Sudan University of Science and Technology
College of Graduate Studies

Characterization of Foramen Magnum and Occipital Condyles in Adult Sudanese by using Computed Tomography.

توصيف الثقبة العظمى واللقم القذالية لدي السودانيين البالغين باستخدام الأشعة المقطعية

A Thesis Submitted for the Requirements of the fulfillment of the Award Ph.D. Degree in Diagnostic Radiological Technology

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الآية الكريمة

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

(قل هل يستوى الذين يعلمون والذين لا يَعلمون إنما يذكر أولى الألباب)

صدق الله العظيم

سورة الزمر

الآية (9)

Dedication

To:

My parents for their patience and encouragement,

My Wife and my Sons & daughter "*Abdallah, Qusi & Reem*" for their patience, understanding and encouragement

My brothers and sisters for their help and support,

My friends for their valuable support,

And

To the dearest people in my life.

I dedicated this work.

Acknowledgement

My full thanks to my God in every thing.

My great thanks and deep gratitude to my supervisor **Prof. Dr. Caroline Edward Eyad Khela**, *for her advices, valuable suggestions and help.*

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My thank to the staff of all **Ibn ALhythm Medical Center** *who gave me permission to conduct the practical part of this work at their center.*

ABSTRACT

The foramen magnum (FM) is an important anatomical region of the skull base and is of significance for anatomy, anthropology and other medical fields. The transcondylar approach has been used in surgeries to access lesions in areas close to the foramen magnum (FM) and is performed directly through the occipital condyle (OC).

This study aims to characterize the foramen magnum shape and contour and determine of the different anatomical variations through the use of reconstructed helical CT images. For verify the morphological characteristics of the (FM) for gender determination in Sudanese individuals by measuring the saggital, transverse diameter, area, circumference and characterizing its shape, and to characterize the anatomical variations related to the (OC) measurements.

A total of 241 Sudanese patients (147 males and 94 females) with mean ages were 40.96±15.21, 41.02±14.32 years respectively were examined using reformatted axial CT and three-dimensional CT, between September 2012 and July 2014, referred to the Radiology Department in the Ibn ALhythm Medical Center, Khartoum, Sudan

The foramen magnum shapes were determined as a round shape in 55(22.9%) of the cases, oval in 115 (47.8%), irregular in 36(14.8%) and arrow head in 35(14.5%), the mean sagittal and transverse diameters of the foramen magnum were determined as 34.0±2.98 mm and 29.3±2.44 mm respectively. Area of the (FM) was 770.0±111.09 and Circumference of the (FM) was 104.1±11.55, a significant difference between genders were detected at p-value =0.05.

Characteristics of the head, and measures related to the (FM) and right and left occipital condyles were examined. The results showed no significant difference between the measurements obtained in the right and in left sides. The (OC) morphometric parameters had significant relationship with (FM) antroposterior and transverse diameters. The study revealed a significant difference between the two genders with no significant relations between (OC) and head characteristics. The data obtained by three-dimensional CT images are important in assessing the morphometric variations of (OC) for Sudanese patients. As the (OC) is the main bony eminences impeded the anterolateral surface of the brainstem, neurosurgeons should be familiar with variations of the (OC) and structures surrounding the (FM) in order to achieve the safest surgical procedure.

knowledge of FM area‘s anatomy is of extreme importance for treating lesion and help the surgeon regarding selection best surgical approach and expected changes in the anatomy of these critical structures and resection of tumors; removal of bony structures such as the occipital condyle (OC) may result in injury to the vascular structures and lower cranial nerves and result in craniocervical instability.

ملخص البحث

الثقبة العظمى هي المنطقة التشريحية الهامة في قاعدة الجمجمة و ذات أهمية لعلم التشريح وعلم الإنسان والمجالات الطبية الأخرى. وفي العمليات الجراحية يتم الوصول للآفات في المناطق القريبة الثقبة العظمى مباشرة من خلال اللقمة القذاليه .

وتهدف هذه الدراسة إلى تحديد خصائص شكل الثقبة العظمى وتحديد الاختلافات التشريحية وذلك باستخدام تقنية إعادة بناء الصور ,بواسطة الأشعة المقطعية. للتحقق من خصائص شكل ألثقبه العظمى لتحديد الجنس . عن طريق قياس- طول ، عرض , مساحة ومحيط وتوصيف شكل ألثقبه العظمى ، وتوصيف الاختلافات التشريحية المتصلة بقياسات اللقمة القذاليه .وقد اشتملت الدراسة علي 241 مريض (147 ذكور و 94 إناث) مع متوسط الأعمار 40.96 ± 15.21 .

وقد وجد الشكل الدائري في (22%) من الحالات، البيضاوي في (47.8%)، والشكل الغير منتظم في (14.8%) وذو الرأس السهمي في (14.5)، ومتوسط طول وعرض الثقبه الثقبة كما يلي 34.0 ± 2.98 ملم و 29.3 ± 2.44 ملم على التوالي . وكان متوسط مساحة الثقبه العظمى 770.0 ± 111.09 ومتوسط محيطها 104.1 ± 11.55، (تم ملحظةان هناك فرق كبير بين الجنسين ,القيمة الاحتمالية = 0.05.)

من خلال قياسات الثقبه الكبرى والأجزاء التشريحية المتصلة بها مثل اللقم القذالي اليمنى واليسرى . أظهرت النتائج عدم وجود فرق كبير بين القياسات التي تم الحصول عليها في اليمين واليسار في الجانبين.كما أظهرت الدراسه علاقة كبيرة لللقمة القذاليه مع طول وعرض الثقبه العظمى. وكشفت الدراسة أيضا وجود فرق كبير بين الجنسين مع عدم وجود علاقة ذات دلالة بين اللقمة القذاليه وخصائص الرأس .

البيانات التي حصلت عليها الصور المقطعية ثلاثية الأبعاد مهمة في تقييم الاختلافات المظهرية من اللقمة القذاليه للمرضى السودانيين. باعتبار ان اللقمة القذاليه هي البروز العظمي الرئيسي للسطح الأمامي الوحشي من جذع الدماغ ، لذالك ينبغي معرفة الاختلافات في اللقمة القذاليه والثقبه العظمى والأجزاء التشريحية ألمحيطه. من أجل تحقيق أسلم طريقه لإجراء العمليات الجراحية.

المعرفة التشريحية لمنطقة الثقبه العظمى ذو أهمية بالغة لعلاج الأورام ومساعدة الجراح بشأن اختيار أفضل نهج جراحي, والتغيرات المتوقعة في تشريح الأجزاء الأساسية واستئصال الأورام. إزالة الأجزاء العظمية مثل اللقمة القذاليه قد يؤدي إلى إصابة الأوعية الدموية والأعصاب القحفية السفلى مما يؤدي إلى عدم الاستقرار في مفصل العنق مع الرأس .

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Abbrivations

AFM	Area of foramen magnum
CT	Coputed Tomography
CFM	Circumference of foramen magnum
CCJ	Cranniocevicle junction
CM	Chiari malformations
CN	Cranial Nerve
CSF	Cerprospinal Fluid
FM	Foramen Magnum
FMM	Foramen Magnum Meningiomas
LRC	Length of Right occipital Condyle
LFM	Length of foramen magnum
LLC	Length of left occipitalCondyle
MnlD	Minimum intercondylar distance
MID	Maximum medial intercondylar distance
MBD	Maximum bicondylar distance
MDCT	Multi Detector Computed Tomography
MRI	Magnetic Resonance Imaging
OC	Occipital Condyle
SFM	Shape of foramen magnum
SDH	Sagittal diameter of the head

SM	sterno-mastoid
TDH	Transverse diameter of the head
WFM	Width of foramen magnum
WRC	Width of Right occipital Condyle
WLC	width of left occipital Condyle
VA	vertebral arteries
VRT	Volume Rendering Technique

Chapter One

1.1 Introduction:

The most prominent feature in the floor of the posterior cranial fossa is the foramen magnum in the occipital bones, this wide communication between the posterior cranial fossa and the vertebral canal, vertebral arteries and the spinal accessory nerve. Anteriorly the apical ligament of the dense and membrane tectoria are in it. Its wider posterior part contains the medulla oblongata and spinal cord continued. Anterior to its transverse diameter it is narrowed by the two occipital condyles. (Standring S. et. al, 2008)

Foramen magnum (FM) is the oval shape opening located at the base of the skull, and bordered by the basilar, squamous, and two lateral parts of the occipital bone. The FM, as a transition zone between spine and skull, plays a vital role as a landmark because of its close association to key structures such as the brain and the spinal cord.(Boni. et. al, 2009).

Since the FM includes specific neuroanatomical structures and their lesions in that region which require particularly microsurgical intervention, choosing and establishing the most suitable surgical techniques need a careful planning mainly based on the FM size to refrain from any neurological injury. (G. Venkatesh. et. al, 2005).

Moreover, intradural and extradural tumors, common congenital abnormalities such as FM syndrome produced by atlanto-occipital assimilation, and cerebellar tissue herniations which invaginated into the FM may lead to neural compression and even death are commonly met pathological disorders in this region. (Fatma Hayat Erdil .et al, 2010)

The occipital condyles are the prominences of the paired lateral exoccipital Segments of the occipital bone, which form the foramen magnum together with the basioccipital segment anteriorly, and the supraoccipital or squamosal segment posteriorly (Lustrin ES, et al., 1994).

The bone around the foramen magnum constitutes the uppermost border of an extremely complex three-unit joint with intricate functional relationships between the occiput, atlas, and axis (ie, the CCJ or occipitoatlantoaxial complex) (Saldinger P, et al., 1990).

The occipital condyles (OC) of the skull are located with the superior articular facets of the atlas vertebra and form an important junction between the cranium and the vertebral column.(Muthukumar N, et al., 2005), (Naderi S, et al., 2005) . Each OC is oval in outline and oriented obliquely so that its anterior end lies nearer the midline. It is markedly convex anteroposteriorly, slightly convex transversely, and its medial aspect is roughened by ligamentous attachments, (Schwaber MK, et al., 1990).

Its integrity is of vital importance for the stability of the craniovertebral junction. The difficulties and high rate of morbidity associated with surgical approaches (Acikbas SC, et al., 1997), (La Marca F, et al., 2008).

The transcondylar surgical approach has been used to access lesions in areas close to the (FM) and it is performed directly through the (OC) (George et al., 1988), therefore the anatomical landmarks of the (FM) should be well known in order to make a safe occipital condyle resection (Barut et al., 2009). The surgical errors in this region may result in injury to the vascular structures and cranial nerves and result in craniocervical instability. Consequently, neurosurgeons should be more familiar with the anatomy and variations of this region. Therefore, radiological (Osborn et al., 1978) and anatomical morphometric studies (Bozbuga et al., 1999; De Oliveira et al., 1985; Prescher, 1997) were performed to contribute to the knowledge of this area.

Computed tomographic scan is noninvasive modality for the imaging the skull base. Since this procedure is widely done, this modality was preferred. (Surwase, et. al., 2013)

Because of the dense bone of the base of skull beam-hardening artifacts are often seen in images of the posterior fossa, thin slices can help to reduce these artifacts and produce high spatial rsolution.

Reviewing published literature, identified many study concerning CT measurements of the foramen magnum in unidentified skulls, and reported studying 3D CT measurements of the foramen magnum with a resultant sex discriminant.

The cranial base is such a complex structure that it is only studied morphometrically. The sites where a number of vital structures have their entrance or exits are very important for clinical application. Therefore the assessment of these morphometrics is helpful for surgical approaches for reaching lesions in the middle and posterior part of cranial base. (Cicekcibasi AE, et al, 2004)

The study of diameters of foramen magnum is interesting due to the important relations of the foramen magnum and also its contents. Dimensions of the foramen magnum have clinical importance because the vital structures that pass through it may suffer compression. It has also been noted that longer antero-posterior dimension of foramen magnum permitted greater contralateral surgical exposure for condylar resection. So, anatomic and radiologic values of foramen magnum dimensions and their relation to gender have been the objectives of several studies. (Murshed K.A., et al, 2003).

The anatomic and radiologic values have been the objectives of several studies. (Murshed K.A., et al, 2003). Recent advances in microsurgical technique and more wide spread use of the operating microscope have now enabled surgeons to approach previously in operable deep seated lesions of the skull base. It is therefore necessary that the clinicians should have a thorough knowledge of anatomy of this region for evaluation of various disease processes affecting this region (Laine FJ, et al 1990).

FM evaluations are very significant in not only to establish the most suitable operational procedures, but also to find valuable data for unidentified sex assessment and determination and individuality in forensic medicine.(Fatma Hayat Erdil .et al, 2010).

Determining the biological sex of unknown skeletal remains is an important aspect of medico-legal investigations seeking to establish the identity of a deceased individual. (R.Gapert, et al 2008).

Anthropologists are often faced with the task of assigning sex to remains that are incomplete, fragmented or damaged as may result from incidents such as mass disasters, airplane crashes, fire, explosions or physical violence (W.R.G.Teixeira,1982). Comprised remains will affect the accuracy of sex estimation and thus necessitate the development of reliable sexing criteria based on isolated bony elements (T.D.Holland 1986).

The foramen magnum has attracted considerable interest for the purposes of sex determination (A.T.Uthman, et al., 2012). The robusticity of the occipital bone and the relatively protected anatomical position of the foramen magnum beneath adepth of soft tissue may make it less vulnerable to fragmentation, or to the effects of inhumation and taphonomic processes in comparison to other cranial and facial bones (T.D.Holland 1989).

1.2 Problem of the Study:

- The FM clinically importance since vital structures that pass through it which may suffer compression; such as in cases of FM achondroplasia and FM brain herniation as well as in a transcondylar surgical approach to the FM, when resection of tumors; removal of bony structures such as the occipital condyle (OC) may result in injury to the vascular structures and lower cranial nerves and result in craniocervical instability. Hence, knowledge of FM area‘s anatomy is of extreme importance for treating lesion and help the surgeon regarding selection best surgical approach and expected changes in the anatomy of these critical structures.
- There is no specific characterization of the morphology and dimensions of the FM as standard in Sudanese population; so this study is obtain to study the anatomical variation of the FM for forensics, anthropologic and surgical purposes.

1.3 Objectives:

1.3.1 General objectives:

To study the Anatomical Variation of foramen magnum and occipital condyles In Adult Sudanese using computed tomography.

1.3.2 Specific objectives

- To characterize the foramen magnum shape and contour.
- To measure the foramen magnum size and dimensions.
- To determine the correlation between the FM shape and size with gender.
- To determine the impact of the anatomical variation of foramen magnum in gender estimation.

- To measure the occipital condyles size and dimensions.
- characterize the anatomical variations related to the (OC) with the relation to the morphometric parameters of the (FM)
- To find out an index for the FM for Sudanese compared to the other populations.

Chapter Two

Literature Review

2.1 An Overview of skull:

The skull is supported on the summit of the vertebral column, and is of an oval shape, wider behind than in front. It is composed of a series of flattened or irregular bones which, with one exception (the mandible), are immovably jointed together. It is divisible into two parts :(Gray, H, 1918; Bartleby.com, 2000).

The skul composed of cranium, which lodges and protects the brain, consists of eight bones, and the skeleton face, of fourteen bones, (Figure 2-1)

The Cranium consist of, 8 bones are, Occipital, Two Parietals, Frontal, Two Temporals, Sphenoidal and Ethmoidal.

The Face consist of , 14 bones , Two Nasals, Two Maxillæ , Two Lacrimals , Two Zygomatics,Two Palatines , Two Inferior Nasal Conchæ , Vomer ,and Mandible.

In the Basle nomenclature, certain bones developed in association with the nasal capsule, viz., the inferior nasal conchæ, the lacrimals, the nasals, and the vomer, are grouped as cranial and not as facial bones.

The hyoid bone situated at the root of the tongue and attached to the base of the skull by ligaments. (Gray, H, 1918; Bartleby.com, 2000).

The occipital bone situated at the back and lower part of the cranium, is trapezoid in shape and curved on itself. It is pierced by a large oval aperture, the foramen magnum, through which the cranial cavity communicates with the vertebral canal.

The skull forms the skeleton of the head. It is rounded in shape. This part of the human body frame work is difficult to study as there are a very large number of named features on it, many of which are very difficult to identify (Singh, 2002). The bone forming the lower jaw is called the mandible. The other bones of the skull are firmly united to one another at joints called sutures. There are numerous openings in the base of the skull they are called foramina. Foramen magnum is the large opening at the lower part of the occipital bone and outlet through which the medulla and spinal cord pass from the skull to the vertebral column (McGraw-Hill, 2002).

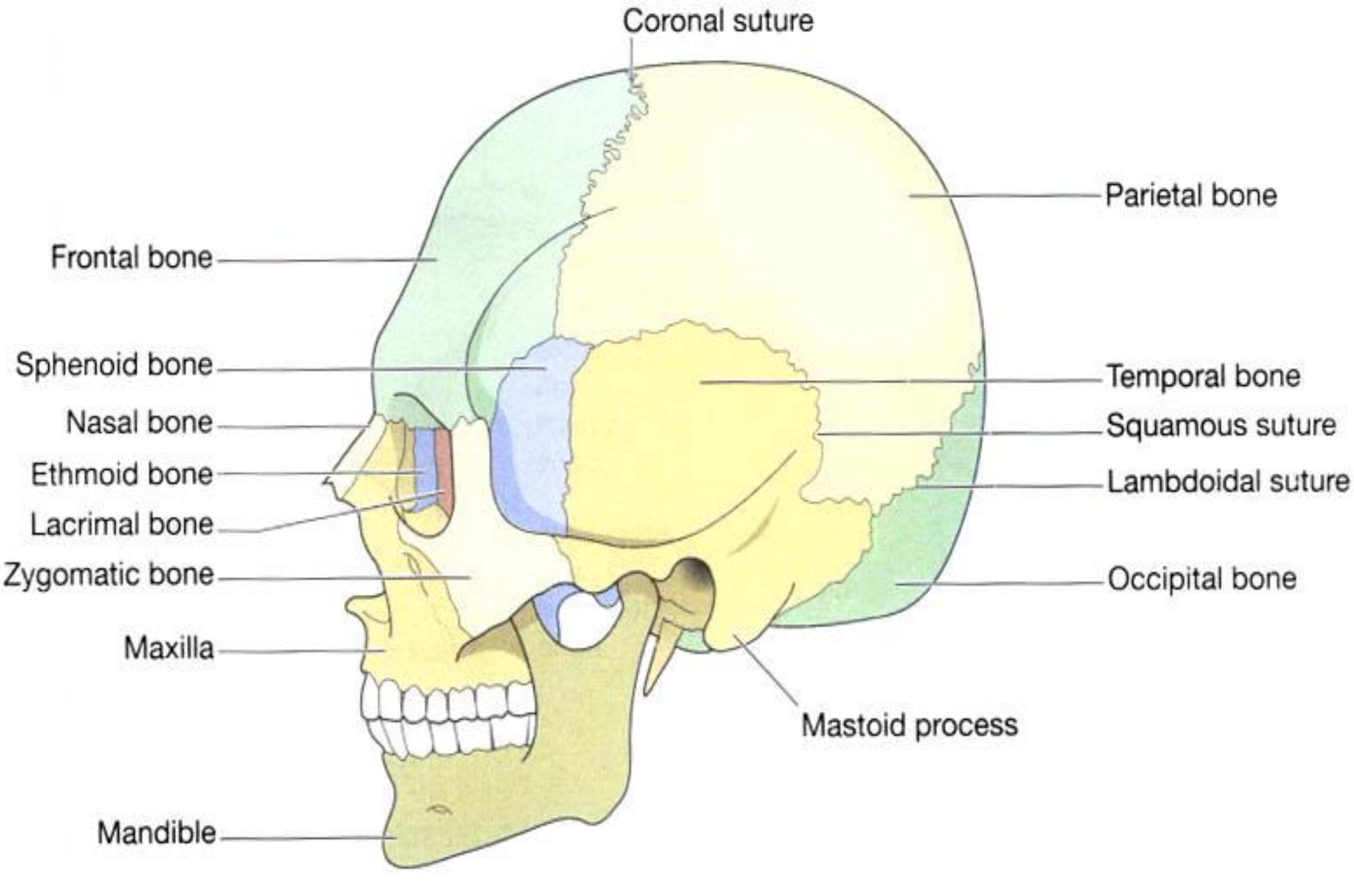


Figure 2.1: The bones of skull and their sutures.

Knowledge of normal and variations of skull base is important for neurosurgeons, and anatomists. (Berlis .A et al, 1992).

In neurosurgery, the assessment of the (FM) dimensions is used for the access of the brainstem lesions (Furtado SV et al 2010).Studies accounted that studying the anatomy of the skull base is important for this approach (Muthukumar N, 2005).

Indexes have been built from the dimensions of the occipital condyles and the foramen magnum, and various authors have reported its usefulness in determining the sex, particularly with incomplete skeleton or cranial bones fractured (Ferreira et al., 1967; Teixeira, 1982; Zadvornov Iu, 1997).

2.2 Embryology Craniocervical Developmental Anatomy

The bony cranial base is developed by a process of enchondral ossification, in which a cartilaginous framework is first developed and subsequently resorbed with further deposition of bone, caused by distorting forces, such as eye development and brain development (Gasser RF., 1976). The clivus and cranial base elongates by sutural growth at the spheno-occipital and sphenopetrosal synchondrosis and by further sutural growth along the lateral portion of the cranial base (Menezes AH., 1998). On the other hand, the facial bones and the majority of the cranium develop by intramembranous ossification. This development bypasses the intermediate cartilaginous phase characteristic of the development of the bony cranial base (Christ B, et al 1992, Dietrich S, 1997, Kessel M, 1991).

During the fourth week of gestation, 42 somites are formed (Ganguly DN, et al, 1964). There are four occipital somites, eight cervical, 12 thoracic, five lumbar, five sacral, and 8 to 10 coccygeal pairs (Gasser RF., 1976). Each somite differentiates into an outer dermatome and inner myotome and a medial sclerotome. The sclerotomes are ventral-medial in their location and will form the vertebral bodies. These ventral-medial bilateral cells migrate toward the midline and surround the notochord. Each sclerotome will develop the fissure of Ebner, which is a central cleft that divides a loose collection of cells cranially from a dense cellular area caudally. In this development, the cells from the fissure of Ebner migrate toward and encase the notochord to become the precursors of the intervertebral disc (Melsen B, 1974). The superior half of one sclerotome unites with the lower half of its neighbor and, thus, forms the earliest manifestation of the vertebral body. The first four sclerotomes, however, will not follow this course, and essentially fuse to form the occipital bone and posterior portions of the foramen magnum. Simultaneously, vascularization of the occipital bone begins and differentiation of ganglia and vascular tissue begins. The hypoglossal and first cervical arteries demarcate the caudal occipital segment (Gladstone J, et al 1915).

The occipital sclerotomes correspond to the segmental nerves that group together to form the hypoglossal nerve, with a path through the individual foramina within the bone (Sensing EC, 1957). The first two occipital sclerotomes ultimately form the basiocciput. The third sclerotome is responsible for the exoccipital bone, which forms the jugular tubercles. The hypocentrum of the fourth occipital sclerotome forms the anterior tubercle of the clivus. The centrum itself forms the apical cap of the dens and the apical ligament (Ganguly DN, et al, 1964, Menezes AH, 1995). The neural arch component of the proatlas divides into a rostral ventral segment and a caudal segment. The ventral portion forms the anterior margin of the foramen magnum as well as the occipital condyle and the midline third occipital condyle.(Gladstone RJ, 1915)

The first spinal sclerotome forms the atlas vertebra. It is modified from the remaining spinal vertebrae, wherein the centrum is separated to fuse with the axis body and, thus, forms the odontoid process. The neural arch of this first spinal sclerotome proceeds to form the posterior and inferior portion of the C1 arch (Menezes AH, 1998). At times, the hypochordal bow, instead of disappearing, may survive and join with the anterior arch of the atlas to form a variant with an abnormal articulation, which then exists between the inferior clivus, the anterior arch of the atlas, and the apical segment of the odontoid process (Menezes AH, 1995). In our hands, recent computed tomographic (CT) evaluation of the atlas has shown that several ossification centers are present in the atlas development (MenezesAH, 1995). However, the lateral atlantal masses must be present at birth. A complete ring must form by 3 years of age. Abnormal development is observed with the skeletal dysplasias, such as spondyloepiphyseal dysplasia; achondroplasia; Goldenhar's syndrome; and in genetic abnormalities, such as Down's syndrome. (Arnold H, et al, 2008)

Posterior fossa expansion occurs because of enchondral resorption, sutural growth, and bony accretion. Growth of the basal aspect of the clivus elongates the basiocciput and lowers the frontal margin of the foramen magnum. Synchondrosial growth occurs until 16 to 18 years of age. The bony abnormality in hindbrain herniation syndrome has significance here. Lack of posterior fossa volume results in herniation of the cerebellar tonsils through the foramen magnum, resulting in tonsillar ectopia (Menezes AH, 2003). Significant muscle development takes place dorsal and lateral to the cervical spine to provide for the top-heavy cranial end of the fetus (Menezes AH, 1998). The stability of the craniovertebral articulation, with its forward inclination, is dependent on maintaining the geometry of the articular surfaces of the craniovertebral junction and the ligamentous attachments and, more importantly, the heavy musculature. (Arnold H, et al, 2008).

2.3 Anatomy and physiology of base of skull

The cranial base is a complex structure with several different significant bony landmarks that forensic anthropologists utilize on a regular basis. (Nevell L et al 2008).

2.3.1 Occipital bone

This bone forms the back of the head and part of the base of the skull. It has immovable joints with the parietal, temporal and sphenoid bones. Its inner surface is deeply concave and the concavity is occupied by the occipital lobes of the cerebrum and by the cerebellum. (Figure 2.2)The occiput has two articular condyles that form hinge joints with the first bone of the vertebral column, the atlas. Between the condyles there is the foramen magnum. (Anne Waugh, et al 2004)**.**

The occipital bone is composed of the curved, expanded plate behind the foramen magnum is named the squama; the thick, somewhat quadrilateral piece in front of the foramen is called the basilar part, whilst on either side of the foramen is the lateral portion**.** (Gray, H, 2005, Berkovitz B, et al 1994).

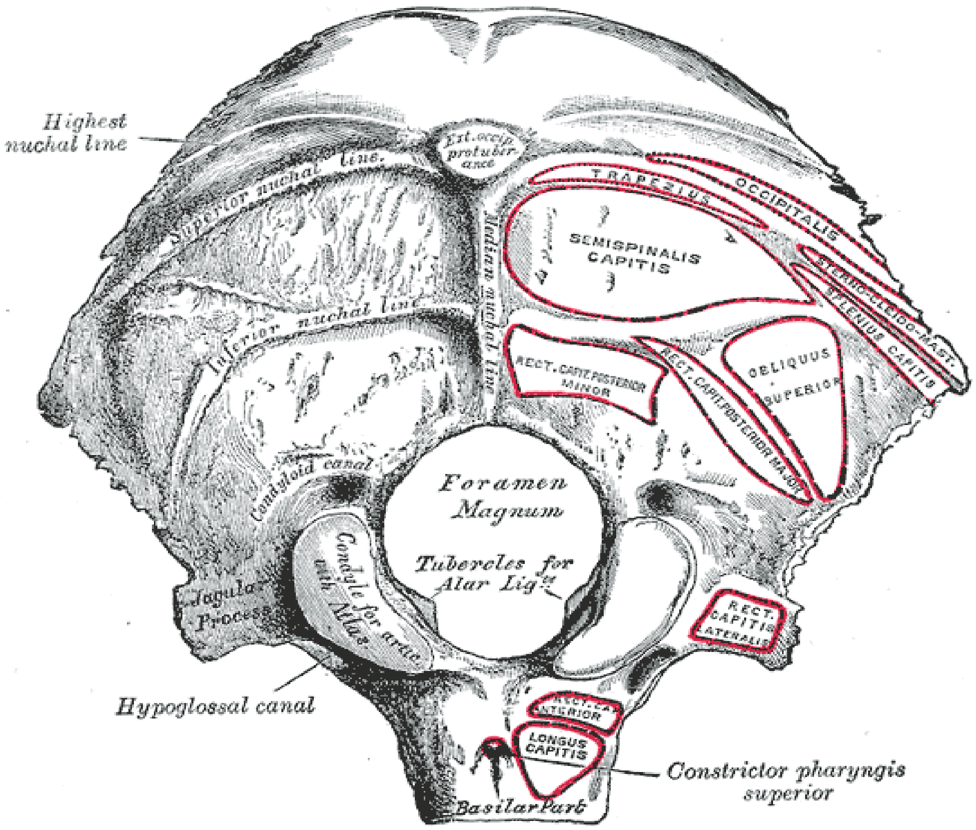


Figure 2.2: Occipital bone. Outer surface (Gray, H, 1918; Bartleby.com, 2000).

2.3.1.1 The Squama (squama occipitalis)

The squama, situated above and behind the FM, is curved from above downward and from side to side. (Berry, AC, 1975)

Surfaces, the external surface is convex and presents midway between the summit of the bone and the foramen magnum a prominence, the external occipital protuberance. Extending lateralward from this on either side are two curved lines, one a little above the other. The upper, often faintly marked, is named the highest nuchal line, and to it the galea aponeurotica is attached. The lower is termed the superior nuchal line. That part of the squama which lies above the highest nuchal lines is named the planum occipitale, and is covered by the Occipitalis muscle; that below, termed the planum nuchale is rough and irregular for the attachment of several muscles. From the external occipital protuberance a ridge or crest, the median nuchal line, often faintly marked, descends to the foramen magnum, and affords attachment to the ligamentum nuchæ; running from the middle of this line across either half of the nuchal plane is the inferior nuchal line. Several muscles are attached to the outer surface of the squama, thus: the superior nuchal line gives origin to the Occipitalis and Trapezius, and insertion to the Sternocleidomastoideus and Splenius capitis: into the surface between the superior and inferior nuchal lines the Semispinalis capitis and the Obliquus capitis superior are inserted, while the inferior nuchal line and the area below it receive the insertions of the Recti capitis posteriores major and minor. The posterior atlantoöccipital membrane is attached around the postero-lateral part of the foramen magnum, just outside the margin of the foramen. (Berry, AC, 1967)

The internal surface is deeply concave and divided into four fossæ by a cruciate eminence**.** The upper two fossæ are triangular and lodge the occipital lobes of the cerebrum; the lower two are quadrilateral and accommodate the hemispheres of the cerebellum. At the point of intersection of the four divisions of the cruciate eminence is the internal occipital protuberance. From this protuberance the upper division of the cruciate eminence runs to the superior angle of the bone, and on one side of it (generally the right) is a deep groove, the sagittal sulcus**,** which lodges the hinder part of the superior sagittal sinus; to the margins of this sulcus the falx cerebri is attached. The lower division of the cruciate eminence is prominent, and is named the internal occipital crest**;** it bifurcates near the foramen magnum and gives attachment to the falx cerebelli; in the attached margin of this falx is the occipital sinus, which is sometimes duplicated. In the upper part of the internal occipital crest, a small depression is sometimes distinguishable; it is termed the vermian fossa since it is occupied by part of the vermis of the cerebellum. Transverse grooves, one on either side, extend from the internal occipital protuberance to the lateral angles of the bone; those grooves accommodate the transverse sinuses, and their prominent margins give attachment to the tentorium cerebelli. The groove on the right side is usually larger than that on the left, and is continuous with that for the superior sagittal sinus. Exceptions to this condition are, however, not infrequent; the left may be larger than the right or the two may be almost equal in size. The angle of union of the superior sagittal and transverse sinuses is named the confluence of the sinuses, and its position is indicated by a depression situated on one or other side of the protuberance. (Bruce V, et al 1993)

2.3.1.2 Lateral Parts (pars lateralis)

The lateral parts are situated at the sides of the foramen magnum; on their under surfaces are the condyles for articulation with the superior facets of the atlas. The condyles are oval or reniform in shape, and their anterior extremities, directed forward and medialward, are closer together than their posterior, and encroach on the basilar portion of the bone; the posterior extremities extend back to the level of the middle of the foramen magnum. The articular surfaces of the condyles are convex from before backward and from side to side, and look downward and lateralward. To their margins are attached the capsules of the atlantoöccipital articulations, and on the medial side of each is a rough impression or tubercle for the alar ligament. At the base of either condyle the bone is tunnelled by a short canal, the hypoglossal canal (anterior condyloid foramen). This begins on the cranial surface of the bone immediately above the foramen magnum, and is directed lateralward and forward above the condyle. It may be partially or completely divided into two by a spicule of bone; it gives exit to the hypoglossal or twelfth cerebral nerve, and entrance to a meningeal branch of the ascending pharyngeal artery. Behind either condyle is a depression, the condyloid fossa, which receives the posterior margin of the superior facet of the atlas when the head is bent backward; the floor of this fossa is sometimes perforated by the condyloid canal, through which an emissary vein passes from the transverse sinus. Extending lateralward from the posterior half of the condyle is a quadrilateral plate of bone, the jugular process, excavated in front by the jugular notch, which, in the articulated skull, forms the posterior part of the jugular foramen. The jugular notch may be divided into two by a bony spicule, the intrajugular process, which projects lateralward above the hypoglossal canal. The under surface of the jugular process is rough, and gives attachment to the Rectus capitis lateralis muscle and the lateral atlantoöccipital ligament; from this surface an eminence, the paramastoid process, sometimes projects downward, and may be of sufficient length to reach, and articulate with, the transverse process of the atlas. Laterally the jugular process presents a rough quadrilateral or triangular area which is joined to the jugular surface of the temporal bone by a plate of cartilage; after the age of twenty-five this plate tends to ossify. (Gill GW, et al 2004)

The upper surface of the lateral part presents an oval eminence, the jugular tubercle, which overlies the hypoglossal canal and is sometimes crossed by an oblique groove for the glossopharyngeal, vagus, and accessory nerves. On the upper surface of the jugular process is a deep groove which curves medialward and forward and is continuous with the jugular notch. This groove lodges the terminal part of the transverse sinus, and opening into it, close to its medial margin, is the orifice of the condyloid canal. (Ilizarov GA, et al 1992, Gray, H, 1918; Bartleby.com, 2000).

The occipital condyles are convex projections located at the anterior-lateral margins of the foramen magnum (Figure 2.3) (Moore, et al, 2006). They articulate

With the superior facets of the atlas to form the atlanto-occipital joints (Menezes, et al, 1989; Moore, et al, 2006). They are condyloid synovial joints with weak capsules that provide little stabilization. These joints are reinforced by anterior and posterior atlanto-occipital membranes, which extend from the anterior and posterior arches of the atlas to the basion and opisthion, respectively (Moore, et al, 2006).

Figure 2.3: Occipital condyles. (Gray, H, 1918; Bartleby.com, 2000).

Within the occipito–atlanto–axial complex, the ovoid occipital condyles fit into the obliquely-oriented, elliptically cupped superior facets of the atlas.

This unique geometry primarily allows flexion-extension some lateral bending, but precludes meaningful rotation. The average range of motion at the atlantooccipital joints is 13–15 (Menezes et al, 1989; Menezes et al., 2001; Moore et al, 2006). In adults, the angle of the axis of the atlanto-occipital joints, the Schmidt–Fisher angle (Fig. 2.4), is normally 124°–127°. In children, the occipital condyles are smaller, and the Schmidt–Fisher angle is more obtuse, making the atlanto-occiptal joints of youth inherently stable than those of adults (Menezes et al, 1989; Piper et al, 1998).

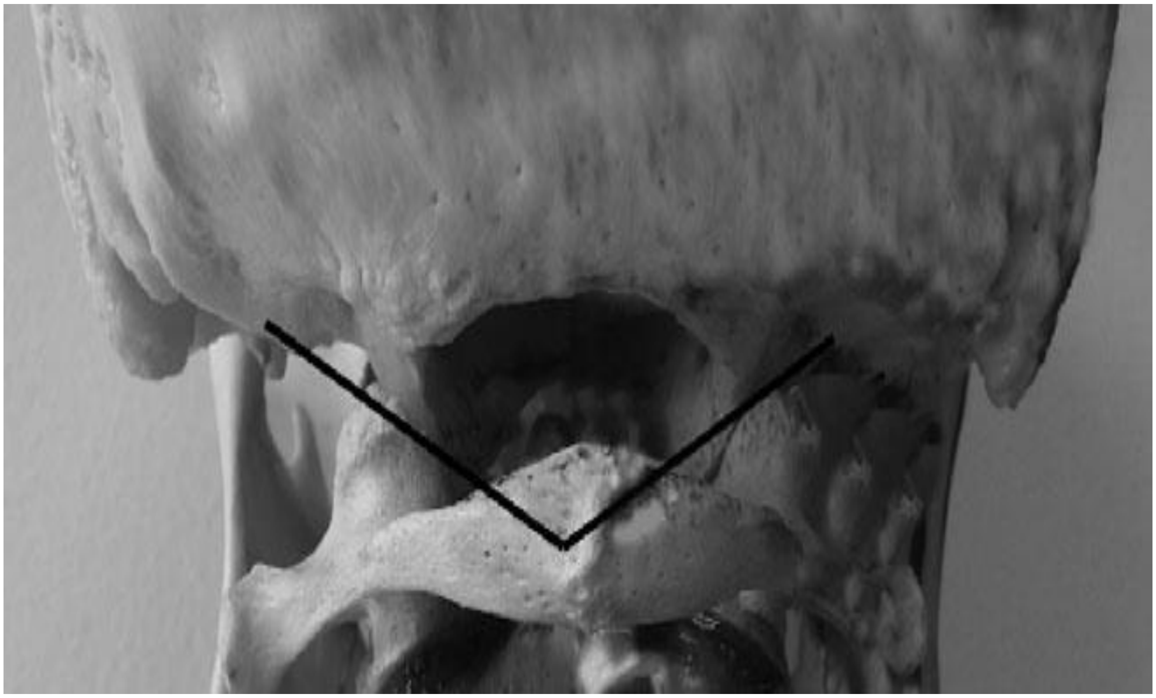


Fig. 2.4 Posterior view of the craniocervical junction of an adult skeleton illustrating the Schmidt–Fisher angle, which is normally 124°–127°. (Menezes et al, 1989)

2.3.1.3 Basilar Part (pars basilaris).

The basilar part extends forward and upward from the foramen magnum, and presents in front an area more or less quadrilateral in outline. In the

young skull this area is rough and uneven, and is joined to the body of the sphenoid by a plate of cartilage. By the twenty-fifth year this cartilaginous plate is ossified, and the occipital and sphenoid form a continuous bone.
(Lahr MM 1996).

Surfaces - On its lower surface, about 1cm. in front of the foramen magnum is the pharyngeal tubercle which gives attachment to the fibrous raphé of the pharynx. On either side of the middle line the Longus capitis and Rectus capitis anterior are inserted, and immediately in front of the foramen magnum the anterior atlantoöccipital membrane is attached. (Lele S, et al 1991).

The upper surface presents a broad, shallow groove which inclines upward and forward from the foramen magnum; it supports the medulla oblongata, and near the margin of the foramen magnum gives attachment to the membrana tectoria. On the lateral margins of this surface are faint grooves for the inferior petrosal sinuses. (Lieberman DE, et al 1999).

2.3.1.3 Foramen Magnum.

In anatomy, the foramen magnum (Latin: “great hole”) is a large opening in the occipital bone of the cranium. The foramen magnum is a large oval aperture with its long diameter antero-posterior; it is wider behind than in front where it is encroached upon by the condyles. (Figure 2.5) .It transmits the medulla oblongata and its membranes, the accessory nerves, the vertebral arteries, the anterior and posterior spinal arteries, and the membrana tectoria and alar ligaments. (Lieberman DE, et al 1999).

In humans, the foramen magnum is farther underneath the head than in great apes. Thus in humans, the neck muscles do not need to be as robust in order to hold the head upright. Comparisons of the position of the foramen magnum in early hominid species are useful to determine how comfortable particular species was when walking on two limbs (bipedality) rather than four. The location of the foramen magnum plays a crucial role in our understanding of human evolution. Usually, the location of the foramen magnum is linked to bipedal behavior. Due to the thickness of the cranial base and its relatively protected anatomical position, this area of skull tends to withstand both physical insults and inhu- mation somewhat more successfully than many other areas of the cranium. (Jain D, et al 2014).

The foramen magnum (FM) is an important landmark of the base of skull and is of particular interest to many fields of medicine. (Gruber P, et al 2009). Variations of the shape of FM have got diagnostic, clinical and radiological importance.(Murshed K.A.,et al,2003). Also there exists some correlation between the shape of FM and ancestry of an individual. The dimensions of FM have clinical importance because the vital structures that pass through it may suffer compression as in cases of FM achondroplasia. (Hecht JT et al 1989, Reich JB et al 1993).

Foramen magnum is about 3cm wide by 3.5cm anteroposteriorly.(Premalatha Gogi et al 2014, Romanes GJ et al 1981). It is located midway between and on a level with mastoid processes. The foramen magnum is surrounded by different parts of the occipital bone, squamous part lies behind and above, basilar part in front and a condylar part on either side (Oliveira Ed, et al 1985, Rhoton AL.2000). On each side its antero-lateral margin is encroached by occipital condyles, hence the foramen magnum is narrow anteriorly. The anterior edge of the foramen magnum is slightly thickened and lies between the anterior ends of the condyles. The posterior half of the foramen magnum is thin and semicircular. Upper ends of anterior and posterior atlanto-occipital membranes are attached to the anterior and posterior margins of the foramen magnum respectively, and their lower ends are attached to the superior surface of anterior and posterior arches of the atlas respectively. (Romanes GJ et al 1981) The foramen magnum is a wide communication between posterior cranial fossa and the vertebral canal. The narrow anterior part of the foramen magnum has apical ligament of dens, upper fasciculus of the cruciate ligament and membrana tectoria; both are attached to the upper surface of basioccipital bone infront of the foramen magnum. Its wide posterior part contains the medulla oblongata and its meninges. In subarachnoid space spinal rami of the accessory nerve and vertebral arteries, with their sympathetic plexus, ascend into the cranium; the posterior spinal arteries descend posterolateral to the brain stem, where as anterior spinal artery descends anteromedian to brain stem. The cerebellar tonsils may project into the foramen magnum. (Bannister, et al1995).

Relations of foramen magnum, anteriorly - basilar part of occipital bone,
Anterolaterally - occipital condyles, hypoglossal canal, jugular foramen
Posteriorly - squamous part of occipital bone with the internal occipital crest. (Drake. 2010).

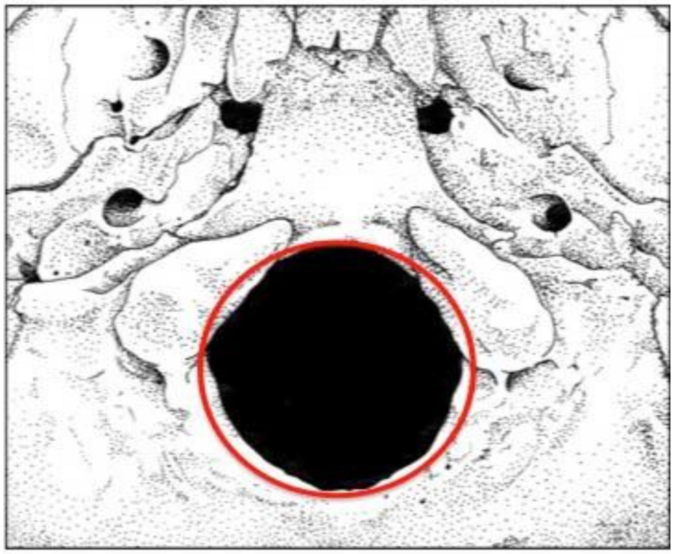


Figure 2.5. Inferior view of the cranial base with a circle around the foramen magnum. (Stephanie 2010)

2.3.2 The viatal structures pass through the foramen magnum:

2.3.2.1 The medulla oblongata (or simply medulla)

Is the most caudal part of the brainstem and sits between the pons inferiorly and spinal cord superiorly. It is the transition from the spinal cord to the brain. The medulla contains the vital autonomic cardiovascular and respiratory centers controlling heart rate, blood pressure, and breathing. It is composed of grey matter, cranial nerve (CN) nuclei IX-to-XII, and white matter tracts (DSc SSP.2011, Grossman RI, et al 2003).

The medulla is approximately 3cm in length and 2cm in greatest diameter (DSc SSP.2011). The caudal border of the medulla is the 1st cervical spinal nerves. The superior broad part of the medulla joins the pons. (DSc SSP.2011, Grossman RI, et al 2003). Medulla is separated into two main parts: ventral (anterior) medulla which contains the olive, pyramidal tracts, and CN 9-12 rootlets, and tegmentum (dorsal) medulla which contain the CN nuclei and white matter tracts.

Ventral medulla: Pyramids are paired structures located at the medial aspect of ventral medulla and flank the anterior median fissure. It contains the the corticospinal tracts. At the caudal end of pyramids the corticospinal tracts decussate (DSc SSP.2011, Grossman RI, et al 2003).

Olivary bodies are paired structures located at lateral aspect of ventral medulla, lateral to the pyramids. They are separated from the pyramids by an anterolateral sulcus (pre-olivary sulcus). There is also a post-olivary sulcus lateral to the olivary bodies. Olivary bodies contain the superior and larger inferior olivary nuclei (DSc SSP.2011).

Medulla tegmentum**:** The dorsal aspect of the medulla contains the posterior median sulcus (most dorsal medial sulcus) and more lateral posterolateral sulcus. Between these sulci are the fasciculus gracilis and nuclei forming gracilis tubercle at the midline and fasciculus cuneatus and nuclei forming cuneate tubercle more laterally (DSc SSP.2011, Grossman RI, et al 2003).

The superior dorsal aspect of medulla forms the floor of the inferior 4th ventricle. It is occupied by the inferior cerebellar peduncle situated between the lower parts of the fourth ventricle. The inferior dorsal and lateral aspect of the medulla is surrounded by the cisterna magna (posterior cerebellomedullary cistern), and lateral cerebellomedullary cistern (DSc SSP.2011, Grossman RI, et al 2003).

The median aperture (foramen of Magendie) and the more superior lateral apertures (foramina of Luschka) open at the level of the pons, with the canals projecting to the level of the medulla region and terminating into the cisterna magna and lateral cerebellomedullary cistern respectively(Rogers L.2008) .

2.3.2.2 The meninges

Is a collective term for the three membranes that cover the brain and spinal cord, cerebral meninges surround the brain and is made up of three layers (from outermost to innermost): dura mater, arachnoid mater and pia mater.

The dura mater can also be known as pachymeninx. The arachnoid mater and pia mater are collectively known as the leptomeninges. (Strominger NL et al 2012).

The spinal meninges are similar but have some important differences.

The meninges function to protect the brain but also provides a framework for blood vessels, nerves, lymphatics and CSF (Ovalle WK,.et al 2013).

2.3.2.3 The spinal accessory nerve

Also called accessory nerve, is the eleventh cranial nerve (CN XI) and is composed of two parts, the cranial part and the spinal part. The cranial part (accessory portion) is the smaller of the two. Its fibers arise from the cells of the nucleus ambiguus and emerge as four or five delicate rootlets from the side of the medulla oblongata, below the roots of the vagus. It runs laterally to the jugular foramen, where it interchanges fibers with the spinal portion or becomes united to it for a short distance. (Wilson et al 2002)

The spinal part (spinal portion) is firm in texture, and its fibers arise from the ventral horn cells in the cord between C1 and C5 of the cervical plexus. The fibres emerge from the cord laterally between the anterior and posterior spinal nerve roots to form a single trunk, which ascends into the skull through the foramen magnum. (Waxman S, et al 2003).

2.3.2.4 The vertebral arteries (VA)

The vertebral artery (VA) arises from the subclavian artery, ascends in the neck to supply the posterior fossa and occipital lobes as well as provides segmental vertebral and spinal column blood supply. (Cloud GC, et al 2003)

The origin of the VA is usually from the posterior superior part of the subclavian arteries bilaterally, although the origin can be variable:

- Brachiocephalic artery (on the right)
- Aortic arch: 6% of cases

The VA is normally 3-5 mm in diameter and the ostium is the most common site of stenosis.

When the origin is from the arch, then it is common for the artery to enter the foramen transversarium at a level higher than normal (C5 instead of C6). (Satti SR, et al 2007).

The duramater around the FM is supplied by the anterior and posterior meningeal branches of the vertebral artery, and the meningeal branches of the ascending pharyngeal and occipital arteries.

2.3.2.5 The venous structures

The venous structures in the region of the FM are divided into three groups:

-Extraduralveins (extraspinal& intraspinalpart)

-Intradural (neural) veins

-Dural venous sinuses (superior petrosal, marginal & occipital).

The three groups anastomose through bridging and emissary veins.

2.3.3 First Cervical Vertebra

The first cervical vertebra (Figure 2.6) is named the atlas because it supports the globe of the head. Its chief peculiarity is that it has no body, and this is due to the fact that the body of the atlas has fused with that of the next vertebra. Its other peculiarities are that it has no spinous process, is ring-like, and consists of an anterior and a posterior arch and two lateral masses. The anterior arch forms about one-fifth of the ring: its anterior surface is convex, and presents at its center the anterior tubercle for the attachment of the Longus colli muscles; posteriorly it is concave, and marked by a smooth, oval or circular facet (fovea dentis), for articulation with the odontoid process (dens) of the axis. The upper and lower borders respectively give attachment to the anterior atlantooccipital membrane and the anterior atlantoaxial ligament; the former connects it with the occipital bone above, and the latter with the axis below. The posterior arch forms about two-fifths of the circumference of the ring: it ends behind in the posterior tubercle, which is the rudiment of a spinous process and gives origin to the

Recti capitis posteriores minores. The diminutive size of this process prevents any interference with the movements between the atlas and the skull. The posterior part of the arch presents above and behind a rounded edge for the attachment of the posterior atlantoöccipital membrane, while immediately behind each superior articular process is a groove (sulcus arteriæ vertebralis), sometimes converted into a foramen by a delicate bony spiculum which arches backward from the posterior end of the superior articular process. This groove represents the superior vertebral notch, and serves for the transmission of the vertebral artery, which, after ascending through the foramen in the transverse process, winds around the lateral mass in a direction backward and medialward; it also transmits the suboccipital (first spinal) nerve. On the under surface of the posterior arch, behind the articular facets, are two shallow grooves, the inferior vertebral notches.The lower border gives attachment to the posterior atlantoaxial ligament, which connects it with the axis. The lateral masses are the most bulky and solid parts of the atlas, in order to support the weight of the head. Each carries two articular facets, a superior and an inferior. The superior facets are of large size, oval, concave, and approach each other in front, but diverge behind: they are directed upward, medialward, and a little backward, each forming a cup for the corresponding condyle of the occipital bone, and are admirably adapted to the nodding movements of the head. Not infrequently they are partially subdivided by indentations which encroach upon their margins. The inferior articular facets are circular in form, flattened or slightly convex and directed downward and medialward, articulating with the axis, and permitting the rotatory movements of the head. Just below the medial margin of each superior facet is a small tubercle, for the attachment of the transverse atlantal ligament which stretches across the ring of the atlas and divides the vertebral foramen into two unequal parts—the anterior or smaller receiving the odontoid process of the axis, the posterior transmitting the medulla spinalis and its membranes. This part of the vertebral canal is of considerable size, much greater than is required for the accommodation of the medulla spinalis, and hence lateral displacement of the atlas may occur without compression of this structure. The transverse processes are large; they project lateralward and downward from the lateral masses, and serve for the attachment of muscles which assist in rotating the head. They are long, and their anterior and posterior tubercles are fused into one mass; the foramen transversarium is directed from below, upward and backward. (Gray, H, 1918; Bartleby.com, 2000).

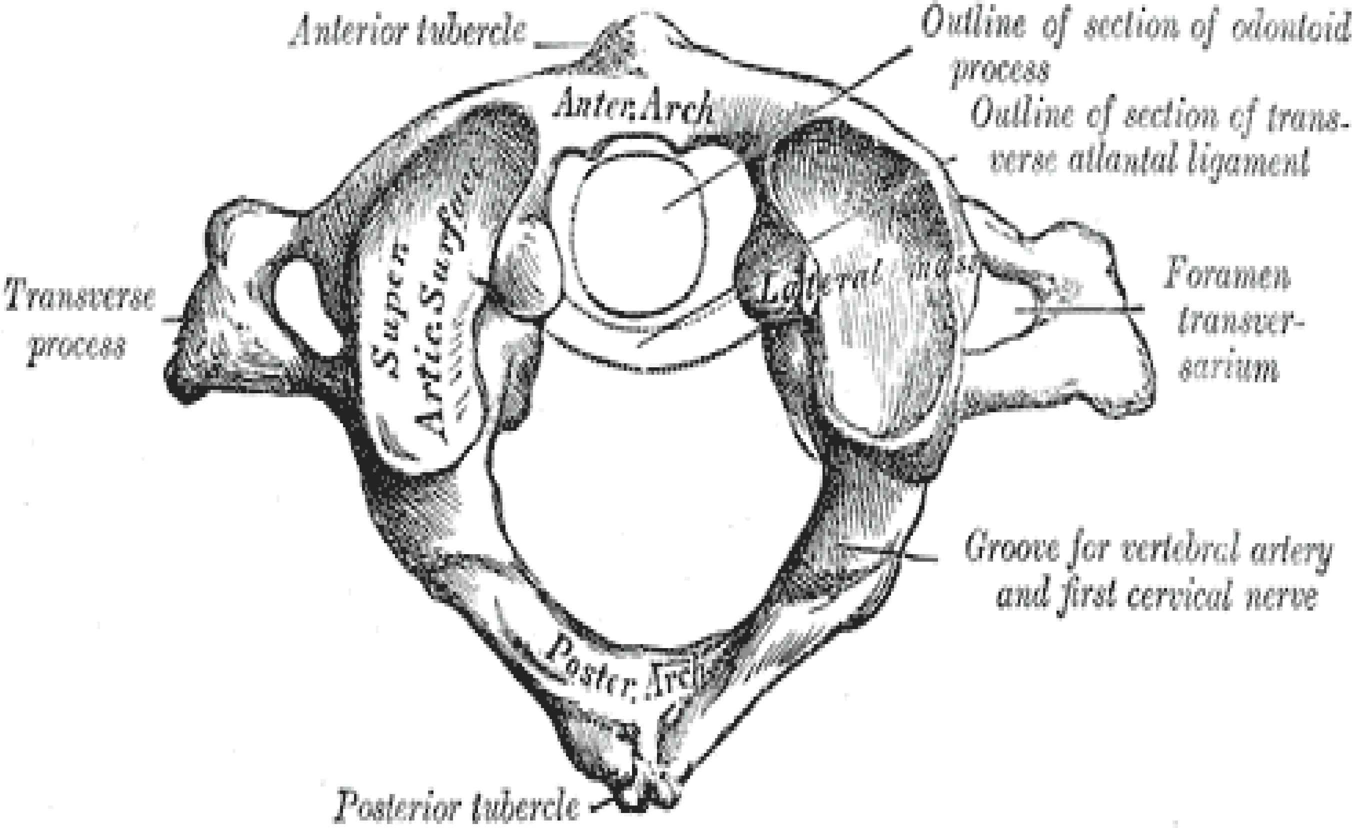


Figure 2.6. First cervical vertebra, or atlas, (Gray, H, 1918; Bartleby.com, 2000).

2.3.3.1 Stabilizing Cranio cervical junction

Principal stabilizing ligaments of C1 -

-Transverse atlantalligament

-Alarligaments

Secondary stabilizing ligaments of CVJ are more elastic & weaker than the primary ligaments.

-Apical ligament

-Anterior & posterior membranes

-Tectorialmembrane

-Ligamentumflavum

-Capsular ligaments

2.4 Pathology of posterior cranial fossa

Congenital and developmental osseous anomalies and abnormalities that affect the craniovertebral complex can result in neural compression, vascular compromise, and can manifest with abnormal cerebrospinal fluid dynamics**.**

2.4.1 Achondroplasia

Achondroplasia is a congenital genetic disorder and the most common skeletal dysplasia. It has numerous distinctive radiographic features and is the most common cause of short limb dwarfism. (Kao SC, et al 1989).

It occurs due to sporadic mutations in the majority of cases but can be inherited as an autosomal dominant condition. Homozygous achondroplasia is lethal. There is a prevalence of approximately 1 in 25,000-50,000 births with males affected more frequently than females.(Wynn J, et al 2007)

Achondroplasia is the most common cause of short limb dwarfism. Patients are of normal intelligence with normal motor function. However, they may have specific neurologic deficits.

The disease results from a mutation in the fibroblast growth factor gene 3 (FGFR3) located on chromosome 4p16.3 which causes abnormal cartilage formation. All bones that form by enchondral ossification are affected. Bones that form by membranous ossification are not affected, thus allowing the skull vault to develop normally. (Cheema JI, et al 2003)

2.4.1.1 Radiographic features

Almost all the bones of the skeleton are affected, and hence all parts of the body have bony changes with secondary soft tissue changes. Antenatally it is difficult to diagnose achondroplastic features until the 3rd trimester (Schramm T, et al 2009).

Antenatal ultrasound :Antenatally detectable sonographic features include: short femur length measurement: often well below the 5th centile the femur length (FL) to biparietal diameter (BPD) is taken as a useful measurement trident hand 11: 2,3 and 4 fingers appearing separated and similar in length separation of 1st and 2nd, 3rd and 4th fingers protruding forehead: frontal bossing (Bowerman RA. 1995).

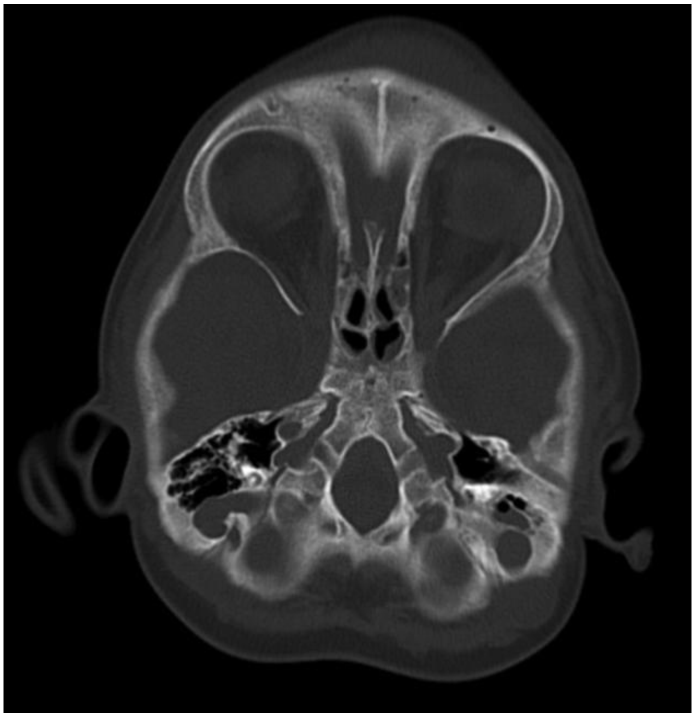
2.4.1.2 Cranial

- Relatively large cranial vault with small skull base
- Prominent forehead with depressed nasal bridge
- Narrowed foramen magnum, a small FM with hypertrophicbone & a posterior duralshelf results in compression of neural structures. (Figure 2.7 & 2.8)
- Cervico medullary kink relative elevation of the brainstem resulting in a large suprasellar cistern and vertically-oriented straight sinus.

2.4.1.3 Treatment and prognosis

There is often a danger of cervical cord compression from due to narrowing of the foramen magnum. The mortality is high in the 1st year of life due to cervicomedullarydysfunction at the FM. (SHAILESH, 2003)

Treatment varies and is usually orthopaedic, particularly to correct kyphoscolioses as well as neurosurgical to decompress the foramen magnum or shunt hydrocephalus. Overall prognosis is good, with near normal life expectancy in heterozygous individuals. When homozygous, the condition is usually fatal due to respiratory compromise (Moreland LW, 2004).



Figur 2.7: axial CT show narrowed foramen magnum due to Achondroplasia. Available at http://images.radiopaedia.org/images/23718

Figure 2.8:3D VRT axial CT show narrowed foramen magnum due to Achondroplasia. Available at http://images.radiopaedia.org/images/23719

2.4.2 Foramen Magnum Meningiomas

Meningiomas are slow-growing benign tumors that arise at any location where arachnoid cells reside. Although meningiomas account for a sizable proportion of all primary intracranial neoplasms (14.3-19%), (Wara WM, et al 1975). Only 1.8 to 3.2% arises at the foramen magnum. (Arnautovic KI, et al 2000). Their indolent development at the craniospinal junction makes clinical diagnosis complex and often leads to a long interval between onset of symptoms and diagnosis. The sensitivity of this region to surgical manipulation has sparked recent debate as to the most advantageous surgical approach. (Melfort R.et al, 2003).

Meningiomas are considered to be located in the FM area if their base of insertion is mainly located within the FM limits. This definition excludes tumors invading secondarily the FM region (Figure).

The definitive objective of a classification system is to define preoperatively the surgical strategy based on preoperative imaging characteristics of the lesion. The surgical strategy in cases of FMMs is the surgical approach but also the anticipation of modified vital structure position. (Michaël, et al, 2008)

2.4.2 .1 Classification of Foramen Magnum Meningiomas

FMMs can be classified according to their compartment of development, their dural insertion, and to their relation to the (VA George B, et al 1997).

According to the compartment of development, FMMs can be subdivided in: (Figure 2.9): Intradural, Extradural and Intra- and extradural.

Intradural meningiomas are the most commonly observed. Extradural meningiomas like at any other locations are very invasive, into the bone, the nerves and vessels sheaths, and soft tissues. The VA sheath and even its adventitia can also be infiltrated. This raises some difficulties and explains the higher incidence of incomplete removal as compared to intradural meningiomas (Levy C, et al 1988, Miller E, et al 1987).

According to the insertion on the dura, FMMs can be defined in the antero-posterior plane as: Anterior, if insertion is on both sides of the anterior midline, Lateral, if insertion is between the midline and the dentate ligament and Posterior, if insertion is posterior to the dentate ligament

Anterior meningiomas push the spinal cord posteriorly. Therefore, the surgical opening between the neuraxis and the FM lateral wall is narrow, and the drilling must extend to the medial part of the FM lateral wall to improve the access. In almost every case, no drilling of the lateral mass of the atlas and occipital condyle is necessary. Exceptionally, anterior meningiomas of small size without anterior compartment enlargement need more bone resection but never includes more than one fifth of these elements. On the other hand, lateral meningiomas displace the neuraxis posterolaterally and widely open the surgical access; therefore, the drilling has never to be extended into the lateral mass of the atlas or the occipital condyle. (Michaël, et al, 2008)

Finally, surgical strategies vary according to the relation to the VA, FMM having the possibility to develop: Above the VA, Below the VA and on both sides of the VA

Meningiomas are more often located below the VA. In this case, the lower cranial nerves are always pushed cranially and posteriorly. There is no need to look for them. They will come into view on reaching the superior tumoral part. On the other hand, if the lesion grows above the VA, the position of the lower cranial nerves cannot be anticipated; the nerves may be displaced separately in any direction. After partial debulking of the tumor, one has to look for them so as to identify and protect them during the tumor resection. In case of tumoral development on both sides of the VA, a similar problem may exist with the position of the lower cranial nerves. Moreover, the dura around the VA penetration may be infiltrated by the tumor. As previously mentioned, the dura is normally adherent to the adventitia, and complete resection of the tumor at this level is hazardous. In this case, which is rarely observed, it may be safer to leave a cuff of infiltrated dura around the VA and to coagulate this zone. (Michaël, et al, 2008).

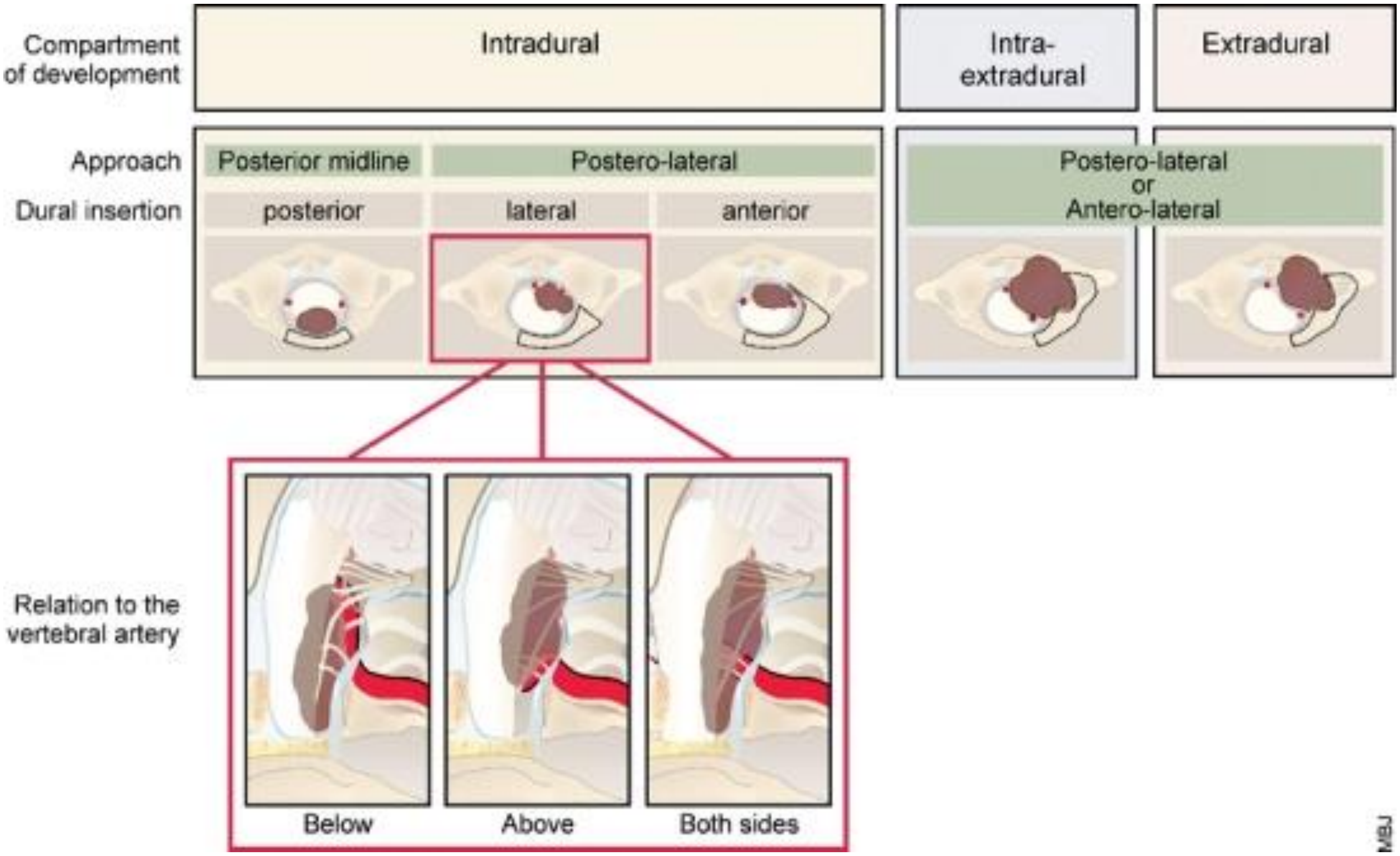


Figure 2.9: Classification of foramen magnum meningiomas. Foramen magnum meningiomas are classified according to their compartment of development, their dural insertion, and their relation to the vertebral artery. The relation to the vertebral artery permits to anticipate the displacement of the lower cranial nerves. (Michaël, et al, 2008).

2.4.2.2 Imaging Features

The role of neuroimaging is to confirm the clinical diagnosis and to allow the planning of a surgical approach. Magnetic resonance imaging is the modality of choice for defining tumors of the foramen magnum because it provides high-resolution images of soft-tissue anatomy that is not susceptible to degradation by surrounding skull base, (Sekhar, et al, 1994).

Although MR imaging provides clearly superior soft-tissue assessment, CT scanning with osseous algorithms remains the tool of choice for identifying calcification, hyperostosis, and osseous anatomy. Axial CT scanning allows planning of the extent of bone resection required to resect tumor safely because of the sharp contrast between bone and soft tissues. It is sometimes difficult to outline bone margins on MR images, and this technique may overestimate the size of the surgical corridor available for extirpation. It is clearly evident that optimal surgical planning requires both CT and MR imaging to assess appropriately bone and soft tissues, respectively. (Farb RI, et al, 2003)

An additional imaging modality that may assist surgery is conventional angiography with optional embolization of vessels that supply tumor exclusively. The dural blood supply typically arises as posterior and anterior meningeal branches from the VAs with the support of meningeal branches via ascending pharyngeal and occipital arteries. The tumor may derive its vascular supply from a dominant vessel, which when subjected to contrast injection, is visualized as a "blush". If vessel is accessible to endovascular catheterization, one might opt for preoperative embolization to diminish intraoperative bleeding during tumor debulking]. (Rosen CL, et al .2002).

2.4.2.3 Preoperative considerations

Standard preoperative workup includes magnetic resonance imaging (MRI), computed tomography (CT) scan, and sometimes angiography.

On MRI, gadolinium-enhanced sequences help to precisely delimit the dural attachment zone, the tumor, and its relation to neural and vascular structures. On T2-weighted images, the presence of an arachnoid plane between the tumor and the neuraxis is sometimes visible. (Figure 2.10)

Bone windows CT scan is helpful in case of extradural extension to investigate bone erosion and to schedule preoperatively the need for fusion.

Conventional angiography is generally useless. There are only two indications for preoperative angiography:

If a highly vascularized tumor is suspected and embolization is contemplated.

To perform a balloon occlusion test in case of VA encasement (extradural or recurrent meningioma and meningioma inserted around the VA). In our experience, it has never been necessary to occlude the VA. (Michaël, et al, 2008)

Intraoperative neurophysiological monitorings have been used by several surgeons .(Arnautovic KI, et al 2000, Boulton MR,et al 2003) and includes somatosensory-evoked potentials, brainstem auditory-evoked potentials, and electromyographic monitoring of lower cranial nerves, by recordings through an endotracheal tube (CN X) and with a needle in the sterno-mastoid (SM) muscle (CN XI) and the tongue (CN XII)

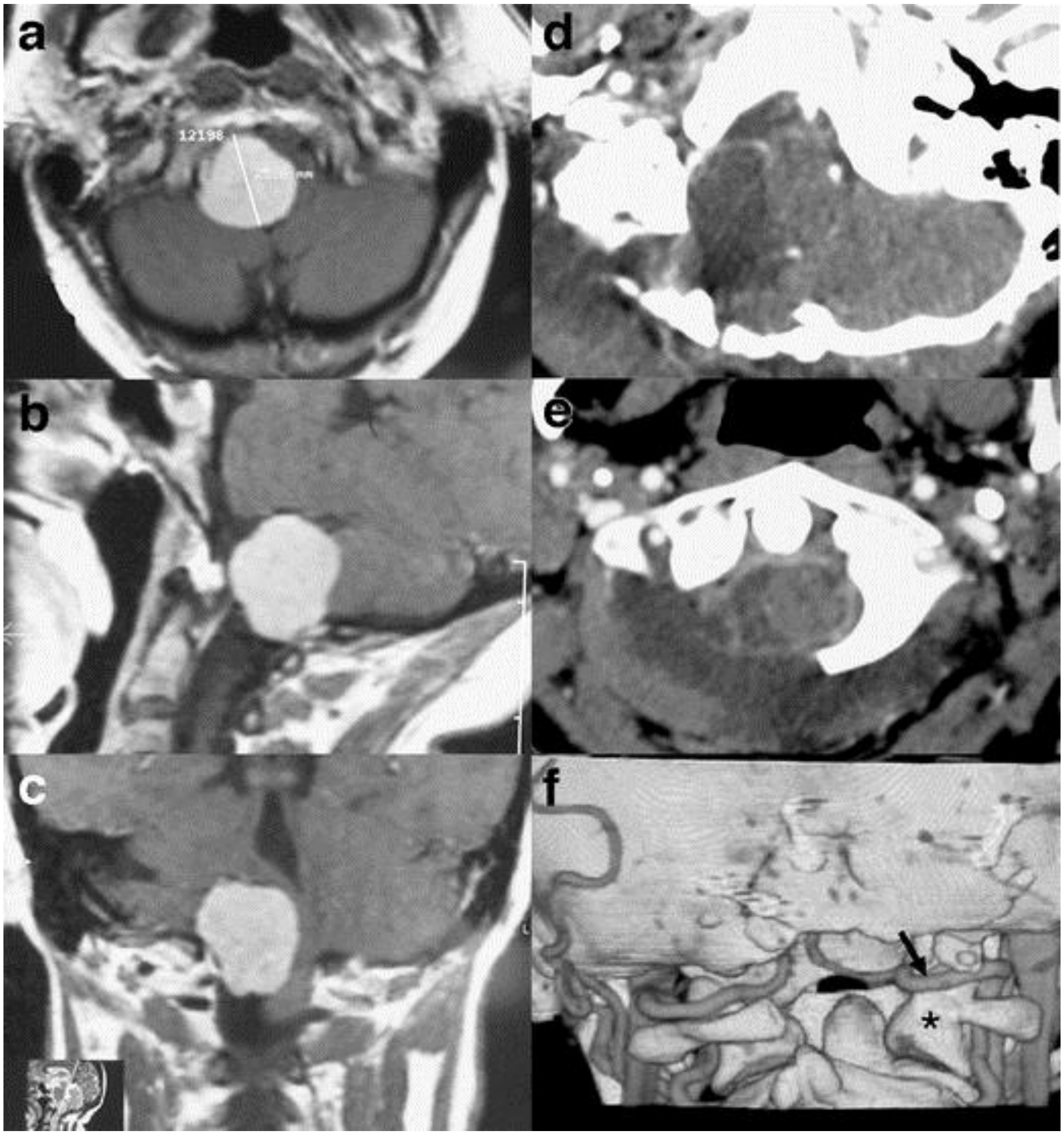
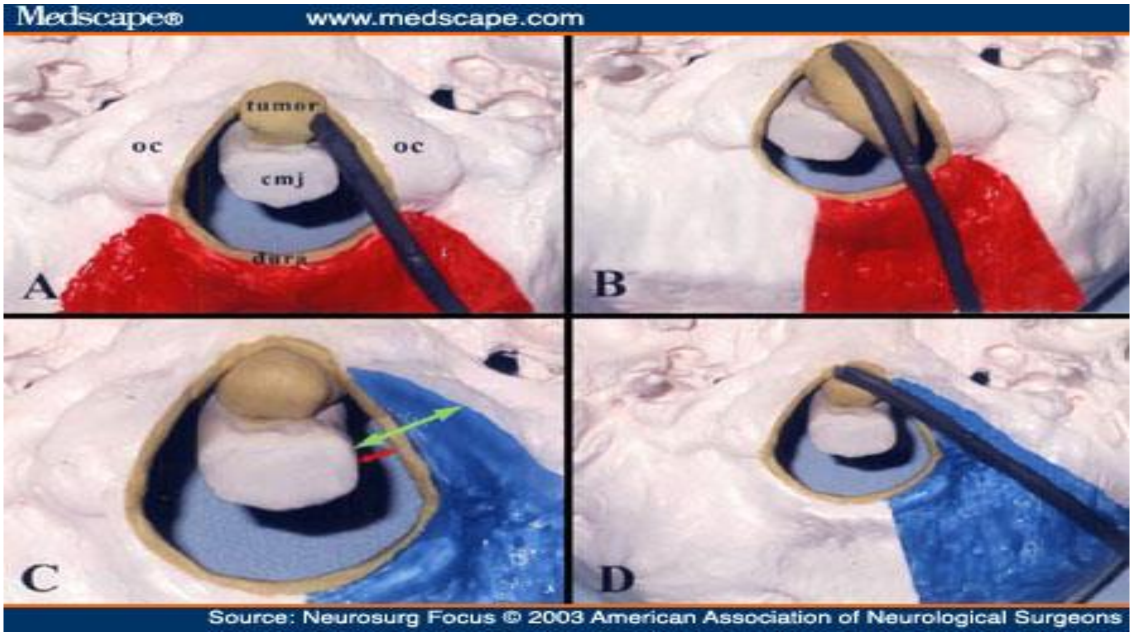


Figure 2.10**:** **a**–**c** Preoperative MRI. A large lateral foramen magnum meningioma displaces the neuraxis. **d**, **e** Postoperative CT scan. The meningioma has been completely resected. The spinal cord has regained a normal shape. **f** Reconstructed 3D CT scan after contrast administration. The resection of the posterior arch of the atlas is visible on the right side. The lateral mass of the atlas (star) was left intact. The vertebral artery (arrow) has been elevated from the C1 posterior arch (compare with the left side) during the dissection. (Michaël, et al, 2008)

2.4.2.3 Surgical Approaches to Foramen Magnum Meningiomas

The FM can be approached via anterior, lateral, and posterior approaches. Each approach serves an important function and each was developed to deal with specific problems. The anterior transoral approach to the foramen magnum is rarely conducted to reach intradural lesions such as meningiomas because of problems with dural repair, risk of CSF leakage, and meningitis. Debate about foramen magnum meningioma resection primarily involves the posterior suboccipital craniectomy and posterolateral approaches, which necessitate drilling of the occipital condyle. (Melfort R.et al, 2003). (Figur 2.11.)



Source: Neurosurg Focus © 2003 American Association of Neurological Surgeons

Figure 2.11. A: Suboccipital craniotomy (red) with a narrow corridor does not provide adequate exposure of the tumor for resection. B: Tumor growth naturally widens the surgical corridor, allowing its safe and effective removal via suboccipital craniotomy without drilling of the condyle. C: Transcondylar exposure (blue) widens the corridor by removing the medial condyle (red arrow represents very narrow corridor before excision of the condyle, green arrow represents adequate corridor after this resection). D: Access to much of the tumor has been created (Melfort R.et al, 2003)

2.4.2.3.1 Suboccipital Craniotomy

Suboccipital craniotomy, or craniectomy, with or without cervical laminectomy represents the classic approach to the foramen magnum meningiomas and is familiar to most neurosurgeons. For posteriorly situated lesions we place the patient prone. For lateral or anterolateral lesions, the patient is placed in the lateral decubitus position with the vertex of the head displaced slightly downward to open the space between occiput and the cervical spine. We also turn the head approximately 20 to 30° toward the floor, depending on the extent to which the tumor is laterally situated. The surgical corridor defined on preoperative imaging must be easily within reach of the surgeon. The corridor should not be hidden under a large bulk of paracervical muscles deflected laterally. Sufficient soft-tissue dissection to create access to the corridor is essential. Routine use of computerized neuronavigation helps to demonstrate subtle variations of anatomical distortions caused by these sessile meningiomas. (Stein et al 1963)

For midline posterior lesions, we make a midline incision. For posterolateral lesions that require exposure up to the condyle, we make a "hockey-stick" or inverted L shaped extension laterally at the superior end of our incision just beneath the superior nuchal line. Whichever the incision, cutting of the C-2 nerve branches and the 11th cranial nerve distally in the neck should be avoided.(Strang et al 2001)

The VA is easily identifiable as it curves above the arch of the atlas, in the depth of the suboccipital triangle, providing proximal vascular control if required. We use neuronavigation to help determine the extent of the craniotomy needed. Although some authors prefer to conduct a craniectomy, we prefer a craniotomy because the incidence of postoperative occipital pain, we believe, is limited by replacing a firm protective covering over the dura, even if it only covers a fraction of the exposed dura.(Schessel DA, et al 1993) . If the "surgical corridor" to the tumor cannot be safely accessed as determined by neuronavigation prior to dura opening, more bone can be removed laterally toward the condyle. The craniotomy almost always has to be combined with a laminectomy to the inferior aspect of the tumor. At C-1 the laminectomy should encompass at least the vertebral groove in the lateral aspect of the C-1 lamina. Care should be taken to not injure the thin-walled vertebral plexus of veins that surround the thick-walled VA. Of help in this procedure is bipolar coagulation with constant saline irrigation to avoid sticking of the tips of the instrument.

The advantage of suboccipital craniotomy includes visualization of the VA, brainstem, cranial nerves, and tumor in a safe, simple, and rapid manner. Criticisms of this approach primarily relate to the interposition of brainstem, cranial nerves, and vessels between an anterior tumor and the surgeon. The purely anterior midline tumor without an adequate surgical corridor is completely obscured by these structures. The unmodified suboccipital craniotomy approach necessitates undue retraction of critical neurological structures in cases in which the lesion is purely anterior. Fortunately, these purely ventrally located tumors are the rarest. (Vishteh, et al, 1999)

2.4.2.3.1Transcondylar Approach

In an attempt to offer effective and safer resections particularly in cases of more anteriorly situated lesions, the transcondylar approach was developed. (Sen CN, et al 1991). A number of different names exist for the variations in this approach, and this leads to significant confusion regarding nomenclature. (Babu RP, et al 1994, Banerji D et al1999,) In the literature on foramen magnum meningiomas, two major variations have evolved: first the far-lateral approach, which necessitates removal of the foramen magnum rim toward the condyle and excision of the ipsilateral atlantal arch, and second variation , the transcondylar approach, in which resection of some or all of the occipital condyle is required. The first of these is ultimately a suboccipital approach involving an appropriate soft-tissue dissection to allow access to the surgical corridor. (Cantore G, et al, 1994)

The transcondylar approach requires an inverted U-shaped incision with one limb of the U in the midline and the other along the anterior border of the sternocleidomastoid muscle. The sternocleidomastoid muscle is detached from the mastoid process and reflected as laterally as possible to avoid hindering access to the skull base. The superficial splenius capitis, semispinalis capitis, and longissimus capitis muscles are reflected downward to expose the underlying suboccipital triangle. Bordered by the superior and inferior oblique muscles and the rectus capitis posterior muscles, the VA courses in the fat of the suboccipital triangle below the occipital condyle. All three muscles are released from their vertebral attachments and reflected toward the midline. The craniotomy should include the bulk of the lesion and often be extended from near the midline, to just medial to the sigmoid sinus, and to just above the rim of the foramen magnum. The residual bone over the sigmoid and foramen magnum is removed using rongeurs or high-speed drill. The C-1 laminectomy is more extensive than the suboccipital craniotomy and extends out into the foramen transversarium. The posteromedial aspect of the occipital condyle and C-1 lateral mass are removed by drilling or careful rongeuring. If necessitated by the anatomy of the lesion, the foramen transversarium and C-2 lamina are also decompressed. The VA is freed from collagenous tissue at the C-1 foramen transversarium and adjacent to the condyle by using a high-speed drill under surgical magnification. A fine prolene stitch can be used to secure the VA in a medial position. Guided by preoperative planning of the surgical corridor and supplemented intraoperatively, if necessary, by computerized neuronavgation, the condyle is progressively removed in a mediolateral direction. Anterior condylar resection can include liberating the hypoglossal nerve from its canal if necessary to create an adequate surgical corridor. Because bone removal is extended much more laterally than in the suboccipital craniotomy, the ipsilateral VA is situated in the center of or medially in the surgical corridor prior to dural opening.. The dura is opened by making an incision that parallels the lateral margins of the craniotomy, with the base of the flap located medially. A ring of dura can be left attached to the VA where it is pierced. This maneuver allows the artery to be retracted away from the surgical corridor, thereby providing a clear view of the anterior portion of the brainstem and ostral cord. Occipitocervical fusion is recommended in condylar resections of 50% or greater.(Vishteh, et al 1999).

2.4.2.3.2 Surgical results

Morbidity–mortality–prognosis factors in the Yasargyl's review of the literature of series published before 1976, the overall mortality rate was approximately 13% but could be as high as 45% in some series (Love JG,et al 1954).

Over the last 20 years, the overall mortality is 6.2%. The mortality rate is comprised between 0 and 25%. Mortality rates higher than 10% were mainly observed in small series (Kratimenos GP et al 1993, Marin, et al 2002, Sharma BS et al 1999).

In the Yasargil’s review, a good outcome was noted in 69% and a fair and poor outcome, respectively, in 8 and 10%. In series larger than ten patients published over the last 20 years, neurological improvement, stability, and worsening were noted, respectively, in 70–100, 2.5–20, and 7.5–10% of the cases. The permanent morbidity rate is comprised between 0 and 60%. The permanent morbidity rate is lower through a far-lateral approach (0–17%), either transcondylar or retrocondylar, than through an extreme-lateral transcondylar approach (21%–56%, considering series without recurrent tumor). Lower cranial nerves dysfunctions are the most frequently encountered preoperative deficits. These deficits have the propensity to recover even completely postoperatively [Arnautovic KI, et al 2000 ,Bassiouni H,et al 2006], except in cases of en plaque meningiomas or recurrent tumor (Samii M , et al 1996).

2.4.3 Chiari malformations

The Chiari malformations are a group of hindbrain herniation syndromes initially, Cleland described the first cases of Chiari malformation in 1883, the disorder is named after Hans Chiari, an Austrian pathologist, who classified Chiari malformations into types I through III in 1891. Chiari's colleague, Julius Arnold, made additional contributions to the definition of Chiari II malformation. (Koehler PJ, et al 1891,) In his honor, students of Dr.Arnold later named the type II malformation Arnold-Chiari malformation. Other investigators later added the type IV malformation. (Pearce JM, et al 2000).

2.4.3.1 Types of Chiari malformations

2.4.3.1.1Chiari type I:

Chiari malformations I, malformation is the most common and the least severe of the spectrum, often diagnosed in adulthood. Its hallmark is caudal displacement of peglike cerebellar tonsils below the level of the foramen magnum, a phenomenon variably referred to as congenital tonsillar herniation, tonsillar ectopia, or tonsillar descent. The resultant impaction of the foramen magnum, compression of the cervicomedullary junction by the ectopic tonsils, and interruption of normal flow of cerebrospinal fluid (CSF) through the region produce the clinical syndrome. (Figure 2.12) (Koehler PJ, et al 1891,)

2.4.3.1.2Chiari type II

Chiari malformations II, malformation is less common and more severe, almost invariably associated with myelomeningocele. Because of its greater severity, it becomes symptomatic in infancy or early childhood. Its hallmark is caudal displacement of lower brainstem (medulla, pons, 4th ventricle) through the foramen magnum. Symptoms arise from dysfunction of brainstem and lower cranial nerves. (Arnold’s 1991)

2.4.3.1.3 Chiari type III and IV

Chiari type III and IV malformations are exceedingly rare and generally incompatible with life and are, therefore, of scant clinical significance. The type III malformation refers to herniation of cerebellum into a high cervical myelomeningocele, whereas type IV refers to cerebellar agenesis. (Dias M.et al 1999).

Importantly, it is not at all clear that the 4 types of Chiari malformation represent a disease continuum corresponding to a single disorder. The 4 types (particularly types III and IV) are increasingly believed to have different pathogenesis and share little in common other than their names. (Peyman, et al 2014)

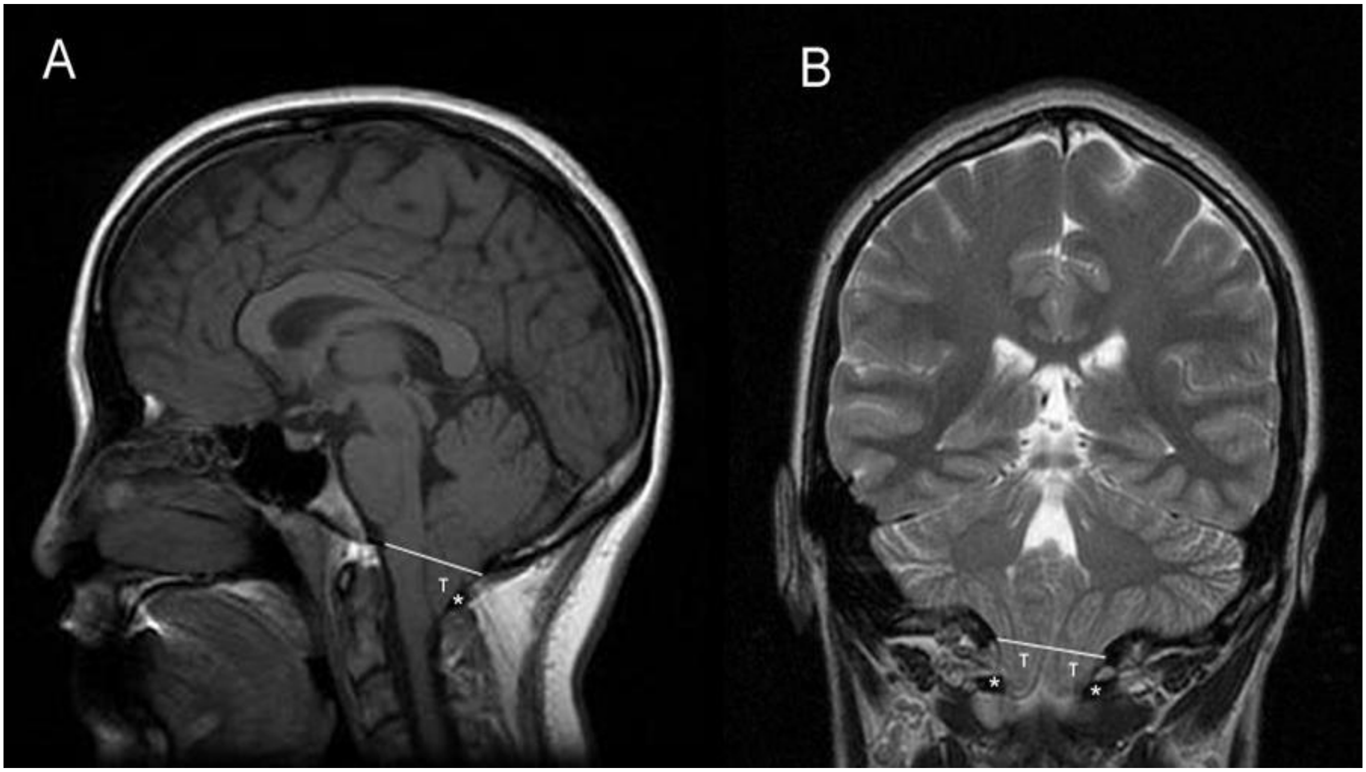


Figure: 2.12: Sagittal and coronal MRI images of Chiari type I malformation. Note descent of cerebellar tonsils (T) below the level of foramen magnum (white line) down to the level of C1 posterior arch (asterisk). (Peyman, et al 2014).

2.4.3.2 Radiographic features

Although historically visible on myelography, cross sectional imaging (especially MRI) is needed to accurately diagnose and assess for Chiari I malformations. In either case the diagnosis is made by measuring how far the tonsils protrude below the margins of the foramen magnum. The distance is measured by drawing a line from the inner margins foramen magnum (basion to opisthion), and measuring the inferior most part of the tonsils. (Ketonen L, et al 2005).

- Above foramen magnum: normal
- 3 mm: also normal but the term benign tonsillar ectopia can be used
- 3 to 6 mm: indeterminate, and needs to be correlated with symptoms and presence of syrnix, etc
- 6 mm: Chiari 1 malformation

Some authors advocate a simpler rule (Elster AD et al 1992):

- Above foramen magnum: normal
- 5 mm: also normal but the term benign tonsillar ectopia can be used
- 5 mm: Chiari 1 malformation

To make matters worse the 'normal' position of the cerebellar tonsils varies with age. In neonates the tonsils are located just below the foramen magnum and descend further during childhood, reaching their lowest point somewhere between 5 and 15 years of age. As the individual ages further the tonsils usually ascend coming to rest at the level of the foramen magnum.

(Kornienko. et al 2008). As such although 5mm descent in an adult should be viewed with suspicion, in a child it is most likely normal (Kornienko. et al 2008).

CT With modern volumetric scanning, and high quality sagittal reformats relatively good views of the foramen magnum and tonsils can be achieved although the intrinsic lack of contrast (compared to MRI) makes accurate assessment difficult. More frequently the diagnosis is suspected on axial images where the medulla is embraced by the tonsils and little if any CSF is present. This is referred to as a crowded foramen magnum. (Chiapparini L, et al 2011)

MRI **is** the imaging modality of choice. On sagittal imaging, the best plane for assessing for the presence of Chiari I malformations, the tonsils are pointed, rather than rounded and referred to as peg-like. The sulci are vertically oriented, forming so-called sergeant stripes. Axial images through the the foramen show crowding of the medulla by the tonsils. A syrinx may be seen in spinal cord. (Chiapparini L, et al 2011)

2.4.3.3 Indications

In Chiari I, radiographic presence of tonsillar herniation must correlate with appropriate clinical signs and symptoms before surgical intervention is undertaken. In frankly symptomatic patients, such as those with lower cranial nerve dysfunction, myelopathy, syringomyelia, cerebellar symptoms, or severe post-tussive suboccipital headaches, the decision in favor of surgery is straightforward. Difficulty arises in minimally symptomatic patients or those with equivocal symptoms. CSF flow studies across foramen magnum with phase-contrast cine MRI may help with surgical decision-making in these cases. Syringomyelia generally improves or resolves after surgical treatment of Chiari malformation (Figure: 2.13). Rarely is shunting of the Chiari syrinx necessary. (Hofkes SK, et al 2007)

Figure: 2.13: Resolution of syringomyelia (asterisk) after decompression of Chiari I malformation (white arrow) (Peyman, et al 2014).

2.4.3.3 Treatment:

There is no role for prophylactic treatment in an asymptomatic patient with an incidental CM. All symptomatic patients require surgical treatment. In patients with CM and hydrocephalus, the primary treatment must be shunting the ventricular system. The placement of a piece of muscle to plug the obex (Gardner's procedure) is no longer accepted. It either confers no added benefit or actually worsens outcome with an increased complication rate. (Guo F, 2007).

In presence of symptomatic ventral compression from BI or retroflexionof the odontoid, the treatment is ventral decompression.

In patients with a CMI, syrinxwith scoliosis, the initial treatment is posterior cervicomedullarydecompression. (Figure2.14)

There is a strong trend toward stabilization or improvement of the curvature following decompression which is especially true if the curvature is less than 30 degrees. (SHAILESH, 2003).

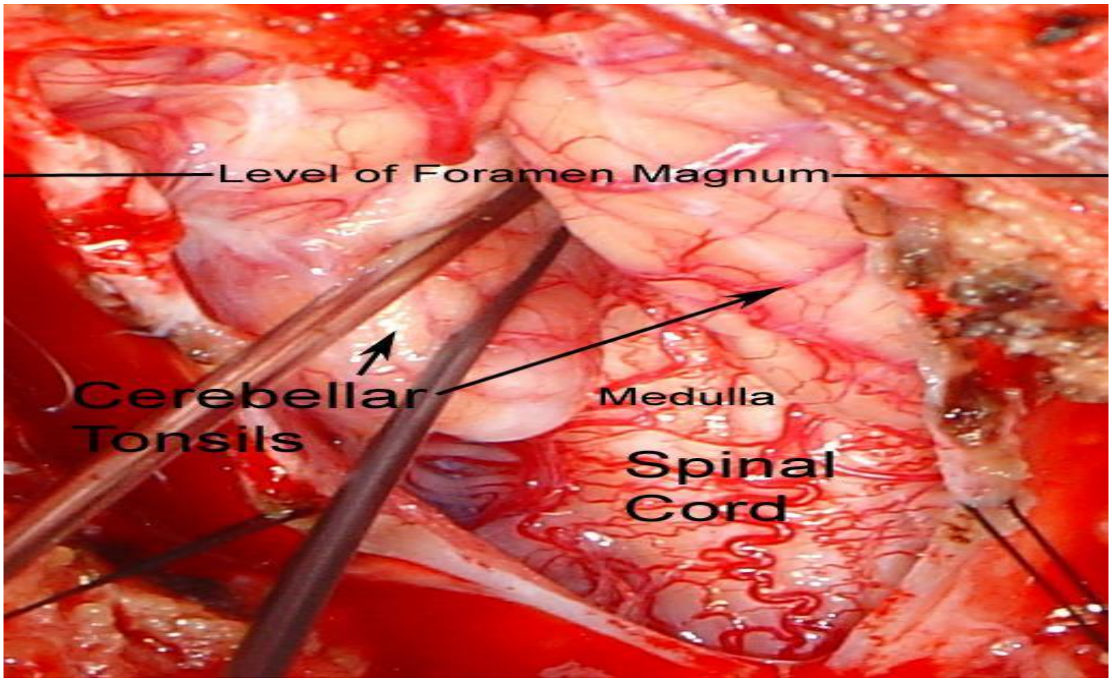


Figure: 2.14: Intraoperative photograph of Chiari type 1 malformation showing descent of cerebellar tonsils well below the level of foramen magnum. (Peyman, et al 2014).

2.5 Pathology of craniocervial junction

Pathologic conditions at the OCJ may compromise normal anatomical relationships and can lead to superior migration of the dens, atlantoaxial instability, and neural compression. Several terms arise in discussions of craniocervical instability, and they should not be used interchangeably. Basilar invagination differs from basilar impression, which differs from cranial settling. Basilar invagination refers to superior protrusion of the dens and loss of skull height secondary to congenital abnormalities. Basilar impression is secondary to skull-base softening caused by an acquired condition, such as Paget disease or osteomalacia. Cranial settling refers to vertical subluxation of the dens caused by loss of ligamentous support structures. Cranial settling can occur with rheumatoid or psoriatic arthritis.(Michael, et al ,2011)

2.5 .1 Primary/Congenital Conditions

Congenital conditions of the occiput, atlas, and axis can lead to basilar invagination and brain-stem compression. (Ross JS, 1994, Smoker 2000).

2.5.1.1Congenital Anomalies of Occiput.

Congenital conditions of the occiput may be secondary to failure of formation (hypoplastic) or failure of segmentation. (VanGilder, et al 1987, McRae, 1953). Hypoplastic disorders of the occiput include basioccipital hypoplasia and occipital condyle hypoplasia. (VanGilder, et al 1987, McRae, 1953) .Basioccipital hypoplasia is caused by failure of formation of the 4 occipital sclerotomes—which results in a shortened or hypoplastic clivus and, often, basilar invagination, best measured with the Chamberlain line. (Smoker 2000). Occipital condyle hypoplasia leads to short, flat condyles, which in turn, lead to limited AOJ motion and basilar invagination. Although the deformity is usually bilateral, unilateral cases have been reported. (Kunicki, et al 2005, Smoker 2000) Failure of segmentation between the skull and the first cervical vertebra results in atlanto-occipital assimilation (Figure 11), which may be complete or partial and invariably results in basilar invagination. (Smoker 2000). Clinically, patients may present with a stiff neck or pain after minor trauma. Restricted range of motion at C0–C1 may lead to instability at C1–C2. Almost 50% of patients with atlanto-occipital assimilation develop C1–C2 instability and myelopathy by the third decade of life. (VanGilder, et al 1987, Guille 2002).

2.5.1.2 Congenital Anomalies of Atlas.

With the exception of atlanto-occipital assimilation, most anomalies of the atlas do not alter OCJ anatomical relationships and are not associated with basilar invagination. (Smoker 2000). As the atlas does not have a true spinous process, failure of formation at the atlas is referred to as rachischisis rather than spina bifida of C1. (Smoker 2000). Posterior arch clefts of the atlas, the most common pattern, are found in 4% in autopsy specimens. (Chambers, et al 1992, Gehweiler, et al 1993). Most of posterior arch clefts are midline (97%); lateral clefts through the sulcus for the vertebral artery account for 3% of posterior arch clefts. (Chambers, et al 1992, Gehweiler, et al 1993). Posterior arch rachischisis may be mistaken for dens fracture when superimposed on an open-mouth-view radiograph. (Smoker 2000). Anterior arch clefts are much less common; they are found in 0.1% of autopsy specimens. (Chambers, et al 1992, Gehweiler, et al 1993). When associated with a posterior cleft, the so-called split atlas may mimic a Jefferson fracture. (de Zoete.et al 2007).

2.5.2 Occipital Condyle Fractures.

Occipital condyle fractures are rare injuries. They were originally described postmortem in trauma victims. The hypoglossal canal is intricately associated with the occipital condyle. Therefore, a displaced fracture demands close cranial nerve examination. These fractures are classified on the basis of bony versus ligamentous involvement. (Anderson, et al 1988) Larger bony fragments are generally more stable and have increased healing potential with nonoperative immobilization.(Hanson, etal 2002). CT with parasagittal and coronal reconstructions is best able to characterize occipital condyle fractures.(Jefferson, 1920).

2.5.3 Trauma to Atlas.

In 1920, Jefferson41 was the first to describe an axial load injury to the atlas resulting in a burst fracture of C1. Stability can be assessed with an open-mouth conventional dens radiograph. In a classic cadaver study, (Spence ,et al,1970) , determined that a combined overhang of the lateral masses of C1 over C2 of more than 6.9 mm on open-mouth radiograph was associated with transverse ligament rupture and a relatively unstable Jefferson burst fracture (Figure : 2.15& 2.16). (Heller et al, 1985) warned that magnification of plain radiographs overestimates this displacement and that the transverse ligament should be considered intact if combined lateral mass displacement is less than 8.1 mm on open-mouth radiograph. Using calibrated coronal CT reconstructions precludes this consideration. In addition to open-mouth dens radiograph and coronal CT, axial T2-weighted MRI can confirm injury to the transverse ligament.

Figure: 2.15. Parasagittal computed tomography of adult with congenital atlanto-occipital assimilation. As there is no joint space between occipital

Condyles and superior articular process of atlas (C1), basilar invagination often results. (Margali et al 2005)

Figure: 2.16. Sagittal computed tomography of trauma patient reporting neck pain. Angulated type II dens fracture is evident. (Margali et al 2005)

2.5.4 Treatment of occipitocervical

2.5.4.1 Occipitocervical stabilization

Is performed in both adults and children for a variety of potentially life-threatening conditions. It has been described as part of the treatment regimen for congenital instability, (Georgopoulos, etal 1987) degenerative spine disease,(Grob,2000). Down syndrome, (Menezes et al 1992), traumatic instability, (Traynelis, et al 1987), tumor involvement of the occipital condyle, (Deeb, et al 1988) instability following lateral skull–based approaches, (Bejjani, et al 2000, Margali et al 2005). (Figure 2.17).

2.5.4.2 Surgical stabilization

Surgical stabilization of the CVJ in the pediatric population presents a unique challenge. The pediatric spine is hypermobile as compared with that of adults because of ligamentous laxity, shallow and angled facets, underdeveloped spinous processes, flat contouring of the occipital condyles, and physiological anterior wedging of vertebral bodies. This hypermobility contributes to high torque and shear forces acting on the C1–2 region. (Figure: 2.17, 2.18, 2.19, 2.20) (Lustrin, et al 2003) Other factors that make surgery challenging include incomplete ossification of the odontoid process and C-1, (Karwacki, et al 2012) a large head compared with body mass, and weak, underdeveloped cervical musculature. (Lustrin, et al 2003).

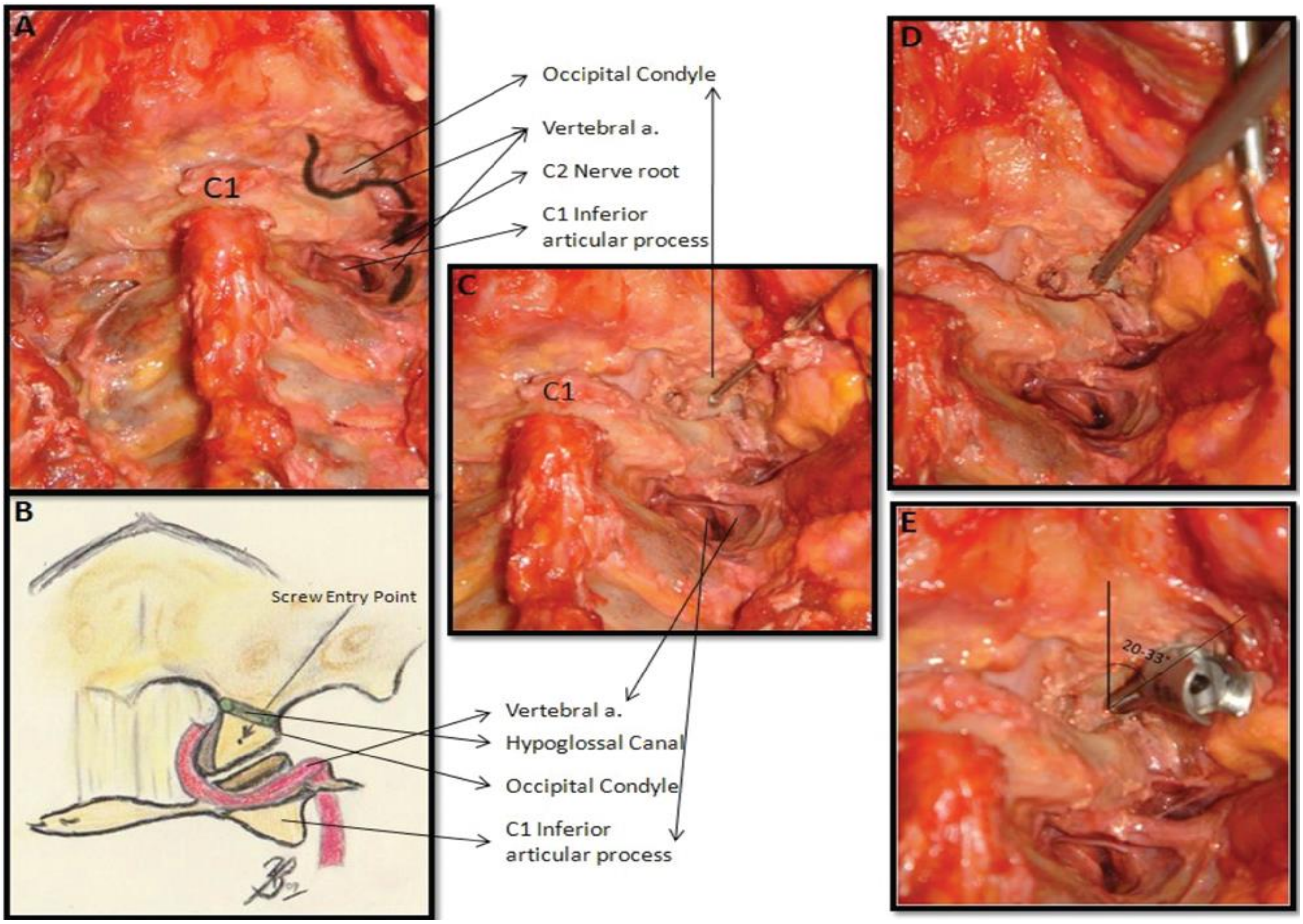


Figure. 2.17. Cadaveric photographs and an illustration showing placement of occipital condyle screws. The vertebral artery (a.) is highlighted in black (A) and in red (B). A ball-tipped probe is shown in the pilot hole (C), which is then hand drilled (D). A smoothshank polyaxial screw is then placed at an angle of 20°–30° degrees from the sagittal plane (E). (Libby, et al 2014).

Figure: 2.18. Preoperative reconstructed sagittal (left) and 3D (right) CT of the cervical spine, demonstrating basilar invagination (left) and changes due to suboccipital craniectomy and C1–2 laminectomies (right). (Kimon,et al 2010)

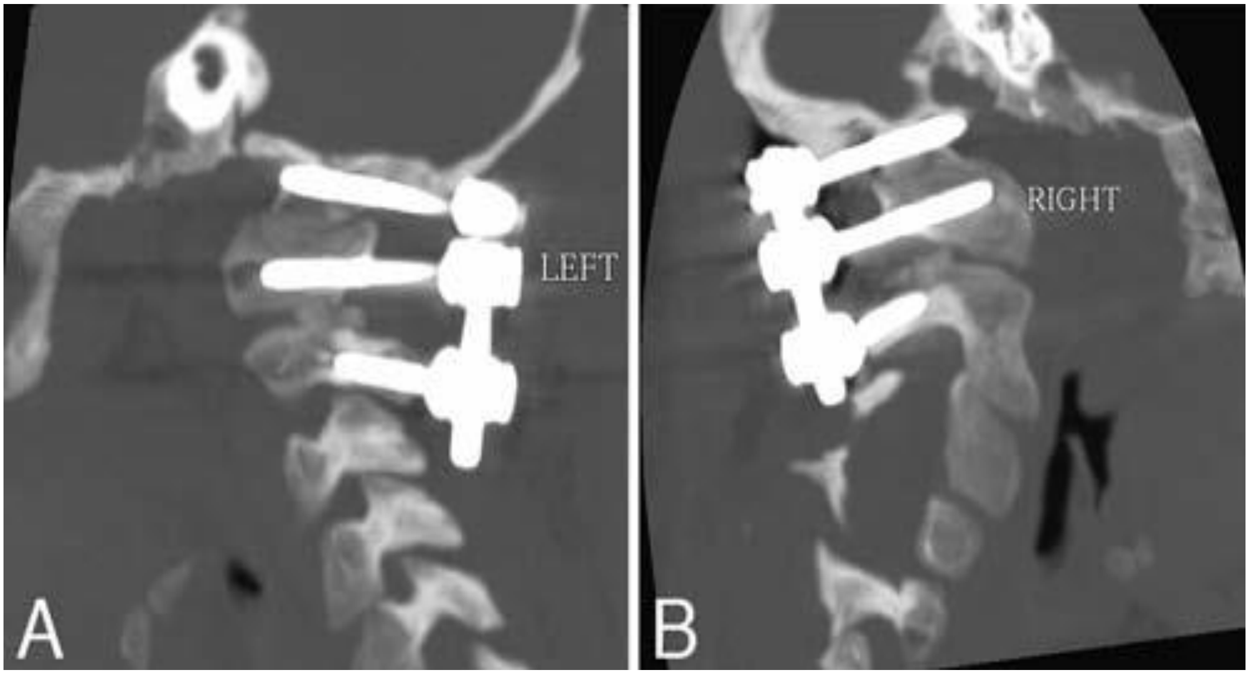


Figure: 2.19. Postoperative reconstructed sagittal CT of the cervical spine showing the position of the left (A) and right (B) construct from the occiput to C-2. (Kimon, et al 2010)

2.8 Computer Tomography posterior cranial fossa:

Neuro imaging of the posterior fossa means a diagnostic challenge for neuroradiology, radiology, neurology and neurosurgery. Due to the dramatical technical progress of imaging modalities increasing knowledge of the clinicians about the technique and indications of these examinations is necessary. (Loevner, et al)

Since 1976 examinations of the head have been performed with computerized tomography. As CT scan times have got faster, more anatomy can be scanned in less time. With an older CT scanner the examination of the posterior fossa was limited because of the artifact produced from the surrounding thick bone. However, with the new technique of multidetector (4-row, 16-row) CT scanners high quality images can be reconstructed in multiple planes from a single volume data set. (Thomas, 2013)

MDCT is rapidly becoming the new standard in radiological imaging.

The most important primary indication for CT imaging including CT angiography and CT venography in neuroradiology are acute head trauma, suspicion of acute intracranial hemorrhage, immediate postoperative evaluation for surgical treatment, shunted hydrocephalus, brain herniation, suspected mass or tumor and acute cerebral infarction. (Thomas, 2013)

Usually, CT is the imaging method of choice performed in patients with posterior fossa masses who often present with nausea, vomiting, ataxia, and other signs of increased intracranial pressure. CT is a quick, available, and relatively inexpensive method to assess neurological emergencies including hydrocephalus, hemorrhage, and herniation syndromes. (Thomas, 2013)

Searching for an intracerebral aneurysm, the second diagnostic procedure to be performed immediately after emergency CT is selective cerebral angiography. Both carotid and vertebral arteries must be injected. External carotid arteries should also be visualized, particularly if intracranial angiography is negative, as subarachnoid haemorrhage may sometimes be due to a rupture not of an aneurysm but of dural arteriovenous malformations. Angiography should aim at recognizing the aneurysm, its precise location, size, size of the neck, relationship with the parent vessel and multiplicity. To achieve this goal the ideal procedure is rotational angiography with three-dimensional reconstruction. (Provenzale, 2000)

2.8 Computer Tomography for head trauma:

Computed tomography (CT) has become the diagnostic modality of choice for head trauma due to its accuracy, reliability, safety, and wide availability. The changes in microcirculation, impaired auto-regulation, cerebral edema, and axonal injury start as soon as head injury occurs and manifest as clinical, biochemical, and radiological changes. Proper therapeutic management of brain injury is based on correct diagnosis and appreciation of the temporal course of the disease process. (Mukerji, et al 2009)

CT scan detects and precisely localizes the intracranial hematomas, brain contusions, edema and foreign bodies. Because of the widespread availability of CT, there is reduction in arteriography, surgical intervention and skull radiography.

CT scanning is an excellent modality at demonstrating intermediate and late sequelae of head trauma, such as hydrocephalus, generalized brain atrophy, encephalomalacia, porencephaly, subdural hygroma leptomeningeal cysts, and vascular complications. (Mukerji, et al 2009)

2.8 Computed Tomography: Technique

Helical and/or multisection CT scanning is helpful in assessing occipital condylar fractures, but 3-dimensional (3-D) reconstruction is usually not necessary. However, 3-D reconstructions are valuable when evaluating facial fractures. The study should always include bone windows to evaluate for fractures, especially when the skull base or orbits are compromised. (Ringl et al 2009)

2.9 Previous Studies:

According to Radu et al (1987), C.T. examination of small structures is made impossible by partial volume effect. Then in 1988 Koster stated that the increased spatial resolution of C.T. has overcome this difficulty. However, because of this uncertainty, only a few publications listing C.T. measurements of these foramina and canals have so far appeared. Muthukumar et al studied the morphometric analysis of foramen magnum for the purpose of transcondylar approach on 50 dry skulls. They had given the anteroposterior length of foramen magnum 33.3 mm and width as 27.9 mm. Also they stated that shape of foramen magnum was ovoid.

Kazikanat and colleagues studied the morphometry of foramen magnum on 59 dry skulls and given anteroposterior and transverse diameter of foramen magnum as 34.8+2.2 mm and 29.6+2.4 mm and stated that morphometric analysis of all these components will help in planning of surgical intervention involving the skull base.

Kosif Rengin studied the midsagittal magnetic resonance images of 194 adults (101females and 93 males) to reveal the relationship between occipitocervical region and cervical height. They measured the diameter of foramen magnum as 38.19+3.85 mm in males and 36.09+2.79 mm in females.

Murshed K.A. evaluated morphometrically the foramen magnum and also studied variations in its shape on C.T. scan of 110 normal subjects with 57 males and 53 females. They had given sagittal diameter as 37.3+3.43 mm and transverse diameter 31.6+2.99 mm in males and sagittal diameter 34.6+3.16 mm and transverse diameter 29.3+2.19 mm in females.

(Schmeltzer et al. 1971) ,(Wackenheim 1974) and (Þendemir et al. 1994), studying the FM measurements of 23 subjects through CT images obtained for the SD and TD a mean of 36.4 mm and 30.0 mm, respectively. These results are very close to our findings, being 0.5 mm greater than ours in the SD and 0.4 mm lower than ours in the TD.

Other authors, such as Fischgold and Wackenheim (1965), reported that the minimum radiographic value for the sagittal diameter is 27 mm, whereas in ours it is 28 mm. Wackenheim (1974) obtained radiographically mean values of 35 mm and 30 mm for the sagittal and transverse diameters, respectively. Compared with our results, without sex distinction, we can see that these values are slightly lower than ours. In Catalina-HerreraÕs(1987) study of the FM, diameters were 35.2 mm for the sagittal and 30.3 mm for the transverse diameter. Similar values were obtained by Testut and Latarjet (Testut, et al 1977). These results are similar to our findings. Other authors said that the normal values for the SD measurements of the FM lie between 28.5 mm (Þendemir et al 1994) and 48.0 mm (Adam , 1987), and for the TD measurements 21.4 mm (Lang , et al1983) and 40.0 mm (Adam , 1987).

In a study of 200 skulls, Zaidi and Dayal reported that oval FMs were found in 128 (64%) skulls. Sindel et al. and Lang et al. reported that this shape was not found in more than 18.94% and 22.35%, respectively, of their samples.
In a measurement of area of foramen magnum in 219 skeletons (170 males, 39 females) of Turkey, it was observed that mean area of the foramen magnum was significantly different (909.91±126.02 mm2 in males, 819.01±117, and 24mm 2 in females).

Giles and Elliot have remarked that "next to the pelvis, the skull is the most easily sexed portion of the skeleton" (Giles E, et al 1963).
There are many studies reported for sex determination by Foramen magnum dimensions.
Teixeira (1982) reported as study of sex identification utilizing size of FM in Brazilian individuals. Gunay (2000) confirmed that the area was smaller in females than in males. Murshed (2003) evaluated CT images of adults that saggital, transverse diameter and area are grater in males. Uysal (2005) resulted 81% accuracy rate and Gapert resulted 65.8% accuracy rate in CT measurements. According to Manoel (2009), linear morphometric method can be effective to know the sex.

Makaju, for example, worked on 300 samples of CT scan image of head (Makaju, et al 2013). He studied the antero posterior diameter, transverse diameter, area, shape of foramen magnum and also the presence of the accessory hypoglossal canal in the posterior margin of foramen magnum based on the ethnicity of Nepal. It was concluded that CT scan image of head can provide valuable measurements of the foramen magnum and could be used for sexual dimorphism and neurosurgery when other methods are inconclusive. Singh et al also analyzed the foramen magnum of human skulls (Singh, et al 2013). Fifty adult skulls of known sex were included in the study. Six standard parameters were measured and analyzed by discriminant function analysis. The accuracy of sex prediction based on discriminant function analysis ranged from 66% to 70% and was found a useful parameter for sex determination.

Uthman et al studied 88 samples for his study (Uthman, et al 2012). Foramen magnum sagittal diameter, transverse diameter, area and circumference were measured. Foramen magnum circumference and area were the best discriminant parameters with an overall accuracy of 67% and 69.3%, respectively. Raghavendra babu et al studied sexual dimorphism of the antero-posterior diameter, transverse diameter and area of foramen magnum in a population of coastal Karnataka region using statistical considerations (Raghavendra Babu, et al, 2012). The predictability of foramen magnum measurements in sexing of crania was 65.4% for the antero- posterior diameter.

Catalina-Herrera (Herrera 1987) indicated that the sagittal and transverse dimensions of the FM were significantly higher in human male than in human female skulls. Zaidi and Dayal, (Zaidi, et al 1988) classified a sample of Indian skulls according to the shape and dimensions of the FM, reporting gender differences which were similar to those reported among Brazilian skulls.(Manoel et al 2009). (Gu¨nay et al 1997) examined the usefulness of determining the dimensions of theFMin the diagnosis of sex and noted that the diameters were of some use while the total area was not a good indicator. (Yusal et al 2005) reported sexual dimorphism by analysing the dimensions of the FM in three-dimensional (3D) CT with 81% accuracy in determining the gender.

In 1963, Giles and Elliot (Giles et al 1963) examined sex determination of the skull by discriminant function analysis using Fisher's method (Fisher, 1936). Their accuracy of Negroid and Caucasoid material range between 82% and 89%.

Hence (Hence, 1977) claimed up to 100% accuracy in predicting sex from foramen magnum region whilst Holland (Holland, 1989) scored between 71 and 90% in the main sample and 70-80% in the control group. Catallina-Hercera (Catalina, 1987) indicated that saggital and transverse dimensions of the foramen magnum were significantly higher in men's skull.

In another study, (Routal, et al 1984) found the dimensions of foramen magnum in Indian sample to be sexually dimorphic and reported up to 100% accuracy of correctly identifying sex using simple demarking points.

Gapert, Black and Last also evaluated the foramen magnum of nineteenth century British adult skulls morphometrically showing significant differences between men and women classifying 70% of the male skulls and 69.7% of the female skulls by the discriminant function and 76% of men and 70% of women by linear regression. This study confirmed the importance of this region to identify the gender. (GAPERT, et al 2008).

The amount of partial condylectomy may cause greater atlanto-occipital instability in shorter OC, especially when more than 2/3 of the OC is removed (Barut, et al 2009). Therefore, the OCL should be measured preoperatively, in order to determine the exact area of resection, paying extra attention when the OC is short. In our study, we found short OC in 7 % of the skulls. These results are in agreement with other investigators' findings [Barut, et al 2009, Naderi, et al, 2004], who observed short OC in 8.6 and in 5 %, respectively. In K. Natsis et al study, also observed that women tend to have shorter OC than men, suggesting that women undertaking partial condylectomy with extensive condyle resection may be more vulnerable to atlanto-occipital instability than men, undertaking the same procedure.(Natsis et al,2013).

Chapter Three

Materials and Methods

3.1 Materials

A prospective study of 241 consecutive Sudanese patients (147 were males and 94 females age range between 20 - 90 years, FM dimensions tend to stabilize after the second decade of life , were enrolled in the study , between September 2012 and July 2015.

They were referred to the Radiology Department in the Ibn ALhythm Medical Center, Khartoum, Sudan, in which the patients subjected to CT Brian for different clinical indications. The study design was approved by the Research Council Ethical Committee –College of Medical Radiological Science. Patients with previous trauma, surgery or pathology in the region of the FM were excluded, because disorders involving skull base may distort the normal Anatomy of skull base, and patient who have sound health of adult age whose skeletal growth is complete were included.

All patients examined on a multislice CT scanner (Asteion, TX-021B Toshiba scanner). The scan is performed with the patient in the supine position, It is very important to ensure that there is no rotation or tilt of head in order to demonstrate any bilateral asymmetry, the protocol used for routine head scanning from base of skull through apex, with kVp of 120 and 200 mAs, slice thickness is depending on the structure being scanned, thin data and bone require slice thickness of 5mm and 2mm for reformatted images. Because of the dense bone of the base of skull beam-hardening artifacts are often seen in images of the posterior fossa, thin slices can help to reduce these artifacts.

Helical mode is primarily used for studies that require 3D reformations.

All FM measurements were taken from reformatted images (axial, maximum intensity projection and 3D volume rendering), by the measurement function available in the CT system (Asteion, TX-021B Toshiba scanner).

3.2 Data Collection & Analysis

3.2.1 Data collection

The Data were collected using the following variables: age, Gender, as well as the measurements relating to foramen magnum and occipital condyles.

- All measurements, of the Foramen Magnum(FM) and occipital condyles in (mm) were taken as follows :
- **Foramen Magnum(FM) measurements :**
  - **Length of the foramen magnum (LFM)**: is the distance taken in a straight line from the end of the anterior border (basion) through the center of the foramen magnum until the end of the posterior border toward the median sagittal plane(Antero posterior diameter) .(appendix A, image :1)
  - **Width of foramen magnum (WFM) -** is the distance in a straight line from the end of the border right side, with the concavity stronger through the center of the foramen magnum to the opposite end of the lateral border of concavity more pronounced, with transverse direction (transverse diameter). (appendix A, image :1)

- **The of foramen magnum area and circumference**, both area and foramn magnum were measured by tracing the bony border in the 3D volume rendering and maximum intensity reformatted CT images.
- **Shape of foramen magnum.**

- **The Occipital Condyles (OC) measurements were taken as follows:** .(appendix A, image :3)

Right occipital condyle maximum width –taken along the articular surface perpendicular to the right occipital condyle length Image 1: measurement length (A1- A2, of foramen magnum Width (B1 – B2) and minimum inter condyle distance (D2- D2 (with maximum bicondyle distance. (C1- C2)

- **Right occipital condyle length –** maximum length taken along the articular surface perpendicular to the right occipital condyle width.
- **Left occipital condyle maximum width –**taken along the articular surface perpendicular to the left occipital condyle length.
- **Left occipital condyle length –** maximum length taken along the articular surface perpendicular to the left occipital condyle width Maximum.
- **Distance between occipital condyles –** maximum distance between the lateral edges of the articular surfaces of the occipital condyles perpendicular to the mid sagittal plane.
- **Minimum distance between occipital condyles –** minimum distance between the medial edges of the articular surfaces of the occipital condyles perpendicular to the midsagittal plane.
- **Maximum internal distance of the occipital condyles –** maximum distance between the medial margins of the occipital condyles, perpendicular to the mid sagittal plane.

- **Head diameter**: including sagittal (SDH) and transverse diameter (TDH) was obtained from axial reformatted images. .(appendix A, image :6)

3.2.2 Statistical analysis

The data obtained were analyzed statistically by computing descriptive statistics like Mean, ± SD values and Percentages, with an independent T-test, ANOVA test, and by correlation analysis using an IBM SPSS Statistics software package (Inc., Chicago, Illinois version 16).

Chapter Four

Result

4.1 Tables and Graphs:

Table 4.1: Distribution of the study sample according to (Gender)

Gender	Frequency	percent
Male	147	61.00%
Female	94	39.00%
Total	241	100.00%

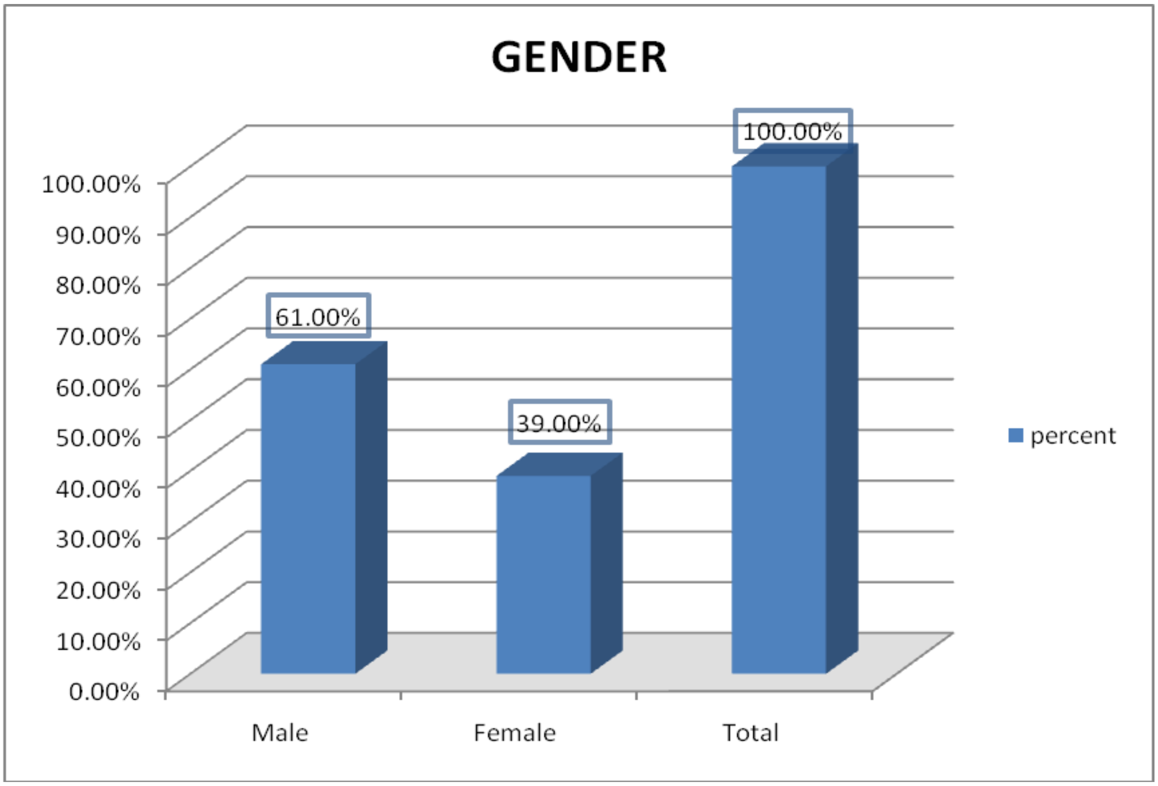


Figure 4.1: Distribution of the study sample according to (Gender)

Table 4.2: Distribution of the study sample according to (Age group)

age group	Frequency	Percent
20-35	107	44.40%
36-50	77	32.00%
51-65	38	15.80%
>66	19	7.90%
Total	241	100.00%

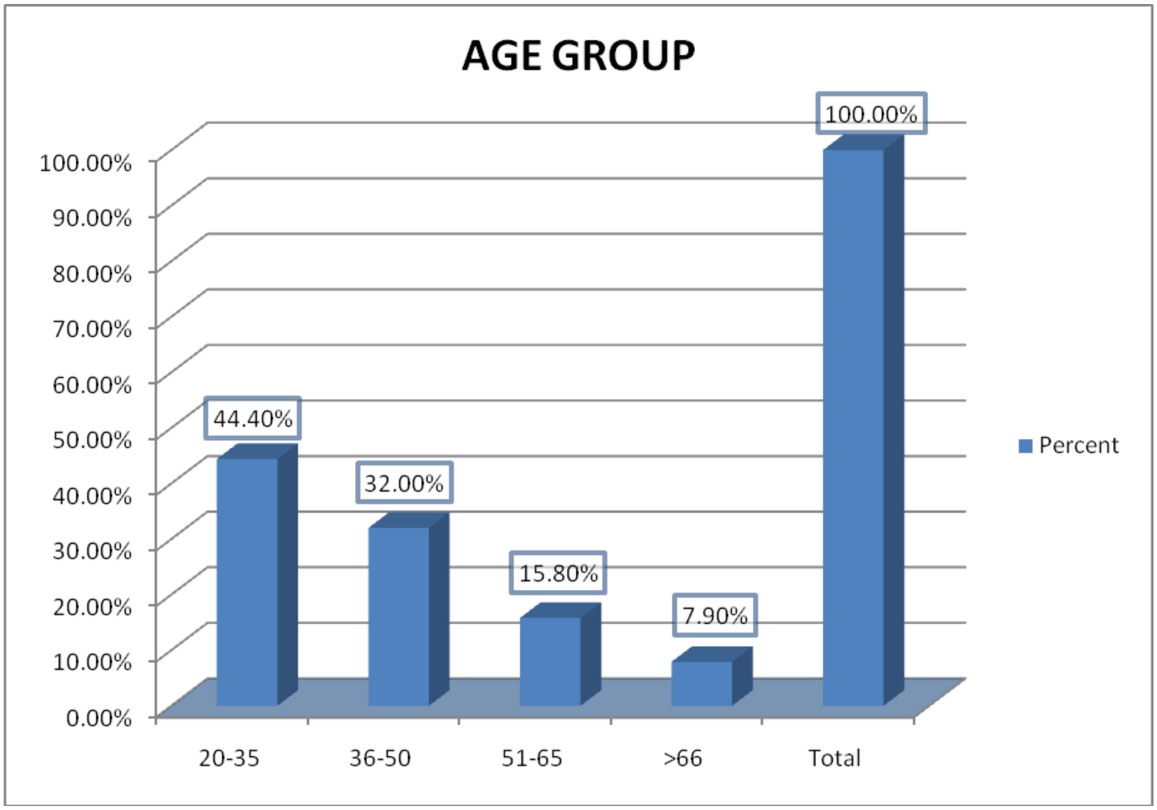


Figure 4.2: Distribution of the study sample according to (Age group)

Table 4.3: The Sudanese foramen magnum morphology, frequency and percentages.

	Frequency	Percent (%)
Round	55	22.8
Ovale	115	47.7
Arrow head	35	14.5
Irregular	36	14.9
Total	241	100.0%

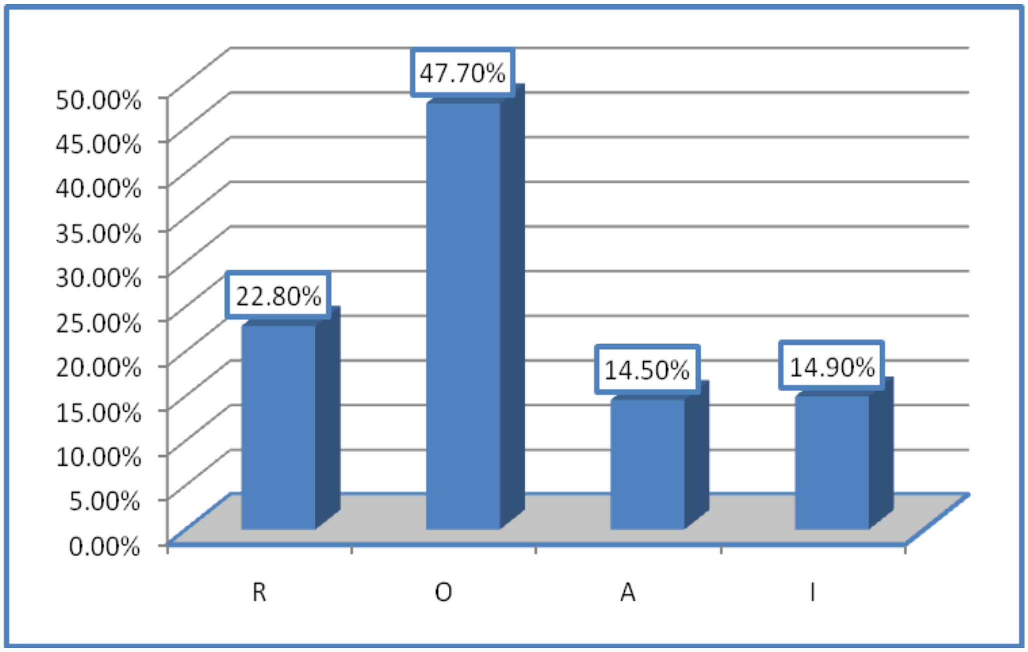


Figure 4.3: The Sudanese foramen magnum morphology, frequency and percentages.

Table4.4: The Sudanese foramen magnum morphology cross tabulated with Gender

Morphology of The Foramen Magnum * Gender Cross tabulation					
			Gender		Total
			Male	Female	
Morphology of The Foramen Magnum	Round	Count	39	16	55
		% of Total	16.6%	6.3%	22.9%
	Oval	Count	71	44	115
		% of Total	29.5%	18.3%	47.8%
	Arrow - head	Count	17	18	35
		% of Total	7.1%	7.4%	14.5%
	Irregular	Count	20	16	36
		% of Total	8.3%	6.5%	14.8%
Total		Count	147	94	241
		% of Total	61.5%	38.5%	100.0%
Chi-Square Tests/ P-value 0.171					

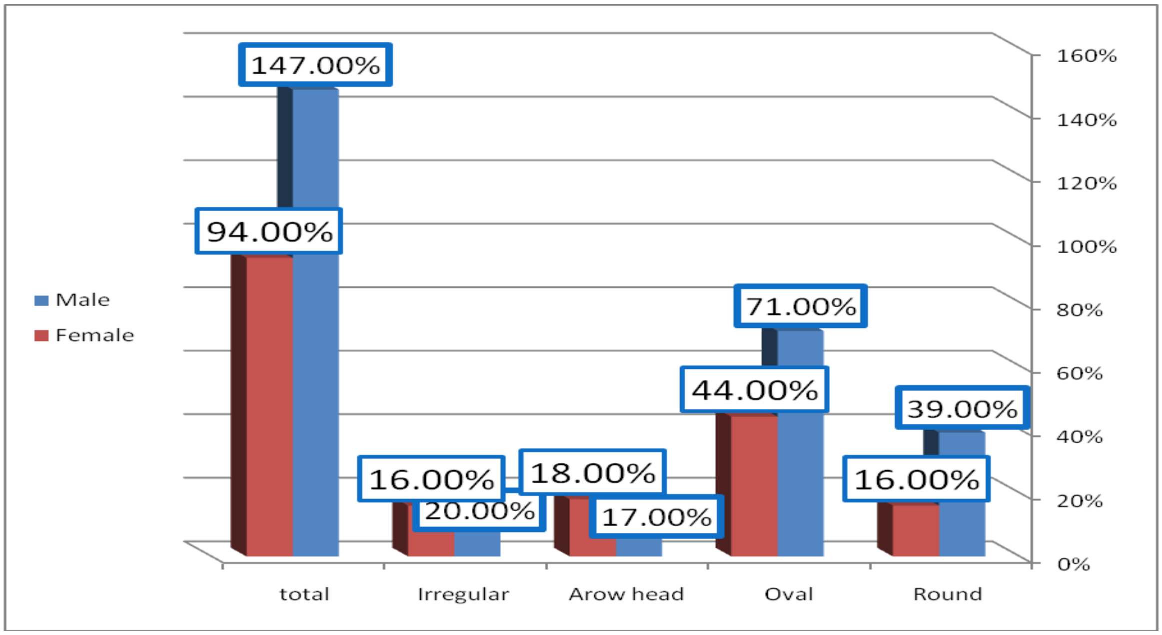


Figure 4.4: Distribution of the foramen magnum morphology according to (Gender)

Table 4.5: Variables related to gender, mean and standard deviations, maximum, minimum, p-value values.

Variables related Gender						Independent Samples Test T-test for Equality of Means
	Gender	N	Mean ± S. D	Min	Max	P-value
LFM	**Male**	147	35.20±2.68	28.70	42.1	<0.001
	Female	94	32.17±2.44	25.8	38.3	
WFM	**Male**	147	30.25±2.33	24.6	39.5	<0.001
	Female	94	27.89±1.78	23	32.8	
AFM	**Male**	147	819.84±96.53	584.00	1102.00	<0.001
	Female	94	692.13±84.64	463.50	980.00	
CFM	**Male**	147	108.84±11.04	87.60	147.30	<0.001
	Female	94	96.63±8.84	74.70	125.00	
TDH	**Male**	147	121.45±10.89	104	143.00	<0.001
	Female	94	115.29±6.50	101.60	136.00	
SDH	**Male**	147	155.39±8.76	136	175	<0.001
	Female	94	147.02±8.86	121	167.1	

Table 4.6: Sudanese foramen magnum morphology area (AFM) and circumference (CFM) correlated with transverse (TDH) and sagittal diameter of the head (SDH), Antro posterior (LFM) and transverse diameter (WFM) of the FM

Correlations between the variables					
		TDH	**SDH**	**LFM**	**WFM**
AFM	Pearson Correlation	.278**	.290**	.826**	.832**
	P-value	.000	.001	.000	.000
	N	241	241	241	241
CFM	Pearson Correlation	.238**	.308**	.727**	.757**
	P-value	.001	.000	.000	.000
	N	241	241	241	241

Table 4.7: Statistical measurements of the foramen mafnum variables correlated with the age classes (mean ± standard deviation, min, max, and p-value)

ANOVA							
		N	Mean ± S. D		Minimum	Maximum	
LFM	20-35	107	33.8019	2.66805	25.80	40.00	.510
	36-50	77	34.1260	3.06403	26.20	42.10	
	51-65	38	34.0553	3.72070	27.30	42.00	
	>66	19	34.9000	2.71968	29.80	41.20	
	Total	241	34.0320	2.98196	25.80	42.10	
WFM	20-35	107	29.6748	2.71130	23.60	39.50	.244
	36-50	77	29.3286	2.31857	23.00	35.00	
	51-65	38	28.7421	2.20266	24.30	33.20	
	>66	19	29.3526	1.51451	27.20	32.40	
	Total	241	29.3917	2.44398	23.00	39.50	
TDH	20-35	107	118.9972	12.55660	18.40	140.00	.586
	36-50	77	118.8636	7.74179	101.60	143.00	
	51-65	38	117.9447	6.85769	104.00	128.00	
	>66	19	121.7842	4.28761	111.30	128.60	
	Total	241	119.0083	9.90157	18.40	143.00	
SDH	20-35	107	152.1449	9.02103	131.00	170.00	.162
	36-50	77	151.5234	10.44901	121.00	175.00	

	51-65	38	151.0079	9.83863	132.50	168.50	
	>66	19	156.7526	9.22427	135.70	169.00	
	Total	241	152.1303	9.68661	121.00	175.00	
AFM	20-35	107	772.1542	115.48239	463.50	1102.00	.966
	36-50	77	767.9818	105.38974	510.60	1022.00	
	51-65	38	764.1974	125.29844	498.80	1005.60	
	>66	19	778.0947	81.66647	605.40	919.40	
	Total	241	770.0349	111.09380	463.50	1102.00	
CFM	20-35	107	104.4280	12.31454	74.70	147.30	.977
	36-50	76	103.7539	10.67505	79.80	137.50	
	51-65	38	103.7632	13.23740	75.90	133.00	
	>66	19	104.4895	6.65022	89.60	116.00	
	Total	240	104.1142	11.55824	74.70	147.30	
SFM	20-35	107	2.2897	1.00948	1.00	4.00	.593
	36-50	77	2.1039	.92600	1.00	4.00	
	51-65	38	2.1842	.83359	1.00	4.00	
	>66	19	2.3158	1.10818	1.00	4.00	
	Total	241	2.2158	.96346	1.00	4.00	

Table 4.8: Descriptive statistics of the studied occipital condyles variables (Mean± SD, Maximum and Minimum values)

Measured Variables	N	Mean± S.D	MAX	MIN
LRC	241	21.1±2.06	16.00	26.10
WRC	241	12.9±1.29	9.00	16.30
LLC	241	19.9±2.05	13.10	25.40
WLC	241	12.2±1.23	8.20	15.00
MnLC	241	13.0±2.42	5.40	19.00
Mic	241	26.5±2.87	16.90	35.00
MBC	241	45.6±3.27	30.40	56.00

Table 4.9: ***Morphometric measurements of the Occipital condyles:*** **Right occipital condyle length (LRC), Left occipital condyle length (LLC), Right occipital condyle maximum width (WRC), Left occipital condyle maximum width (WLC). **Significance at level 0.01**

Group Statistics			*Independent Samples Test*
	N	*Mean*	*P-value*
LRC	241	21.1	0.000**
LLC	241	19.9	
WRC	241	12.9	0.000**
WLC	241	12.2	

Table 4.10: Morphometric measurements of the Occipital condyles related to gender (mean ± standard deviation, min, max, p-value).

Group statistic		Independent Samples Test T-test for Equality of Means					
		N	Mean	Std. Deviation	Minimum	Maximum	P-value
LRC	Male	147	21.7701	1.97017	16.00	26.10	.000
	Female	94	20.2160	1.83943	16.40	23.80	
	Total	241	21.1639	2.06141	16.00	26.10	
WRC	Male	147	13.1844	1.19741	9.00	16.30	.001
	Female	94	12.6202	1.37650	9.70	15.30	
	Total	241	12.9643	1.29710	9.00	16.30	
LLC	Male	147	20.5952	1.80780	15.20	25.40	.000
	Female	94	19.0255	2.05206	13.10	22.30	
	Total	241	19.9830	2.05146	13.10	25.40	
WLC	Male	147	12.4844	1.21637	8.20	15.00	.002
	Female	94	11.9819	1.19802	9.20	14.60	
	Total	241	12.2884	1.23148	8.20	15.00	
MnLC	Male	147	13.2975	2.43330	7.40	19.00	.039
	Female	94	12.6372	2.36852	5.40	18.20	
	Total	241	13.0400	2.42485	5.40	19.00	
Mic	Male	147	27.3286	2.84326	20.40	35.00	.000
	Female	94	25.3819	2.50157	16.90	30.00	
	Total	241	26.5693	2.87194	16.90	35.00	
MBC	Male	147	46.6844	2.81071	35.00	56.00	.000
	Female	94	44.0085	3.29067	30.40	55.00	
	Total	241	45.6407	3.27300	30.40	56.00	

Table 4.11 Statistical measurements of the variables correlated with the age classes (mean ± standard deviation, min, max,p-value)

ANOVA							
		N	Mean ± S. D		Minimum	Maximum	
LRC	20-35	107	21.1776	1.99151	16.80	26.10	.812
	36-50	77	21.1909	2.18856	16.00	25.10	
	51-65	38	21.2842	2.09240	16.40	25.40	
	>66	19	20.7368	1.96277	16.90	23.70	
	Total	241	21.1639	2.06141	16.00	26.10	
WRC	20-35	107	12.8822	1.38072	9.00	16.30	.584
	36-50	77	13.1078	1.20980	9.50	15.20	
	51-65	38	13.0132	1.35650	10.20	16.30	
	>66	19	12.7474	1.03030	10.60	14.80	
	Total	241	12.9643	1.29710	9.00	16.30	
LLC	20-35	107	19.9140	1.99454	15.00	25.40	.923
	36-50	77	20.1169	2.05448	15.20	24.00	
	51-65	38	19.9263	2.45739	13.10	24.30	
	>66	19	19.9421	1.52909	17.50	22.40	
	Total	241	19.9830	2.05146	13.10	25.40	
WLC	20-35	107	12.1785	1.28834	9.10	15.00	.668
	36-50	77	12.3922	1.27184	8.20	14.60	
	51-65	38	12.3658	1.06169	9.70	14.70	
	>66	19	12.3316	1.08015	10.00	14.20	
	Total	241	12.2884	1.23148	8.20	15.00	

MnLC	20-35	107	12.7405	2.54735	5.40	17.60	.014
	36-50	77	13.6857	2.37164	7.80	19.00	
	51-65	38	12.3763	1.89429	7.80	17.30	
	>66	19	13.4368	2.37655	8.10	16.40	
	Total	241	13.0400	2.42485	5.40	19.00	
Mic	20-35	107	26.7187	3.06253	21.00	35.00	.071
	36-50	77	26.8455	2.35576	21.50	34.30	
	51-65	38	25.4474	3.41608	16.90	32.20	
	>66	19	26.8526	2.03015	22.50	30.00	
	Total	241	26.5693	2.87194	16.90	35.00	
MBC	20-35	107	45.5383	3.13894	35.00	52.00	.742
	36-50	77	45.9221	2.61477	40.80	55.00	
	51-65	38	45.2605	4.59621	30.40	55.20	
	>66	19	45.8368	3.43110	40.60	56.00	
	Total	241	45.6407	3.27300	30.40	56.00	

Table 4.12: Correlation between the foramen magnum (FM) measurements (Length and width) and the occipital condyles morphometric measurements

		LFM	WFM
LRC	Pearson Correlation	.336(**)	.319(**)
	Sig. (2-tailed)	.000	.000
	N	241	241
WRC	Pearson Correlation	.195(**)	-.004
	Sig. (2-tailed)	.002	.953
	N	241	241
LLC	Pearson Correlation	.336(**)	.246(**)
	Sig. (2-tailed)	.000	.000
	N	241	241
WLC	Pearson Correlation	.198(**)	-.040
	Sig. (2-tailed)	.002	.535
	N	241	241
MnLC	Pearson Correlation	.244(**)	.241(**)
	Sig. (2-tailed)	.000	.000
	N	241	241
Mic	Pearson Correlation	.386(**)	.596(**)
	Sig. (2-tailed)	.000	.000
	N	241	241
MBC	Pearson Correlation	.358(**)	.409(**)
	Sig. (2-tailed)	.000	.000
	N	241	241

Table 4.13 Correlation between the head dimensions (transverse and sagittal diameter) and the occipital condyles morphometric measurements. **. Correlation is significant at the 0.01 level (2-tailed).

		THD(mm)	SHD(mm)
LRC	P-value	.075	.084
	N	241	241
WRC	P-value	.191	. 082
	N	241	241
LLC	P-value	.082	.065
	N	241	241
WLC	P-value	.367	.256
	N	241	241
MnLC	P-value	.077	.082
	N	241	241
Mic	P-value	.098	.087
	N	241	241
MBC	P-value	.187	.257
	N	241	241

Chapter Five

Discussion, Conclusion & Recommendation

5.1 Discussion:

5.1.1 Foramen magnum shape:

Since the FM includes specific neuroanatomical structures and their lesions in that region which require particularly microsurgical intervention, choosing and establishing the most suitable surgical techniques need a careful planning mainly based on the FM size to refrain from any neurological injury (Muthukumar,et al ,2005).

The difference in the FM morphology from various reports indicates racial variability. (Chet Han et al 2012) but the irregular shape of FM is highlighted by the developmental cranial anomalies (Furtado SV et al 2010). The FM is most common described as oval in shape. In a study of 200 skulls, Zaidi and Dayal reported that oval FMs were found in 128 (64%) skulls (Zaidi et al 1988), Radhakrishna et al, study revealed, 39% with oval shape, Gupta Chandni et al., reported that oval FMs in 35%, Sindel et al. and Lang et al. reported that this shape was not found in more than 18.94% and 22.35%, respectively, of their samples (Sindel et al 1989, Lang et al 1983).

In present study a total of four shape categories were identified, Round Oval, Arrowhead, and Irregular, oval-shaped FM, was the morphological type of most frequently found in Sudanese; (Zaidi SH et al 1988, Espinoza et al. 2011, Radhakrishna et al. 2012, Avci et al. 2011) reported similar findings. Table (4.4) shows that there is variation in the morphological types of FM in

Sudanese. The variations have been attributed, among some authors due to different factors such as sexual dimorphism (Ukoha U et al 2011), types of population (Krıshnamurthy A et al 2012), and ethnic groups (Espinoza E et al 2011). The oval morphological types of FM substituted 115 (47.8%) of the sample and the rounded proceeded 55(29.49%) , other types with their respective frequencies of occurrence have been found as arrow head shape in 36 (14.8%) and the irregular shape achieved 35(14.5%),similar findings were described by many authors (Chethan P et al 2012 , Natsis K et al 2013).

The Pearson’s chi-square test (P-value 0.171) revealed that there is no association between foramen magnum shape and gender in the study.

5.1.2 Foramen magnum length and width:

The comparison of the morphometric analysis obtained in this study with the results of other studies had the following results: the length of the foramen magnum sudnese (35.2 ± 2.68) was lower than some population studied , which was the of Brazilian male skulls (36.5 ± 0.29) , Turkish (37.2 ± 3.43) Murshed, Cicekcibasi and Tuncer (2003), Spanish (36.2 ± 0.3) Herrera (1987), and English populations (35.91 ± 2.41) Gapert, Black and Last (2008), and Indian population (35.5 ± 2.8) Routal, Pal, Bhagwat et al. (1984). Also is lower measure for the female skulls (32.17 ± 2.44) than Brazilian population (35.1 ± 0.33), Turkish (34.6 ± 3.16) Murshed, Cicekcibasi and Tuncer (2003), Spanish (34.30 ± 0) Herrera (1987), Indian (32.0 ± 2.8) Routal, Pal, Bhagwat et al. (1984), and English populations (34.71 ± 1.91) Gapert, Black and Last (2008).

Regarding the width of the foramen magnum, the values of the Sudanese male skull(30.25 ± 2.33) same of Brazilian male skulls (30.3 ± 0.20) and were higher than those of the Indians (29.6 ± 1.9) Routal, Pal, Bhagwat et al. (1984) only and lower than the Turkish (31.6 ± 2.99) Murshed, Cicekcibasi and Tuncer (2003), Spanish (31.1 ± 0.3) (HERRERA, 1987), and English populations (30.51 ± 1.77) Gapert, Black and Last (2008). Also near to be the same (27.89± 1.78) measure for the female skulls of the Indian (27.1 ± 1.6) Routal, Pal, Bhagwat et al. (1984) and measure lower than and Turkish populations (29.3 ± 2.19) Murshed, Cicekcibasi and Tuncer (2003) and lower than Spanish (29.6 ± 0.3) Herrera (1987), English populations (29.36 ± 1.96) Gapert, Black and Last (2008), and Brazilian (29.5± 0.23).

In this study, the results were 42.1 and 39.5 mm as the maximum sagittal and transverse diameter, respectively, in male subjects, and 38.3 and 32.8 mm, respectively for female subjects. The minimum values were 28.70 and 24.6 mm for the sagittal and transverse diameters in male subjects, and 25.8 and 23 mm for the same parameters in female subjects. The mean in males was 35.20±2.68 mm for the sagittal diameter and 30.25±2.33 mm for the transverse. In females, the mean was 32.17±2.44 mm and 27.89±1.78 mm, respectively. Table (4.5)

Obviously, the result of this study was different to the findings of the studies, in foramen magnum length and width measurement, but slightly near to (AT Uthman, NH 2011) measurements who was studied Iraqy population. Lastly in the agreement to present study they stated that there was significant sex difference in quantified parameters indicating that the foramen magnum is larger in males.

The (FM) measurements, including length and width and its correlation with the occipital condyles characteristics, including right occipital condyle length (LRC), left occipital condyle length (LLC), maximum distance between occipital condyles (MDC), minimum distance between occipital condyles (MnLC), maximum internal distance of the occipital condyles (Mic), were found to be significant at p=0.01, and no significant relations were detected between right and left occipital condyle maximum width (WRC, WLC) with the length and width of the foramen magnum (LFM,WFM), these were noticed in (table 4.12).

5.1.3 Foramen magnum area and circumference:

Regarding FMC, the mean values were greater in males than in females (108.84 mm ±11.04 mm vs 96.63 mm ± 8.84 mm). To our knowledge, the study of (AT Uthman, NH 2011) was the first that used this measurement variable and no literature has previously discussed it.

In the present study the area of the foramen magnum of male skulls (819.84 mm^2) Table(4.5) was significantly larger than female skulls (692.13 mm^2) the mean area of the foramen magnum of males in present study was similar to the observations made by (Routal , et al 1984) on Gujarati male skulls (819.0mm^2), However it was lower than the observations made by Catalina Herrera , on Spain white male skulls (888.4 mm^2) and Gunay on Turkey male skulls (909.9mm^2), and show greater measurement from that found by (Muralidhar P Shepur et al ,2014) (748.6mm^2) and (Sayee, et al 1987) on male skulls of Karnataka (769.0mm^2).

The mean area of the foramen magnum of female skulls (692.13 mm^2) it was lower in comparison with observations of Catalina Herrera, on Spain white female skulls (801.0mm^2) and Gunay on Turkey female skulls (819.0mm^2). (Sayee, et al 1987) on Karnataka female skulls (746.0 mm^2) and (Routal, et al 1984) on Gujarti female skulls (771.0mm^2). Muralidhar P Shepur et al (711.1 mm^2).

5.1.3 Foramen magnum transverse and saggital diameter of the hesd

Regarding craniometric measurements, there was a highly significant statistical difference in head width measurements between genders, in the study of Deshmukh and Devershi (Deshmukh et al 2006) measured head width using sliding vernier calipers directly on the crania, which resulted in mean values of 131mm±0.49 mm for males and 127 mm± 0.49 mm for females. (AT Uthman,NH 2011) study which is first and only study using CT in craniometric measurements assessing head width diameter for gender determination , measured TDH, 143 mm ± 6.49mm for male and 137 mm ± 4.2mm .These values were higher than those recorded in the present 121.45mm ± 10.89mm, for male and 115.29mm ±6.50 mm for female. Table (4.5)

Current measured 155.39 mm ± 8.76 mm, for male and 147.02 mm ±8.86 mm for female, Table (4.5), for SHD which there is no previous literature in this case, with statistically significant differences existed between males and females.

The sex determination is of great value in forensic medicine as well as in anthropology. Therefore the corroborate that the sagital and transverse diameters of the FM are of great value for this determination and the correlation between the area and circumference of the FM is of highly significance with the transverse and sagital diameter of the head and FM as shown in table (4.6).

5.1.4 The occipital condyles measurement:

The occipital condyles (OC), is an important area in craniovertebral surgery, but neither its anatomical features, nor the procedures concerning the (OC) for Sudanese have been studied yet. The morphological analyses of the structures were made in totally 246sides of the occipital bones of adult Sudanese craniums by 3DCT images. The length and width of the (OC) were found to be 21.1±2.06 mm (right), 19.9±2.05 mm (left) and 12.9±1.29 mm (right), 12.2±1.23 mm (left), respectively.

The maximum distance between occipital condyles, and minimum distance between inter condyles, and maximum internal distances of the occipital condyles were measured as 45.6±3.27 and 13.0±2.42 mm and 26.5±2.87, respectively. These were presented in table (4.9), and these findings were considered less than the measurements done previously (Mehmet et al., 2011).

The significance for transcondylar surgical procedure needs information regarding the morphometric aspects of the OC and surrounded structures (Muthukumar et al., 2005; Naderi et al., 2005; De Oliveira et al., 1985).

The main issues to be countered in the pre-operative decision-making process is whether the measurements of the OC may affect surgical technique, therefore present study was planned to determine the length, and width of the OC which is important in cases requiring craniovertebral surgery. When we measured the right and left occipital condyle maximum length and width, no significant differences were detected between the two sides at p value =0.000. Similar findings were detected (Mehmat et al., 2011); this was noticed in table (4.9).

The radiological evaluation using 3D CT to the anatomical measurement strengthens the accepted view that preoperative radiological evaluation is of greatest importance for attaining successful surgical achievement. The study, showed that there are significant differences at p value =0.000, between the males and females regarding the variables.

The Sudanese males were found to have greater measurements than females. The variables including right occipital condyle length (LRC), left occipital condyle maximum width (WLC), left occipital condyle length (LLC), maximum distance between occipital condyles (MDC), maximum internal distance of the occipital condyles (Mic), transverse head diameter (THD), sagittal head diameter (SHD),area of the foramen magnum (AFM), circumference of the foramen magnum (CFM). No significant difference were detected between right occipital condyle maximum width (WRC) and minimum distance between occipital condyles (MnLC) with genders this was observed in table (4.10) , as well as the correlations between all of the variables and different age groups as seen in table (4.11) .

5.1.5 The occipital condyles and FM measurement:

The morphologic variations, including area, circumference, length and width of the (FM) are important, because the ability of the surgeon to adequately expose the anterior portion of the (FM) might be difficult.

The (FM) measurements, including length and width and its correlation with the occipital condyles characteristics, including right occipital condyle length (LRC), left occipital condyle length (LLC), maximum distance between occipital condyles (MDC), minimum distance between occipital condyles (MnLC), maximum internal distance of the occipital condyles (Mic), were found to be significant at p=0.01, and no significant relations were detected between right and left occipital condyle maximum width (WRC, WLC) with the length and width of the foramen magnum (LFM,WFM), these were noticed in table (4.12) .

(FM) measurements, and the length of the (OC) are important factors because protrusion of the (OC) into (FM) may indicate more extensive bony removal during surgery and the amount of partial condylectomy may cause greater occipitocervical instability in short (OC) (Barut et al., 2009). This also was discussed by (Muthukumar et al., 2005).

The differences between the OC Sudanese measurements, and other previous studies measurements, (Mehmet et al., 2011) proved that there are anatomical variations detected regarding the OC.

(Naderi et al., 2005), have done the first study which made a systematic and detailed classification of the (OC), based on its shape. Shapes have been described, including two-semicircles, oval type, and rhombus, beanshaped, prismatic, flattened, convex, flattened-convex, short and broad, flat and long, small and convex types. (Bozbuga et al., 1999; Muthukumar et al., 2005; Acikbas et al., 1997) but current study didn’t characterize its shape but did comprehensive measurements for the (FM),(OC) and surrounding structures, as well as, the head sagital and transverse diameters. Table (4.13) shows the correlations between the transverse head diameters (THD) and sagittal head diameter (SHD) and the occipital condyles measurements for Sudanese, the presented data showed no significant relationship between the variables and similar results were found by (Naderi et al., 2005) .

5.2 Conclusion

To conclude, the present study regarding morphometry of foramen magnum was in agreement with earlier studies done so far, hence it shows diameters of foramen magnum were greater in males than in females.

FM measurements are valuable in studying sexual dimorphism in forensic investigations with high significant difference was observed between sexes.

The area and circumference of FM varies in relation with gender and ethnicity group. However, it should be noted that sex differences in the dimensions of the FM and the variations should be taken into concern during the performance of clinical and radiological diagnostics and during surgical approach.

Current study results show the shape of the foramen magnum is not indicative of a specific ancestral group; and gender; however, the oval shape is predominated and followed by round one , arrow head and irregular shape respectively .

Measurements of the Occipital condyles diameter and protrusion contribute to the shape and size of FM diameter, considering the vital structures that pass through FM.

The OC the main bony prominences obstructing the anterolateral surface of the brainstem for the far lateral approaches. The radiological and anatomical measurements indicated that the radiological assessment greatly helps to organize the preoperative preparation.

Most of the data obtained in CT corroborate previous studies and are important parameters in the evaluation of morphometric variations of pre-surgical preparation in regard to the transcondylar approach, thus helping to reduce the risk of neurovascular injury during the procedure.

Computed tomographic scan is noninvasive modality for the imaging the skull base. Since this procedure is widely done, this modality was preferred. CT/3D CT can be accurately used in further investigations to provide basis for anthropometric and forensic issues

Current study findings may consider as reference for Sudanese, and the measurements may describe the normal morphological variants of FM for Sudanese. Since the anatomy of the FM is of interest to many radiological fields. The radiologists must have knowledge of normal anatomy of skull base to determine the presence of abnormality and to help in surgical planning. The information gained from the present study will be of useful to all of the medical and radiological fields.

5.3 Recommendation

- The importance of that fact and studying that area comprehensively; is that the surgeon should not decide about the achievement of condylectomy based on the head transverse and sagital diameters.
- Neurosurgeon has to be familiar with the anatomical structures of the FM region and the probable variations of the structures in order to achieve the widest exposure with the best surgical outcome.
- The radiological and anatomical measurements indicated that radiological assessment using CT scan greatly helps to organize the preoperative preparation, so radiologists must enrich their knowledge to the variations of this region. FM dimensions tend to stabilize after the second decade of life and the reconstructed CT images can provide reliable measurement of these dimensions.
- Future research is needed to further confirm the results acquired with this study for foramen magnum and occipital condyles measurement.
- Future research is recommended for foramen magnum and occipital condyles measurement, in different Sudanese state; since Sudan rich with ethnic diversity.

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Appendices:

Appendix: A

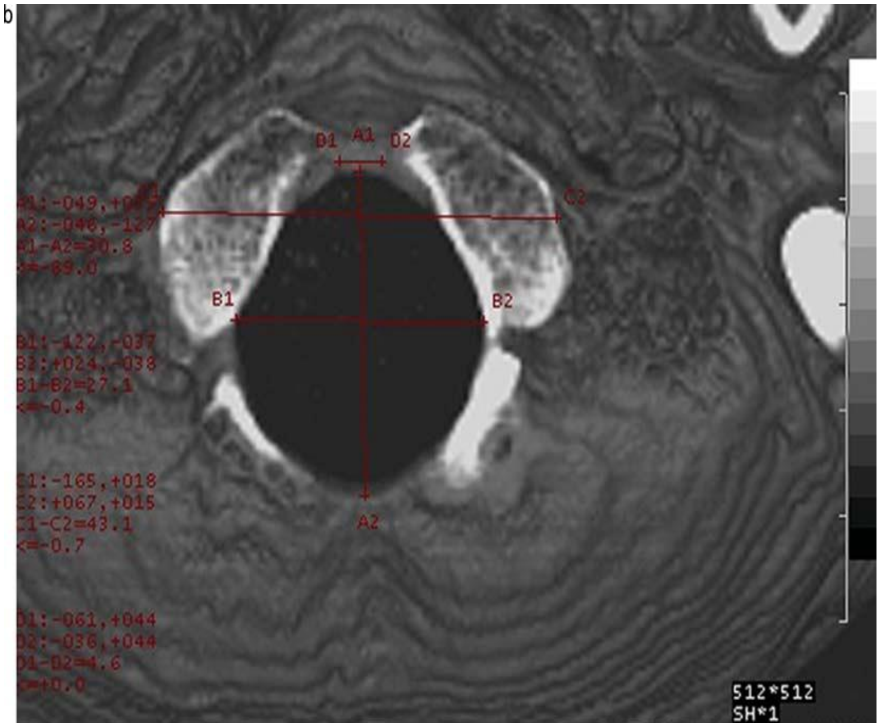

Image 1: measurement length (A1- A2, of foramen magnum Width (B1 – B2) and minimum inter condyle distance (D2- D2 (with maximum bicondyle distance. (C1- C2)

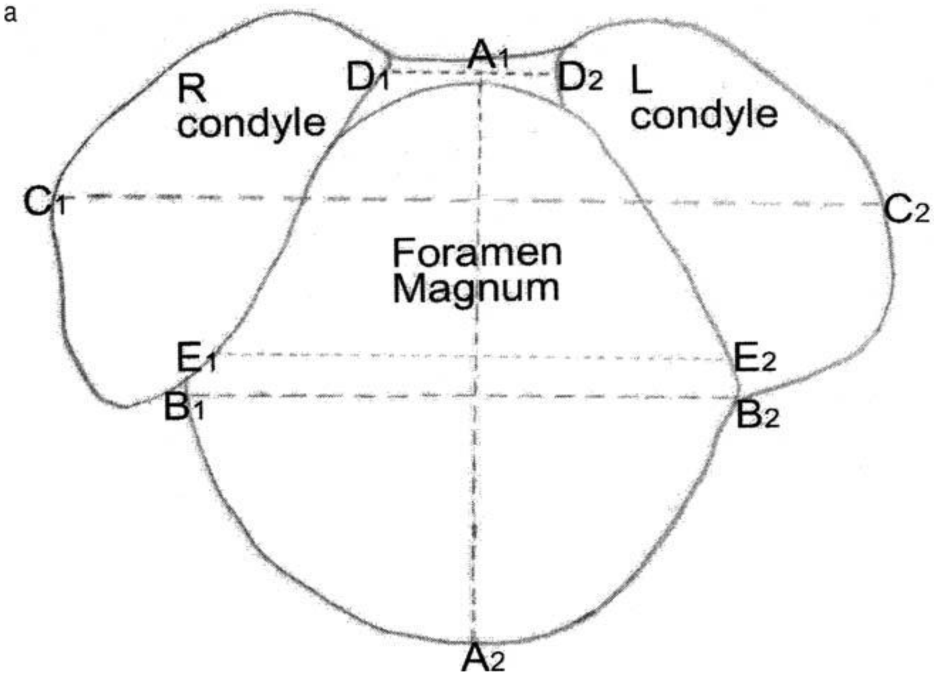

Image 2: measurement length (A1- A2, of foramen magnum Width (B1 – B2) and minimum inter condyle distance (D2- D2 (with maximum bicondyle distance. (C1- C2)

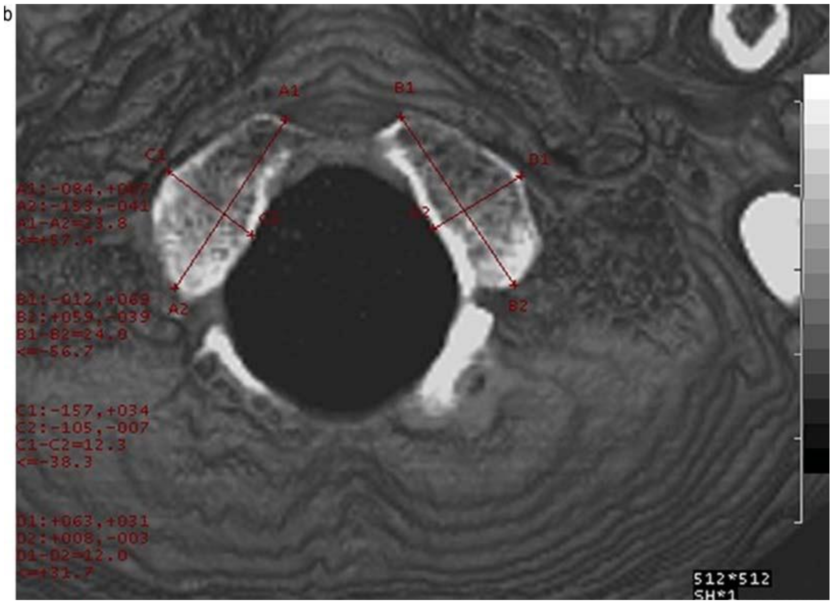

Image 3: Measurement of length and width of occipital condyles left for left and right (A1-A2, B1- B2, C1- C2 AND D1- D2)

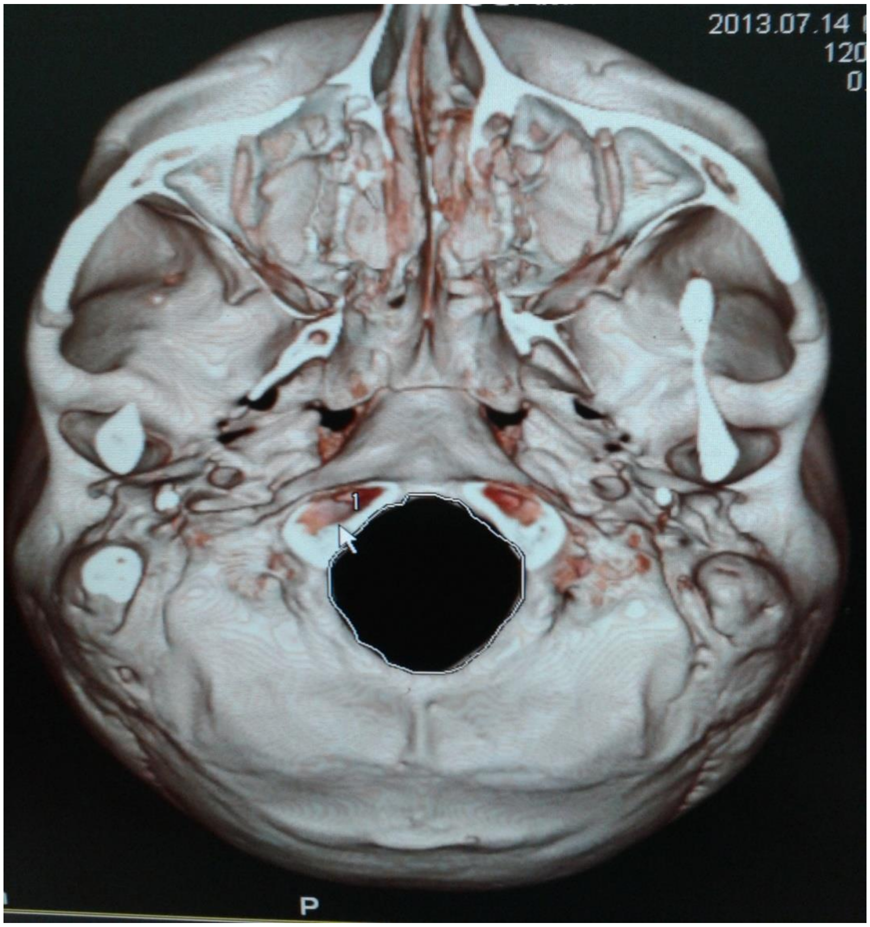

Image 4: 3D volume renderning technique, measuring area of foramen magnum,

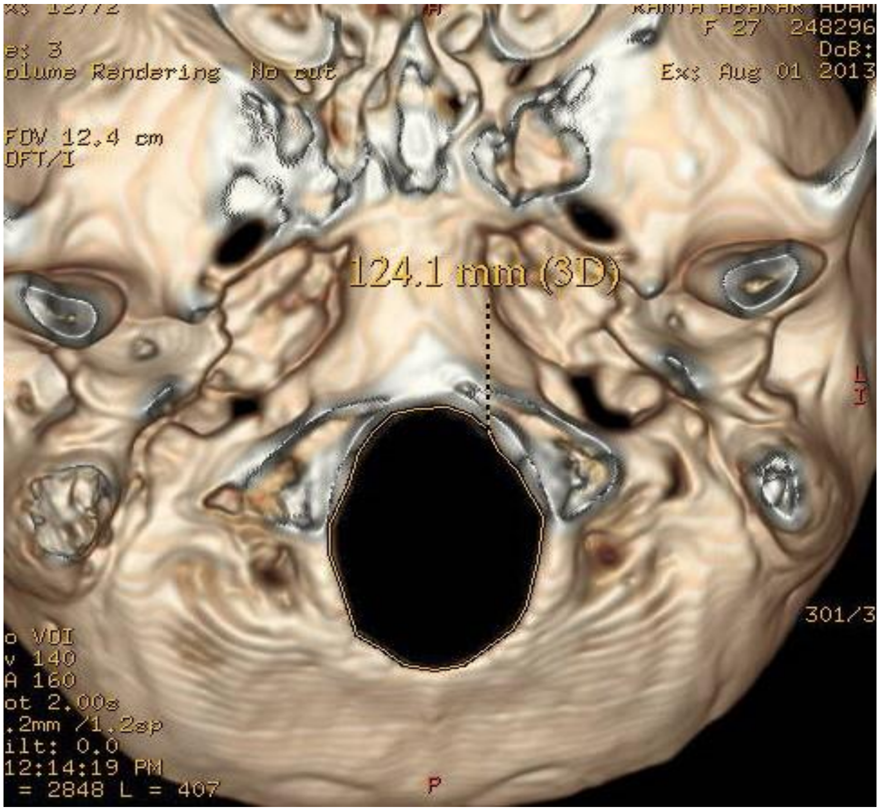

Image 5: 3D volume renderning technique, measuring cicumferenc of foramen magnum,

Image 6: Axial CT image measurement of transverse diameter of head.

Appendix: B

PATIENT DATA SHEET

AGE	GENDER	LRC	WRC	LLC	WLC	MIC	MnIC	MBC	LFM	WFM	TDH	SDH	AFM	CFM	SFM