, Chu, & Law, 2014). Fry et al. (2016) did a study on vertical relationship of maxillary posterior teeth roots with sinus floor superiorly (Fry, Patidar, Goyal, & Malhotra, 2016). They found that, the mesiobuccal root of first maxillary sinus were commonly seen protruded into the maxillary sinus. Having said so, there are high possibility the gutta percha, endodontic file as well as root filling materials extruded into the sinus during root canal treatment of that particular tooth (Y. Kfir & Shem-Tov, 1980).

Even though dental implant rehabilitation provides a good aesthetic outcome, but maintaining the stability of implant fixture is a nightmare to surgeon and patient. The rare complication of dental implant treatment is the migration of implant fixture into the maxillary sinus few months or year after post insertion. There are three possible theories that explain the migration of implant in the studies: unequal occlusal force distribution that leads to bone resorption, changes in nasal pressure and peri-implantitis (Fusari, Doto, & Chiapasco, 2013). Other foreign bodies such as impression materials, glass fragment and metallic object were found in maxillary sinus by other authors (Y. Kfir & Shem-Tov, 1980; Kozlowski & Lajp, 1964; Shao, Qin, & Ma, 2014). The sequele of foreign body in the maxillary sinus can be either it may remain symtompless or it will cause sinus disease such as sinusitis, polyps, mucosal cyst as well as pus discharged. There is also possibly the foreign body has been expelled while patient coughing and give a risk to swallow into gastrointestinal tract (Sims, 1985).With these possible risk, there is strong indication to remove the foreign body either by transalveolar, caldwell luc approach or endoscopic sinus surgery. With the current technologies, endoscopic sinus surgery has become a common practice in sinus surgery and widely accepted. Several studies show better result in term of less invasive procedure, good controlling hemorrhage and faster recovery rate in endoscopic assisted sinus surgery than the conventional open sinus surgery (Nashawany et al., 2014; Nataraj et al., 2014; Oinam, Ningombam, Puyam, & Thingbaijam, 2016). However, pronounced septa on the sinus floor can make removal of displaced foreign bodies, root remnants or pathological sinus mucosa more difficult when the surgery is performed via transnasal approach (Bhatia, Gupta, & Sasibabu, 1977). This may happen if septa is located adjacent or next to the maxillary ostium which block the access and impede visualisation. Therefore, the septa must be broken first in order to reach the sinus and allow proper sinus drainage.

2.4.3 Forensic anthropology

Forensic anthropology plays the important role to identify personal identification based on physical markers available on the skeleton. The main component in forensic anthropology is to determine the age and gender of unknown body, especially in cases such as burnt, decomposition, explosion, aircraft crash and war. With the accuracy of 100% if the complete set of skeleton is available, it has been reported that skull, the pelvis and the long bone can be used to determine the gender (Teke, Duran, Canturk, & Canturk, 2007).

In reality, the bone that found are mostly fragmented and destroyed leads to imperfect state. Some studies found in denser bone such as the maxillary sinus, it remains intact even though other bones badly destroyed (Naeem, Nadia, Saluja, Taseer, & Akhtar, 2015; Paknahad, Shahidi, & Zarei, 2017; Tambawala, Karjodkar, Sansare, & Prakash, 2016;

Teke et al., 2007; Urooge & Patil, 2017). The intact shape and size of maxillary sinus can be used for personal identification using radiograph or computed tomography (Xavier, Terada, & da Silva, 2015). Hence, the knowledge about the size and volume of maxillary sinus can be applied to determine the age and sex of the person in forensic and for a criminal case where the traditional methods are unfeasible.

CHAPTER 3: MATERIAL AND METHOD

3.1 Study design and sample size

This study retrospectively evaluated the prevalence, location, height and possible anatomical variation of maxillary sinus septa in relation to the antral volume of patients with different skeletal profiles, performed by analyzing the CBCT images of included patients. This research had received ethical approval from the Medical Ethic Committee of Faculty of Dentistry, University of Malaya [Reference number: DF OS 1508/0032(U)].

CBCTs of 400 patients who underwent imaging for various dentally related reasons at the Oral & Maxillofacial Radiology Division, Faculty of Dentistry, University of Malaya from Jan 2010 to December 2015 were collected and screened.

For the purpose of this study, each right and left maxillary sinus was defined as an individual segment. A total of 300 maxillary sinus segments were evaluated from 150 CBCTs that showed maxillofacial images with complete visualization of both maxillary sinuses. The exclusion criteria were:

a) Pathological changes seen in the maxillary sinus (e.g. fracture, inflammation, cysts or tumour)

b) Low quality images that were either overexposed or underexposed, or showing patient movement during CBCT acquisition

c) Images without the lower border of the mandible and/or the nasion seen

3.2 Imaging Methods

i-CAT cone-beam computed tomography (Next Generation, Imaging Sciences International, Hatfield, USA) was used to capture the images of maxillofacial area concerned. The scan was medically justified in all patients based on guidelines of the European Commission in radiation protection of CBCT (SEDENTEXCT). Informed consent was obtained from all patients regarding the use of CBCT data post consultation for other dental examinations and for research purpose.

The CBCT images were obtained in a standardized manner where patients were scanned in a sitting position, with their head immobilized and adjusted against a headrest and chin cup. The mid-sagittal plane was aligned to be perpendicular to the horizontal plane using vertical and horizontal alignment beams as recommended by the manufacturer. The i-CAT is equipped with an amorphous Silicon Flat Panel, and a single 360^{o} scan collects the projection data for reconstruction (Hamdy & Abdel-Wahed, 2014). The X-ray field size applied was 16 cm diameter x 13 cm height, and the scanning time was 20 s. The settings of the operating parameters were 120 kVp and 5 mA with slice thickness of 0.3 mm voxel size (the standard resolution for scanning at i-CAT machine). The obtained diacom were processed using proprietary i-CAT image reconstruction software, the i-CAT Vision (Imaging Sciences International) which allows users to obtain linear measurements of all images.

3.3 Methods of assessment

3.3.1 Determination of skeletal profile

The ANB value was used to determine maxilla-mandible relationship in anteroposterior position based on cephalometric analysis. To do so, four anatomic landmarks were identified from the Cephalic view image and were connected to make up the SNA and SNB lines (Figure 3.1). The reference points which represent the anatomic landmark are as below:

a) A point (A): The point of deepest concavity anteriorly on the maxillary alveolus

b) B point (B): The point of deepest concavity anteriorly on the mandibular symphysis

c) Sella (S): The midpoint of the sella turcica (pituitary fossa)

d) Nasion (N): The most anterior point on the fronto-nasal suture

The skeletal profiles were classified into Class I, Class II and Class III according to the ANB value, calculated from difference between SNA and SNB angle. Mitchell (2013) (Mitchell & Oxford University, 2013) described the ANB value as:

Class I: ANB 2-4 degrees

Class II: ANB of >4 degrees

Class III: ANB of <2 degrees

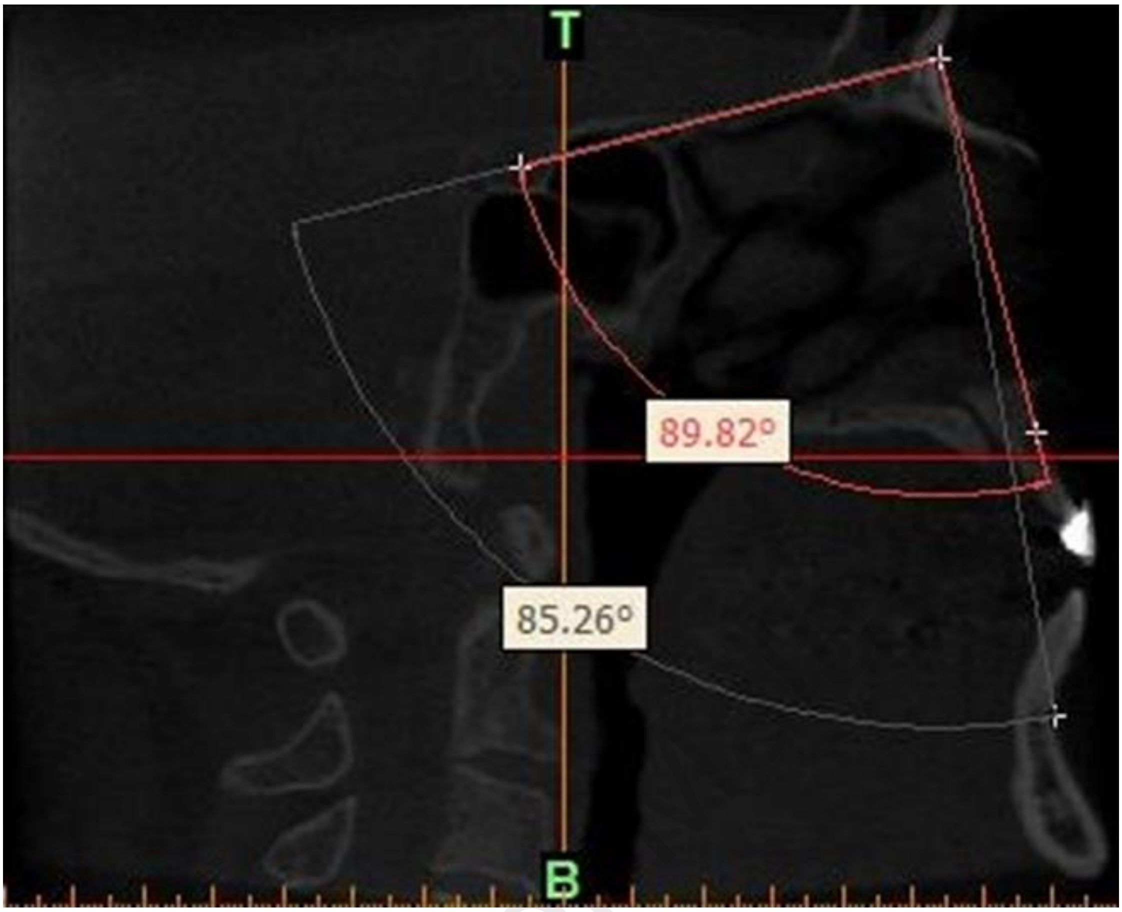

Figure 3.1: Method to determine skeletal profile analysis using the Cephalometric view of CBCT image. The ANB of this example is 4.56º, resulting in a Class II profile

3.3.2 Determination of septa height and location

The existence and orientation of the septa in the maxillary sinus were detected from multiplanar reconstruction (MPR) module in axial, sagittal and coronal planes while the three-dimensional module was used when necessary. At least two images of septa must be seen in any of those 3 planes before they were deemed to be present. First, the septa were identified either on the walls or sinus floor and were counted. The height of the septa were determined using a line perpendicular to the line drawn at the more inferior point of the two possible sides of the septum that represent the base (Figure 3.2). That means, incomplete septa requires one base while two bases were needed in complete septa before a perpendicular line was drawn. The minimum septa height of 2.5mm was used to describe as real septum, otherwise it was recorded as a lath of the sinus floor. All measurements were acquired in millimeters using the proprietary i-CAT Vision software measuring tool.

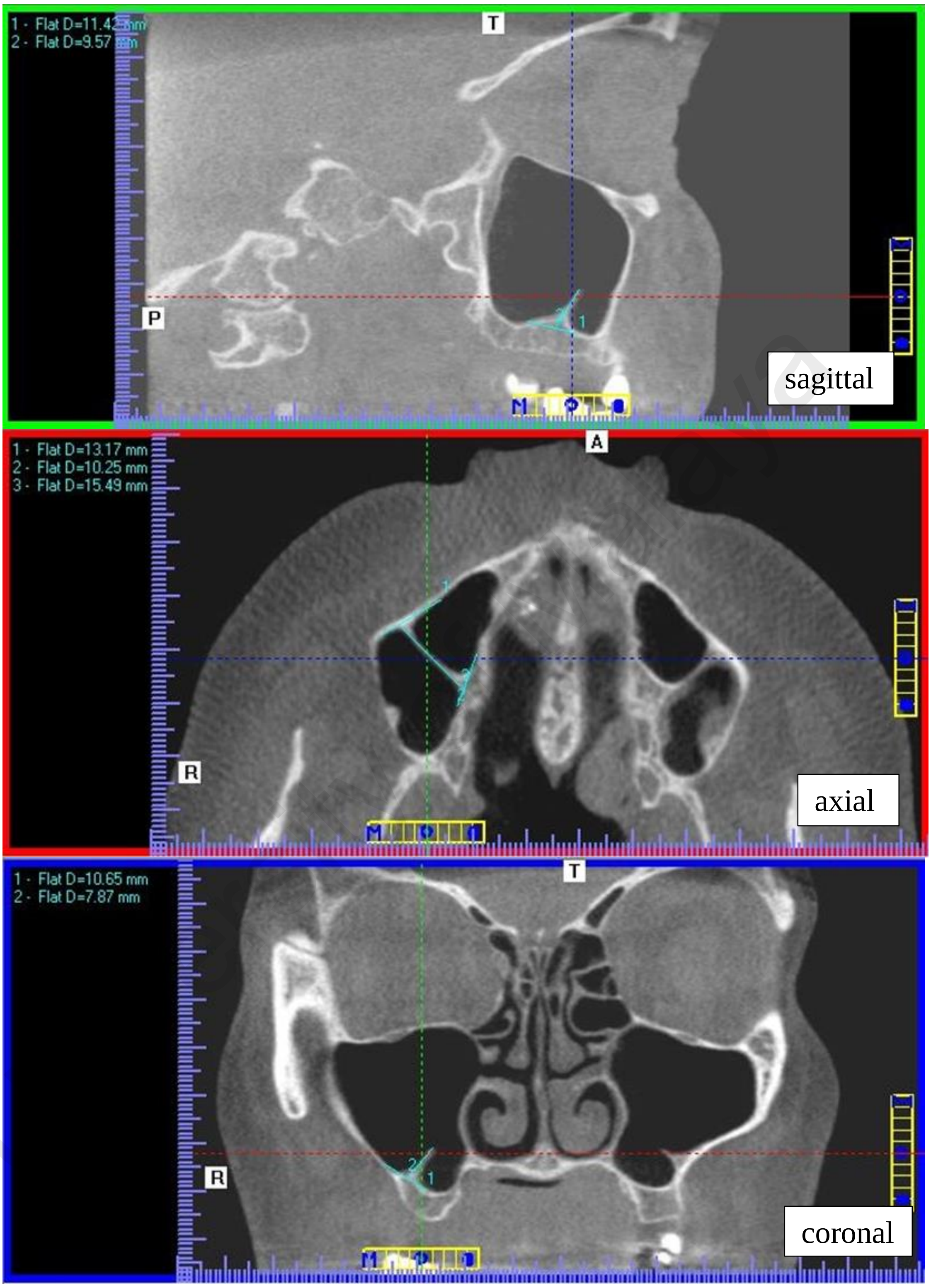

Figure 3.2: Image shows a septum at right maxillary sinus being measured in sagittal, axial and coronal planes, resulting in it having 3 different measurements.

3.3.3 Determination the configuration of septa

The septa were classified according to their presence in the maxillary segments, either unilateral or bilateral. For clarity, a “configuration” nomenclature was developed to denote the number of septum present in each maxillary segment. The configuration was described in a simplified digit form, as such that the first digit denotes the number of septum in the right maxillary sinus and the second digit denotes the number of septum in the left side. For example, the term “1-0 configuration” denotes the presence of one septum in the right sinus only, while “1-1 configuration” is used to describe the presence of one septum in each maxillary sinus bilaterally, and so forth with other combinations depending on the number of septa encountered.

3.3.4 Determination location of septa in relation to the dentition

The panoramic view module was used to investigate the exact location of the septa in relationship to the roots of maxillary teeth. The location was categorized into 3 regions of the floor: anterior (from mesial aspect of 1st premolar to distal aspect of 2nd premolar), middle or mid-sinus (from mesial aspect of 1st molar to distal aspect of 2nd molar) and posterior (mesial aspect of 3rd molar).

3.3.5 Determination of maxillary antral volume

Volumetric analysis of maxillary sinus was conducted using MIMICS 16.0 software (Materialise, Leuven, Belgium) by converting diacom from CBCT scans into a function of this software. The antral volume was distinguished from surrounding anatomical structures by using volume render tool, where opacity seen was adjusted until the airway became prominent. After editing the mask, the maxillary sinuses were extracted from the rest of the image and these three-dimensional images were edited until solid sinus formed. Then, volumetric analysis was conducted for right and left sinus individually using the software programme and the measurement was recorded in mm^3 as shown in Figure 3.3. For easier statistical analysis, the measurements in mm^3 were converted manually to cm^3 [$1mm^3 = 0.001cm^3$].

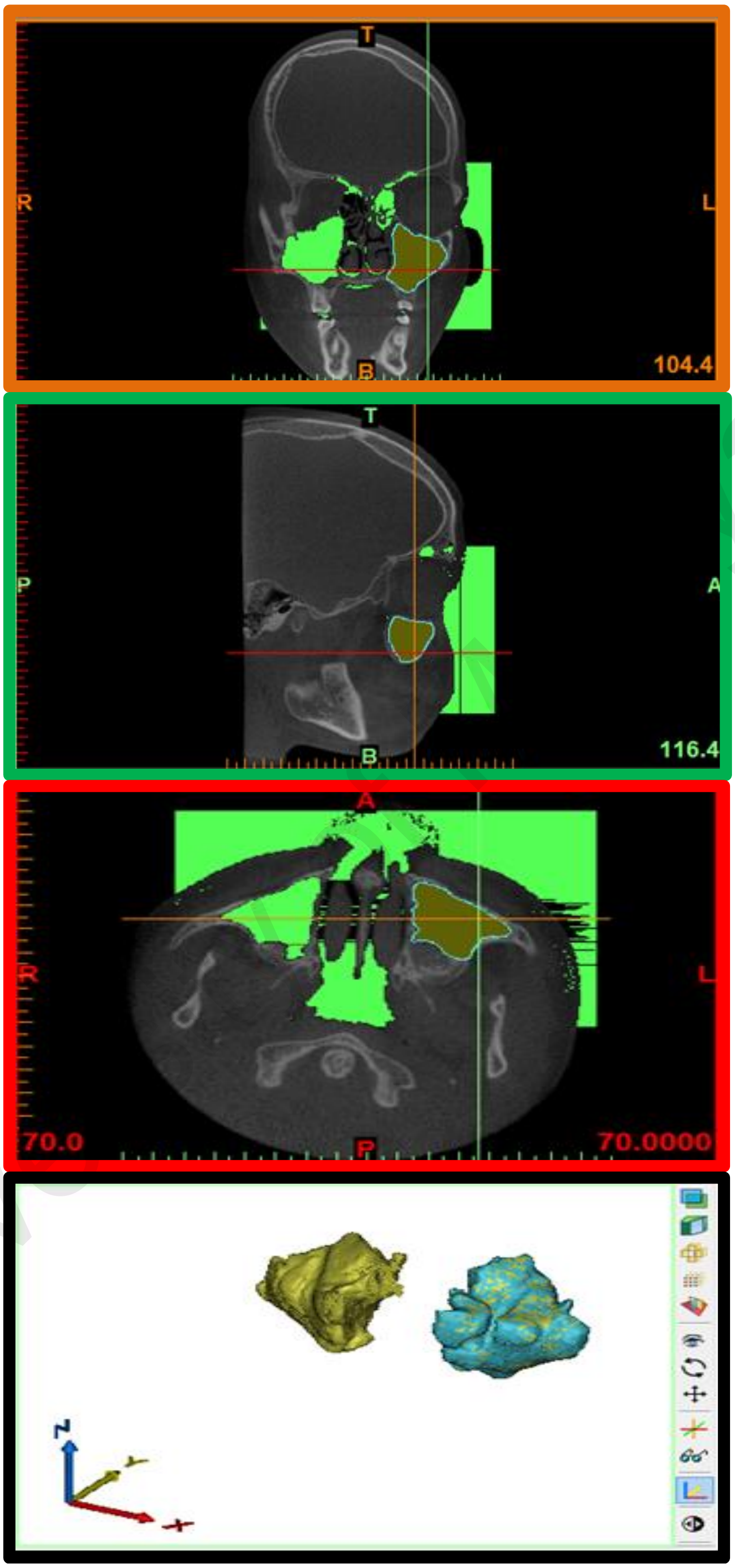

Figure 3.3: An example of volumetric analysis using MIMICS 16.0 software to obtain the volume of the left and right maxillary sinus.

3.4 Data Analysis

Data were entered and analyzed using IBM SPSS Statistic software version 12 (SPSS, v.12.0, IBM, Chicago, USA) and Microsoft Excel 2013. Descriptive results were expressed as means ± standard deviation (SD). For analytical statistics, the volume of the maxillary sinus in each group according to gender (male and female) was compared using independent t-test while the ethnicity (Malay, Chinese and Indian) and skeletal profile (Class 1, Class II and Class III) related volume were compared using ANOVA where appropriate. The chi-square test was employed to compare the prevalence of septa observed in different gender, with the significant value set at ($P<0.05$). Pearson's correlation test was performed to determine for a possible relationship between the volume of maxillary sinus and type of skeletal profile.

3.5 Funding

This research was self-funded.

CHAPTER 4: RESULTS

4.1 Demographic profile

From 400 CBCTs belonging to 400 patients that were retrieved, only 150 CBCTs showed complete visualization of both maxillary sinuses, hence they were included in this study. The other 250 CBCTs were excluded due to following reasons:

a) Signs of pathological changes in the maxillary sinus (fracture, inflammation, cysts or tumour)

b) Low image quality that affects the process of analysing these images. These images were either overexposed or underexposed, or the patient moved when CBCT was taken.

c) Images without the lower border of the mandible and the nasion, hence inhibiting the process of classifying patients according to their skeletal profile.

The mean age of the patients was 41.13 (SD 17.23) years with a range from 8 to 77 years. They consisted of 4 children aged <13 years and 146 patients aged ≥13 years. The age range of children was 8-11 years whereas that of the adolescence and adult population was 14-77 years.

4.1.1 Ethnicity of patients

Differentiated by ethnicity, the majority were 60 Malay (40%) and 72 Chinese (48%) patients, with the remaining being 18 Indian. The last contributed toward 12% of the remaining CBCTs included (Figure 4.1).

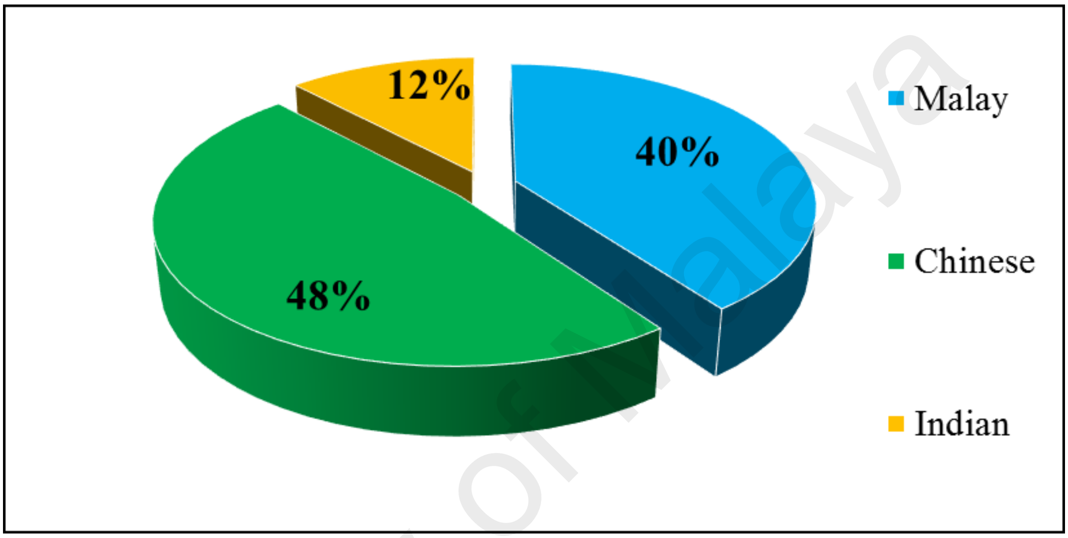

Figure 4.1: Patient's ethnicity

4.1.2 Skeletal profile of patients

Patients were divided into three groups, with each group (Class I, Class II and Class III skeletal profile) having at least 50 sets of images included. They consisted of 78 females and 72 males from three major ethnicities (Malays, Chinese and Indian); in essence there was almost equal distribution in term of the gender of patients included. They were 48% male and 52% female patients with even distribution for each class of skeletal profile, except for Class I. Their breakdown is shown in Figure 4.2.

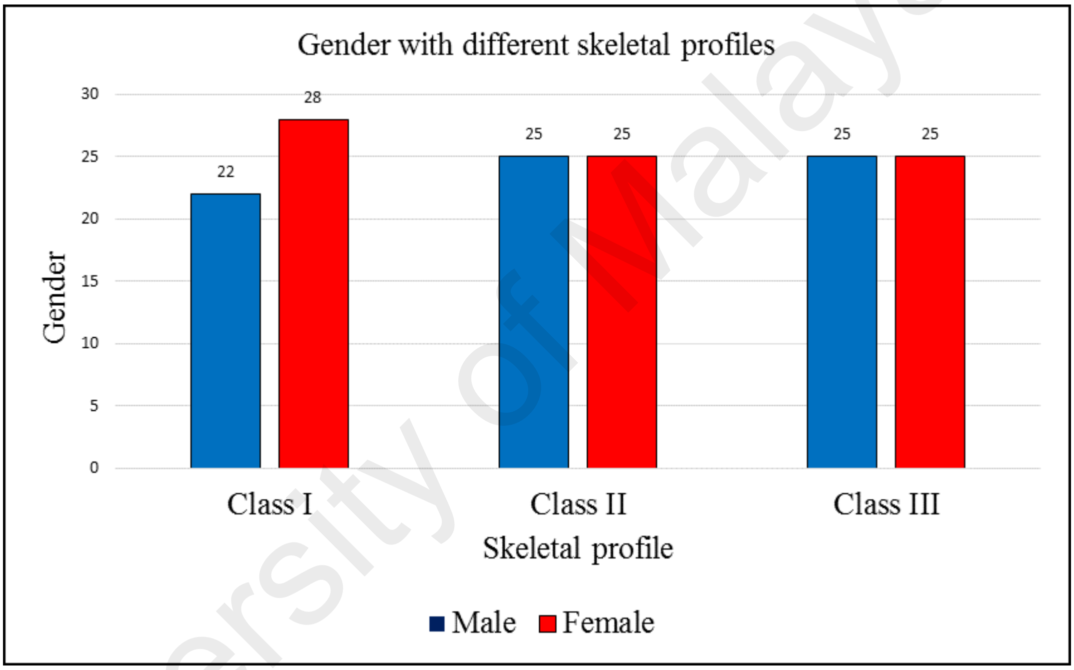

Figure 4.2: Distribution of gender according to skeletal profile

4.2 Maxillary sinus septa

Figure 4.3 shows the flow involved in the process of examining sinus septa. In summary, 85 patients showed the presence of at least one septum in either maxillary sinus. Sixty-one percent of them showed that septa were present in bilateral maxillary sinuses. There were no septa found in the few children included.

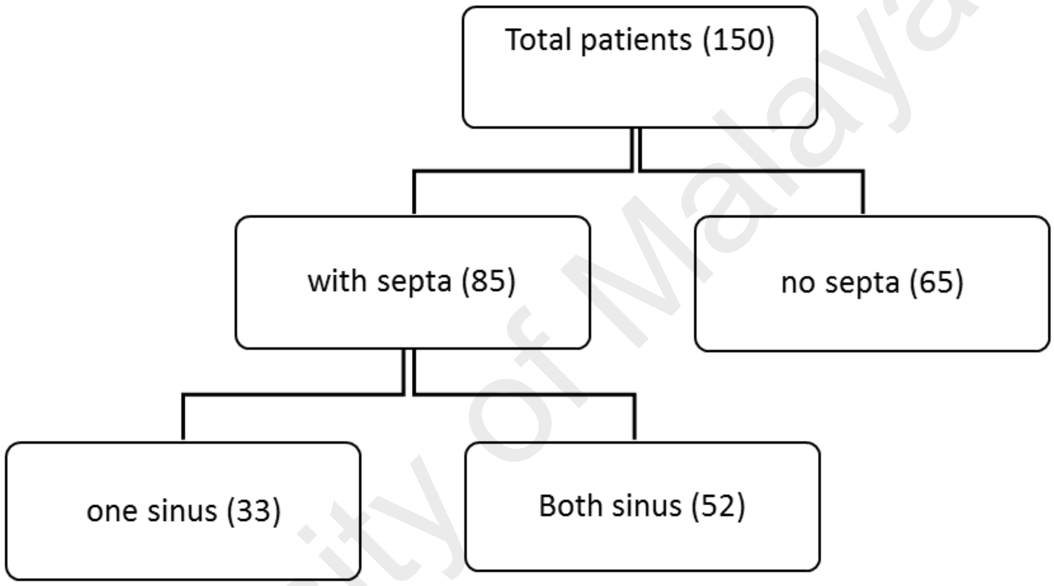

Figure 4.3: The flow involved in examining sinus septa

4.2.1 Sinus presenting with septa

One hundred thirty seven (137) maxillary sinuses from the total of 300 sinuses examined showed the presence of at least one septum in any wall, giving rise to a prevalence of 45.7%. A great majority of them (n=104; 75.9%) were bilateral, with the remaining 33 (24.1%) being unilateral. Of the maxillary sinus presenting with septa, 62.8% (n=86) had a single septum, 27.7% (n=38) had two septa, 8% (n=11) had three septa and remaining 0.7% had four and five septa respectively. The left sinus (n=72; 52.6%) was more frequently involved than the right sinus (n=65; 47.4%).

All the septa were further analyzed in detail with regards to their height, location, variation and relationship to adjacent dentition. Overall, there appears to be slightly more septa found in males (n=72; 52.6%) than in females (n=65; 47.4%). The detailed distribution of both genders with septa according to their skeletal profile is shown in Table 4.1. In both gender, differences in skeletal profile did not influence the prevalence of septa present (P=0.937; Pearson chi-square test). There were altogether 204 septa observed in the 85 patients and 137 maxillary sinuses, giving rise to a ratio of 2.4 septa per individual.

Table 4.1: Distribution of septa in patients of both genders, with three different skeletal profiles

Skeletal profile	Septa present (number ;%)		Total (n ;%)
	Male	Female	
Class I	13 (15.29)	11 (12.94)	24 (28.23)
Class II	15 (17.65)	15 (17.65)	30 (35.30)
Class III	17 (20.00)	14 (16.47)	31 (36.47)
Total	45 (52.94)	40 (47.06)	85 (100.0)

4.2.2 Height of sinus septa

Table 4.2 shows the mean septal height and the total number of septa observed in three different planes. In general, there were little differences in mean height when viewed from the axial, sagittal and coronal planes. The mean height was the smallest when measured in axial plane i.e. 10.32 (SD 4.57) mm with a wide range from 3.01 to 33.98 mm. A similar pattern of wide variation in height was also observed for septa measured at the coronal (3.31 – 31.54 mm) and sagittal (3.9 – 34.32mm) planes. In all planes, there was no septum with size less than 2.5 in height that can be considered as a lath instead of a septum. The height of septa on the right sinus was higher than those on the left sinus, when viewed from the sagittal and coronal planes. However, this difference was not statistically significant.

It can be noted that the total number of septa present was different depending on the plane where these septa were examined. More septa can be found when viewed from the axial plane (n=201) followed by sagittal (n= 195) and coronal (n=174), although the actual number of septa was slightly different (n=204).

Table 4.2: The mean septal height and the number of septa observed in sagittal, coronal and axial planes

Site	Mean septal height			Presence of septa (N)		
	Right	Left	Average	Right	Left	Total
Sagittal	12.39 ± 0.52 (4.99-34.32)	12.07 ± 0.52 (3.9-26.82)	12.23 ± 5.15 (3.9-34.32)	94 (48.2)	101 (51.8)	195
Coronal	11.46 ± 0.63 (3.5-27.69)	11.17 ± 0.57 (3.31-31.54)	11.32 ±5.61 (3.31-31.54)	88 (50.6)	86 (49.4)	174
Axial	10.17 ± 0.42 (4.21-28.12)	10.47 ± 0.49 (3.01-33.98)	10.32 ± 4.57 (3.01-33.98)	101 (50.2)	100 (49.8)	201

4.2.3 Location and configuration of septa

When viewed from different planes, the septa can be found at the floor, roof or any of the walls and sometimes they connected from one wall to another in various shape

(Table 4.3). This gives an impression of the difficulty an examiner faces in trying to identify the most common location of a septum due to inconsistent relation to sinus walls.

Overall, a great majority of septa were seen at the floor of the maxillary sinus when it viewed from the sagittal plane. However, when the septa examined from the coronal plane, the infraorbital projections give rise to a high percentage together with a roof. It is suspected that the septa observed here were made up of part of the floor of the infraorbital canal.

Most of the septa found in axial plane were connected from the medial to the lateral wall (n=48) which indicate a complete bony septa separating the maxillary sinus into two bony cavities. Incomplete bony septa can be seen in medial walls (n=20) followed by lateral walls (n=14) and a small number at the posterior wall (n=4). The detailed location of septa in the sagittal, coronal and axial plane are as shown in Table 4.3.

Table 4.3: The location of septa as observed from the sagittal, coronal and axial planes

Plane	Location	Number					
		Septa 1	Septa 2	Septa 3	Septa 4	Septa 5	Total
SAGITTAL	Wall	11	7	2	-	1	21
	Floor	44	7	3	-	-	54
	Roof	8	7	1	-	-	16
	Inferior orbital opening	34	8	1	-	-	43
	Wall-wall	2	-	1	-	-	3
	Wall-floor	2	-	1	-	-	3
	Wall-roof	31	14	2	2	-	49
	Floor-roof	4	1	1	-	-	6
	Total	**136**	**44**	**12**	**-**	**1**	**195**
CORONAL	Wall	20	12	3	-	-	35
	Floor	8	3	1	-	-	12
	Roof	17	17	2	-	-	36
	Inferior orbital opening	34	8	1	-	-	43
	Wall-wall	18	5	2	-	-	25
	Wall-floor	4	-	1	-	-	5
	Wall-roof	7	1	1	-	-	9
	Floor-roof	5	1	-	2	1	9
	Total	**113**	**47**	**11**	**2**	**1**	**174**
AXIAL	Posterior wall	3	1	-	-	-	4
	Medial wall	15	2	3	-	-	20
	Medial-lateral wall	38	9	1	-	-	48
	Medial-anterior wall	5	1	-	-	-	6
	Medial-posterior wall	1	-	1	-	-	2
	Lateral wall	5	7	2	-	-	14
	Lateral-anterior wall	1	-	-	-	-	1
	Inferior orbital opening	34	8	1	-	-	43
	Total	**136**	**49**	**13**	**2**	**1**	**201**

In general, the septa can be found anywhere in relation to the permanent dentition from anterior region (between first and second premolar), middle (first and second molar) to the posterior region (third molar) as shown in Figure 4.4. There was unequal distribution of septa found at the floor of the maxillary sinus in relation to the dentition with a significantly higher percentage of septa located at middle (mid-sinus) floor (n=28; 66.7%). This finding suggests that the most common location to find the septa is in close relation to first and second molar. More septa were found in the left sinus (n=26) than in the right (n=16). In children, no septa were found in relation to the developing crown of permanent teeth (Figure 4.4).

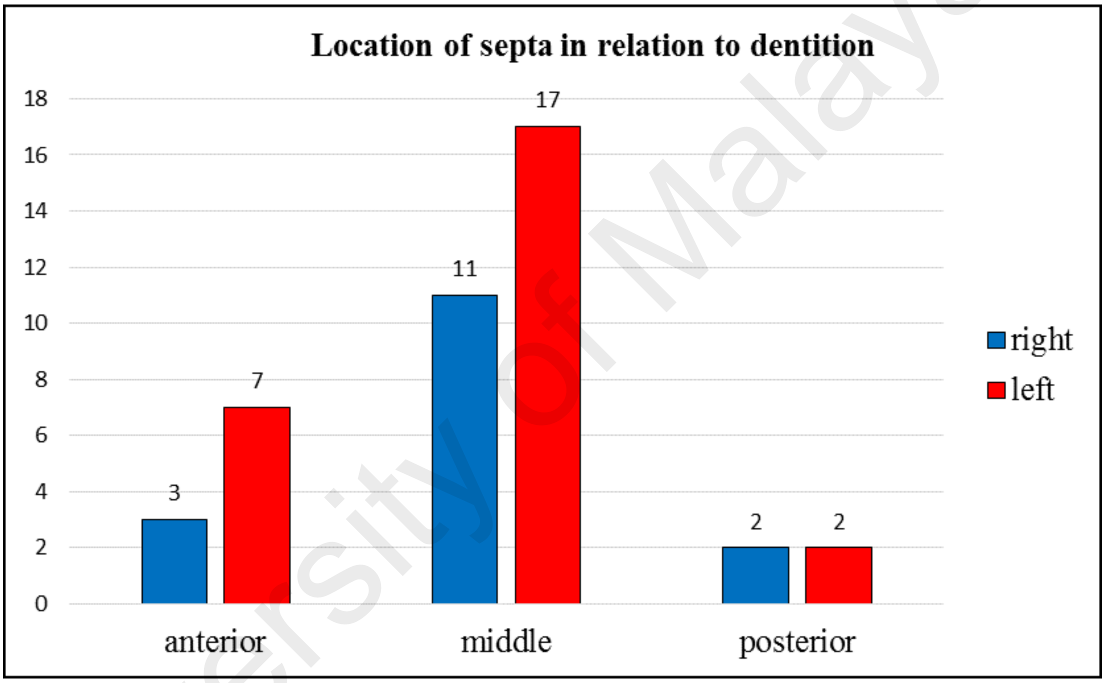

Figure 4.4: Location of septa in relation to maxillary dentition

Table 4.4 shows the distribution and configuration of septa. Half of the patients presented with a single septum either in unilateral (n=23) or bilateral sinus, giving a 1-1 configuration (n=22). The remaining patients presented with various patterns of septa distribution that can be seen as any of the 17 configurations listed in Table 4.4. There was one patient with the maximum septa five and six each, giving rise to the 4-1 and 5-1 configuration respectively.

Table 4.4: Distribution and configuration of septa

Maxillary septa type	Configuration R-L	(number)	Total patient n=85	Total septa n=204
1 septum on unilateral sinus	**1-0**	**(9)**	**23**	**9**
	0-1	**(14)**		**14**
1 septum on bilateral sinuses	**1-1**	**(22)**	**22**	**44**
2 septa on one sinus and 1 septa on the contralateral sinus	**1-2**	**(6)**	**14**	**18**
	2-1	**(8)**		**24**
3 septa on one sinus and 1 septa on the contralateral sinus	**1-3**	**(2)**	**3**	**8**
	3-1	**(1)**		**4**
4 septa on 1 sinus and 1 septa on the contralateral sinus	**1-4**	**(0)**	**1**	**0**
	4-1	**(1)**		**5**
5 septa on 1 sinus and 1 septa on the contralateral sinus	**1-5**	**(0)**	**1**	**0**
	5-I	**(1)**		**6**
2 septa on unilateral side	**2-0**	**(2)**	**6**	**4**
	0-2	**(4)**		**8**
2 septa on bilateral sinuses	**2-2**	**(7)**	**7**	**28**
3 septa on one sinus and 2 septa on the contralateral sinus	**2-3**	**(1)**	**4**	**5**
	3-2	**(3)**		**15**
3 septa on unilateral sinus	**3-0**	**(2)**	**4**	**6**
	0-3	**(2)**		**6**

4.3 Volume of the maxillary sinus

The average volume of maxillary sinus segment was 16.36 (SD 0.51) cm^3 in class I, 17.96 (SD 0.59) cm^3 in class II and 16.65 (SD 0.55) cm^3 in class III patients. In essence, the results show that patients with a Class II skeletal profile had larger volume when compared to those with Class I or Class III skeletal profile, although this difference was not statistically significant (ANOVA; P > 0.05). It was noted the volume of maxillary sinus is larger on the right side for patients with class II and class III skeletal profile, and conversely on left side for those with class I skeletal profile. The minimum volume of maxillary sinus was 5.04 cm^3 while the maximum volume was 37.45 cm^3, both of which were recorded on the right sinus of patients with class II skeletal profile. Table 4.5 shows in detail the volume of maxillary sinus in patients with different skeletal profiles.

Table 4.5: Antral volume in patients with different skeletal profile

Skeletal profile	**Volume of maxillary sinus in cm^3 (Range; min - max)**		
	Right	**Left**	**Overall**
Class I	16.02 (SD 0.69) (5.78 - 27.68)	16.71 (SD 0.76) (5.7 - 29.49)	16.36 (SD 0.51) (5.7 - 29.49)
Class II	18.18 (SD 0.84) (5.04 - 37.45)	17.74 (SD 0.84) (6.41 - 34.8)	17.96 (SD 0.59) (5.04 - 37.45)
Class III	16.86 (SD 0.79) (6.68 – 33.5)	16.45 (SD 0.78) (7.57 – 34.26)	16.65 (SD 0.55) (6.68 - 34.26)

Gender-wise, the mean total volume of the maxillary sinus in male was higher when compared to female. However, this difference was not statistically significant (Independent t-test; P>0.05). Patients with Class II skeletal profile had greater volume regardless of gender and ethnicity, followed by the class III and class I respectively. An exception to this finding involved the Indian patients, where the sinus for those with class I skeletal profile shows slightly larger volume than those with a class III skeletal profile.

When the total volume of maxillary sinus further analyzed according to ethnicity and skeletal profile, ANOVA test showed that ethnicity and skeletal profile did not affect total volume of maxillary sinus (P>0.05). This indicates that the volume is varied among different skeletal profile. Table 4.6 shows the summary of mean sinus volume according to gender and ethnicity.

Table 4.6: Summary of mean antral volume according to gender and ethnicity

		Mean total volume of bilateral maxillary sinuses (in cm^3)					
		Skeletal profile[#]					
		n	**Class 1**	**n**	**Class II**	**n**	**Class III**
GENDER *	**Male**	22	34.31 ± 2.56 (11.4 -57.17)	25	38.54 ±2.62 (16.35-72.25)	25	34.45 ± 2.37 (18.0-67.76)
	Female	28	31.48 ± 1.51 (15.42-45.24)	25	33.30 ± 1.83 (11.45-51.69)	25	32.16 ± 1.82 (14.5 - 48.87)
ETHNICITY ¤	**Malay**	17	32.72 ± 2.60 (11.4 -51.63)	23	37.11 ± 2.45 (21.2-72.25)	20	34.13 ± 2.58 (18.36-67.76)
	Chinese	26	33.39 ± 2.00 (15.42-57.17)	2	36.23 ± 2.77 (11.4 - 67.51)	26	33.36 ± 2.04 (14.59-56.56)
	Indian	7	30.30 ± 2.83 (15.8 - 36.16)	7	31.14 ± 2.75 (16.35-38.37)	4	28.77 ± 2.65 (22.69-33.45)

* No significant gender difference was observed. Independent t-test; *P*>0.05

¤ No significant ethnicity difference was observed. ANOVA test; *P*>0.05

No significant skeletal profile difference was observed. ANOVA test; *P*>0.05

CHAPTER 5: DISCUSSION

The maxillary sinus is a unique structure with significant variations between individuals. It increases in size through a process called 'pneumatization' that happens throughout human life. Pneumatization can result in the formation of septa and an increase in antral volume. More than a century ago, Underwood (1910) reported that the inner surface of the maxillary sinus was not even and was irregular especially at the floor (Underwood, 1910). Study found the maxillary sinus contains bony crypts of developing teeth and shows classical features of the bony septum, also known as ridge that may divide the sinus into few compartments. One potential limitation of this study is related to the divergent criteria of septa definition and the measurement of septal height as they may present in various morphology. Naitoh et al. (M. Naitoh et al., 2009) and (Munetaka NAITOH et al., 2010) defined septa as bony projection and exostosis that appeared as rounded bone structure when examining dry skulls of adult and children. In addition, bony projection that develops following tooth loss and alveolar ridge resorption may also look like classical septum even though it is not a true septum (Krennmair et al., 1997). This also indirectly may contribute to higher prevalence at edentulous area which may jeopardize the result of any study. Having said so, way back in 1995, Ulm et al included all bony projections with the minimum height of 2.5mm (Ulm et al., 1995) and use the term "septa" to describe them as no study had tried to clearly define septa then. In contrast, the bony projections less than 2.5mm were not taken into consideration because they were clinically insignificant in maxillary sinus procedure. This definition has since been widely adopted by many researchers.

The presence of septa becomes significance to the dental and oral surgeons especially during preoperative implant treatment planning. The understanding of surrounding tissue anatomy is a prelude to successful implant surgery. Hence, radiographic analysis is considered a must for each implant case when determining the anatomy and anatomical variation of maxillary sinus, alveolar bone height and width (Orhan et al., 2013) as well as the maxilla-mandible relationship (Worthington, Rubenstein, & Hatcher, 2010). Recently, the application of CBCT has received high demand in implantology due to its high geometry accuracy and low absorbed dose in addition to its ability to support volumetric analysis (Mozzo, Procacci, Tacconi, Martini, & Andreis, 1998). In contrast, Kasabah et al. (2002) found that 2D panoramic radiograph demonstrated false diagnosis in the identification of septa present that led to a negative result and showed that it is not suitable for maxillary sinus evaluation (Kasabah et al., 2002).

For the purpose of this study, the author categorized patients according to skeletal profile based on Steiner's analysis on cephalometric images. Steiner analysis was chosen for determination of skeletal profile due to it is widely usage among dental colleagues. The reason for doing so is because till now, no study has been conducted to look into the relationship between different skeletal profile with antral volume and the prevalence of maxillary sinus septa. According to Neugebauer et al. (2010) and Steiner (1953) the analysis was based on Sella-Nasion plane which represents anterior cranial base and angle of point A and B (Neugebauer et al., 2010; Steiner, 1953). Hence, ANB result indicates the maxilla-mandible discrepancy in relation to the cranial base. However, the drawback of this analysis is the variations on the steepness of the S-N plane and the inconsistent location of nasion (Naragond, Kenganal, Sagarkar, & Kumar, 2012) which the author experienced during tracing. In addition, the S-N plane is considered as not stable in growing patient, hence may not reflect the true position of the jaws compared to the cranial base.

The overall prevalence of maxillary sinus septa in this study was 45.7% and is almost similar to the study done by Kfir et al. (E. Kfir et al., 2009). This finding reported a significantly higher prevalence in comparison to that described by Underwood (1910) and a recent systematic review (11 studies) where the septa prevalence ranged between 18-35.3% (Maestre-Ferrin et al., 2010). The difference in the prevalence of septa could be due to different ways in the identification of septa, types of edentulism, geo-ethnic difference and the criteria of septa definition, as described above. As stated earlier, the author includes all bony projection with a minimum height of 2.5mm as a septum.

Following the same approach used by Orhan et al. (2013) in the detection of septa, it was observed that the number of septa decreased in a downward trend when viewed from the sagittal, coronal and axial planes respectively (Orhan et al., 2013). The current study has shown more septa with different configurations being found in bilateral maxillary sinuses (n=104; 75.9%). In comparison, Neuegebaur et al. (2010) reported that septa were more often observed in coronal and axial planes when using the same approach (Neugebauer et al., 2010). Surprisingly, Krennmair et al. (1999) and Velasquez-Plata et al. (2002) restricted the determination of septa present only to the axial plane of CT scans (Krennmair et al., 1999; Velasquez-Plata et al., 2002). With regards to the high prevalence of septa in this study, the author tried to look the ratio of septa per individual. The ratio of 2.4 septa per individual was considered as superior in comparison to a systematic review which the reported value of less than 1 (Maestre-Ferrin et al., 2010). These results showed the reliability of CBCT in the detection of septa over other methods.

The higher prevalence of 62.8% of sinus segment featuring at least one septum either in unilateral or bilateral sinus segments seemed to be consistent with other studies. Although several studies reported that the more common feature observed is having a single septum, one maxillary sinus can have as many as 3 septa present simultaneously (Krennmair et al., 1999; Neugebauer et al., 2010; Orhan et al., 2013; Velasquez-Plata et al., 2002). In fact, van Zyl & van Heerden (2009) reported that multi septa with a maximum number of 4 can be presented in one maxillary sinus segment (van Zyl & van Heerden, 2009). So far, this current study preceded previous study with the maximum number of septa present simultaneously in one maxillary sinus segment at 5, and in an individual at 6 which is extremely rare. The one patient who fitted this finding was 18 years old and it is suspected that these septa were primary septa which correspond to different period of tooth eruption.

Gender-wise, there was no gender difference concerning the prevalence of septa hence this current study agreed with several authors like Gosau et al., Koymen et al. and Orhan et al. (Gosau et al., 2009; Koymen et al., 2009; Orhan et al., 2013). Only one study W. J. Lee et al. (2010) reported that the prevalence of septa was significant higher in males (W.-J. Lee et al., 2010). On further analysis, the present study found that difference in skeletal profile had no influence in the prevalence of septa present in both genders. The distribution of septa was found more on the left side than the right, corresponding with two other reports (Orhan et al., 2013; Underwood, 1910) but contradicts the finding of Gosau et al. (Gosau et al., 2009).

The alveolar ridge undergoes rapid and irreversible resorption once tooth loss; this can cause to instability of implant placement. The significant height of sinus septa may impede the preparation of sinus lifting procedure proposed by Tatum (Tatum, 1986) for bone graft augmentation on posterior maxillary region. Ella et al. (2008) reported the bony septa with minimum height 4mm may increase the risk of Schenidерian membrane perforation during sinus lift procedure (Ella et al., 2008). As stated earlier, this study identified the septa present and measured their height in three different planes. Such an approach of recording the results accordingly will result in discrepancies in mean septal height. The smallest height at 3.01mm was found on the anterior wall of left side when viewing from the axial plane. However, in the sagittal plane, the maximum height of 34.32mm was recorded from the roof to floor direction on the right sinus; hence it divided the sinus into two cavities. This septum presented as straight and long paper-thin bone with a narrow base which differed from inverted gothic arch feature described by Kim et al. (Kim et al., 2006). Therefore, it can be concluded that complete septa have bigger septal height, while incomplete septa show the opposite.

The current study noticed the mean septal height to range from 10.32mm to 12.23mm, regardless of their planes of study. This is larger than those reported in previous studies where the mean septal height ranged from 3.8mm to 9.2mm (Krennmair et al., 1997; M. Naitoh et al., 2009; Orhan et al., 2013; Pommer et al., 2012). Based on this result, the author made the assumption that the difference in mean septal height may be due to variability of septa morphology. This has been proven by the discovery of long irregular C-shaped and S-shaped septa either as incomplete or complete septa (not shown in Result). With regards to this issue, the author tried their best to measure the septa following these shapes in a straight line, however discrepancies in measurements may still arise.

Advances in technology in recent decades make sinus surgery less invasive with the assistance of endoscope. The introduction of endoscope through the transnasal or Caldwell Luc approach requires the surgeon to have good knowledge of the maxillary sinus septa orientation for successful endoscopic sinus surgery. Naitoh et al. (2010) suggested that the direction of septa might be influenced by the growth of maxilla and palatine bone (Munetaka NAITOH et al., 2010). The author had difficulties in determining the orientation of the septa as they can be found everywhere in the inner part of sinus when viewed from different planes. Similar to that reported by Underwood (Underwood, 1910), the current study found septa on the roof, walls and sometimes connecting each other at different walls, while a great majority were on the floor.

The septa were observed tend to be in the medio-lateral orientation which connected one wall to another wall similar to previous reports (Koymen et al., 2009; Orhan et al., 2013; Ulm et al., 1995). Having said so, this septa orientation will hamper endoscopic sinus procedure if the transnasal approach is used. Other than that, a large number of septa were seen on the roof as the infraorbital projection which sometimes hangs down into the sinus. Selcuk et al.(2008) found their septa were related to widened infraorbital fissures (Selcuk, Ozcan, Akdogan, Bilal, & Dere, 2008). Based on this finding and that of Underwood's on dried skulls (Underwood, 1910), an assumption can be made that the septa observed here may be part of the floor of the infraorbital canal.

The septa observed on the floor can be related to the dentition present. Underwood (1910) divides the floor into three compartments: anterior (from mesial aspect of 1st premolar to distal aspect of 2nd premolar), middle or mid-sinus (from mesial aspect of 1st molar to distal aspect of 2nd molar) and posterior (mesial aspect of 3rd molar) (Underwood, 1910). This study demonstrated a greater number of septa present in the middle region, followed by anterior and posterior regions, respectively. This result agrees with the result of previous studies (Kim et al., 2006; Koymen et al., 2009; Orhan et al., 2013). The author tried to relate this finding with teeth eruption time and arrive at an assumption that secondary septa develop more frequently in the area above lost molar teeth because of early extraction of molar teeth. In contrast, Krennmair et al. (1999) and

Damlar et al. (2013) reported a conflicting result with the greatest number in the anterior region and posterior region respectively (Damlar, Evlice, & Kurt, 2013; Krennmair et al., 1999). One limitation of this part of the study is the fact that the location of the septa in relation to dentition was viewed from panoramic view. Sometime, the images were distorted due to superimposition with the metal artefact and soft tissue shadow.

Surprisingly, some septa seen in relation to teeth appear to be the result of the projection of the developing teeth or root apices into the floor of the maxillary sinus. With regards to the high number septa found on the floor, indirectly it indicates the difficulty any surgeons face in creating lateral bony window for sinus lift procedure. Boyne and James (1980) modified the lateral window sinus by making W-shape following the discovery of septa (Boyne & James, 1980). In this study, there were no septa found in the few children included. Therefore, the author cannot relate the changes in maxillary expansion and developing tooth germ with the timing and mechanism of septa formation.

The maxillary sinus continuously increases in volume from infant to elderly throughout the process of maxillary growth. However, the antral volume may decrease or increase in a certain condition, with the skeletal profiles being suspected as one of them. In general, the mean total antral volume in this study was higher at between 28.77cm^3 and 38.54cm^3 when compared with previous studies Gosau et al. (Gosau et al., 2009) and Uchida et al. (Uchida et al., 1998). There were slight discrepancies in the sinus volume among Class 1, Class II and Class III patients. In addition, we noticed the mean volume per sinus segment and total volume were higher in class II profile patient, as compared to Class I and Class III profiles. This suggested in Class II patients, the maxilla is more prominent and hyperplastic while in class III patients, the maxilla is usually hypoplastic. Several authors (Ariji et al., 1994) and (Ariji, Ariji, Yoshiura, & Kanda, 1996) reported the males to have larger sinus volume than females, which the current study concurs with. As we know, males have larger body size with massive muscle which requires more oxygen. Therefore, the males by physiology were born with big maxillary sinus as a result of continuous nasomaxillary complex changes to compensate for the body demand, (Sharma et al., 2014). Previously, Ariji et al. (1994) stated that there was a discrepancy in antral volume among different ethnics (Ariji et al., 1994). Hence, the present study also looked into the effect of ethnicity on the antral volume as Malaysia is known to have three major ethnic groups. However, when further analyzed, there were no significant gender, ethnic and skeletal profile influence on the antral volume. Lastly the current study found that mean antral volume was more on right side. The theory behind the difference of volume between the right and left sinuses could be due to differences in dominant chewing side.

For the future study, we would recommend larger sample size that includes syndromic patients, i.e. those with craniofacial deformities since no study has looked into their septa and antral volume. Perhaps, it is good for the future study to use other cephalometric analysis method in determining the skeletal profile as Steiner's analysis is not suitable in growing patient.

CHAPTER 6: CONCLUSION

1.This study has provided knowledge on maxillary sinus septa and antral volume in different skeletal profiles among patients of three ethnicities.

2. The study showed a high prevalence of septa present, with wide variations in septal height, location, morphology, distribution and antral volume.

3. The skeletal profile of patients did not influence the occurrence of maxillary sinus septa and antral volume

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