A COMPUTED TOMOGRAPHIC STUDY OF CRANIOFACIAL ASYMMETRY AMONG SELECTED AGE GROUPS OF MALAY PATIENTS IN HOSPITAL UNIVERSITI SAINS MALAYSIA

by

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بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

ٱقْرَأْ بِٱسْمِ رَبِّكَ ٱلَّذِى خَلَقَ ﴿١﴾ خَلَقَ ٱلْإِنسَٰنَ مِنْ عَلَقٍ ﴿٢﴾ ٱقْرَأْ وَرَبُّكَ
ٱلْأَكْرَمُ ﴿٣﴾ ٱلَّذِى عَلَّمَ بِٱلْقَلَمِ ﴿٤﴾ عَلَّمَ ٱلْإِنسَٰنَ مَا لَمْ يَعْلَمْ ﴿٥﴾

سُورَةُ العَلَق

[96:1-5] Read! In the name of your Lord who created - Created the human from something which clings. Read! And your Lord is Most Bountiful - He who taught (the use of) the Pen, Taught the human that which he knew not.

Chapter 96: AL-ALAQ

DEDICATION

To my parents who are the candles that burn to give me the light and power to go through my life. Your satisfaction and love are my endless pleasure.

To my brothers and sisters who are the eyes by which I can see the future and the beats that keep my heart alive.

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LIST OF ABBREVIATIONS

Al	Alare
ANS	Anterior Nasal Spine
Au	Auriculare
AW	Advantage Workstation
Br	Bregma
Cd	Condylion Laterale
CD-R	Recordable Compact Disk
CT	Computed Tomography
CV	Coefficient of Variation
Go	Gonion
HUSM	Hospital Universiti Sains Malaysia
ICC	Intra Class Correlation Coefficient
IOF	Infraorbital foramen
LOr	Lateral Orbitale
Me	Menton
mm	Millimeter
MOr	Medial Orbitale
N	Nasion
Or	Inferior Orbitale
OSA	Obstructive Sleep Apnea
Po	Porion
Pr	Prosthion

SD	Standard Deviation
SOr	Superior Orbitale
ZMI	Zygomaxillare Inferius
Zt	Zygotemporale
3D-CT	3-dimensional computed tomography

GLOSSARY

- Alare left/right (All/Alr): The most lateral point on the anterior nasal aperture.
- Anterior Nasal Spine (ANS): The apex of the anterior nasal spine. (Also known as Spinal point (Sp) or Acanthion (Ac)).
- Auriculare left/right (Aul/Aur): The most superior point on the root of the zygoma nearest to craniometric point porion.
- Bregma (Br): The intersection of the sagittal and the coronal sutures on the surface of the cranial vault.
- Condylion Laterale left/right (Cdl/Cdr): The most lateral point on the condylar head.
- Gonion left/right (Gol/Gor): A point on the angle of the mandible located by the bisection of the angle formed by the mandibular line and the ramus line.
- Infraorbital foramen left/right (IOFl/IOFr): The centre of the infraorbital foramen.
- Lateral Orbitale left/right (LOrl/LOrr): The most lateral point on the orbital rim.
- Medial Orbitale left/right (MOrl/MOrr): The most medial point on the orbital margin in the region of the fronto-lacrimal suture.

- Menton (Me): The most inferior point on the mandibular symphysis in the mid-sagittal plane.
- Nasion (N): The most anterior point of the frontonasal suture. If suture not clearly identified then the deepest point on the nasal notch can be substituted in the midline.
- Orbitale left/right (Orl/Orr): The most inferior point on the infraorbital margin.
- Porion left/right (Pol/Por): The most superior point on the margin of the external auditory meatus.
- Prosthion (Pr): The most antero-inferior point on the maxillary alveolar margin in the mid-sagittal plane.
- Superior Orbitale left/right (SOrl/SOrr): The most superior point on the supra-orbital margin.
- Zygomaxillare Inferius left/right (ZMIl/ZMIr): The most inferior point on the zygoma, in the region of the craniometric landmark, zygomaxillare - the lowest point on the external suture between zygomatic and maxillary bones.
- Zygo-temporale left/right (Ztl/Ztr): The mid-point of the bony concavity formed between the frontal and temporal processes of the zygomatic bone.

KAJIAN TOMOGRAFI BERKOMPUTER ASIMETRI KRANIOFASIAL DALAM KALANGAN KUMPULAN UMUR TERPILIH PESAKIT MELAYU DI HOSPITAL UNIVERSITI SAINS MALAYSIA

ABSTRAK

Objektif kajian ini adalah untuk membuat perbandingan dan menentukan kewujudan asimetri kraniofasial sewaktu tumbesaran dalam kumpulan umur yang berbeza dan membuat perbandingan asimetri kraniofasial antara lelaki dan perempuan. Hipotesis yang menyatakan bahawa terdapat kewujudan asimetri kraniofasial sebelum pertumbuhan gigi susu juga di uji. Data tomografi komputer 3 dimensi (3D-CT) di kumpul secara retrospektif dari pangkalan data Hospital Universiti Sains Malaysia (HUSM). Ia terdiri dari 80 orang subjek Melayu yang juga pesakit hospital berumur dari 1 hari ke 25 tahun. Subjek yang mempunyai kecacatan kraniofasial disingkirkan. Sampel kajian dibahagikan kepada tiga kumpulan iaitu kumpulan bayi berumur 1 hari ke 6 bulan, kanak-kanak berumur 7 bulan ke 17 tahun dan dewasa berumur dari 18 ke 25 tahun. Kumpulan bayi terdiri dari 12 lelaki dan 8 perempuan. Kumpulan kanak-kanak pula terdiri dari 22 lelaki dan 16 perempuan. Manakala kumpulan dewasa pula seramai 10 lelaki dan 10 perempuan dimasukkan ke dalam kajian. Bagi setiap tengkorak, 13 ukuran linear di ambil berdasarkan tanda kefalometrik ortodontik untuk setiap bahagian dari imej 3D-CT yang telah di format menggunakan perisian pembayangan dan penganalisasan. Min bagi setiap ukuran linear di ambil. Min bahagian kiri di tolak

dengan min bahagian kanan. Perbezaan antara kedua-dua min kemudian ditukarkan kepada peratusan indeks asimetri. Perbandingan di buat menggunakan varians analisis 2 hala. Keputusan menunjukkan kehadiran asimetri kraniofasial di dalam semua sampel yang di ambil. Asimetri kraniofasial kemudiannya di bandingkan dan di tentukan sewaktu tumbesaran antara kumpulan bayi, kanak-kanak dan dewasa. Kesemua kumpulan menunjukkan tahap asimetri kraniofasial yang hampir sama. Ukuran Or-ZMI (jarak antara Inferior Orbital ke Zygomaxillare Inferius). IOF-ANS (jarak antara Infra Orbital Foramen dan Anterior Nasal Spine) dan Au-Zt (jarak antara Auriculare dan Zygotemporale) tahap asimetri amat ketara kalangan kumpulan umur. Kumpulan bayi menunjukkan kewujudan tahap asimetri yang paling besar, di ikuti oleh kanak-kanak dan dewasa. Asimetri kraniofasial juga di bandingkan dan di tentukan antara lelaki dan perempuan. Kedua-dua lelaki dan perempuan menunjukkan tahap asimetri kranofasial yang hampir sama. Bagi ukuran Go-Me (jarak antara Gonion dan Menton) tahap asimetri kraniofasial amat ketara antara lelaki dan perempuan, di mana perempuan menunjukkan asimetri yang lebih besar. Bagi ukuran ZMI-Pr (jarak antara Zygomaxillare Inferius dan Prosthion) tahap asimetri amat ketara antara lelaki dan perempuan di mana lelaki menunjukkan tahap asimetri yang lebih besar. Kewujudan asimetri kraniofasial dalam bayi menunjukkan pertumbuhan gigi susu tidak berkait dengan kewujudan asimetri kraniofasial.

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ABSTRACT

The objectives of the present study were to determine and compare the presence of craniofacial asymmetry during development across different age groups and to compare the craniofacial asymmetry between males and females. The hypothesis that there was presence of craniofacial symmetry before the establishment of deciduous dentition was also tested. The three dimensional-computed tomography (3D-CT) data were collected retrospectively from the database at Hospital Universiti Sains Malaysia (HUSM). It consisted of 80 Malay subjects who were patients of the hospital aged 1 day to 25 years. Subjects with craniofacial deformities were excluded. The sample was divided into three groups, 1 day to 6 months age group; 7 months to 17 years age group and 18 years to 25 years age group. For 1 day to 6 months age group, 12 males and 8 females were included. For 7 months to 17 years age group, 24 males and 16 females were included. For 18 years to 25 years age group, 10 males and 10 females were included. For each skull thirteen linear measurements based on orthodontic cephalometric landmarks were obtained for each side from the 3D-CT reformatted images using a 3D visualization and analyzing software. Means were obtained for each linear measurement. The left-side means were subtracted from the right-side means. The differences between means were converted into a percentage asymmetry index.

Comparisons were made by Two-way analysis of variance. The results showed that craniofacial asymmetry was found throughout the whole sample. The craniofacial asymmetry was determined and compared during development across the 1 day to 6 months age group; 7 months to 17 years age group and 18 years to 25 years age group. All age groups demonstrated near similar degrees of craniofacial asymmetry. For the measurements Or-ZMI (distance between the Inferior Orbitale to the Zygomaxillare Inferius), IOF-ANS (distance between the Infra Orbital Foramen and the Anterior Nasal Spine) and Au-Zt (distance between the Auriculare and the Zygotemporale) the degrees of craniofacial asymmetry were significantly different among the age groups. The 1 day to 6 months age group presented with the largest degree of asymmetry, followed by 7 months to 17 years age group and 18 years to 25 years age group. The craniofacial asymmetry was determined and compared between the males and females. Both males and females demonstrated near similar degrees of craniofacial asymmetry, however, for the measurement Go-Me (distance between the Gonion and the Menton) the degree of craniofacial asymmetry was significantly different between males and females, with females presenting a larger degree of asymmetry. For the measurement ZMI-Pr (distance between the Zygomaxillare Inferius and the Prosthion) the degree of asymmetry was significantly different between males and females, with males presenting a larger degree of asymmetry. The presence of craniofacial asymmetry in the 1 day to 6 months age group indicated that eruption of the deciduous dentition could not be associated with the onset of craniofacial asymmetry development.

CHAPTER ONE

INTRODUCTION

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1.1 Background

Asymmetry presents difficulties in orthodontic diagnosis and treatment because of the asymmetric occlusal relation and obscurity of the underlying factors, which are responsible for a malocclusion. Studies that had attempted to find a relationship between occlusion and craniofacial asymmetry include Letzer and Kronman (1967), and Janson *et al*. (2001).

There is no defined criterion to determine what could be considered an asymmetry in the presence of a group of measurements. Some authors have stated that asymmetry presented when the means of the differences between the right and left sides were different than zero (Shah *et al*., 1978). Other authors used paired *t*-test to detect the differences between the left and right sides as asymmetries (Letzer and Kronman, 1967; Melnik, 1992) or considered the measurements done on the face as asymmetries when the difference between the right and left sides was equal or larger than two millimeters (Farkas, 1981). Also a bilateral craniofacial difference over four mm was defined as asymmetry by Kwon *et al*. (2005). Any difference between the homologous distances of the right and left sides was considered as an asymmetry as according to Rossi *et al.* (2003).

Absolute symmetry could be considered as ideal (Shah *et al.*, 1978), however, in reality this is not so. Craniofacial asymmetry is generally observed throughout the population (Ferrario *et al.,* 1997). Asymmetry is a usual finding in human craniofacial bones and may be present in patients and in people without medical problems (Rossi *et al*., 2003). The differences between the left side and right side that occur in variable degrees in the population might lead to an interference with normal dental function and esthetic appearance or might be so insignificant that it could not be detected by visual observation (Rossi *et al.,* 2003). Harmonious faces, which looked symmetrical, also showed skeletal asymmetry, suggesting that the soft tissues minimized the subjacent asymmetry (Farkas *et al.,* 1981).

The organism does not favor identical growth of homologous bilateral structures (Cassidy *et al.,* 1998). Genetic factors might cause the differences in the degree of growth between the right and left sides (Melnik, 1992). The expression of the craniofacial asymmetry could be related to heredity, as well as to the musculoskeletal system functional activity, especially the masticatory apparatus (Pirttiniemi, 1994).

Craniofacial asymmetry had been investigated using various methods. Direct measurement on dry skulls (Woo, 1931) was the oldest method, but the most common method was the cephalometric radiographic image analysis (Melnik, 1992). Postero-anterior radiographic pictures (Chebib *et al.,* 1981), anthropometrics (Farkas, 1981) and stereophotogrammetry (Ras *et al.,* 1995) were also used, although by fewer researchers (Ras *et al.,* 1994). Three dimensional computed tomography (3D-CT) had been used to investigate craniofacial asymmetry by researchers of recent (Kwon *et al*., 2005; Katsumata *et al.*, 2005).

1.2 Statement of the Problem

Understanding cephalometric standards and the components of facial asymmetry is important for diagnosing and planning in the fields of orthodontics, orthognathic surgery, TMJ splint and functional jaw orthopedics (Hayashi *et al*., 2003). 3D-CT offers the ability of observing craniofacial bones from several viewing angles with interactive and rapid repositioning of the 3D images (Katsumata *et al*., 2005).

In this study we aim to look at the presence of craniofacial asymmetry using 3D-CT images in patients without any craniofacial deformities from age 1 day to 25 years in Kelantan.

1.3 Objectives

1.3.1 General Objectives

The aim of this research was to study the presence of craniofacial asymmetry in different age groups in Malays.

1.3.2 Specific Objectives

- To determine and compare the presence of craniofacial asymmetry in different age groups: 1 day to 6 months age group, 7 months to 17 years age group and 18 years to 25 years age group in Malay subjects seen at Hospital Universiti Sains Malaysia (HUSM).

- To compare the craniofacial asymmetry between males and females in Malay subjects at Hospital Universiti Sains Malaysia (HUSM).

- To determine if craniofacial symmetry is present before the establishment of deciduous dentition and using it for mastication.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO

LITERATURE REVIEW

2.1 Craniofacial Growth and Development

The American Heritage Dictionary of the English Language (2004) defined growth as an increase in size, number, value or strength. It also defined development as a significant event occurrence or change. Moyers (1988) defined growth as normal changes that happen in amount in living substances; it is the quantitative form of biologic development and is measured in units of increase per unit time. He defined development as unidirectional changes that occur naturally in the life of an individual from its existence as a single cell to its elaboration as a multifunctional unit ending in death. Proffit (1993) defined development as a process of increasing specialization. He stated that development is a physiological and behavioral process, while growth is an anatomic phenomenon.

2.2 Prenatal Craniofacial Development and Growth

The human craniofacial complex consists of the cranium, face, oral cavity and neck. It develops at about day 23 of embryogenesis from the neural crest cells (Bhaskar, 1990). At the end of the third week, the head begins to take shape. In that period, the head is positioned downward and forward above the heart (Sperber, 1981). By the end of the tenth week, the face will have a distinct human appearance (Graber, 1988).

2.2.1 Branchial Arches

The branchial arches develop on day 28 of embryogenesis. Each arch contains a central cartilage rod, a muscular component, a vascular component and a nervous component (Poswillow, 1974). They are formed by the mesenchymal process from the neural crest. The branchial arches are five to six in number separated by four branchial grooves on the external aspect of the embryo (Mills, 1987). The branchial arches play the major role in the formation of the face, the oral cavity, the teeth, the nasal cavities, the pharynx, the larynx and the neck. The derivatives of the first branchial arch are the trigeminal nerve; the maxillary process including the maxilla, the zygoma and the zygomatic process; the mandibular process including, Meckel's cartilage, the mandible and sphenomandibular ligament and the muscles of mastication; and the anterior digastric and mylohoid muscles. The derivatives of the second branchial arch are the facial nerve, Reichert's cartilage, the styloid process of temporal bone, the lesser horn and superior body of the hyoid bone, the stylohyoid ligament, the muscles of facial expression, the stylohyoid muscle and the posterior belly of digastric. The derivatives of the third branchial arch are the glossopharyngeal nerve, the greater horn and inferior body of the hyoid bone and the stylopharyngeus muscle. The derivatives of the fourth and sixth branchial arches are the vagus nerve, the laryngeal cartilages, the cricothyroid muscle, the intrinsic muscles of the larynx, and the constrictor muscles of the pharynx (Bishara, 2001).

2.2.2 Early Development of the Facial Structures

The face of the embryo is bounded by a neural plate cranially, the pericardium caudally and the mandible laterally (Snell, 1995). Development of the face occurs by fusion of the frontonasal, maxillary and mandibular processes (Houston, 1983). Frontal prominence develops in the most caudal portion of prosencephalon. Inferior to this process is the developing oral groove and on the lateral aspects of the oral groove are the rudimentary maxillary processes which are the precursor of lateral aspect of maxilla and maxillary arch. The mandibular arch is below the oral groove. The oral groove, the mandibular arch and maxillary process are called the stomodeum (Bishara, 2001).

The two mandibular arches grow forward and fuse with each other to separate the pericardium from the forebrain (Mills, 1987). The frontal process grows down in the mesenchyme over the forebrain and it is divided by an olfactory pit into the medial and lateral nasal processes (Houston *et al*., 1986; Mills, 1987; Snell, 1995). The fusion of the two maxillary processes starts at the 8th week and is usually completed by the 12th week of embryogenesis forming the secondary palate (Diewert, 1983; Graber, 1988). At same time, the maxillary process comes in contact with the lateral nasal process along the line of the future nasolacrimal duct (Mills, 1987). The lateral nasal processes create the ala of the nose, while the medial nasal process forms the columella, the philtrum and labial tuberculum of upper lip, the frenulum and the entire primary palate (Anthony and Henry, 1971).

At the end of the 8th week, the nasal septum is completely developed. It is formed from the cells of the medial nasal process and the frontal prominence (Anthony and Henry, 1971). The secondary palate is fused with the triangular-shaped primary palate forming the hard palate. At this time, the nasal septum grows down and joins the cephalic aspect of the newly formed palate, thus the stomodeum is divided into two nasal cavities and one oral cavity (Sperber, 1981).

The bony elements of the face are ossified either endochondrally as the nasal capsule and the sphenoid bone or intramembranousely as the nasal bone, the maxilla, the lacrimal bone, the zygomatic bones, the palatal bones, the medial pterygoid palate and vomer (Warwick and Bannister, 1989).

The skeleton of the face is formed by cartilage before the appearance of centers of ossification and also during the early stages of bone formation (Scott and Symons, 1982). The bone is formed from connective tissue by intramembranous ossification, but hyaline cartilage is converted to bone by endochondral ossification (Sperber, 1981; Enlow, 1982).

The mandible is developed in an association with, but not arising from the Meckel's cartilage (Graber, 1988). The upper jaw and lateral parts of the upper lip are formed from a maxillary process. The lower lip is formed from the mandibular process (Moore, 1982).

Ossification of mandible commences in the angle between the incisal and mental branches of the inferior dental nerve. The maxilla ossifies laterally to a cartilaginous nasal capsule at the angle between two nerves, the infra-orbital and anterior superior dental branch of the second division of the trigeminal nerve (Mills, 1987).

The nose is more prominent and nasal septum elongates and becomes more narrowed by the eighth week (Diewert, 1985). Morphometric evaluation of human embryos and foetuses in the Carnegie Embryological Collection showed that between the 7th and 10th weeks of embryogenesis, the facial structures grew predominantly in a sagittal plane, with a four-fold increase in length, a two-fold increase in height but little changes in width (Ortiz and Brodie, 1949).

Rossi *et al*. (2003) evaluated the presence of craniofacial asymmetry in foetuses aged from four to nine months of intra uterine life. It was found to be present in foetuses and the hypothesis that symmetry occurs before eruption of primary teeth and establishment of mastication was rejected.

2.3 Postnatal Growth and Development of Craniofacial Complex

There are two mechanisms whereby the bone may grow. Firstly, it may grow as a result of surface deposition by osteoblast in the cellular layer of periosteoum. This can occur in a suture, at a bony surface or in a periosteal membrane. Secondly it may grow through the intermediary of cartilage, in which the cartilage can grow interstitially and the proliferation cartilage becomes calcified and replaced by bone (Mills, 1987).

2.3.1 Growth of the Maxilla

Growth of the maxilla is intramembranous, upper face grows in two ways which are sutural growth and surface apposition and resorption (Rani, 1995)

2.3.1.1 Suture growth

Sutures are all oblique and more or less parallel with each other and their slant is in an upward and forward direction before the age of seven years. The growth at these sutures will thrust the maxilla downward and forward. It will also increase the height and lower the floor of the orbits. After the age of seven years, the sutures may play a small part in the vertical growth of the face (Rani, 1995). Intermaxillary suture growth has a great importance before birth but it reduces in extent after the age of 12 years after surface apposition accounts for lateral growth (Rani, 1995).

2.3.1.2 Surface apposition and resorption

Bone is laid by the periosteum on the anterior surface of maxilla and on the inferior surface of the palate. The maxilla increases in size and the maxillary antrum is expanded by the resorption with deposition on the surfaces of its walls (Rani, 1995).

2.3.2 Growth of the Mandible

2.3.2.1 Condylar growth

A cap of cartilage representing the condyle is present at each upper end of the mandible and it merges into the ramus. The growth occurs from these two caps which are centres of growth. The mandible grows downward and forward by interstitial and appositional growth of cartilage at this site (Charles *et al*., 1975).

2.3.2.2 Surface growth

The bone increases in thickness by surface apposition, but there is surprising little addition of the bone to the lower border (Foster, 1990). Hans *et al*. (1995) found that mandibular remodeling has more variability during the period of rapid growth and it is not a simple time linked process.

2.3.2.3 Alveolar growth

The alveolar process grows upward, outward and forward by an addition of bone to its free border, which is associated with the presence and eruption of the teeth and their attachment to the occlusal plane. The increase in the vertical height of the jaw increases as the height of the mandibular body increases due to the alveolar growth (Bishara, 2001).

2.4 Controlling Factors of the Craniofacial Development and Growth

The mechanisms and procedures for controlling a craniofacial growth and morphogenesis must be derived from many biological, physiological and clinical fields of knowledge (Enlow, 1977; Sperber, 1981).

2.4.1 Genetic Factors

Lundstrom (1964) concluded that genetic factors have greater influence than non-genetic factors. Other researchers suggested that hereditary influences are more prominent in a skeletal proportion while environmental influences are more important in determining dental relationships (Markovic, 1992; Graber and Robbert, 1994; Kitahara *et al*., 1996).

The shape of the craniofacial system is the end result of biochemical and developmental processes that are under the genetic control, so each gene is likely to influence many morphological characters (Suzuki and Takahama, 1991; Kitahara *et al.,* 1996; Mossey, 1999).

2.4.2 Environmental Factors

It includes nutritional and biochemical interactions, physical phenomena as temperature, pressure and hydration, and pathological lesions (Moss, 1997; Mossey, 1999). The environmental influences may be divided into two types either neonatal or postnatal environmental factors.

In the foetal environmental pressure during a fetal growth, which is called "intrauterine molding", distorts the developing face and results in some congenital anomalies (Graber and Robbert, 1994).

Postnatal environment refers to the effect of a group of factors that can alter a genetic determinant of morphogenisis (Graber, 1988).

Muscular function and neuromuscular adaptation may be controlling factors of the craniofacial development and growth. Some studies on patients with congenital progressive atrophy of the jaw muscles showed significant distortion of craniofacial morphology (van Spronsen *et al.,* 1991; Kubota, 1998). The increased activity of muscles was also found to be associated with the change in facial morphology (Varrela, 1992). The effect of muscles is not related only to the muscular force magnitude but also to the spatial orientation of the force vector (van Spronsen *et al*., 1997). Another example of abnormal muscle activity and its relation with a high incidence of malocclusion are those seen in children with speech problems (Pahkala *et al.,* 1995).

Trauma may cause growth changes as occurs after a mandibular condyle fracture followed by the displacement of condyle and alteration of mandibular growth which affect the facial morphology (Graber, 1988).

Head posture is capable of producing abnormal morphological changes in face by affecting a cranial base rotation (Huggare, 1991; Dibbets, 1996).

Nasal obstruction also may also be a controlling factor of the craniofacial development and growth. Czarnecki *et al.* (1993) found that there was an increase in the lower facial height in mouth breathing patients when they were compared to normal control group. Other studies of changes of craniofacial growth and enlarged adenoid showed an abnormal posterior rotation of the mandible in relation to the palate when compared with the normal control group (Hojensgaard and Wezle, 1987; Kerr *et al.,* 1989). Studies of Obstructive Sleep Apnea (OSA) showed a decreased sagittal dimension of cranial base, retrognathic mandible and maxilla, with increased lower facial height (Mayer and Ewert, 1995; Tangugsorn *et al*., 1995).

Abnormal position and form of vertebrae were studied and showed a correlation with craniofacial growth anomalies. The patients showed larger faces and an increased prevalence of class II malocclusion (Huggare and cooke, 1994; Huggare, 1995).

2.4.3 Functional Factors

Craniofacial bones are influenced by the stress of muscle attachment and oronasopharyngeal function (Kubota *et al.,* 1998). It was found that soft or liquid diet caused a decrease in the muscular activity and resulted in bony underdevelopment (Mossey, 1999). Graber (1988) showed that enlarged nasal sinuses had an effect on bone morphology with resulting in an enlarged bony size and deformity of facial structures.

2.5 Factors Influencing the Craniofacial Size and Form

2.5.1 Genetic Factors

Bishara *et al*. (1994) reported that the cause of asymmetry of the jaw may be genetic (e.g. hemifacial microsomia). The craniofacial complex was believed to have moderate to high heritabilities (Saunders *et al.,* 1980; Lundstrom, 1984).

King *et al*. (1993) found that the craniofacial size and form had a lower genetic component that anticipated. Manfredi *et al*. (1997) compared horizontal and vertical cephalometric distances with regard to heritability. It was suggested that vertical variables were more influenced by heredity than the horizontal.

2.5.2 Climatic Factors

Trauma can cause facial deformity and affect the final form and size of the face (Graber, 1972). Habits can also cause deformity of the face leading to facial asymmetry (Bishara *et al*., 1994). The relationship between chemo-radiation therapy for treatment of rhabdo-mysosarcoma and the craniofacial morphology was studied by Moller and Perrier (1998) and showed deficiency in the mandibular size and maxillary hypoplasia.

According to Burston *et al.* (1963), the external environment can act on genes, and genes thus act on the internal environment of a cell, however, it is not transmitted to the next generation. In their study Beals and Kenneth (1972) indicated that there was an inverse relationship between the mean cephalic index (Head length/ Head breadth) and temperature in subjects from different climates.

2.5.3 Nutritional Factors

Nutritional deficiencies are uncommon in rich countries, but more than two billion people do not receive what we consider the essential elements of minimum diet (Graber, 1972).

Malnutrition delays the growth and may affect body proportions, body chemistry, the quality of some tissues, and may affect facial size (e.g. teeth and bone). One example of nutritional factor affecting the craniofacial growth was following World War II, when many Japanese children suffered from nutritional deprivation that caused retardation of skeletal development (Suto, 1953).

2.5.4 Functional Factors

Mouth breathing and finger sucking habits predispose to a narrow maxillary arch; the dropping of the tongue in the floor of the mouth in case of mouth breathing habit and pressure of the cheek on the maxillary posterior teeth are the important causes of posterior cross bite (Graber, 1972).

Relationship between craniofacial morphology and functional forces was evaluated by many authors who found a significant correlation between them (Ringquist, 1973). It was in agreement with Profitt (1993) and Tangugstron *et al*.

(1995), who described the pathophysiology of this habit on growth and the resultant malformation of face.

Septal deviations, spurs polyp, mucosal hypertrophy and other causes of nasal obstruction disturb the respiratory currents and then predispose to mouth breathing habit in the affected persons (Weimert, 1987; Timms, 1987). The higher the degree of severity of septal cavity, the higher the degree of facial deformity (Sandham and Murray, 1993).

2.6 Etiology of Facial Asymmetry

Bishara *et al*. (1994) suggested that a facial asymmetry may be due to different factors which were genetic or congenital malformations, environmental and functional factors.

2.6.1 Genetic or Congenital Malformations

Hemifacial microsomia and clefts of the lip and palate can cause facial asymmetry (Bishara *et al.*, 1994). Many authors support the theory of the effect of genetical and congenital factors on facial malformation (Sandham and Murray, 1993).

Genetic and environmental effects not only differ in their contribution in determining structures, but also in determining the growth dimension. Some investigations found a differential effect of genes on craniofacial growth and development (Lundstorm and McWilliam, 1987; Markovic, 1992), which means that certain dimensions of the face and the body are affected by genetic factors more than another factors. Mossey (1999) concluded that during the embryonic development, genetic determination and regulation are responsible for the craniofacial morphogensis.

2.6.2 Environmental Factors

Habits and trauma such as direct trauma on the face may result in damage and fracture of the nose leading to nasal septal deviation and facial asymmetry (East and O'Donaghue, 1987; Bove *et al*., 1988). Birth trauma had been studied as a causative factor (Soboczynski *et al.,* 1992). Birth molding which happens, when the infant's head passes through the birth canal and the calvarium is compressed anteroposteriorly, can be regarded as a causative intrauterine environmental factor in generation of asymmetry of the face (Brain, 1979), and the concept was supported by many authors (Podoshin *et al.,* 1991; Saim and Said, 1992).

2.6.3 Functional Factors

Functional factors include extrinsic and intrinsic forces of the muscular actions, the space occupying organs and cavities, and the growth expansion (Nepola, 1969). The functions of orofacial complex are secured by a set of organs and tissues that constitute a functional matrix. Their presence and action influence the configuration of face and jaws (Moss *et al*., 1968). The orthodontic treatment may constitute a functional matrix designed to direct the growth or the dentoskeletal relationship in a desired shape. Although each of the craniofacial bone has a genetic influence on size and shape (Hinds *et al*., 1960),

Moss (1997) concluded that the controlling factors are genetic and epigenetic factors including the local and general environmental factors. The epigenetic factors refer to the entire series of interactions among the cells and cells' products leading to the morphogenesis and differentiation. All these controlling factors interact in a controlled relation to produce the final shape and size of a craniofacial complex (Fanibunda, 1995; Tallaro *et al.,* 1996).

Nanda (1990) found that while the linear measurements did not follow a constant growth rate in various parts of the face and cranium, their reciprocal relations were maintained from childhood to adulthood. According to the counterpart principle, the development of any facial or cranial part relates specifically to other structural and geometric counterpart in the face and cranium (Graber, 1994), for example the anterior cranial fossa is a counterpart of the maxilla (Kasai *et al.,* 1995).

Woo (1931) mentioned that the dominance of the right side of the skull is related to the rapid development of the right hemisphere of the brain. Bjork and Bjork (1964) also supported that idea. However, Graber (1988) suggested that the growth of the brain was related to the growth of the brain itself, while the growth of facial bone was relatively independent of the brain growth. It depended on the interaction of intrinsic genetic factors and environmental factors as an asymmetric muscular habit.

2.7 Classification of Craniofacial Asymmetries

Many attempts had been made to classify craniofacial asymmetries e.g. on the basis of overgrowth or recessive growth, or divide them into genetically determined or acquired types (Hinds *et al*., 1960).

The following overview was based mainly on the time of onset of asymmetric development in the craniofacial region, and it excluded tumors because of their wide variety and later expression (Pirttiniemi, 1994).

2.7.1 Craniofacial Asymmetries Originating During the Prenatal Period

2.7.1.1 Embryonal period

These include the following conditions:

- Congenital hemifacial hypertrophy (Poswillo, 1974; Nakata *et al.,* 1995; Seow *et al*., 1998).
- Complete unilateral cleft lip and palate: the patients manifest asymmetry of the mandible. This asymmetry develops in a parallel pattern with the affected maxilla (Laspos *et al*., 1997).

2.7.1.2 Fetal period

These include the following:

- Muscular torticollis (Pirttiniemi, 1994).
- Unilateral coronal synostosis (Arvystas *et al.*, 1985).
- Temporomandibular joint involvement.