INTRODUCTION
Chapter - 1

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Knowledge of the normal and variant positions of the foramina and canals of the skull base is important for Anatomists, Radiologists and Neurosurgeons. The cranial base is a complex structure with several different significant bony landmarks that forensic anthropologists utilize on a regular basis. A detailed knowledge of the morphologic variation in the foramina of skull base is vital to performing safe radical surgery. Familiarity of the topographical anatomy of the skull structures in three planes and their morphometric values is necessary and detailed knowledge of morphological variations is also vital.

Morphologic and morphometric variabilities of the occipital bone structures may coexist in the same individual or among different subjects of the same or different populations, as a result of genetic and heritable epigenetic interactions. Skull base variations may also be part of a pathological process (tumors, aneurysms, congenital or acquired malformations and trauma) and their surgical approach is technically demanding and requires the profound knowledge of anatomy.

Awareness of FM, OCs and HC's morphometric details enable an improved angle of surgical exposure with a wider access for a safe and successful surgery. The far lateral trancondylar approach and its modifications demand the extensive vertebral artery dissection, the HC exposure and the OCs and jugular tubercle removal. During condylectomy, clumsy manipulations may injure vertebral artery, jugular vein and bulb, damage the lower cranial nerves and cause craniocervical instability with the increasing high imaging capabilities of magnetic resonance imaging (MRI) and computed tomography (CT), foramina of the skull are being seen as never before in living individuals. Thus, evaluation of these foramina is becoming an important part of diagnostic medicine. Knowledge of the range of size and incidence of symmetric in variations of foramina of human skull is helpful in diagnostic evaluation of radiologic film. Awareness of foramina variants is not only important for understanding the complex regional neurovascular anatomy but is also relevant for distinguishing normal from potentially abnormal structures. Use of landmarks for the
The English word "skull" is derived from "skulle" which means head. It shields the brain, the organs of special sense and the cranial part of the respiratory and digestive systems. The cranium is the skull without mandible. The limit of Indian crania is around 1400ml. The posterior part of the cranial base is formed by the occipital and temporal bones. The cranial capacity of the adult cranial cavity varies between 1,000 and 1,800 c.c. with an average of about 1,400 c.c. Prominent features are the foramen magnum and associated occipital condyles; jugular foramen; mastoid and styloid processes of the temporal bone; stylomastoid foramen; mastoid notch and squamous part of the occipital bone up to the external occipital protuberance and the superior nuchal lines; hypoglossal canals (anterior condylar canals) and condylar canals (posterior condylar canals).

The word foramen is derived from the Latin word ‘foro’ (to pierce) which means an aperture or perforation through a bone or membranous structure. The other foramina lying in this fossa are jugular foramina and condylar canals (Anterior and posterior). Many important nerve and vessels pass in and out of the skull via these foramina.

Foramen magnum lies in an anteromedian position and is the biggest foramen in the skull. It is oval, wider behind, with its greatest diameter being anteroposterior. It contains the lower end of medulla oblongata, meninges, vertebral arteries and spinal accessory nerves. The apical ligament of dens and the tectorial membrane pass through it to attach to the internal basiocciput.

The foramen magnum (F M) carries a lot of interest for radiologists and neurosurgeons as variations in the base of foramen magnum have clinical and radiological significance. Knowledge of normal and variations of skull base is important for neurosurgeons, and anatomists. Likewise, there exists some relationship between the shape of foramen magnum and the heritage of a person. The foramen magnum is around 3 cm wide by 3.5 cm anteroposteriorly.

The dimensions of the foramen magnum are very important in dealing with compression during achondroplasia of foramen magnum, brain herniation and
in neurosurgical approach to access the lesions located anterior to the brainstem\textsuperscript{84} and in malformations like Arnold Chiari syndrome, which shows expansion of transverse diameter\textsuperscript{124}. The shape of foramen magnum varies. The importance of variations in shape is due to its effects on the vital structures passing through it and also plays an important role in various surgical approaches. 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 anteroposterior dimension of foramen magnum permitted greater contralateral surgical exposure for condylar resection\textsuperscript{83}.

The surgical errors in this region might result in injury to the vascular structures and cranial nerves and result in craniocervical instability. Consequently, neurosurgeons ought to be more familiar with the anatomy and variations of this region. Therefore, radiological and anatomical morphometric research have been performed to make contributions to the information about this area\textsuperscript{25,31,100}. The deference in the foramen magnum morphology from different reports shows racial inconstancy\textsuperscript{29}. Irregular shape of foramen magnum is featured by the formative cranial anomalies\textsuperscript{41}.

The jugular foramen, a large irregular hiatus, lies at the posterior end of the petro-occipital suture between the jugular process of the occipital bone and the jugular fossa of the petrous part of the temporal bone. A number of important structures pass through this foramen: inferior petrosal sinus (anterior); glossopharyngeal, vagus and accessory nerves (midway); internal jugular vein (posterior). A mastoid canaliculus runs through the lateral wall of the jugular fossa and transmits the auricular branch of the vagus nerve. The canaliculus for the tympanic nerve - a branch of the glossopharyngeal nerve to the cavity of the middle ear - lies on the ridge between the jugular fossa and the opening of the carotid canal. A small notch, related to the inferior glossopharyngeal ganglion, may be found medially, on the upper boundary of the jugular foramen (it is more easily identified internally). The orifice of the cochlear canaliculus may be found at the apex of the notch\textsuperscript{125}. Posterior fossa expansion occurs because of enchondral resorption, sutural growth, and bony accretion. Growth of the basal aspect of the clivus elongates the basisiocciput 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\textsuperscript{79}.

Typically, JF tumours produce the Jugular Foramen syndrome (Vernet’s syndrome) characterised by IX, X and XI cranial nerve palsy and may produce other related syndromes depending on the extension of the tumour\textsuperscript{44}.

The Hypoglossal (Anterior condylar) canal, lies medial to and below the lower border of jugular foramen. It might be somewhat or entirely isolated by a spicule of bone and transmits the hypoglossal nerve, its recurrent branch and a meningeal branch of the ascending pharyngeal artery and an emissary vein which links the basilar plexus with the internal jugular vein\textsuperscript{134}. Hypoglossal canal is of great clinical importance when considering certain pathological conditions like occipital bone fractures, intracranial and extracranial neoplasms and in congenital defects\textsuperscript{26,70}. Hypoglossal canal transmits hypoglossal nerve that supplies motor innervations to the tongue. The canal also contains venous plexus and an arterial branch leading to dura mater. Studies on anatomical variations of hypoglossal canal was been a considerable interest to research workers because of their regional and racial importance\textsuperscript{28}. The skull is a prime site for fractures resulting from trauma which means that these structures can be damaged as a result of head injury\textsuperscript{134}.

Recent advances in microsurgical approach and greater use of the running microscope have now enabled surgeons to operate deep-seated lesions of the skull base. It is, therefore, necessary that the clinicians have thorough information on the anatomy of this region for assessment of various disorders affecting this area\textsuperscript{69}.

Many clinical conditions have been associated with the variability in the dimensions of skull foramina. Neuro fibromatosis type 1 is found to be associated with increased in size of foramina and erosion at the base of skull. Similarly, stenosis of foramina at the skull base is associated with osteopetrosis. Other clinical conditions like metabolic disorders, achondroplasia, Crouzon syndrome are associated with variations in foramina\textsuperscript{135}. As endoscopic surgeons become more comfortable working along the skull base and beyond the skull base, they develop increased ability to repair larger, more difficult lesions\textsuperscript{150}. 

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Abnormal development is observed with the skeletal dysplasia’s, such as spondyloepiphysial dysplasia; achondroplasia; Goldenhar’s syndrome; and in genetic abnormalities, such as Down’s syndrome.

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. 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.

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 hemorrhage 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.

The newest and most advanced computed tomography (CT) and Magnetic Resonance Imaging (MRI) methods can evaluate anatomical variations of living human subjects. Since 1976 examinations of the head have been performed with computerized tomography. CT is a speedy, accessible, and moderately economical technique to survey neurological crises including hydrocephalus, discharge, and herniation disorders. As a rule, CT is the imaging technique for decision making in patients with posterior cranial fossa masses with symptoms of ataxia. The Multidetector Computed Tomographic (MDCT) is quickly turning into the new standard in radiological imaging. The most essential indications for CT imaging are intense head trauma.
suspicion of intense intracranial drain, quick postoperative assessment for surgical
treatment, shunted hydrocephalus, cerebellar herniation and suspected mass or
tumor.\textsuperscript{135,136} Computed tomographic scan is a noninvasive modality for imaging cranial
base. Since this process is widely done, this modality used to be preferred\textsuperscript{106}
Computed tomography (CT) has turned into the symptomatic methodology of
decision for head injury because of its precision, unwavering quality, security, and
wide accessibility. The adjustments in microcirculation, impeded auto-direction,
cerebral edema, and axonal damage begins when head damage happens and show as
clinical, biochemical, and radiological changes. CT examines, distinguishes and
exactly confines the intracranial hematomas, cerebrum contusions, edema and outside
bodies\textsuperscript{82}.

Because of the dense bone of the base of skull, beam-hardening artifacts are
frequently seen in images of the posterior cranial fossa. Thin slices can assist to
reduce these artifacts and produce an excessive spatial resolution.

MR imaging gives plainly prevalent delicate tissue appraisal while CT imaging still
remains the device of decision for recognizing calcification, hyperostosis, and bony
life structures. CT helps us to assess the degree of bone resection required to resect
tumor securely in view of the sharp difference amongst bone and delicate tissues. It is
hard to layout bone edges on MR pictures. The ideal imaging for surgery requires
both CT and MR Imaging to evaluate suitably bone and delicate tissues, individually\textsuperscript{36}. Helical and multidetector CT is useful in surveying occipital condylar
breaks. The examination incorporates bone windows to assess breaks, particularly
when the skull base is compromised\textsuperscript{111}. 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\textsuperscript{123}.

Physical anthropologists have long studied cranial metric data in order to reconstruct
population affinities. The present study might be useful to Anatomists and
furthermore to the Neurosurgeons in microsurgical strategies performed for injuries of
the foramina. In view of such a significant area for the neurosurgeons, this study was
carried out to bring some informative data in the measurements of foramen magnum,
jugular foramen and hypoglossal canal in north Indian population.