"MORPHOMETRIC ANALYSIS OF HUMAN FORAMEN MAGNUM AND OCCIPITAL CONDYLES FOR SEX DETERMINATION IN DRY ADULT SKULLS OF BELGAUM DISTRICT- A CROSS SECTIONAL STUDY''

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LIST OF ABBREVATIONS

FM	-	Foramen magnum
OC	-	Occipital condyle
ELTICA	-	Extreme lateral trans-condylar approach
APD	-	Antero-posterior diameter
TD	-	Transverse diameter
M	-	Male
F	-	Female
i.e	-	that is
b/w	-	Between
Rt	-	Right
Lt	-	Left
mm	-	Millimeters
SD	-	Standard deviation
%	-	Percentage
&	-	And
n	-	Total number

ABSTRACT

Background and Objectives:

Anthropological study of bones play an important role in determining the sex, age and stature of an individual. Cranium is one of the good indicators for sexual dimorphism by morphometric and morphological analysis. The basi-cranium is protected by a large soft tissue mass comprising of muscles, tendons and ligaments. So in case of fragmentary human remains where no other skeletal remains are preserved the intact occipital region may prove useful for determining the gender. Hence this study was conducted to analyze morphometrically the foramen magnum and occipital condyles for sex determination in dry adult skulls of Belgaum district.

Methods:

This study was conducted on 100 foramina magna and 200 occipital condyles of 100 dry adult human skulls (50 male & 50 female) in the Department of Anatomy, J. N. Medical College, Belgaum. Morphological variants in the shape of foramen magnum and occipital condyles were noted. The antero-posterior diameter, transverse diameter and the indices of foramen magnum and occipital condyles (right and left) were measured using standard techniques. Students 't' test was employed for statistical analysis.

Results:

It was observed that 36% of foramina magna were oval shaped, 20% were tetragonal, 19% were egg shaped, 14% were hexagonal, 9% were pentagonal and 2% were round shaped. The incidence of oval and hexagonal shaped foramen magnum was higher in male skulls and that of egg-shaped, pentagonal & round foramen

magnum was higher in female skulls. The antero-posterior diameter of foramen magnum of male skulls was higher than the female skulls. No significant difference in the transverse diameter of foramen magnum of male and skulls was found. The foramen magnum index of male skulls was higher than the female skulls. 26% of right occipital condyles were oval shaped, 22% were S-shaped, 14% were triangular, 13% were kidney-shaped, 12% eight-shaped, 7% quadrangular, 2% round, 2% two-portioned and 2% were deformed. 23% of left occipital condyle were oval, 18% triangular, 18% eight-shaped, 18% S-shaped, 8% kidney shaped, 8% quadrangular, 3% deformed, 2% round and 2% were two-portioned. The antero-posterior diameter of occipital condyles (right and left) in male skulls was higher than the female skulls. There was no significant difference in the transverse diameter of occipital condyles (right and left) in male and female skulls. The occipital condyle index (right and left side) in male skulls was higher than the female skulls.

Interpretation and Conclusion:

The results of this study with respect to the morphometric analysis of foramen magnum and occipital condyle are in correlation with the results of various studies mentioned in the literature. This study also provides additional information on different shapes and indices of foramen magnum and occipital condyles and its relation to sex determination which is useful for anthropologists, morphologists & forensic experts and the neurosurgeons in dealing with lesions of posterior cranial fossa.

Keywords:

Morphometry, Foramen magnum, Occipital condyle, Antero-posterior diameter, Transverse diameter, Sex determination.

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INTRODUCTION

Anthropological study must be well versed in many areas in order to assess human remains properly. These areas of knowledge are human osteology, human growth and development and skeletal pathology. Each of these specialties is essential to construct a biological profile successfully. A biological profile includes age, sex, living stature and ancestory.[1] Anthropological knowledge of human osteology is one of the important steps in identification of this biological profile. Several studies have shown that cranium is an excellent indicator for sexual dimorphism by morphometric and morphological analysis, and it is probably the second best region of the skeleton, next to pelvis for this purpose.[2] The most accurate results in anthropometry are obtained when the entire skeleton is available for study, but in most of the forensic studies the skeleton is incomplete and this makes the sex determination difficult. It is therefore important to establish methods for determining sex from skeletal elements that are likely to survive and be recovered.[3] Due to thickness of the base of skull and its relatively protected anatomical position, this area of skull tends to withstand both physical insults and inhumation more successfully than any other areas of cranium.[4] The cranial base and cranio-vertebral junction have been studied on several different occasions to determine the sexual variations and its relation to surgical approach. The cranial base of the skull is a complex structure with several different significant bony landmarks which are useful in anthropology and to determine abnormalities in basal region. Anomalies of cranio-vertebral junction are important not only to anatomists but also to clinicians because many of these deformities produce clinical symptoms. The occipital bone is the main site of this variations.[5] The skull base, more so the occipital bone is thus used in procedures to determine sex in forensic science and anthropology. From qualitative point of view, the roughness of nuchal lines and the

prominence of the external occipital protuberance are good indicators for the diagnosis of sex.[6] On the other hand, from quantitative point of view, the indices obtained from dimensions of foramen magnum and occipital condyles are reported to be useful in determining the sex, particularly with incomplete skeleton or fractured cranial bones.[7]

Base of the skull extends from the upper incisor teeth to the superior nuchal line of the occipital bone posteriorly. This region contains many of the important foramina through which structures enter and exit the cranial cavity. The word foramen is derived from the Latin word ‘FORO’ (to pierce) which means an aperture or perforation through a bone or membranous structure. Foramen magnum is the largest foramen in the skull. It lies in an antero-median position and leads into the posterior cranial fossa. It is wider behind with antero-posterior diameter being the greatest diameter. Foramen magnum transmits many important structures like the lower end of the medulla oblongata, meninges, vertebral arteries, spinal arteries and spinal accessory nerve. The apical ligament of dens, vertical band of cruciate ligament and the tectorial membrane pass through it to attach to the internal basiocciput.[8] Foramen magnum is a three dimensional aperture within the basal central region of the skull. The anterior border of the foramen magnum is formed by basilar process of the occipital bone, the lateral border by the left and right ex-occipitalis and posterior border is formed by the supra occipital part of the occipital bone.[9]

A convex condylar process is present on either side of foramen magnum called occipital condyle. Each occipital condyle is oval in outline and is oriented obliquely so that its anterior end lies nearer the midline than its posterior end. It is markedly convex antero-posteriorly than transversely, and its medial aspect is roughened by ligamentous attachments.[8]

The basi-cranium is protected by a large soft tissue mass comprising of muscles, tendons and ligaments. So in cases of fragmentary human remains compromised by different types of inhumation or physical insult like explosion, fire, trauma, the intact occipital region (foramen magnum and occipital condyles) may prove useful for determining the gender.[10]

Dimensions of the foramen magnum are clinically important because the vital structures that pass through it may suffer compression. Also it is reported that the etiology of cerebellar tonsillar herniation is closely related to the size of foramen magnum. Various studies done on foramen magnum have drawn attention to the fact that the size of foramen magnum is larger in males in comparison to females.[11] Catalina-Herrera (1987) indicated that the sagittal and transverse dimensions of the foramen magnum were significantly higher in men's skulls.[12] Zaidi & Dayal (1988) classified a sample of Indian skulls according to the shape and dimensions of the foramen magnum, reporting differences between the skulls of male and female.[13] In another study, Günay & Altinkök (2000) examined the usefulness of determining the dimensions of the foramen magnum in the diagnosis of sex, and noted that the diameters were of some use, while the total area was not a good indicator.[14] Uysal et al. (2005) reported sexual dimorphism by analyzing the dimensions of the foramen magnum in 3D computed tomography with 81% accuracy in determining the sex .[15]

The occipital condyles represent the cranial portion of the cranio-cervical junction. The space-occupying lesion ventral to the spinal canal at the level of the foramen magnum can be reached using a ventral or dorsal approach. Owing to the difficulties and high rate of morbidity associated with ventral approaches, the dorsal approach is preferred to reach the space occupying lesion ventral to the spinal cord at the cranio-vertebral junction. Partial resection of the occipital condyle as made during

trans-condylar surgical approaches is an important step for access to the ventral and ventro lateral foramen magnum.[16, 17]

The occipital condyle measurements are helpful for the neurosurgeons for performing lateral transcondylar approaches for reaching the lesions lying ventral and ventrolateral to foramen magnum because it improves the surgical exposure to the ventrolateral clivus and anterior foramen magnum. The advantage of this approach is that the procedure enhances exposure of the brain stem while markedly reducing the need for brain retraction.[18] Although there is still controversy about the extent of resection of occipital condyles, most authors agree with that the 1/3rd condylar removal does not affect the atlanto-occipital stability. However the extensive condylar resection may result in craniocervical instability.[8]

The extreme lateral trans-condylar and trans-jugular approach (ELTCA) offers a very lateral view of the structures located at the lower clival area and craniovertebral junction. This lateral cranial base approach permits a controlled resection of the lesions in this area through direct view of the vertebral artery, lower cranial nerves, and the interface between the lesion and the brainstem. It is also possible to achieve an occiput-to-C1-C3 fusion during the same operation, if necessary. Furthermore, because there is a well vascularized muscle covering of this area, reconstruction of the operative field is perfect and infectious or vascular complications in the postoperative period often can be managed with good results. Surgical anatomy and morphometry of the occipital condyles (OC) is thus critical for ELTCA.[19]

A three dimensional understanding of the anatomy is crucially important for any kind of surgery in cranio-vertebral region. Various authors have reported incidence of vertebral artery injury during transarticular screw (occipital screw)

implementation and during lateral approaches to the foramen magnum. The injury to the artery during surgery can lead to catastrophic intra-operative bleeding and compromise the blood flow. This can lead to unpredictable neurological deficits which will depend on the adequacy of blood flow from contralateral vertebral artery.[20, 21]

There is scanty information about the detailed morphometry in sexual dimorphism based on foramen magnum and occipital condyles in South Indian population especially in Northren Karnataka region. Hence there is a need for more knowledge about morphometric variations of foramen magnum and occipital condyles and its relation to sex in the region of Belgaum district.

OBJECTIVES

Primary: To analyse foramen magnum and occipital condyles morphometrically for sex determination.

Secondary: To study the surgical importance of foramen magnum and occipital condyles.

REVIEW OF LITERATURE

Evolution of cranial base

The interesting and complex evolution of the cranial base is well represented in the fossil record.[22] Nevell and Wood (2008) extensively studied hominin cranial bases in order to document the changes that occurred as a result of evolution.[23] They stated that, "the cranial base undergoes significant change within the hominin clade".[22] The entire cranial base underwent change from our early hominin ancestors to modern H. sapiens. In order for one cranial structure to change during evolution, the different bones of the cranial base flex to allow for the required expansion.[24] Some of the osteological features that have undergone evolutionary changes include: the petrous portion, the tympanic bone, the squamosal portion of the temporal bone, the postglenoid process and the foramen magnum.[22,23,25] Nevell and Wood found H. sapiens were the first species to have an unossified petrous apex, while antecedent hominins (P. aethiopicus, P. boisei, A. africanus and H. habilis) possessed an ossified petrous apex. The tubular tympanic bone in Pan and early Homo is also significantly different from the tympanic bones that modern humans possess.[23]

Bruner (2008) compared the endocranial casts (endocasts) of modern humans and Neanderthals using geometric superimposition to examine the differences between the two groups and found that substantial differences exist between the two groups. He stated "bulging of the parietal and posterior cerebellar areas" was among the biggest differences between modern humans and Neanderthals. He suggested these changes are a result of the evolution for advanced cerebral complexity in modern humans.[26] Finally, the foramen magnum has also undergone significant change throughout hominin history. While it is unusual for foramen magnum to be preserved on fossilized remains, techniques have been developed to determine the

original location. Triangulation of osteological landmarks around the occipital condyles (basion, nasion, and opisthocranion) can provide insight as to the original location of the foramen magnum.[27] Once this location was identified, paleoanthropologists have found no backward migration of the foramen magnum position throughout evolution. In fact, the foramen magnum is situated more anteriorly in hominins than in apes.[24] However, it is situated posteriorly in early hominins compared to modern humans.[22,23]

Normal anatomy of Occipital bone

Occipital is derived from the Greek word : 'OB' meaning back and 'CAPUT' meaning head and thus referring to the back of head. Occipital bone forms much of the back and base of cranium. It is trapezoid in shape, concave internally and encloses foramen magnum. It has four parts namely, basilar (basioccipital) which is quadrilateral part in front of foramen magnum; squamous which is expanded plate posterior superior to foramen magnum and lateral (condylar) part on each side of foramen magnum. On the inferior surfaces of lateral condylar part, a pair of occipital condyles are present for articulation with the superior articular facets of atlas vertebra.[8]

Foramen magnum

Foramen magnum is derived from a Latin word 'FORO' means to pierce or aperture and 'MAGNUM' means large, thus meaning the largest aperture in skull. Foramen magnum is situated in an antero-median position, is oval in shape, being wider behind with its antero-posterior diameter being the greatest diameter.[8] The foramen magnum lies one third in front and two third behind the line formed by joining tips of mastoid processes.[28] Foramen magnum is the most conspicuous feature of the cranial base. Four parts of occipital bones are arranged around it.

The major structures passing through this large foramen are medulla oblongata with the meninges, vertebral arteries, anterior and posterior spinal arteries and accessory nerves. The fibrous duramater is attached to the margins of foramen magnum as it sweeps down from the posterior cranial fossa. Within the tube of duramater the lower medulla oblongata with the anterior and posterior spinal arteries and veins, the vertebral arteries and cervical roots of accessory nerves traverse the foramen in the subarachnoid space. Meningeal branches of the vertebral artery and communicating veins from the occipital sinuses to the internal vertebral venous plexus lie outside fibrous dura, between it and the periosteum of foramen magnum. Anteriorly the margin of the foramen gives attachment to the ligaments sweeping up from axis. Adherent to the dura is the membrana tectoria and in front of this is the vertical limb of cruciform ligament; in front again are the apical and pair of alar ligaments of the odontoid process. The alar ligaments are attached to a triangular area, medial to the anterior pole of occipital condyle. The anterior atlanto-occipital membrane is attached to the ridge that joins the anterior poles of occipital condyles. The posterior atlanto occipital membrane is attached to the posterior margin of foramen magnum. Basion is the middle point of the anterior margin of foramen magnum. Opisthion is middle point of posterior margin of foramen magnum.[8]

Occipital condyles

Each occipital condyle is noriented obliquely so that its anterior end lies nearer the midline. It is markedly convex anteroposteriorly, less so transversely, and its medial aspect is roughened by ligamentous attachment. The hypoglossal canal is directed laterally and slightly forwards, traverses each condyle and transmits hypoglossal nerve, a meningeal branch of ascending pharyngeal artery and emissary

vein from basilar venous plexus. A depression condylar fossa lies immediately posterior to the condyle and sometimes contains a posterior condylar canal for an emissary vein from sigmoid sinus.[8] The condyles are oval or reniform, in their long axes converging anteromedially. They are occasionally constricted and a condyle may be in two parts. Two thirds of occipital condyle lies in front of the line formed by joining tips of mastoid process and one third behind it.[28]

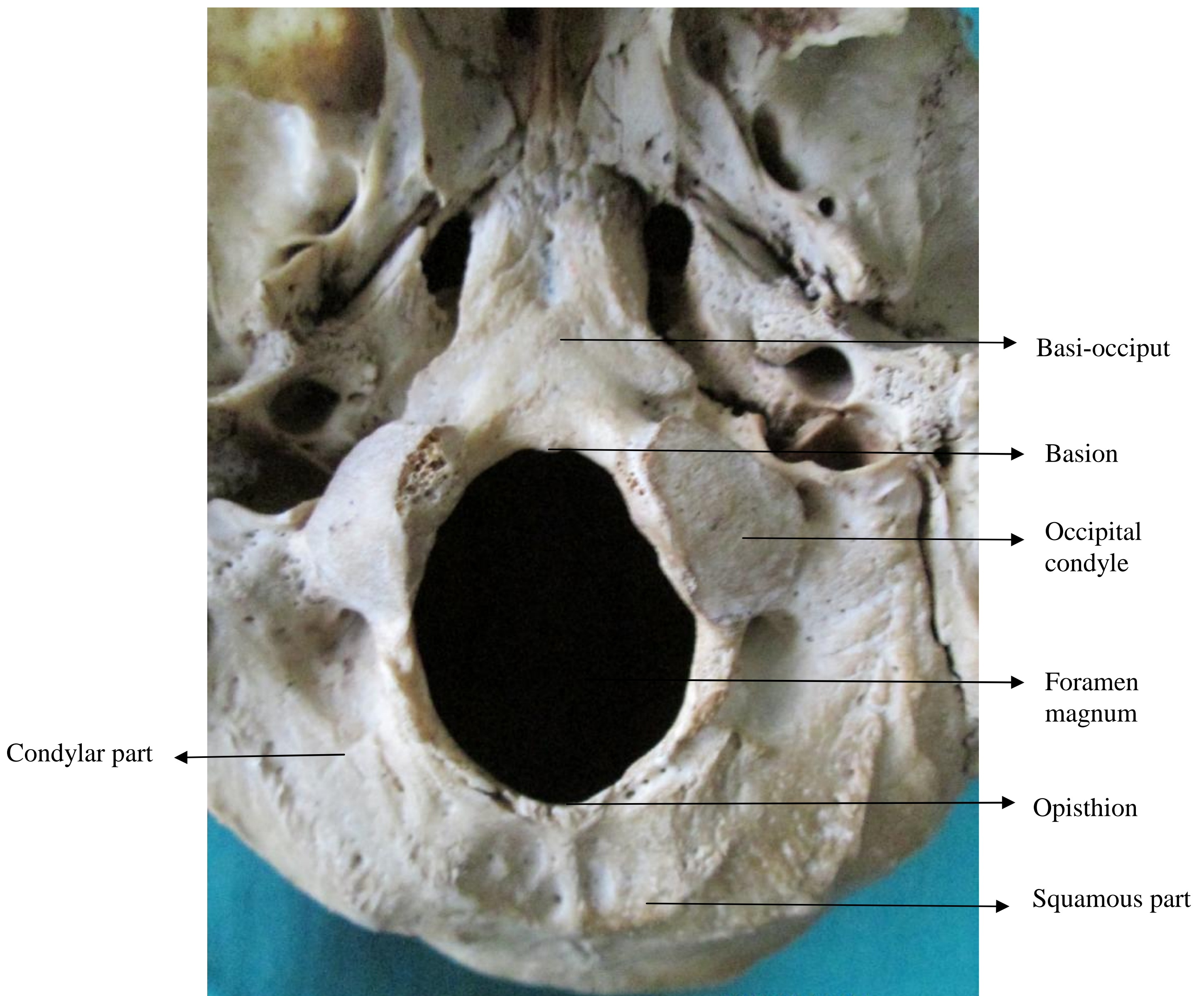


FIGURE 1: Base of skull, exterior view showing foramen magnum and occipital condyles

The articulation between the cranium and the vertebral column is specialized to provide wider range of movement than rest of the axial skeleton. It functions like universal joint which permits horizontal and vertical scanning movement and is adapted for eye-head co-ordination. The atlanto-occipital joint is an ellipsoid synovial joint between the convex occipital condyle and the concave facet on the lateral mass of atlas. Both surfaces are covered by articular cartilage. The factors maintaining stability include the fibrous capsule, atlanto-occipital membrane, the shape of articulating surface, the ligaments connecting the axis and the occipital bones, the ligamentum nuchae and posterior neck muscles. The long axis of the joints runs anteromedially. Taken together with their articular curvature, this means that the joints act as one around both transverse and anteroposterior axes of movement, but not about vertical axis. The main movement is flexion, with few degrees of lateral flexion and rotation.[8]

Development

The skull has two distinct portions: the neurocranium and the viscerocranium. The bones of the skull are developed from the mesenchyme. Before the osseous state is reached, it passes through blastemal and cartilaginous stage. The neurocranium develops from the paraxial mesenchyme in the head i.e. the first five somites and the unsegmented somatomeres rostral to the first somite. The viscerocranium develops from the pharyngeal arches.[29]

The blastemal skull (desmocranium) begins to appear at the end of first month as a condensation and thickening of the mesenchyme which surrounds the developing brain, forming localized masses which are the earliest distinguishable cranial elements. The first masses evident are in the occipital region, outlining the basilar (ventral) part of the occipital bone. These form an occipital plate from

which two extensions grow laterally and spread to complete the foramen around each hypoglossal nerve.[29]

The development of the cranial base begins during early fetal growth as a cartilaginous mass with multiple centers of ossification. The foramen magnum alone is one such center. The growth of the cranial base during fetal development is most rapid between the “14th and 32nd week”.[25] Basal regions of the skull are initially preformed in cartilage which may be named parachordal, hypophyseal, and interorbitonasal region. The parachordal cartilage is developed from the paraxial mesenchyme related to the cranial end of the notochord and the first five (occipital) somites; caudally it exhibits traces of four primitive segments separated by the roots of hypoglossal nerve. It is notable that the region of fusion between the rostral part of the occipital bone and the portion of parachordal plate that is of somatomeric origin corresponds to the spheno-occipital synchondrosis, which is the site of growth for up to twenty years of age. The hypophyseal cartilage ossifies to form the post sphenoid part of sphenoid bone. The interorbitonasal cartilage is perhaps to be equated with the trabeculae cranii of the lower vertebrates and is usually known as the trabecular cartilage. The trabeculae cranii and the ethmoidal complex are of neural crest origin.[29]

In human embryo the cranial chondrification begins in the second month; the cartilaginous foci first appear in the occipital plate, one on each side of the notochord (the parachordal cartilages) these later fuse at the end of seventh week. The bones of the cranial base which are preformed in cartilage are:

- The occipital (excepting the upper parts of its squama),
- The petromastoid part of the temporal,
- The body, lesser wings and roots of greater wings of the sphenoids

- The ethmoid.

Ossification commences before the chondrocranium has fully developed. At the birth unossified chondrocranium still persists at:

- The alae, lateral nasal and septum of the nose
- The spheno-ethmoidal junction
- The speno-occipital and spheno- petrous junctions
- The apex of the petrous bone (foramen lacerum)
- Between ossifying elements of the sphenoid bone & between elements of the occipital bone.[29]

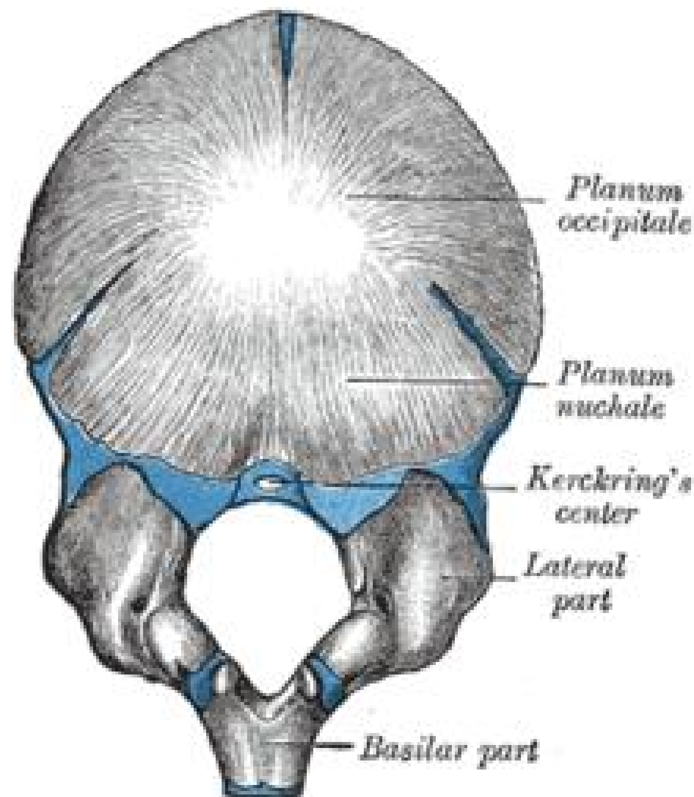
Ossification of occipital bone

Above the highest nuchal lines the squamous part is developed in fibrous membrane, and is ossified from two centers, one on each side from about second fetal month. Below the highest nuchal lines, the squamous part ossifies from two centers, appearing in the seventh week and soon uniting. The remainder of cartilage of occipital bone is ossified from five centers, two each for the lateral parts during eighth week and one for the basilar part commencing around sixth week. An occasional center (Kerckring) appears in the posterior margin of the foramen magnum during the fifth month; this forms a separate ossicle (sometimes double) which unites with the rest of the squama before birth.[8]

At birth

At birth the occipital bone consist of four separate parts, a basilar part, two lateral part & a squamous part all joined by cartilage and forming a ring around the foramen magnum.[8]

FIGURE 2 : Showing occipital bone at birth



Postnatal development

The two components of squamous part unite in the third postnatal month but the line of union is recognizable at birth. The squamous part above the highest nuchal lines may remain separate as the interparietal bone.[8] The squama fuses with condylar parts at the end of the second year. By sixth year bone is a single entity. The fusion is sometimes incomplete and the condyle may then possess two separate articular surfaces.[29]

Clinical Anatomy

Abnormalities affecting occipital bone in the foramen magnum region can be congenital, neoplastic, inflammatory, traumatic, occurring either alone or in combination.

Congenital abnormalities

In humans, cranial half of first cervical sclerotome becomes assimilated into occipital condyles and also forms tip of dens. If it is incompletely assimilated into the occiput various expressions of occipital vertebra occurs. On the other hand if normal segmentation fails to occur, it results in atlantooccipital fusion. Thus occipital vertebra and atlantooccipital fusion represents opposite ends of a continuous spectrum.[30] A variety of congenital anomalies of craniovertebral junction exists, that may occurr singly or in combination in the same individual. Congenital anomalies and malformations of the craniocervical junction include:

A. Malformations of the occipital bone

1. Manifestations of the occipital vertebra

a. Clivus segmentations

b. Remnants around the foramen magnum

c. Atlas variants

d. Dens segmentation anomalies

2. Basilar invagination

3. Condylar hypoplasia

4. Assimilation of the atlas.

B. Malformations of the atlas

1. Assimilation of the atlas

2. Atlantoaxialfusion

3. Aplasia of the atlas arches.[31]

Atlanto Occipital Fusion/ Occipitalization of Atlas

Fusion of atlas with occiput may be unilateral or bilateral. When bilateral, fusion may not be symmetrical. It may occur as an isolated anomaly or with other vertebral abnormalities. It results from failure of segmentation and separation of the most caudal occipital sclerotome and the first cervical sclerotome during the first few weeks of fetal life.[32] Varying degrees of bony fusion between atlas and occiput described are complete and partial assimilation.[33,34] In a majority of cases, assimilation occurs between the anterior arch of the atlas and the anterior rim of the foramen magnum and is associated with other skeletal malformations such as basilar invagination, occipital vertebra, spina bifida of atlas, or fusion of the second and third cervical vertebrae (Klippel-Feil syndrome).[35] The incidence of atlanto-occipital fusion ranges from 0.14 to 0.75% of the population, with both sexes being equally affected.[32] Occipitalization of atlas is associated with abnormalities as a result of narrowing of the foramen magnum, compressing the spinal cord or the brain stem.[36,37] However, this anatomical variation may often go unnoticed but, incidentally, reveals its presence as a radiological, operative or autopsy finding.[38]

Arnold- Chiari Malformation

Arnold-Chiari malformation comprises of hind brain abnormalities ranging from simple herniation of the cerebellar tonsils through the foramen magnum to complete agenesis of cerebellum. Decreased skull base height and decrease volume in the posterior fossa are structural anomalies associated with Arnold-Chiari malformation. Foramen magnum decompression (posterior approach), excision of

posterior arch of atlas and lax duraplasty are the surgical procedures involved in the treatment of Arnold-chiari malformation.[39]

Basilar Invagination

This is a primary developmental defect of bones at the base of skull around margin of foramen magnum. The floor of the skull appears to be indented by upper cervical spine and therefore the tip of odontoid is more cephalad protruding into foramen magnum.[40] Basilar invagination accounts to 33% of Carniovertebral junction anomalies.[41] Other anomalies associated with basilar invagination include Arnold-Chiari malformation, occipitalisation of atlas and fused cervical vertebrae.[40]

Neoplastic Diseases

Tumors arising in the region of foramen magnum are divided by Cushing and Eisenhardt into cranio-spinal group that arises above and grow downwards towards the foramen magnum and spino-cranial group that grows upwards towards the foramen magnum. [42]

Inflammatory Diseases

Various inflammatory diseases can cause erosion and destruction of carnio-vertebral junction. The common diseases are

- Rheumatoid arthritis
- Osteoarthritis
- Osteomyelitis.[43]

Trauma

In about 80% of the cases, injury in the region of foramen magnum by high-velocity motor vehicle accidents can cause the following:

1 . Occipital condyle fractures.

It was first described by Bell in 1817.

Anderson and Montesano classified these fractures into three types.

- Type I - Occipital condyle fracture is an impacted fracture resulting from axial loading and is typically stable. The fragments are generally comminuted with minimal displacement.
- Type II - Occipital condyle fracture occur as part of a basilar skull fracture resulting from a direct blow on the skull. These fractures are also stable because of the alar ligaments and membrane.
- Type III - Occipital condyle fractures; however, are considered potentially unstable as a result of lateral flexion or rotatory forces pulling the alar ligaments. Computed Tomography Scan remains the diagnostic procedure of choice and helps to direct intracerebral complications such as bone displacement or hemorrhage. The correct and early diagnosis of occipital condyle fractures is crucial because delayed nerve palsies can develop even if the fracture initially is associated with no cranial nerve deficits. Although external rigid fixation might suffice, surgical stabilization of the fractured occipital condyle should be considered for patients with unstable (Type III) fractures. For stable fractures (Type I and II) immobilization in a hard collar is the treatment of choice.[44]

2. Traumatic atlanto-occipital dislocations.
3. Atlanto-axial rotatory subluxations.
4. Fractures of atlas: anterior arch & posterior arch fractures ,Jefferson fractures.
5. Hangman’s fracture
6. Odontoid fractures.[40]

Morphometric study of foramen magnum and occipital condyle

Many studies have been performed on the cranial base to determine whether or not sexual dimorphism can be assessed. Teixeria (1982) published an initial study on estimation of sex based on the size of the foramen magnum. His findings based on a small sample of 40 adult (20 males, 20 females) Brazilian skulls indicated that if the area of the foramen magnum was 963 mm^2 or larger, it was a male skull and if it was 805 mm^2 or less it was female skull. He however acknowledges that even though his study shows that males have larger foramen magnum than females ,his sample size is far too small to make such an allegation and a larger sample size needs to be tested.[45] 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.[46]

Many other studies have been conducted on different populations with respect to sexual dimorphism in foramen magnum and occipital condyles using different statistical considerations. Gunay and Altinkok (2000) set out to do a follow up on the method used by Fatteh, Teixeira and Catalina-Herrera. The sample population used were Turkish Adult skulls consisting of 170 males and 39 females skulls. The longest and the shortest diameter of the foramen magnum was measured; the area within was determined using the mean of the diameters as the radius for calculation. They found out that the dimensions of foramen magum mainly the antero-posterior and the transverse diameters are useful in sex determination but the total area of foramen magnum is not a good indicator for sex determination.[14]

Murshed (2003) used Computerized Tomography to evaluate the radiological measurements of foramen magnum and their relation to sex and also to

note variations in the shape of foramen magnum. 110 normal subjects (57 males and 53 females) were examined in the study. According to the study the anteroposterior diameter was found to be 37.2 ± 3.43 mm in males and 34.6 ± 3.16 mm in females. The transverse diameter was 31.6 ± 2.99 mm in males and 29.3 ± 2.19 mm in females. Different type of foramen magnum shapes identified were oval, egg, round, tetragonal, pentagonal, hexagonal, irregular types A and B. He finally concluded that foramen magnum is larger in males and the different shapes of foramen magnum are controversial for sex determination.[47]

Sait-et-al (2003), have analysed the occipital condyles in detail. They studied 404 occipital condyles of 202 dry skulls morphomertrically. They measured 27 parameters including the length , width , height of the occipital condyle,the distance between the occipital condyle and hypoglossal canal,as well as some important condyle related angles. The average length, width and height of occipital condyle were found to be 23.4mm, 10.6mm, 9.2mm respectively. Variation in the shape of the occipital condyles were noted and classified into 8 types as follows.

- Type 1- oval like condyle
- Type 2- kidney like condyle
- Type 3- S like condyle
- Type 4- 8 like condyle
- Type 5- triangle like condyle
- Type 6- Ring like condyle
- Type 7- Two portioned condyle
- Type 8- Deformed condyle

Most common type was found to be type 1 (50%) whereas most unusual type was type 7 (0.8%). The shape may affect the amount of condylectomy. It was stated that

among different types of occipital condyle, the triangle type, the deformed type, kidney like condyle may require extensive condylectomy to reach the ventral lesions. Authors have also classified occipital condyles according to its length.

- Type 1- Short (length less than 20 mm)
- Type 2- Moderate (length 20- 26 mm)
- Type 3- Long (length more than 26 mm)

Occipital condyle was found to be short in 35 condyles (8.6%), moderate in 312 (77.2%) and long in 57 (14.1%).[48]

N. Muthukumar et-al in 2005 did a similar morphometric study of foramen magnum and occipital condyle, comprising of 50 dry skull. The average anteroposterior diameter of foramen magnum was 33.3 mm and width was 27.9 mm. The average anteroposterior length of the occipital condyle was found to be 23.6mm and transverse diameter was 14.72mm. The condylar foramen was absent on the right side in 4 skulls and on left side in 16 skulls. It was reported that when foramen magnum index was > 1.2, the foramen was ovoid. 46 % of the skulls exhibited an ovoid foramen magnum. In 20% of the skulls the occipital condyle protruded significantly into the foramen magnum. From this study authors concluded that occipital condyle can be safely drilled for a distance of 12 mm from the posterior margin before encountering the hypoglossal canal.[49] Both the above studies however did not take into consideration the co-relation between morphometry and sexual dimorphism.

Manoel C et-al (2009) evaluated 215 Brazilian skulls (139 males and 76 females) between the age of 20 to 80yrs using a digital caliper . The length and width of foramen magnum were measured. The mean length of foramen magnum in male skulls was 35.7 ± 0.29 mm and 35.1 ± 0.33 in females. The mean width of

foramen magnum in male skulls was 30.3 + 0.20 and 29.4 + 0.23 in females.[50] In the similar year Suazo et al studied 211 skulls (144 male and 71 female skulls) to assess the presence of sexual dimorphism in foramen magnum size. The maximum anteroposterior diameter in male was 36.5 ± 2.6 mm and in females it was 35.6 ± 2.5 mm. The maximum transverse diameter of foramen magnum in male was 30.6 ± 2.5 mm and 29.5 ± mm 1.9 in females.[51] Both these studies concluded that foramen magnum dimensions is of limited practical value and should be supplemented with qualitative indicators of sexual dimorphism in the occipital bones to improve the accuracy in sex diagnosis.

A study was done by Raghvendra Babu et-al (2011) on 230 skulls (146 males and 84 females) of South Indian population. They included antero-posterior diameter, transverse diameter and area of foramen magnum for sex determination. The mean length , breadth and area of foramen magnum in males were 36.4 mm, 32.93 mm and 939.50 mm^2 respectively whereas that of females were 31.62mm, 28.32 mm and 700.5 mm^2 respectively. The authors therefore inferred that the measurements were significantly higher in males as compared to females.[52]

Gagandeep et-al studied 50 dry adult human skull (26 males and 24 females). They considered parameters like length, width, maximum bicondylar diameter, minimum distance between occipital condyles, external hypoglossal canal distance and area of foramen magnum. The mean length of foramen magnum in males and in females was 33.54 ± 2.30 mm and 32.31 ± 3.24 mm repectively whereas the mean breadth of foramen magnum in males and in females was 27.77 ± 2.10 mm and 32.31 ± 3.24 mm respectively. The results clearly indicated that males displayed larger mean values than females for all measured variables. However, statistically significant differences between sexes was observed only for a sigle measurement of maximum

bicondylar length.[53] Radhakrishna et-al (2012) studied 100 skulls (55 males and 45 females) for the anteroposterior diameter (APD), transverse diameter (TD) and the shape of foramen magnum using vernier caliper. Results suggested that the anterioposterior diameter was significantly higher in males and commonest shape of foramen magnum was oval followed by round, tetragonal and pentagonal in both males and females.[54]

A recent study was done by Santosh et-al (2013) on 101 dry South Indian human skulls to determine the antero-posterior diameter (APD), the transverse (TD) of foramen magnum and its relation to sex. The mean APD of foramen magnum in males and females was 34.37 mm and 33.80 mm respectively. The mean TD of foramen magnum in males was 28.98mm and in females was 27.90 mm thus concluding that significant sexual dimorphism is present in the foramen magnum of South Indian population.[55]

A review of literature reveals scanty information in sexual dimorphism based on foramen magnum and occipital condyles in South Indian population. Therefore, the present study has been undertaken to augment the data in this regard, since this type of study has not been done so far in Northern Karnataka region.

METHODOLOGY

Material:

To carry out this study, 100 dry adult human skulls (50 males and 50 females) available in the Departments of Anatomy and Forensic medicine, Jawaharlal Nehru Medical College, Belgaum were used.

Study design: Cross sectional study.

Duration of study: 2 years.

Sample size: 100 dry adult human skulls. Sample size was based on the number of dry adult human skulls available during the course of study period.

Inclusion criteria: Dried, complete, adult human skulls of known sex were included.

Exclusion criteria: Fractured, mutilated skulls with gross deformity were excluded.

The following instruments were used for the study:

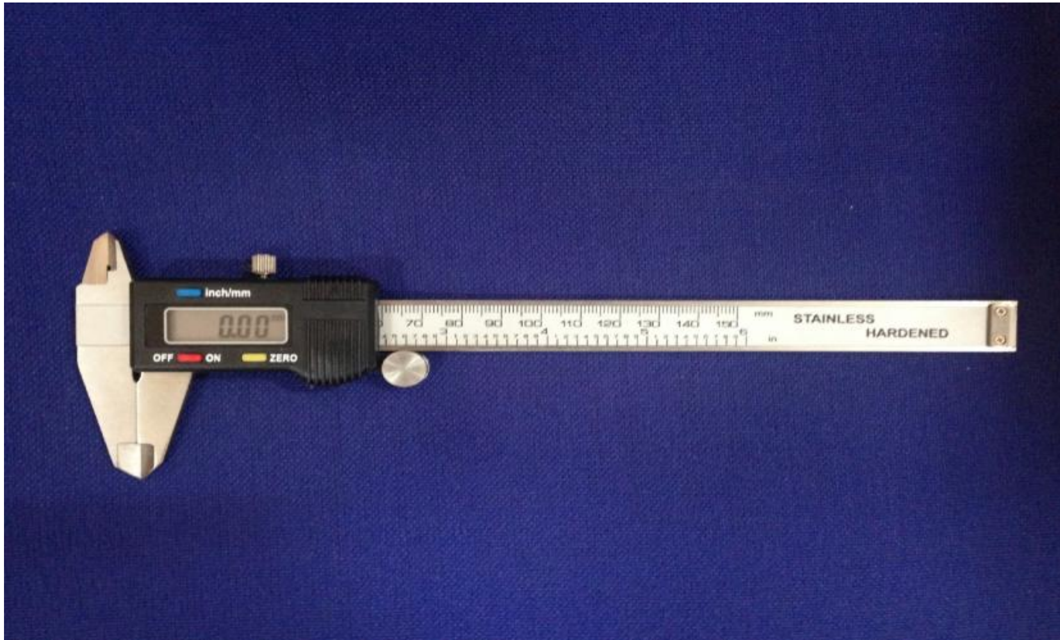
1. Digital Vernier caliper (of accuracy 0.01 mm)
2. Coloured marker pens

Method:

The study was conducted on 100 dry adult human skulls (50 males and 50 females). All measurements were recorded using digital vernier caliper. The shape of foramen magnum and occipital condyles were identified and noted down. Measurements were based on following bony landmarks on the skull:

- **Basion:** Midpoint on the anterior margin of the foramen magnum.
- **Opisthion:** Midpoint on the posterior margin of the foramen magnum.
- **Anterior tip of occipital condyle.**
- **Posterior tip of occipital condyle.**

Figure 3 : Digital Vernier caliper.

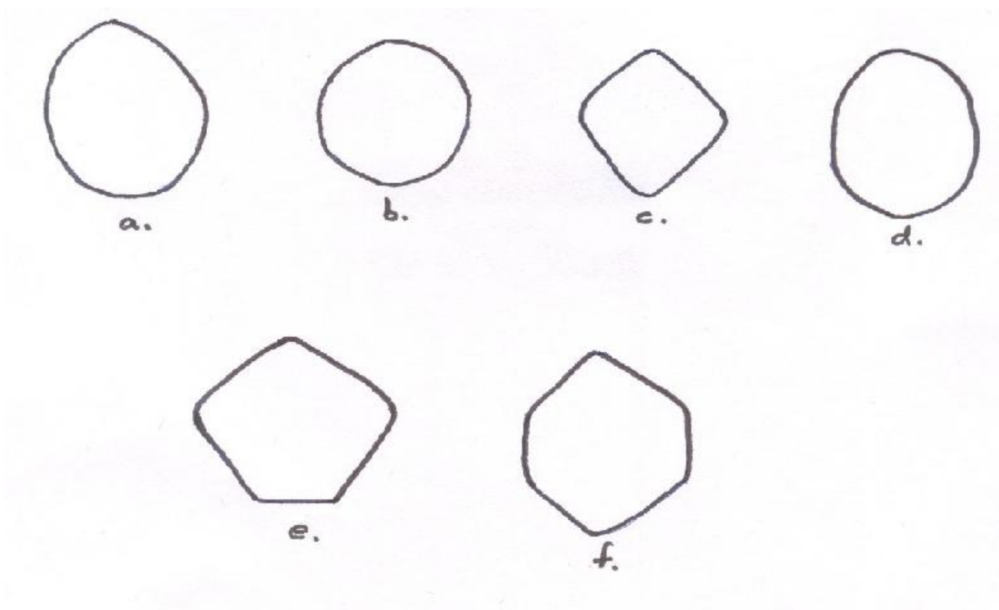


The following parameters were recorded:

1. Shape of foramen magnum.

Different shapes of foramen magnum observed are shown in the figure 4.

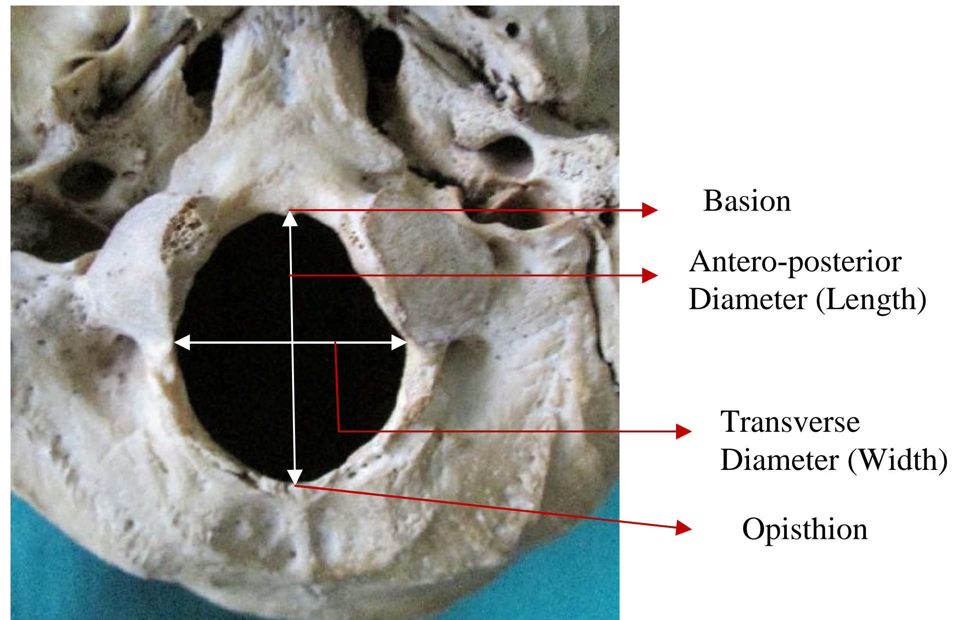
Figure 4: Different shapes of foramen magnum



a-Egg shaped , **b-**Round , **c-**Tetragonal , **d-**Oval , **e-**Pentagonal , **f-**Hexagonal

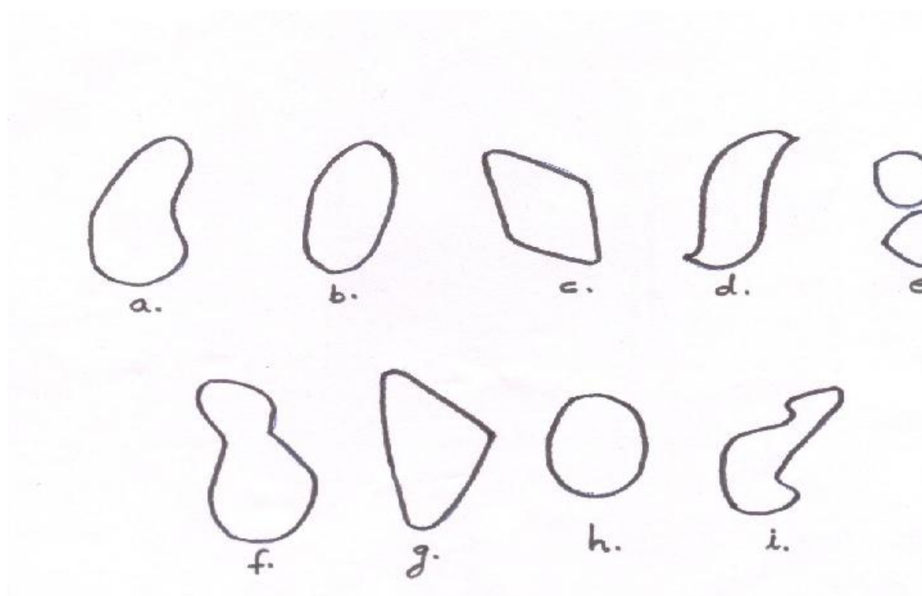
2. Antero-posterior diameter of foramen magnum: between Basion & Opisthion.
3. Transverse diameter of foramen magnum: Measured at right angles to antero-posterior diameter.

Figure 5: Measurements of foramen magnum



4. Shape of the occipital condyles (Right and Left).

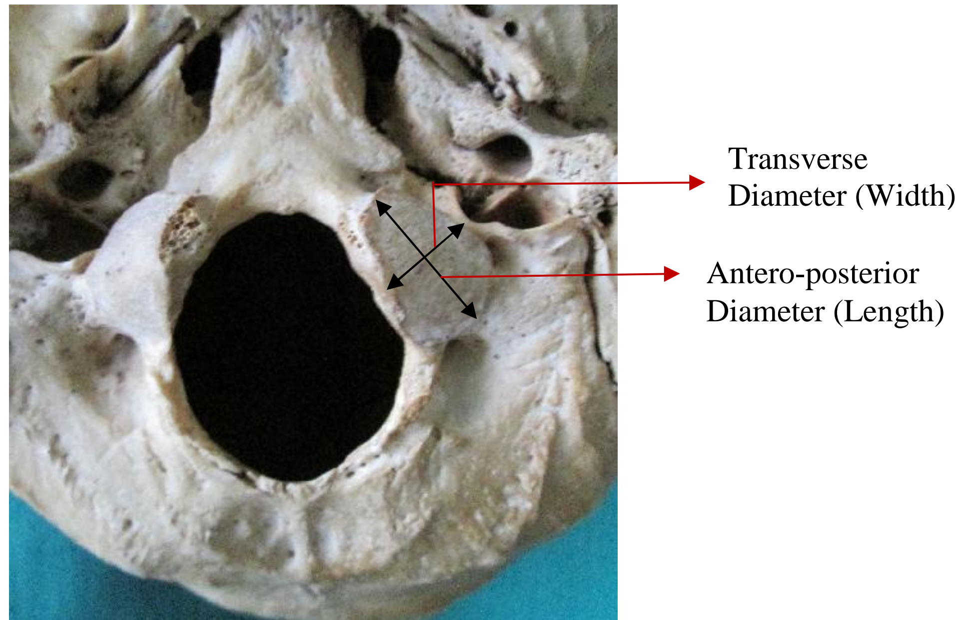
Figure 6: Different shapes of occipital condyles



a-Kidney shaped, **b-**Oval , **c-**Quadrangular , **d-**'S' shaped , **e-**Two portioned , **f-**Eight shaped , **g-**Triangular **, h-**Round **, i-**Deformed

5. Length of occipital condyles (right and left): From its anterior tip to posterior tip.
6. Width of occipital condyles (right and left): Maximum distance measured at the right angles to the line joining its anterior and posterior tip.

Figure 7: Measurements of occipital condyles



With these measurements following indices were calculated:

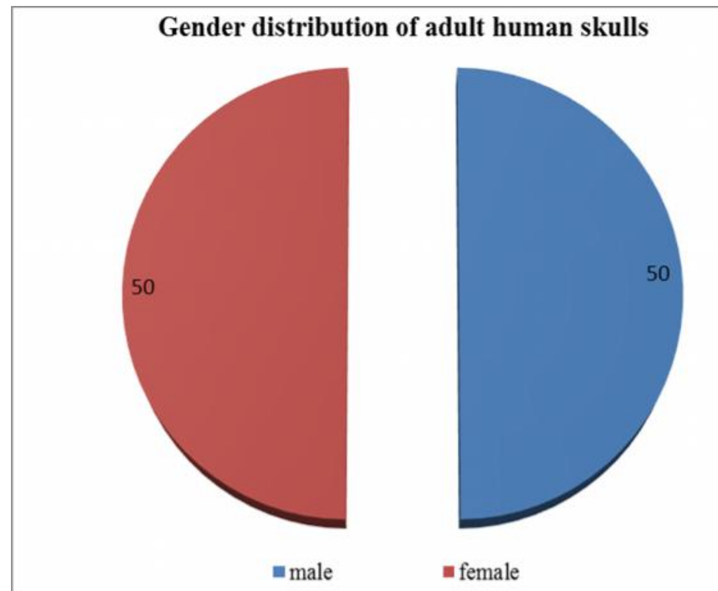
- **Foramen magnum index :** Calculated by dividing antero-posterior diameter of foramen magnum with transverse diameter of foramen magnum.(APD/TD)
- **Condylar index :** Calculated for right and left occipital condyle respectively by dividing length of occipital condyle with width of occipital condyle.(Length/Width)

The data obtained was analyzed statistically by computing descriptive statistics, the mean, standard deviation and percentages of each variable. The inferential statistics was done using student t–test. The results were considered statistically significant whenever p 0.05.

RESULTS

Study was done on 100 dry adult human skulls (50 males and 50 females) i.e 100 foramina magna and 200 occipital condyles.

Graph1 : Gender distribution of adult human skulls



Different shapes of foramen magnum

In our study six different shapes of foramen magnum were determined. 36 out of 100 skulls had oval shaped foramen magnum of which 25 were male and 11 were female. 20 foramina were tetragonal in shape with equal incidence in males & females (10 each). 19 foramina (4 males & 15 females) were egg-shaped, 14 foramina (9 males & 5 females) were hexagonal and 9 foramina magna (2 males & 7 females) were pentagonal in shape. Only 2 foramina magna were round in shape and both were females. There was no round shaped foramen magnum found in male skulls. (Table.1 & Graph.2) The incidence of oval and hexagonal shaped foramen magnum was higher in males while that of egg-

shaped, pentagonal & round foramen magnum was higher in females with ($p<0.05$) statistical significant difference.

Table 1: Incidence of different shapes of foramen magnum in male and female skulls. (n=100)

Shape	Oval	Tetragonal	Egg-shaped	Hexagonal	Pentagonal	Round
Male	25 (50%)	10 (20%)	4 (8%)	9 (18%)	2 (4%)	0 (0%)
Female	11 (22%)	10 (20%)	15 (30%)	5 (10%)	7 (14%)	2 (4%)
Total	36	20	19	14	9	2

Using fisher exact test for r x c table, p=0.002*

Graph: 2 Incidence of different shapes of foramen magnum in male & female skulls. (n=100)

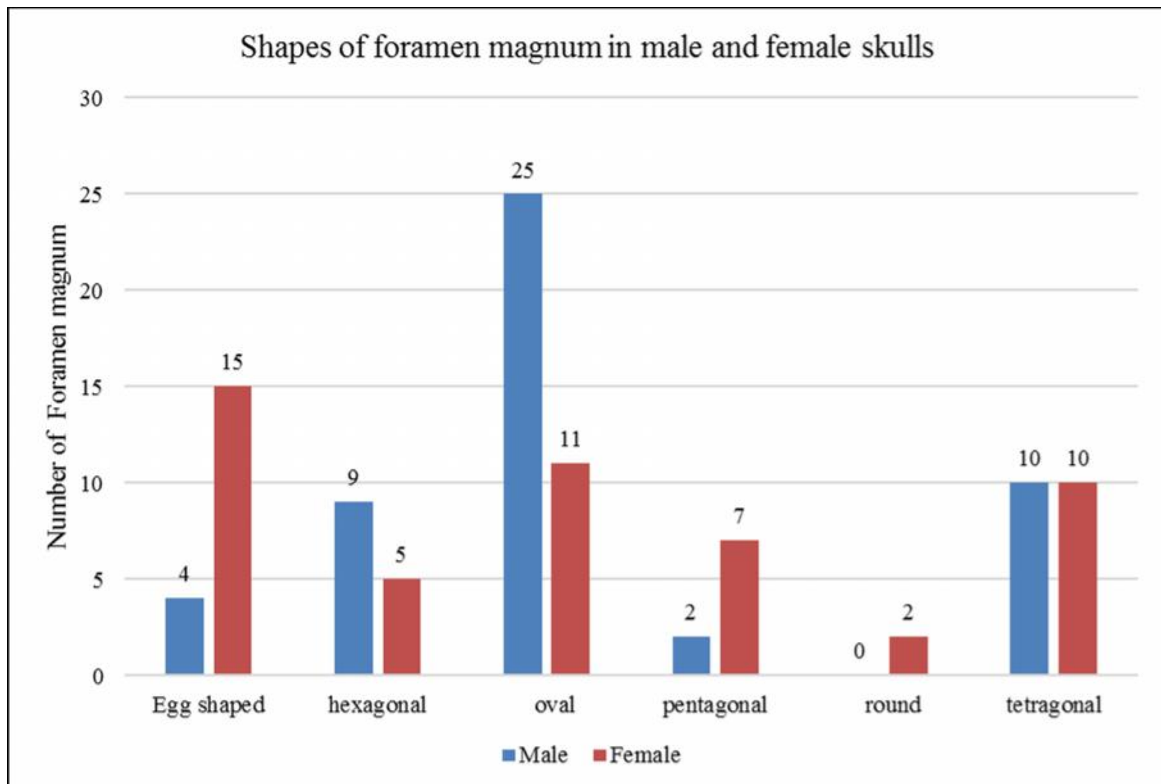


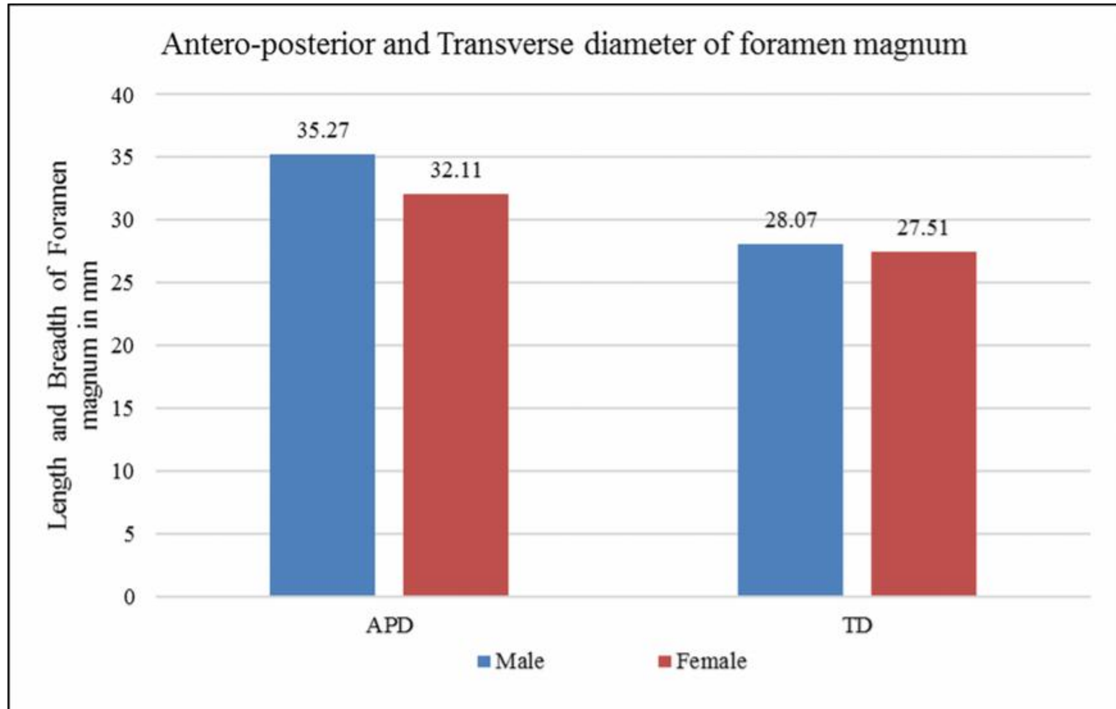
Table 2. Foramen magnum parameters in adult human skulls. (n=100)

PARAMETERS	Antero-posterior Diameter in mm	Transverse Diameter in mm	Index (APD/TD)
Male	35.27 ± 2.37 (30.15 - 41.04)	28.07 ± 2.09 (23.25 - 32.16)	1.26 ± 0.07 (1.13 - 1.42)
Female	32.11 ± 2.31 (27.35 - 35.57)	27.51 ± 1.91 (22.56 - 31.101)	1.17 ± 0.09 (0.93 - 1.13)
t-value	6.753	1.401	5.390
p value	< 0.001*	0.164	< 0.001*

Values are Mean ± SD, Statistical significance (Student t-test) *p<0.05

Table 2 & Graph 3 & 4 showed comparison of foramen magnum parameters in male and females skulls. The antero-posterior diameter of foramen magnum of male skulls was higher than the female skulls with statistical significant difference (p<0.05), the transverse diameter of foramen magnum was also high in male skulls but the difference was not significant. The average foramen magnum index obtained was 1.21±0.08. The foramen magnum index (APD/TD) was higher in male skulls with (p<0.05) statistical significant difference.

Graph 3. Comparison of Antero-posterior and Transverse diameters of foramen magnum in male and female skulls. (n=100)



Graph 4. Comparison of Foramen magnum Index in male and female skulls.

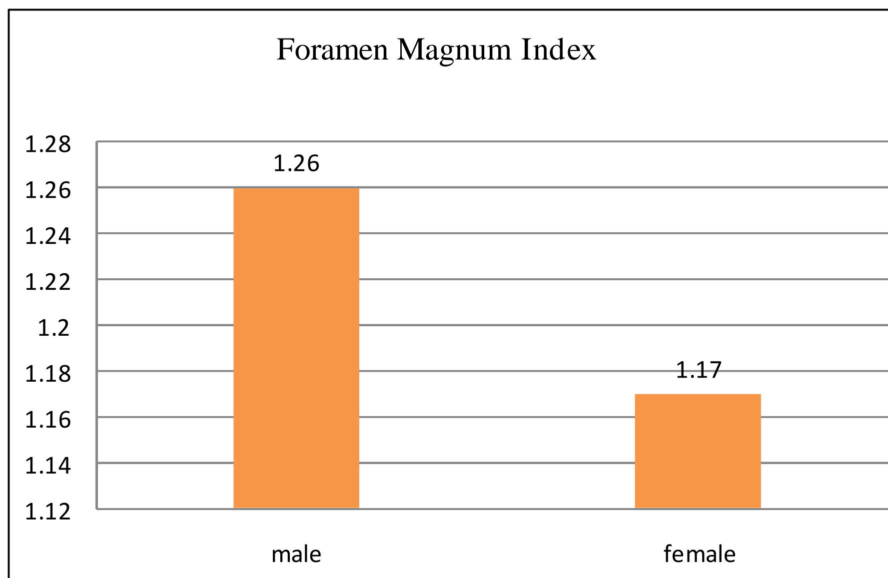


Table 3. Incidence of shapes of occipital condyles (Right side) in male and female skulls. (n=100)

SHAPE	Male	Female	Total
Oval	9 (18%)	17 (34%)	26
S-shaped	12 (24%)	10 (20%)	22
Triangular	10 (20%)	4 (8%)	14
Kidney-shaped	6 (12%)	7 (14%)	13
Eight-shaped	11 (22%)	1 (2%)	12
Quadrangular	1 (2%)	6 (12%)	7
Round	0 (0%)	2 (4%)	2
Two-portioned	0 (0%)	2 (4%)	2
Deformed	1 (2%)	1(2%)	2

Using Fisher Exact test for r x c table, $p < 0.001$*

Statistical significance (Fisher Exact test), $p<0.05$

Shapes of occipital condyle (Right sided) in male and female skulls.

In our study 9 different shapes of occipital condyles were determined. 26 out of 100 right sided occipital condyles were oval in shape with higher incidence 17(34%) in females. 22 occipital condyles were S-shaped out of which 12 belonged to male skulls and 10 female skulls. 14 occipital condyles (10 males & 4 females) were triangular in shape. 13 condyles (6 males & 7 females) were Kidney-shaped. 12 right sided occipital condyles were 8-shaped with much higher incidence in male skulls (22%) as compared to female skulls (2%). The incidence of quadrangular shaped condyles was higher in female skulls (12%). 2 round shaped and 2 two-portioned occipital condyles were found only in female skulls. Two occipital condyles (1male&1female) were deformed. (Table3 & Graph 5).To summarize the incidence of S-shaped, triangular and eight-shaped occipital condyles (Right sided) was higher in male skulls while the incidence of oval, kidney-shaped, quadrangular, round & two-portioned occipital condyles (Right sided) was higher in female skulls with statistical significant difference ($p<0.05$).

Graph 5. Incidence of shapes of occipital condyle (Right sided) in male and female skulls. (n=100)

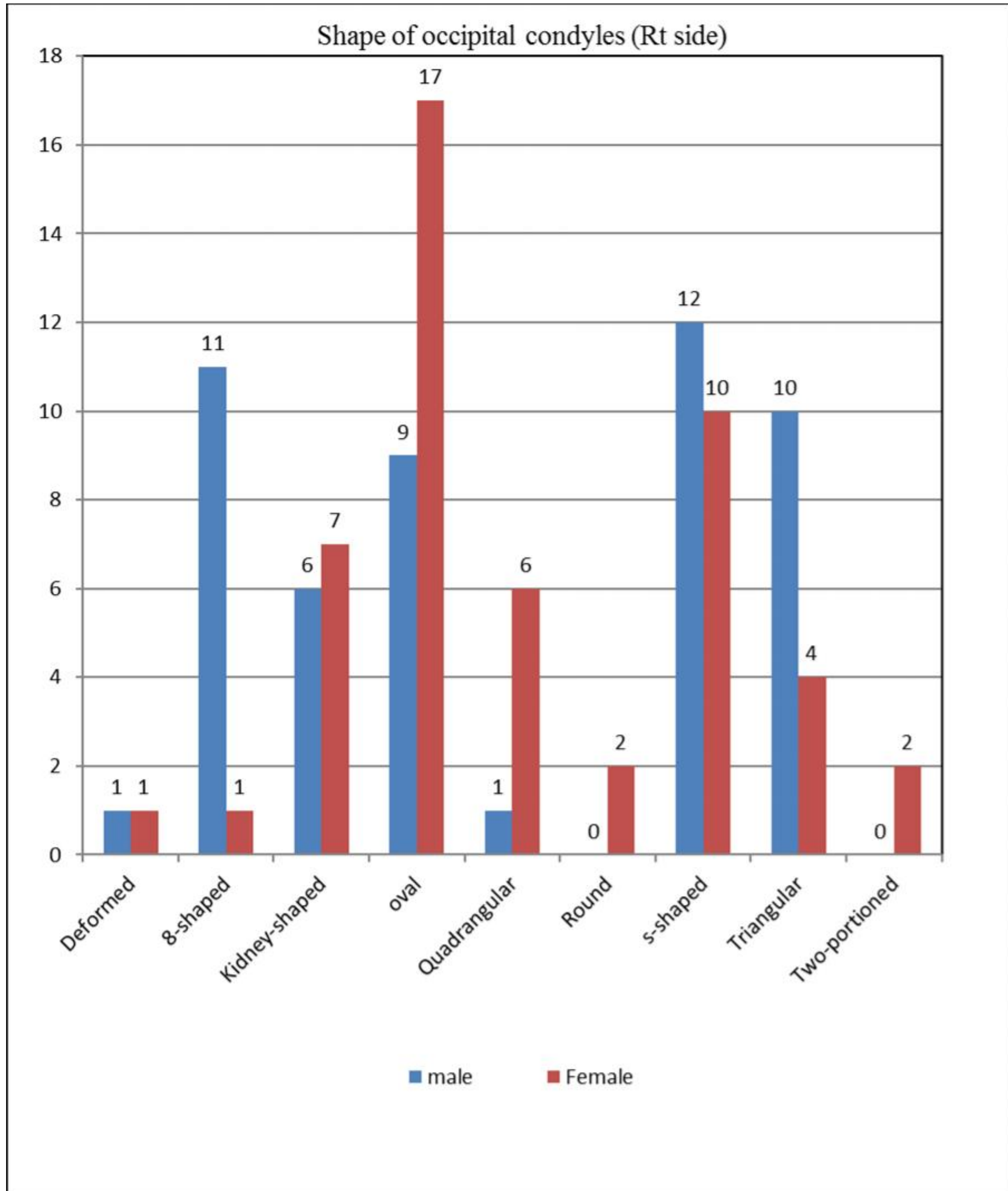


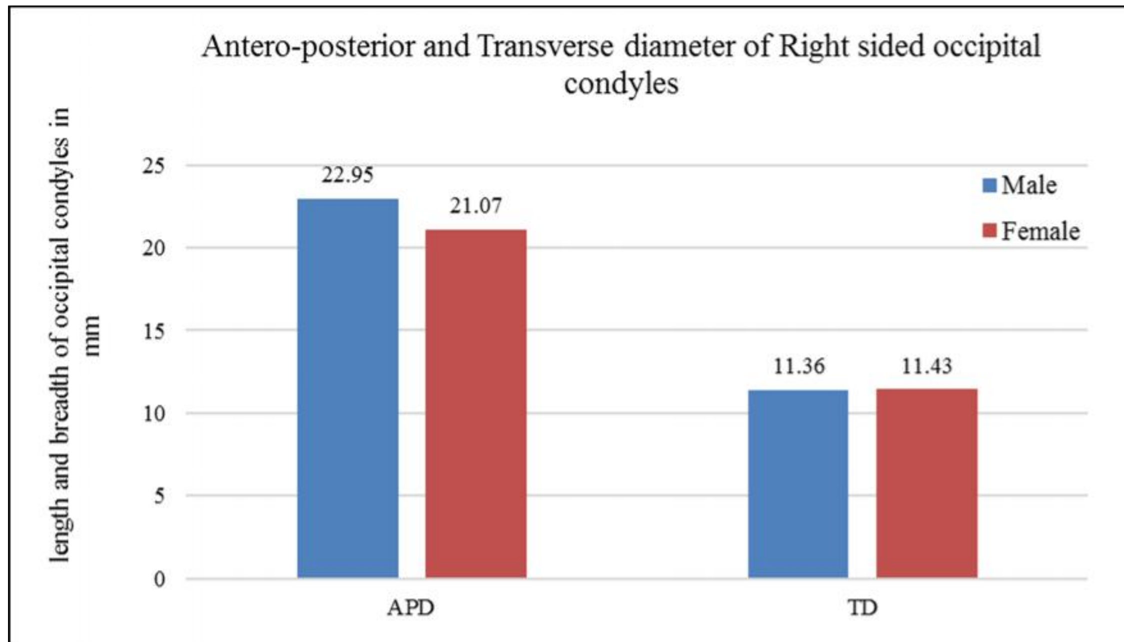
Table 4. Occipital condyle parameters (Right sided) in male and female skulls. (n=100)

PARAMETERS	Antero-posterior Diameter in mm	Transverse Diameter in mm	Index (APD/TD)
Male	22.95 ± 2.98 (16.46 - 28.12)	11.36 ± 1.77 (7.83 - 16.34)	2.07 ± 0.43 (1.40 - 3.21)
Female	21.07 ± 3.09 (14.46 - 30.38)	11.43 ± 1.67 (7.67 - 14.80)	1.88 ± 0.39 (1.17 - 3.04)
t-value	3.107	0.193	2.249
p value	0.002*	0.847	0.027*

Values are Mean ± SD, Statistical significance (Student t-test) *$p<0.05$

Table 4 & Graph 6 & 7 showed comparison of Right sided occipital condyle parameters in male and females skulls. The antero-posterior diameter of occipital condyle of male skulls was higher than the female skulls with statistical significant difference ($p<0.05$). The transverse diameter of right sided occipital condyle was slightly higher in female skulls but the difference was not significant. The occipital condyle index (APD/TD) was higher in male skulls with ($p<0.05$) statistical significant difference.

Graph 6. Comparison of Antero-posterior and Transverse diameters of occipital condyle (Right sided) in male and female skulls. (n=100)



Graph 7. Comparison of Occipital condyle Index (Right sided) in male and female skulls.

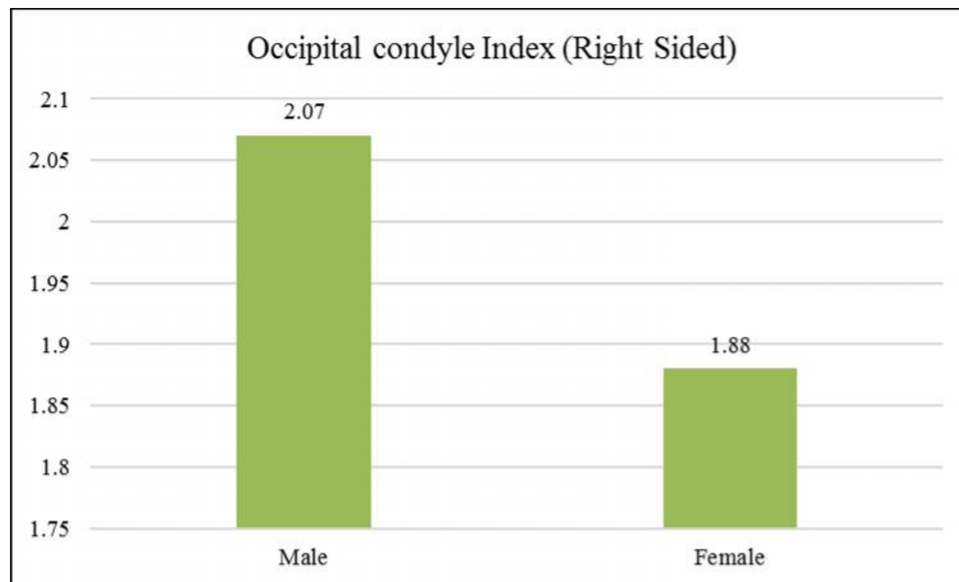


Table 5. Incidence of shapes of occipital condyles (Left side) in male and female skulls.

(n=100)

SHAPE	Male	Female	Total
oval	8 (16%)	15 (30%)	23
Triangular	12 (24%)	6 (12%)	18
8-shaped	12 (24%)	6 (12%)	18
S-shaped	10 (20%)	8 (16%)	18
Kidney-shaped	4 (8%)	4 (8%)	8
Quadrangular	1 (2%)	7 (14%)	8
Deformed	2 (4%)	1 (2%)	3
Round	1 (2%)	1 (2%)	2
Two-portioned	0	2 (4%)	2

Using Fisher Exact test for r x c table, $p = 0.109$

Statistical significance (Fisher Exact test), $p<0.05$

Shapes of occipital condyle (Left sided) in male and female skulls.

9 different shapes of left side occipital condyles were determined in our study. 23 out of 100 left sided occipital condyles were oval in shape with higher incidence 15(30%) in female skulls. 18 occipital condyles were S-shaped out of which 10 belonged to male skulls and 8 to female skulls. 18 occipital condyles (12 males & 6 females) were triangular and other 18 occipital condyles were 8-shaped with higher incidence in male skulls (24%) as compared to female skulls (12%). 8 left sided occipital condyles were kidney-shaped with equal incidence in male & female skulls (8%). Two occipital condyles (1 male & 1 female) were round in shape. 2 two-portioned occipital condyles were found only in female skulls (Table 5 & Graph 8). Thus to summarize the incidence of oval, quadrangular & two-portioned condyles (left sided) was higher in female skulls but the difference was not statistically significant ($p>0.05$). Similarly the incidence of triangular, S-shaped and 8-shaped condyles (left sided) was higher in male skulls but the difference was not statistically significant ($p>0.05$).

Graph 8. Incidence of shapes of occipital condyle (Left sided) in male and female skulls. (n=100)

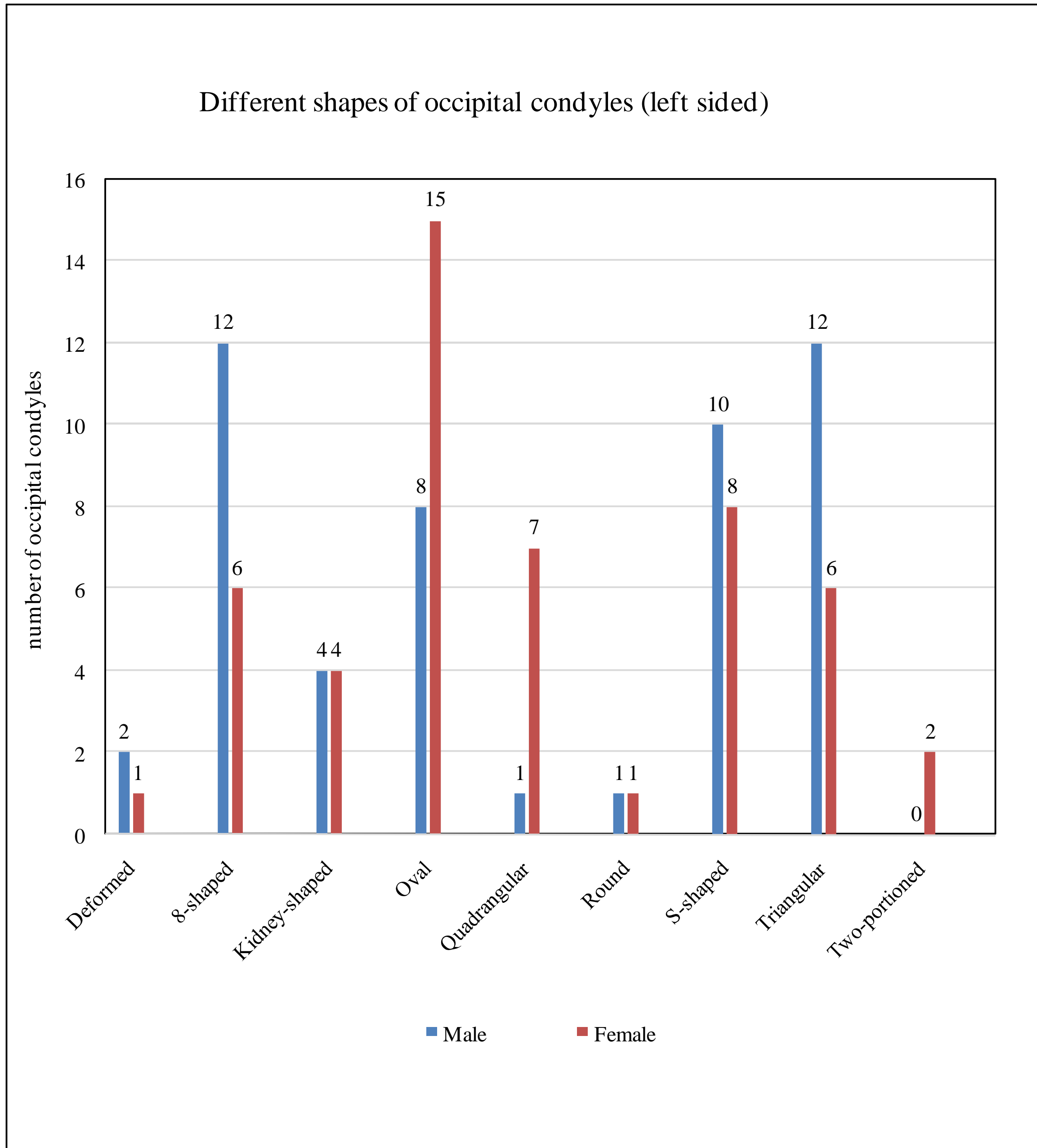


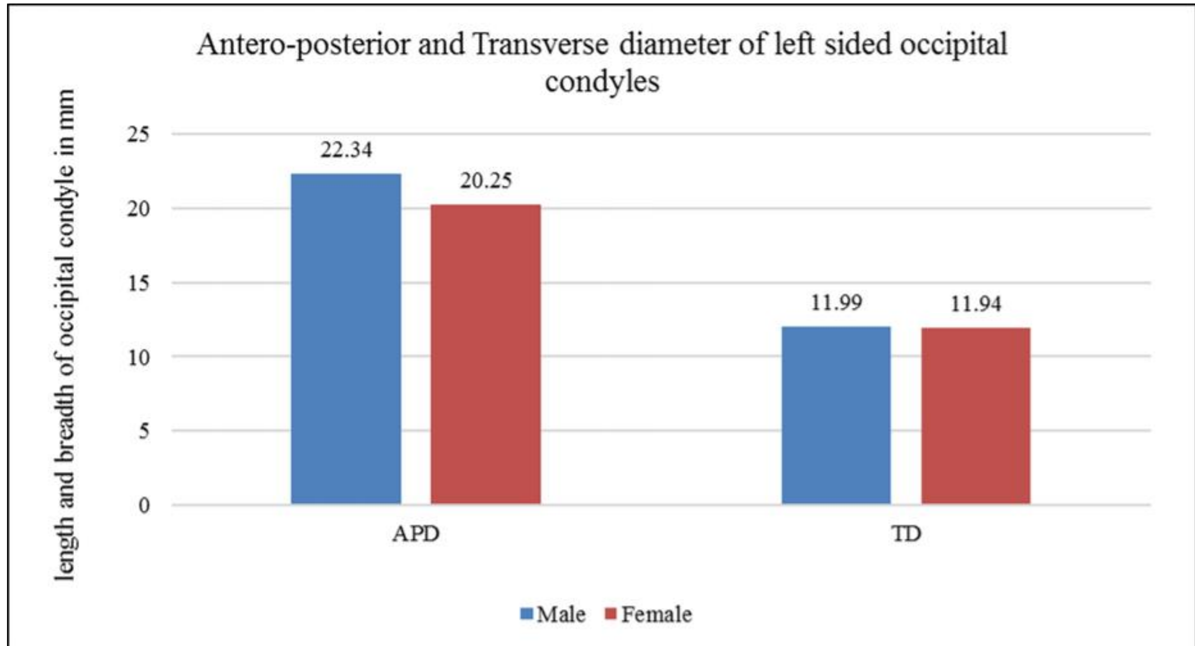
Table 6. Occipital condyle parameters (Left sided) in male and female skulls. (n=100)

PARAMETERS	Antero-posterior Diameter in mm	Transverse Diameter in mm	Index (APD/TD)
Male	22.34 ± 3.35 (11.6 - 27.63)	11.99 ± 1.31 (8.45 - 17.07)	1.90 ± 0.39 (0.99 - 2.94)
Female	20.25 ± 2.65 (14.05 - 28.71)	11.94 ± 1.75 (7.49 - 15.68)	1.74 ± 0.38 (1.15 - 3.21)
t-value	3.454	0.167	2.103
P value	0.001*	0.868	0.038*

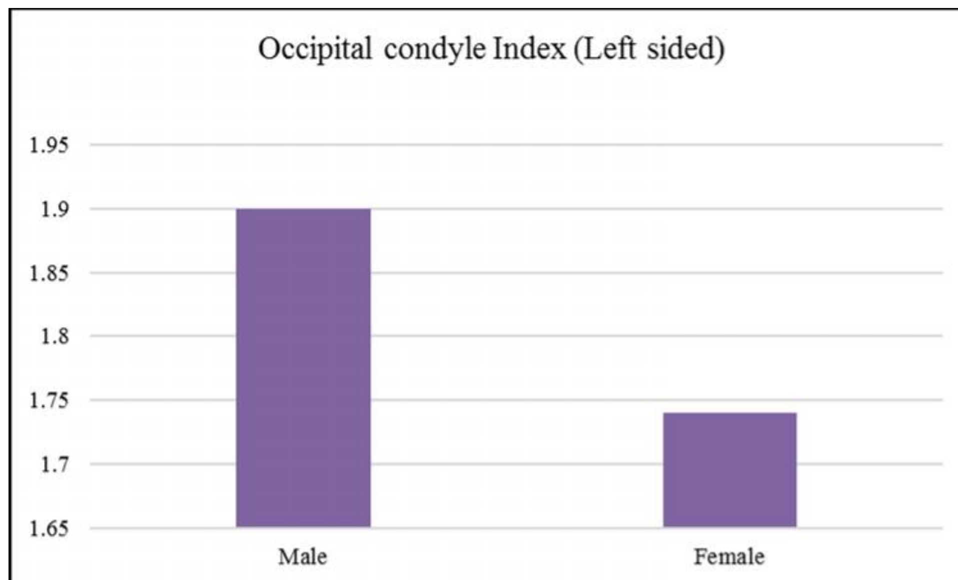
Values are Mean ± SD, Statistical significance (Student-test) *p<0.05

Table 6 & Graph 9 & 10 showed comparison of Left sided occipital condyle parameters in male and female skulls. The antero-posterior diameter of occipital condyle of male skulls was higher than the female skulls with statistical significant difference ($p<0.05$). The transverse diameter of left sided occipital condyle was slightly higher in male skulls but the difference was not statistically significant. The occipital condyle index (APD/TD) was higher in male skulls with ($p<0.05$) statistical significant difference.

Graph 9. Comparison of Antero-posterior and Transverse diameters of Occipital condyles (Left sided) in male and female skulls. (n=100)



Graph 10. Comparison of Occipital condyle Index (Left sided) in male and female skulls.



DISCUSSION

The sex determination of incomplete or damaged skeletons is an important but a difficult task.[4] Cranium is an excellent indicator for sexual dimorphism by morphometric and morphological analysis, and it is probably the second best region of the skeleton, next to pelvis for this purpose.[2] The basi-cranium plays a vital role because of its ability to remain intact in cases where the rest of the cranium has been damaged.[4] From a mechanical point of view, no muscles act upon the shape and size of the foramen magnum and its prime function is to accommodate the passage of structures into and out of the cranial base region and in particular, medulla oblongata which occupies the greatest portion of the foramen space. Population differences are also important in defining sexual differences in the cranium.[55] Therefore sex discriminant value of the foramen magnum and the occipital condyles has attracted attention of many authors. The present study was conducted on 100 dry adult human skulls (50 males & 50 females) i.e 100 foramina magna and 200 occipital condyles. (Graph 1). Different studies have quoted different facts and figures which have led to spectrum of findings.

Shape of foramen magnum

The Foramen magnum is usually described as oval in shape.[47] Several different shapes of the foramen magnum were observed by various authors. Zaidi and Dayal, observed the oval shape FM in 64% of their specimens followed by the hexagonal shape in 24.5%, pentagonal in 7.5%, irregular in 3.5% and round in 0.5% of the skulls.[13] In contrast, Chetan et al observed round shaped foramen magnum in 22.6% skulls, followed by egg shape & tetragonal in 18.9%, oval shape in 15.1%, irregular in 15.1%, hexagonal in

(5.6%) and pentagonal in 3.8% of the cases.[57] Sindel et al reported oval foramen magnum in 18.9% of skulls followed by hexagonal in 5.3%, pentagonal in 4.2%, irregular in 6.3%, round in 15.8% and tetragonal in 49.4% of the subjects.[59] Murshed (2003) used Computerized Tomography to evaluate the radiological variations in the shape of foramen magnum in 110 normal subjects (57 males & 53 females). According to him foramen magnum was found to be oval in 8.1%.egg-shaped in 6.3%, round in 21.8%, tetragonal in12.7%, pentagonal in 13.6%, hexagonal in 17.2%, irregular type A in 10.9% and irregular type B in 9.09%. He finally concluded that in adults the different shapes of foramen magnum are variable and remain controversial for sex determination in reports of different authors.[47] However all the above studies did not take in account the incidence of shapes of foramen magnum in male and female skulls separately.

Different shapes of foramen magnum determined in the present study were egg-shaped, hexagonal, oval, pentagonal, round and tetragonal. The commonest shape of foramen magnum in male skulls was oval followed by tetragonal, hexagonal, egg-shaped and pentagonal whereas the commonest shape in female skulls was egg-shaped followed by oval, tetragonal, pentagonal, hexagonal and round. There was no round shaped foramen magnum found in male skulls. The incidence of oval and hexagonal shaped foramen magnum was higher in males while that of egg- shaped, pentagonal & round foramen magnum was higher in females with ($p<0.05$) statistical significant difference (Table 1). In a study conducted by Radhakrishna et al oval shaped foramen magnum was most common followed by round, tetragonal and pentagonal in both male and female skulls.[54] (Table 7).

Table 7: Comparison of incidence of shapes of foramen magnum with other studies.

Shape of foramen magnum	Male skulls		Female skulls	
	R.krishna [54] (n=55)	Present study (n=50)	R.krishna [54] (n=45)	Present study (n=50)
Oval	22	25	17	11
Round	16	0	12	2
Tetragonal	10	10	9	10
Pentagonal	8	2	6	7
Egg-shaped	-	4	-	15
Hexagonal	-	9	-	5

Antero-posterior and transverse diameter of foramen magnum

The mean antero-posterior diameter of foramen magnum of male skulls in our study (35.27 ± 2.37) was lower than the Turkish male skulls (37.2 ± 3.43)[47], English population (35.91 ± 2.41)[10], Spanish (36.2 ± 0.3)[12] and the Brazilian male skulls (35.7 ± 0.29)[51]. Similarly the antero-posterior diameter of female skulls in our study (32.11 ± 2.31) was lower than Turkish population (34.6 ± 3.16)[47], English population (34.71 ± 1.91)[10], Spanish (34.30 ± 0)[12] and the Brazilian skulls (35.1 ± 0.33)[51]. Likewise the transverse diameter of foramen magnum of male skulls in our study (28.07 ± 2.09) was lower than the Turkish (31.6 ± 2.99)[47], English population (30.51 ± 1.77)[10], Spanish (31.1 ±0.3)[12] and the Brazilian male skulls (30.3 ± 0.20)[51]. The same measure for the female skulls in our study (27.51 ± 1.91) was lower than the Turkish population (29.3 ± 2.19)[47], English (29.36 ± 1.96)[10], Spanish (29.6 ± 0.3)[12] and the Brazilian female skulls (29.4 ± 1.64)

Table 8: Comparison of foramen magnum measurements with other Indian studies.

Authors and year of study	Antero-posterior diameter of foramen magnum (mm)		Transverse diameter of foramen magnum (mm)	
	Male	Female	Male	Female
Routal RR et.al [46] (1984)	35.5 ± 2.8	32.0 ± 2.80	29.6 ± 1.9	27.1 ± 1.6
Raghvendra et.al[52] (2011)	36.40 ±3.27	31.62 ± 2.05	32.93 ±2.35	28.32 ±2.12
Radhakrishna et.al[54] (2012)	34.04 ±2.36	31.72 ± 2.14	28.63 ± 1.89	26.59 ±1.64
Singh G et.al[53] (2012)	33.54 ± 2.8	32.31 ± 3.24	27.77 ±2.10	27.21 ±2.99
Kanchan T et.al[56] (2013)	34.51 ±2.77	33.60 ± 2.63	27.36 ±2.09	26.74 ±2.36
Santosh et.al[55] (2013)	34.37 ±2.38	33.80 ±2.56	28.98 ±2.22	27.60 ± 2.67
Present study (2014)	35.27 ±2.37	32.11 ±2.31	28.07 ±2.09	27.51 ± 1.91

When compared the measurements of foramen magnum with other Indian studies, it was observed that the values obtained in our study were similar to those obtained by Routal RR et al [46] and slightly higher than those obtained by Radhakrishna et al [54], Singh G et al [53], Kanchan T[56] et al and Santosh et al [55] while lower than that obtained by Raghvendra et al [52] (Table 8). From the results obtained, it was observed in our study that there was statistically significant difference ($p<0.05$) in the mean antero-posterior diameter of male skulls and female skulls but the mean transverse diameter of male skulls even though higher than the female skulls, the difference was not statistically significant. (Table 2 & Graph 3).

Foramen magnum index

Foramen magnum index was calculated by dividing the antero-posterior diameter of foramen magnum with the transverse diameter. The mean foramen magnum index in the present study was 1.21 ±0.08. The foramen magnum index of male skulls (1.26 ± 0.07) was found to be higher than the female skulls (1.17 ± 0.09) and the difference was statistically significant. (Table 2 & Graph 3) The value of average foramen magnum index obtained in the present study was similar to other study done by P Chetan et al (1.2 ± 0.1).[57] Testut and Latarjet opined that wide, sagittally inclined and medially protruberant occipital condyles along with a foramen magnum index more than 1.2 will require much more extensive bony resection while surgeries.[58] N muthukumar stated that when foramen magnum index was > 1.2, the foramen was found to be ovoid in shape.[49]

Shapes of occipital condyles

The commonest shapes of right occipital condyle in our study was oval (26%) followed by S-shaped (22%), triangular (14%), kidney-shaped (13%) eight shaped (12%), quadrangular (7%), round, two-portioned and deformed (2%) (Table 9). The commonest shape of left occipital condyle in our study was found to oval (23%), followed by eight-shaped, S-shaped, triangular (18%) each, kidney-shaped & quadrangular (8%) each, deformed 3%, round & two-portioned (2%) each.

Table 9: comparison of incidence of different shapes of occipital condyles with other study

Shape of occipital condyle	Right side		Left side	
	Sait et al[48] (n=202)	Present study (n=100)	Sait et al[48] (n=202)	Present study (n=100)
Oval	96 (23.8%)	26 (26%)	106 (26.2%)	23 (23%)
S-shaped	47 (11.6%)	22 (22%)	47 (11.6%)	18 (18%)
Triangular	22 (5.5%)	14 (14%)	14 (3.5%)	18 (18%)
Eight-shaped	12 (3.0%)	12 (12%)	5 (1.2%)	18 (18%)
Deformed	10 (2.5%)	2 (2%)	12 (3.0%)	3 (3%)
Kidney-shaped	8 (2.0%)	13 (13%)	6 (1.5%)	8 (8%)
Round	6 (1.5%)	2 (2%)	10 (2.5%)	2 (2%)
Two-portioned	1 (0.3%)	2 (2%)	2 (0.5%)	2 (2%)
Quadrangular	-	7 (7%)	-	8 (8%)

In a study conducted by Sait et al the commonest shape of right occipital condyles was found to be oval followed by S-shaped, triangular, eight-shaped, deformed, kidney-shaped, round and two-portioned while the commonest shape of left occipital condyles was oval followed by S-shaped, triangular, deformed, round, kidney-shaped, eight-shaped and two-portioned.[48] The commonest shape of occipital condyles was oval in both the studies but there was variation in the incidence of other shapes of occipital condyles in both the studies. (Table 9) In addition to this incidence of different shape of occipital condyles in male and female skulls separately was observed in the present study. The incidence of S-shaped, triangular and eight-shaped occipital condyles (right side)

was higher in male skulls while the incidence of oval, kidney- shaped, quadrangular, round, two-portioned & deformed occipital condyles was higher in female skulls with statistical significant difference ($p<0.05$) (Table 3) whereas the incidence of oval, quadrangular & two-portioned condyles (left sided) was higher in female skulls & the incidence of triangular, S-shaped & 8-shaped condyles was higher in male skulls but the difference was not statistically significant ($p>0.05$). (Table 5).

Antero-posterior diameter of occipital condyles in male and female skulls.

In the present study the mean antero-posterior diameter of right occipital condyles in male skulls (22.95 ±2.98) was higher than the female skulls (21.07 ± 3.09) with statistically significant difference. ($p<0.05$) (Table 4 & Graph 6). The antero-posterior diameter of left occipital condyles of male skulls (22.34 ± 3.35) was also higher than the female skulls (20.25±2.65) and the difference was statistically significant. (Table 6 & graph 9). These finding were in corroboration with the study done by Olivier et al.[60] (Table 10) The mean antero-posterior diameter of right occipital condyle of male skulls in the present study (22.95 ± 2.98) was lower than the Brazilian male skulls (26.74 ± 2.96)[60] while that of female skulls (21.07 ± 3.09) in the present study was also lower than the Brazilian population (25.45 ± 3.21)[60]. Similarly the mean antero-posterior diameter of left occipital condyle of male skulls in the present study (22.34 ± 3.35) was lower than the Brazilian skulls (26.85 ± 2.97)[60] and that of female skulls in the present study (20.25 ± 2.65) was also lower than the Brazilian population (24.65 ± 3.23)[60]. (Table 10)

Table10: Comparison of antero-posterior diameter of occipital condyles in male and female skulls with other study

Antero-posterior diameter	Right occipital condyle		Left occipital condyle	
	Male skulls	Female skulls	Male skulls	Female skulls
Oliveira et al[60] (2013)	26.74 ± 2.96	25.45 ± 3.21	26.85 ± 2.97	24.65 ± 3.23
Present study (2014)	22.95 ± 2.98	21.07 ± 3.09	22.34 ± 3.35	20.25 ± 2.65

Transverse diameter of occipital condyles

From the results obtained it was observed that the mean transverse diameter of right occipital condyles of male skulls (1.36 ± 1.77 mm) was slightly lower than female skulls (11.43 ± 1.67 mm) but the difference was not statistically significant. (Table 4 & Graph 6). The mean transverse diameter of left occipital condyles in male and female skulls was 11.99 ± 1.31 mm & 11.94 ± 1.75 mm respectively. Though the measurements in male skulls were slightly higher than the female skulls the difference was not statistically significant (Table 6 & Graph 9). In contrast, a study done in Brazil the average transverse diameter of right occipital condyle in male & female skulls was 13.51 ± 11.38 mm & 12.68 ± 1.56 mm respectively while the transverse diameter of the left occipital condyles in male female skulls was 13.79 ± 1.39 mm & 12.71 ± 1.75 mm respectively and the difference was statistically significant.[60]

Table 11: Comparison of Transverse diameter of occipital condyle in male & female skulls with other study.

Transverse diameter	Right occipital condyle		Left occipital condyle	
	Male skulls	Female skulls	Male skulls	Female skulls
Oliveira et al[60] (2013)	13.51 ± 1.38	12.68 ± 1.56	13.79 ± 1.39	12.71 ± 1.75
Present study (2014)	11.36 ± 1.77	11.43 ± 1.67	11.99 ± 1.31	11.94 ± 1.75

Occipital condyle index

The occipital condylar index was calculated by dividing the antero-posterior diameter (Length) of the condyle with the transverse diameter (Width). The average index of right sided occipital condyles in male and female skulls was found to be 2.07 ± 0.43 & 1.88 ± 0.39 respectively and the difference was statistically significant. (Table 4 & Graph 7). Similarly the index of left sided occipital condyles in male and female skulls was 1.90 ± 0.39 & 1.74 ± 0.38 with statistical significant difference. (Table 6 & Graph 10).

In contrast to the present study, Oliveira et al applied the Baudoin condylar index for sex determination and evaluated its reliability. Baudoin condylar index = (maximum width of the condyle/ maximum length of the condyle) x 100. The results obtained by Oliveira et al showed that the percentage of success in applying the Baudoin index was 44.83% to males and 51.93% to females, amounting to 47.5% matching. He thus concluded that the accuracy of the Baudoin index to sex determination was quite low for

the Brazilian sample and that was the reason why this method was disregarded as criterion to sexing skulls in forensic experts.[60]

The comparison of the morphometric analysis obtained in the present study are in correlation with the results of other studies and literatures. Morphometric analysis of the foramen magnum and occipital condyles thus may provide a statistically useful indicator for sex determination of the unknown skull.

CONCLUSION

After studying 100 dry adult human skulls (50 male & 50 female), i.e 100 foramina magna and 200 occipital condyles the following conclusions were drawn.

1. The commonest shape of foramen magnum was oval. (36%).
2. The incidence of oval and hexagonal shaped foramen magnum was higher in male skulls while that of egg-shaped, pentagonal & round foramen magnum was higher in female skulls ($p<0.05$).
3. The antero-posterior diameter of foramen magnum in male skulls was more than the female skulls ($p<0.05$).
4. Statistical significant difference was not observed in the transverse diameter of foramen magnum of the male and female skulls ($p>0.05$).
5. The foramen magnum index of male skulls was higher than the female skulls. ($p<0.05$).
6. The commonest shape of right sided occipital condyles was oval (26%).
7. The incidence of S-shaped, triangular and eight-shaped occipital condyles was higher in male skulls while the incidence of oval, kidney- shaped, quadrangular, round, two-portioned & deformed occipital condyles was higher in female skulls ($p<0.05$).
8. The antero-posterior diameter of right occipital condyles was higher in male skulls than in female skulls ($p<0.05$).
9. Statistical significant difference was not observed in the transverse diameter of right occipital condyles of the male and female skulls ($p>0.05$).

10. The occipital condyle index (Right sided) of male skulls was higher than the female skulls ($p<0.05$).
11. The commonest shape of left occipital condyle was oval (23%).
12. Statistical significant difference was not observed in the incidence of different shapes of left occipital condyles in male and female skulls ($p>0.05$).
13. The antero-posterior diameter of left occipital condyles was higher in male skulls than in female skulls ($p<0.05$).
14. Statistical significant difference was not observed in the transverse diameter of left occipital condyles of the male and female skulls ($p>0.05$).
15. The occipital condyle index (Left sided) of male skulls was higher than the female skulls ($p<0.05$).
16. With the data obtained from the present study we conclude that, metric analysis of foramen magnum and occipital condyles may be a useful indicator of sex determination of an unknown skulls, especially in fragmentary human remains, where no other skeletal remains are preserved.
17. This study is useful for anthropologists, morphologists, forensic experts for sex determination in medico-legal cases and for the neurosurgeons in dealing with lesions of posterior cranial fossa during surgery.

SUMMARY

The primary objective of this cross sectional study was to analyze the foramen magnum and occipital condyles morphometrically for sex determination. The secondary objective was to study the surgical importance of foramen magnum and occipital condyles.

The morphometric study was conducted on 100 dry adult human skulls (50 male & 50 female). All measurements were recorded using Digital Vernier caliper. The shape of foramen magnum and occipital condyles were noted and all the other parameters were analyzed.

The obtained results of the study were tabulated and compared with the available literature. 36% of foramina magna were oval shaped, 20% were tetragonal, 19% were egg shaped, 14% were hexagonal, 9% were pentagonal and 2% were round shaped. The incidence of oval and hexagonal shaped foramen magnum was higher in male skulls and that of egg-shaped, pentagonal & round foramen magnum was higher in female skulls. The antero-posterior diameter of foramen magnum of male skulls was higher than the female skulls. No significant difference in the transverse diameter of foramen magnum of male and female skulls was found. The foramen magnum index of male skulls was higher than the female skulls. 26% of right occipital condyles were oval shaped, 22% were S-shaped, 14% were triangular, 13% were kidney-shaped, 12% eight-shaped, 7% quadrangular, 2% round, 2% two-portioned and 2% were deformed. 23% of left occipital condyle were oval, 18% triangular, 18% eight-shaped, 18% S-shaped, 8% kidney shaped, 8% quadrangular, 3% deformed, 2% round and 2% were two-portioned. The antero-posterior diameter of occipital condyles (right and left) in male skulls was higher than the

female skulls. There was no significant difference in the transverse diameter of occipital condyles (right and left) in male and female skulls. The occipital condyle index (right and left side) in male skulls was higher than the female skulls. All the above findings correlated with the available data from the literature.

These findings are of clinical significance to neurosurgeons, as in dealing with the lesions of posterior cranial fossa prior basic knowledge about its anatomy and its variations is necessary. The data obtained is also useful to anthropologists, morphologists and forensic experts in identification of sex in medico-legal cases. Hence our study adds to the knowledge about metric analysis of foramen magnum and occipital condyles for sex determination in dry adult skulls of Belgaum district.

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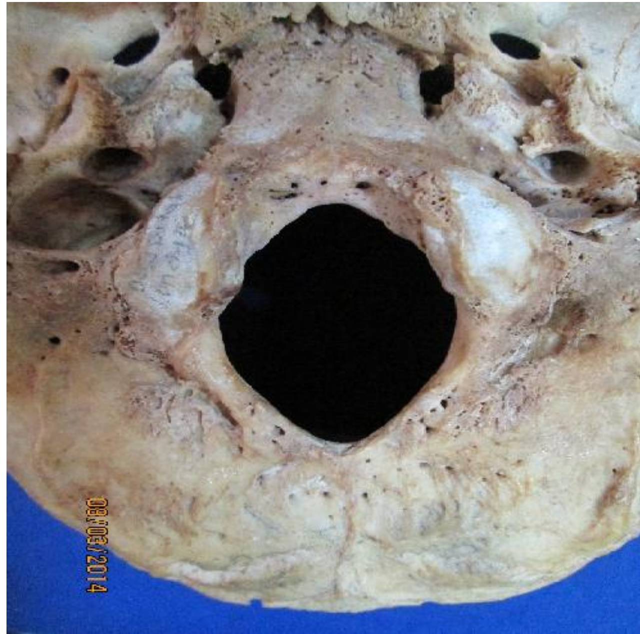
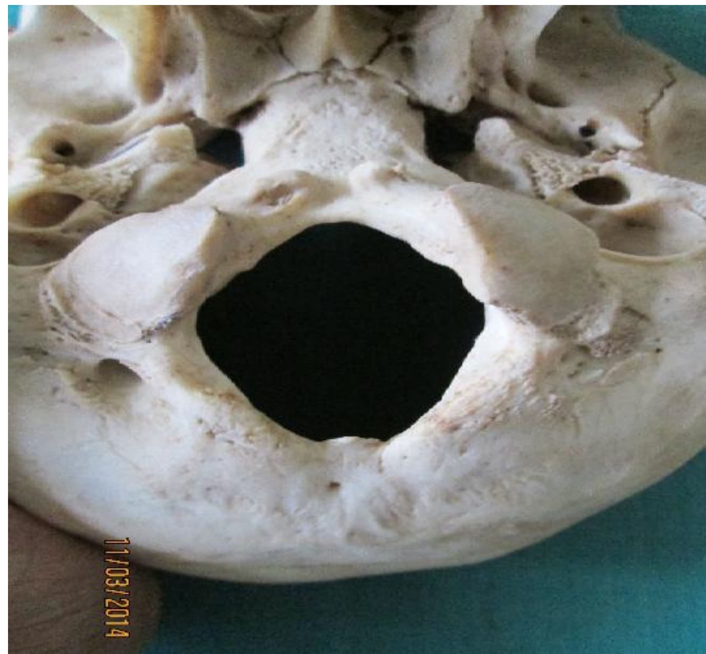
PHOTOGRAPHS

Photograph 1 : Egg shaped foramen magnum

Photogarph 2 : Round shaped foramen magnum

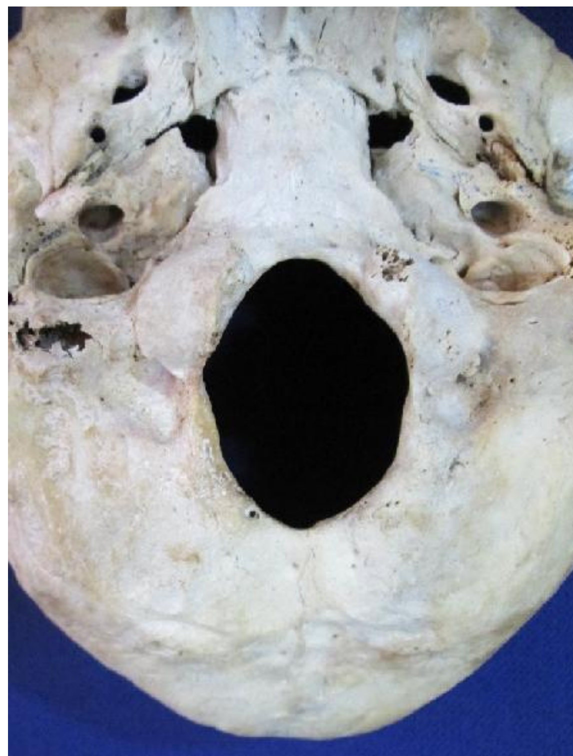


Photograph 3 : Tetragonal foramen magnum



Photograph 4 : Pentagonal foramen magnum

Photograph 5: oval shaped foramen magnum

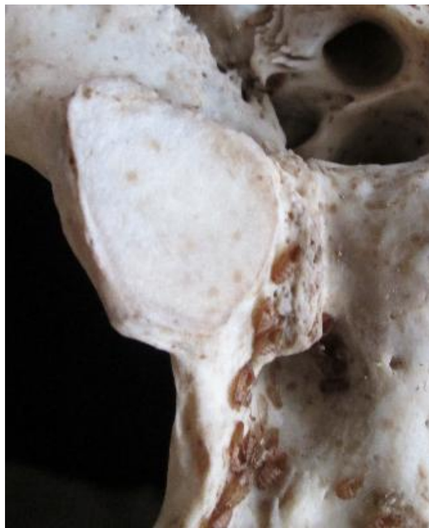


Photograph 6 : Hexagonal foramen magnum

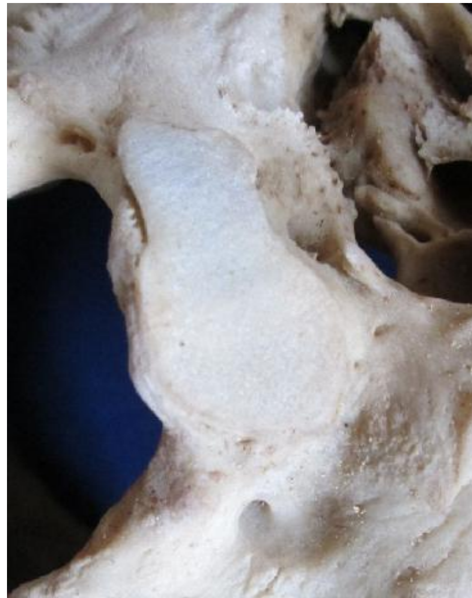
Photograph 7: Measurement of Antero-posterior diameter of foramen magnum

Photograph 8 : Measurement of Transverse diameter of foramen magnum

Photograph 9: Kidney shaped occipital condyle

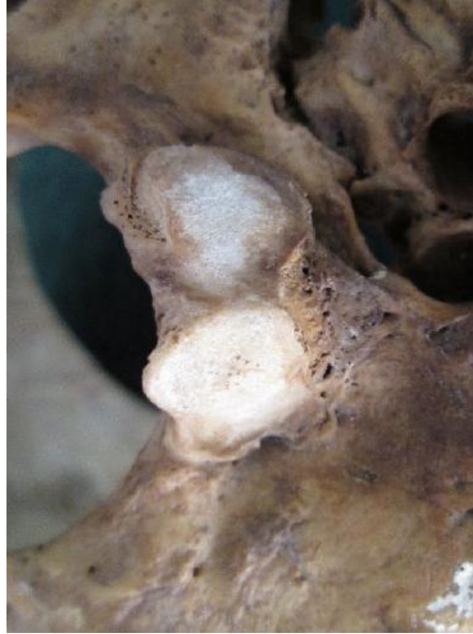


Photograph 10 : Triangular occipital condyle

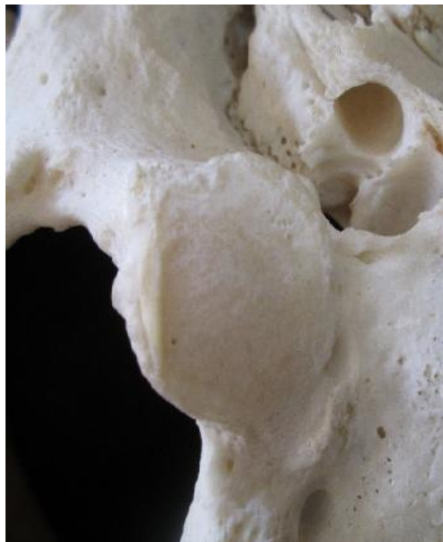


Photograph 11: Eight shaped occipital condyle

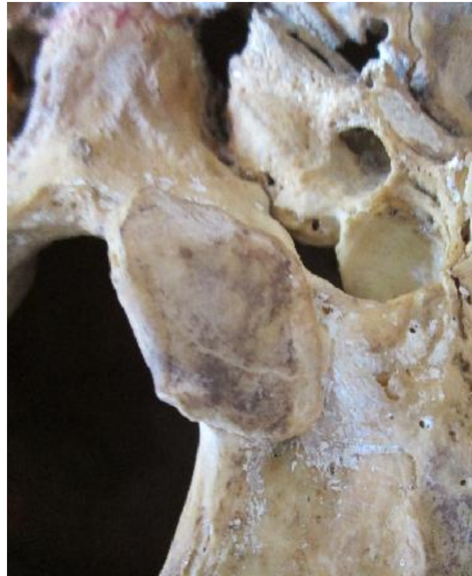
Photograph 12 : S-shaped occipital condyle



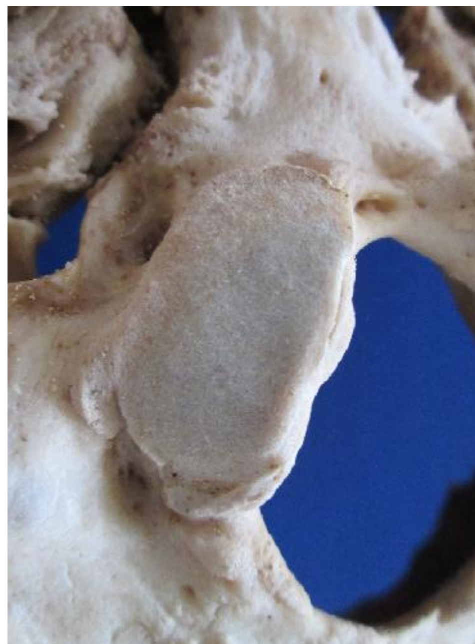
Photograph 13: Two-portioned occipital condyle



Photograph 14: Round occipital condyle



Photograph 15: Quadrangular occipital condyle



Photograph 16: oval occipital condyle

Photograph 17 : Deformed occipital condyle

Photograph 18:Measurement of antero-posterior diameter of occipital condyle

Photograph 19 : Measurement of transverse diameter of occipital condyle

Proforma of the Study

1. Specimen Number:
2. Sex: Male / Female
3. Parameters (measurements taken in mm):

<table>
<tr><th colspan="2">Parameters</th><th>Shape</th><th>Antero-posterior Diameter</th><th>Transverse Diameter</th><th>Index</th></tr>
<tr><td colspan="2">Foramen magnum</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Occipital condyle</td><td>Right Side</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Left side</td><td></td><td></td><td></td><td></td></tr>
</table>

MASTER CHART

FORAMEN MAGNUM					
specimen no:	M/F	shape	APD(mm)	T D(mm)	Index
1	m	hexagonal	35.4	26.12	1.355283
2	m	egg	30.15	23.25	1.296774
3	m	tetragonal	36.56	30.08	1.215426
4	m	oval	33.75	26.06	1.295088
5	m	oval	34.81	24.93	1.39631
6	m	oval	35.35	26.62	1.327949
7	m	tetragonal	32.54	24.97	1.303164
8	m	oval	36.65	30.24	1.211971
9	m	egg	37.61	30.35	1.239209
10	m	hexagonal	37.97	30.25	1.255207
11	m	oval	33.32	26.29	1.267402
12	m	oval	39.47	32.16	1.227301
13	m	tetragonal	36.31	28.57	1.270914
14	m	oval	34.75	26.81	1.296158
15	m	oval	35.75	28.68	1.246513
16	m	oval	35.12	25.56	1.374022
17	m	hexagonal	34.61	26.09	1.326562
18	m	oval	37.14	31	1.198065
19	m	oval	34.56	25.8	1.339535
20	m	oval	35.33	28.86	1.224186
21	m	oval	37.64	30.86	1.219702
22	m	tetragonal	31.87	24.78	1.286118
23	m	oval	35.9	29.74	1.207128
24	m	oval	41.04	31.02	1.323017
25	m	tetragonal	31.69	27.24	1.163363
26	m	oval	31.62	23.94	1.320802
27	m	tetragonal	35.02	30.01	1.166944
28	m	tetragonal	32.7	28.66	1.140963
29	m	hexagonal	32.11	27.08	1.185746
30	m	tetragonal	37.66	29.76	1.265457
31	m	oval	36.25	29.65	1.222597
32	m	oval	37.46	29.4	1.27415
33	m	hexagonal	32.77	27.65	1.185172
34	m	oval	32.35	26.74	1.209798
35	m	oval	36.8	28.99	1.269403
36	m	egg	35.15	29.53	1.190315
37	m	hexagonal	37.05	29.03	1.276266
38	m	pentagonal	35.04	29.54	1.186188
39	m	pentagonal	35.29	31.2	1.13109
40	m	hexagonal	38.59	28.54	1.352137
41	m	hexagonal	33.92	27.04	1.254438
42	m	oval	32.63	26.15	1.247801
43	m	tetragonal	35.24	25.06	1.406225
44	m	oval	35.24	28.81	1.223186
45	m	hexagonal	34.35	29.25	1.174359
46	m	egg	33.92	28.92	1.172891
47	m	tetragonal	40.95	28.92	1.415975
48	m	oval	33.09	27.65	1.196745
49	m	oval	34.7	27.06	1.282336
50	m	oval	38.44	28.68	1.340307

FORAMEN MAGNUM					
specimen no:	M/F	shape	APD(mm)	TD (mm)	Index
1	f	oval	28.65	26.24	1.091845
2	f	round	31.6	29.6	1.067568
3	f	tetragonal	33.49	28.27	1.184648
4	f	tetragonal	32.06	26.34	1.21716
5	f	hexagonal	33.74	27.41	1.230938
6	f	tetragonal	30.79	30.41	1.012496
7	f	egg	34.08	27.99	1.217578
8	f	round	27.35	29.44	0.929008
9	f	egg	35.17	30.69	1.145976
10	f	egg	32.29	27.06	1.193274
11	f	oval	31.16	27.2	1.145588
12	f	egg	31.92	25.62	1.245902
13	f	oval	32.62	25.67	1.270744
14	f	tetragonal	29.8	24.17	1.232933
15	f	tetragonal	37.57	28.63	1.31226
16	f	oval	35.33	28.75	1.22887
17	f	pentagonal	30.4	28.54	1.065172
18	f	hexagonal	31.63	27.24	1.16116
19	f	pentagonal	32.97	27.77	1.187252
20	f	egg	28.8	25.73	1.119316
21	f	oval	33.28	23.28	1.429553
22	f	egg	27.76	24.23	1.145687
23	f	oval	31.2	26.43	1.180477
24	f	egg	35.52	30.12	1.179283
25	f	pentagonal	30.51	28.26	1.079618
26	f	pentagonal	32.7	29.3	1.116041
27	f	egg	29.32	28.38	1.033122
28	f	tetragonal	32.02	25.37	1.262121
29	f	hexagonal	32.44	27.26	1.190022
30	f	tetragonal	29.65	25.6	1.158203
31	f	pentagonal	28.28	26.16	1.08104
32	f	pentagonal	28.35	28.96	0.978936
33	f	tetragonal	34.15	26.09	1.308931
34	f	oval	33.98	29.9	1.136455
35	f	oval	32.35	25.52	1.267633
36	f	hexagonal	34.35	31.1	1.104502
37	f	egg	31.97	29.58	1.080798
38	f	egg	30.18	22.56	1.337766
39	f	hexagonal	34.92	28.55	1.223117
40	f	egg	32.02	26.09	1.22729
41	f	oval	30.32	25.63	1.182989
42	f	egg	33.41	28.32	1.179732
43	f	pentagonal	30.24	27.66	1.093275
44	f	oval	32.39	27.96	1.158441
45	f	oval	36.74	28.74	1.278358
46	f	tetragonal	31.44	27.25	1.153761
47	f	tetragonal	32.2	27.52	1.170058
48	f	egg	34.1	29.6	1.152027
49	f	egg	33.73	29.27	1.152374
50	f	egg	34.57	28.03	1.233321

OCCIPITAL CONDYLE - RIGHT SIDE					
specimen no:	M/F	shape	APD (mm)	TD (mm)	Index
1	m	kidney	22.2	13.21	1.680545042
2	m	triangular	18.23	10.59	1.721435316
3	m	eight	27.55	12.08	2.280629139
4	m	s-shaped	22.8	11.16	2.043010753
5	m	s-shaped	28	11.12	2.517985612
6	m	triangular	19.16	12.8	1.496875
7	m	triangular	21.86	13.65	1.601465201
8	m	s-shaped	26.05	16.34	1.594247246
9	m	oval	19.58	13.95	1.403584229
10	m	triangular	23.22	14.36	1.616991643
11	m	oval	22.54	12.69	1.776201734
12	m	kidney	26.06	11.55	2.256277056
13	m	s-shaped	22.96	9.3	2.468817204
14	m	eight	23.71	9.32	2.543991416
15	m	eight	22.76	12.06	1.887230514
16	m	eight	23.74	9.48	2.504219409
17	m	triangular	20.75	10.91	1.90192484
18	m	oval	24.64	11.55	2.133333333
19	m	eight	22.71	9.62	2.360706861
20	m	triangular	24.88	13.48	1.845697329
21	m	s-shaped	28.12	12.06	2.331674959
22	m	eight	23.04	9.63	2.392523364
23	m	triangular	20.59	13.21	1.558667676
24	m	s-shaped	25.66	10.78	2.380333952
25	m	triangular	23.57	13.98	1.685979971
26	m	eight	22.23	9.71	2.289392379
27	m	s-shaped	23.79	10.54	2.25711575
28	m	triangular	16.46	11.6	1.418965517
29	m	s-shaped	21.78	10.16	2.143700787
30	m	eight	25.16	12.64	1.990506329
31	m	kidney	19.86	11.66	1.703259005
32	m	s-shaped	27.95	10.73	2.604846226
33	m	triangular	18.85	9.76	1.931352459
34	m	oval	19.7	9.59	2.054223149
35	m	kidney	23.63	8.29	2.850422195
36	m	eight	25.53	10.2	2.502941176
37	m	s-shaped	24.47	11.06	2.212477396
38	m	deformed	25.13	7.83	3.20945083
39	m	s-shaped	26.49	9.98	2.654308617
40	m	oval	18.75	12.35	1.518218623
41	m	oval	19.08	12.12	1.574257426
42	m	kidney	23.46	10.06	2.332007952
43	m	oval	26.19	10.45	2.506220096
44	m	kidney	27.84	11.85	2.349367089
45	m	quandrangular	24.6	14.36	1.713091922
46	m	s-shaped	20.09	13.35	1.504868914
47	m	eight	24.38	9.12	2.673245614
48	m	eight	18.78	11.29	1.663418955
49	m	oval	17.34	11.55	1.501298701
50	m	oval	22.02	9.26	2.377969762

OCCIPITAL CONDYLE - RIGHT SIDE					
specimen no:	M/F	shape	APD (mm)	TD(mm)	index
1	f	kidney	18.65	12.19	1.529942576
2	f	two portioned	23.5	12.25	1.918367347
3	f	s-shaped	21.31	12.73	1.673998429
4	f	round	17.51	13.82	1.267004342
5	f	triangular	16.41	10.51	1.561370124
6	f	kidney	18.55	10.77	1.722376973
7	f	s-shaped	24.05	12.46	1.930176565
8	f	oval	17.5	12.48	1.40224359
9	f	oval	21.71	11.34	1.914462081
10	f	triangular	22.03	14.76	1.492547425
11	f	kidney	23.19	10.04	2.309760956
12	f	s-shaped	24.42	11.11	2.198019802
13	f	oval	21.75	10.54	2.063567362
14	f	oval	16.49	10.42	1.582533589
15	f	kidney	19.52	8.3	2.351807229
16	f	two portioned	23.33	7.67	3.041720991
17	f	s-shaped	30.38	13.34	2.277361319
18	f	oval	19.22	9.82	1.957230143
19	f	s-shaped	25.13	13.29	1.89089541
20	f	s-shaped	24.65	11.94	2.064489112
21	f	quadrangular	16.36	12.32	1.327922078
22	f	oval	19.84	11.31	1.754199823
23	f	oval	20.3	9.71	2.090628218
24	f	deformed	26.77	14.8	1.808783784
25	f	triangular	22.14	12.18	1.81773399
26	f	round	16.55	13.07	1.266258607
27	f	oval	23.97	11.91	2.012594458
28	f	oval	22.03	10.09	2.183349851
29	f	quadrangular	19.62	11	1.783636364
30	f	eight shaped	20.05	8.3	2.415662651
31	f	s-shaped	22.35	11.07	2.01897019
32	f	s-shaped	21.45	8.75	2.451428571
33	f	oval	19.58	11.85	1.652320675
34	f	s-shaped	20.12	10.08	1.996031746
35	f	oval	23.37	13.54	1.725997046
36	f	quadrangular	16.67	11.18	1.491055456
37	f	oval	17.04	13.19	1.291887794
38	f	s-shaped	22.33	9.87	2.262411348
39	f	quadrangular	19.77	12.94	1.527820711
40	f	oval	20.72	9.24	2.242424242
41	f	oval	21.53	11.16	1.92921147
42	f	kidney	19.16	12.36	1.550161812
43	f	kidney	21.8	9.89	2.204246714
44	f	triangular	20.24	14.53	1.392980041
45	f	quadrangular	14.46	12.37	1.168957154
46	f	oval	22.22	11.32	1.962897527
47	f	oval	26.35	9.15	2.879781421
48	f	quadrangular	22.08	11.96	1.846153846
49	f	kidney	24.21	11.94	2.027638191
50	f	oval	21.11	10.86	1.943830571

OCCIPITAL CONDYLE - LEFT SIDE					
specimen no	M/F	shape	APD (mm)	TD (mm)	index
1	m	triangular	23.27	16.45	1.414589666
2	m	eight	18.18	11.62	1.56454389
3	m	eight	25.1	12.65	1.984189723
4	m	s-shaped	21.73	11.16	1.947132616
5	m	s-shaped	26.92	12.15	2.21563786
6	m	s-shaped	24.24	13.04	1.858895706
7	m	triangular	22.05	13.46	1.638187221
8	m	triangular	22.93	16.89	1.357608052
9	m	deformed	17.49	10.91	1.603116407
10	m	eight	27.62	11.23	2.459483526
11	m	oval	27.04	14.09	1.919091554
12	m	kidney	23.73	11.77	2.016142736
13	m	s-shaped	24.65	9.31	2.647690655
14	m	kidney	22.08	11.43	1.93175853
15	m	eight	22.45	11.63	1.930352537
16	m	kidney	22.26	11.31	1.968169761
17	m	triangular	20.49	11.06	1.852622061
18	m	triangular	23.38	12.51	1.868904876
19	m	eight	21.08	8.45	2.494674556
20	m	oval	24.23	12.46	1.944622793
21	m	s-shaped	27.3	13.9	1.964028777
22	m	quadrangular	20.89	10.54	1.981973435
23	m	triangular	18.9	13.52	1.397928994
24	m	s-shaped	25.33	11.56	2.191176471
25	m	triangular	22.92	14.18	1.616361072
26	m	eight	21.21	9.41	2.253985122
27	m	s-shaped	24.23	11.31	2.142351901
28	m	triangular	14.17	9.87	1.435663627
29	m	s-shaped	22.72	10.09	2.25173439
30	m	eight	26.17	11.75	2.227234043
31	m	triangular	19.19	14.14	1.357142857
32	m	s-shaped	26.82	10.59	2.532577904
33	m	round	11.6	11.71	0.990606319
34	m	oval	18.82	11.37	1.655233069
35	m	triangular	20.15	10.89	1.850321396
36	m	deformed	25.24	15.05	1.677076412
37	m	s-shaped	21.68	12.73	1.703063629
38	m	eight	25.97	8.83	2.941109853
39	m	eight	21.99	10.16	2.164370079
40	m	eight	21.14	11.17	1.892569382
41	m	triangular	17.37	13.34	1.302098951
42	m	oval	20.38	12.02	1.695507488
43	m	oval	22.73	11.75	1.934468085
44	m	kidney	27.63	12.2	2.264754098
45	m	triangular	25.65	17.07	1.502636204
46	m	oval	21.47	12.65	1.697233202
47	m	eight	20.85	10	2.085
48	m	oval	20.19	13.41	1.505592841
49	m	oval	19.21	11.84	1.622466216
50	m	eight	24.35	9.35	2.604278075

OCCIPITAL CONDYLE - LEFT SIDE					
specimen no	M/F	shape	APD (mm)	TD(mm)	index
1	f	oval	16.63	12.86	1.293157076
2	f	eight	23.2	12.55	1.848605578
3	f	s-shaped	21.09	13.5	1.562222222
4	f	round	18.53	15.68	1.181760204
5	f	oval	23.14	9.49	2.438356164
6	f	kidney	20.25	12.3	1.646341463
7	f	oval	22.57	13.16	1.715045593
8	f	triangular	19.28	13.62	1.415565345
9	f	kidney	21.82	11.78	1.85229202
10	f	eight	21.02	14.6	1.439726027
11	f	s-shaped	21.5	11.14	1.929982047
12	f	kidney	21.4	12.13	1.76422094
13	f	triangular	20.22	10.87	1.860165593
14	f	oval	19.18	10.33	1.856727977
15	f	kidney	18.24	9.04	2.017699115
16	f	two portioned	24.02	7.49	3.20694259
17	f	s-shaped	28.71	14.16	2.027542373
18	f	oval	18.56	11.15	1.664573991
19	f	s-shaped	25.2	11.51	2.189400521
20	f	quadrangular	17.87	13.28	1.34563253
21	f	oval	20.75	11.17	1.857654432
22	f	eight	17.15	10.95	1.566210046
23	f	eight	20.09	10.91	1.841429881
24	f	s-shaped	21.81	11.92	1.829697987
25	f	deformed	21.24	14.04	1.512820513
26	f	quadrangular	21.78	13.78	1.580551524
27	f	oval	18.88	13.5	1.398518519
28	f	oval	21.33	11.66	1.829331046
29	f	quadrangular	21.64	11.82	1.830795262
30	f	oval	20.9	10.78	1.93877551
31	f	s-shaped	22.06	10.5	2.100952381
32	f	oval	19.5	8.3	2.34939759
33	f	oval	19.65	12.53	1.568236233
34	f	s-shaped	23.23	11.18	2.077817531
35	f	quadrangular	23.45	15.56	1.507069409
36	f	quadrangular	14.05	12.2	1.151639344
37	f	triangular	15.89	12.71	1.250196696
38	f	s-shaped	21.8	9.8	2.224489796
39	f	quadrangular	19.55	12.8	1.52734375
40	f	oval	19.57	10.7	1.828971963
41	f	oval	15.19	10.8	1.406481481
42	f	oval	17.13	10.48	1.634541985
43	f	triangular	18.99	13.78	1.37808418
44	f	triangular	20.41	13.93	1.465183058
45	f	quadrangular	16.05	12.51	1.282973621
46	f	oval	18.74	12.11	1.54748142
47	f	two portioned	18.35	12.03	1.525353283
48	f	eight	22.33	9.37	2.383137673
49	f	eight	20.91	10.6	1.972641509
50	f	triangular	17.8	13.87	1.28334535