INTRODUCTION

Paediatrics head injuries is a frequent cause of emergency department (ER) visits. The incidence of head traumas in children varies from one country to other with an estimated 47 to 280 per 100,000 children presented to the ER each year due to traumatic brain injury (TBI) worldwide ***(Dewan et al., 2016).*** The highest reported incidence rate is in the united states, were about half a million children are presented to the ER due to TBI each year ***(Thurman, 2016).*** The frequency of minor head injuries that doesn't fall within the definition of TBIs is even higher. Head injuries are the most frequent cause of mortality due to trauma in paediatrics population. Infants younger than 1 year old are at higher risk for sustaining head trauma than other paediatrics age groups, usually secondary to falls and child abuse.

Computerized tomography (CT) is the gold standard diagnostic modality for detection of skull fractures and associated intracranial haemorrhage. Although CT scanning provides an immediate diagnostic benefit which can be lifesaving, it has long term side effects because of the considerably high dose of ionizing radiation receive by patients.

Head CT is the most frequent CT scan performed in paediatrics population, about quarter of those scans are done to evaluate trauma. Although head CT usually utilizes a lower dose of radiation when compared to pelviabdominal CT or spine CT, it is associated with highest risk of brain and haematological malignancies in children when compared to other CT scans ***(Miglioretti et al., 2013).***

There is a significant increase in risk of developing brain malignancies and leukemia in patients exposed to ionizing radiation from head CT scans, with an estimated threefold increase in the risk of developing brain tumours in children exposed to an equivalent radiation dose of 3 brain CTs ***(Pearce et al., 2012).*** It is also estimated that one case of leukemia will result for every 5000 head CT done for children younger than 5 years old ***(Miglioretti et al., 2013).***

The risks versus benefits of performing head CT in children with minor head injuries have long been debated. About 5% of children with blunt head traumas have evidence of TBIs on CT ***(Kuppermann et al., 2009).*** Furthermore, only 15% of patients with evidence of TBIs on CT will require neurosurgical intervention ***(Kuppermann et al., 2009).***

Many efforts have been made to limit the use of CT in children with head injuries to those who are likely to have clinically important traumatic brain injuries (ciTBIs) ***(Puffenbarger et al., 2019).***

The Pediatric Emergency Care Applied Research Network (PECARN) derived a set of clinical prediction rules to identify those at low risk of ciTBI to exclude them from CT scanning (Kuppermann et al., 2009). This significantly reduced

CTs done to children with low and intermediate risk for ciTBI ***(Nigrovic et al., 2015; Puffenbarger et al., 2019).***

Alongside efforts made to disseminate and implement the PECRAN clinical prediction rules, extensive research work was done during the last years to decrease the use of head CT in children with minor head injuries. Ultrasound (US) was an attractive alternative to head CT because of its low cost, availability and it doesn’t require sedation.

Children with head injury and skull fracture are 4 times more likely to have an underlying intracranial injury ***(Quayle et al., 1997),*** thus exclusion of skull fracture along with other clinical tools like the PERCAN clinical predictive rules may help decrease the need for CT scan in children presenting with head trauma.

Few observational studies were done to investigate the sensitivity and specificity of point of care US in diagnosis of skull fractures in children with comparable results ***(Parri et al., 2013; Rabiner et al., 2013; Riera and Chen, 2012).***

More research studies involving this specific age group (children less than 2 years) is required to define the role of US Vs head CT in patients presenting with closed head injuries. In our study, we aim to investigate the sensitivity and specificity of US scanning of the skull vault compared to head CT in detection of skull fractures in children younger than 2 years old presenting with closed head injuries requiring evaluation by head CT according to the decision of the attending emergency physician, and its relation to the clinical outcome of those patients.

Aim of the Work

Our aim was to evaluate the role of skull US in assessment of children younger than two years old with closed head injuries.

Chapter 1

SKULL VAULT EMBRYOLOGY AND ANATOMY

The skull consists of 22 bones, all joined by immobile fibrous joints called sutures, except for the mandible. The skull is divided into the neurocranium and the viscerocranium which is the facial skeleton ***(Tubbs et al., 2012).***

The skull vault or the calvarium is the uppermost protective bony envelop of the cerebrum. It consists of flat bones that constitutes the roof and the lateral sides of the skull. The calvarium along with the skull base forms the neurocranium which encases the brain.

The pediatric skull overall resembles adult skull in many anatomical aspects. Intramembranous ossification of skull vault bones begins around the 8^{Th} week of the intrauterine life, ossification centers start in the outer layer of the connective tissue membrane encasing the developing encephalon. This ossification process results in the formation of the different bones forming the calvarium. One the other hand, skull base bones ossifies by means of endochondral ossification process ***(Tubbs et al., 2012).***

The mesoderm remaining in between skull bones further develop into the fibrous tissues that form the syndesmotic articulations named sutures ***(Patel et al., 1994).***

Sutures are narrow irregular lines of fibrous connective tissue that interconnect the flat bones of the skull. Fontanels are the fibrous, membrane-filled spaces that are found in between two opposing cranial bony plates in infants and neonates ***(Hegazy and Hegazy, 2018).*** Fontanels main function is to capacitate the gradual increase in the size of the developing brain without being compressed by the skull. Furthermore, if pathological increase in CSF pressure as in hydrocephalus occurred after closure of the fontanels and sutures, it may result in compression of the cerebrum causing cerebral dysfunction and damage ***(Kahle et al., 2016).***

The anterior fontanel (AF) is thought to be an embryonic remnant from the ectomeninx, which is a neural crest derivative that later on forms a segment of the calvaria ***(Jiang et al., 2002).*** The diameter of the AF is influenced by many factors including the dura mater beneath it, volume expansion of the brain, changes in the related sutures, and regional rate of ossification of the neighboring bones. The AF is thought to play a key role in regulating the rate of ossification of the skull vault bones or the rate of increase in brain size ***(Dechant et al., 1999).***

The fontanels and sutures play a crucial role in normal vaginal delivery. They allows flexibility and overriding of the neonatal skull bones thus decreasing skull circumference during passage of the neonate through the relatively small birth canal ***(Pu et al., 2011).*** This process is known as molding. This occurs by posterior and superior displacement of the parietal bones and elevation of the occipital bone. Skull bones usually assume their original position after one week ***(Pekçevik et al., 2013).*** Molding is frequently encountered in head CT scans done to neonates for variable reasons, and if the radiologist is not aware of the normal physiological time that skull bones take to return back to their normal alignment, molding could be misdiagnosed as a depressed skull fracture ***(Pekçevik et al., 2013).***

The anatomy of the pediatric skull evolves with age resulting in morphological changes in different age groups. These changes accompany the normal developmental changes of the skull sutures and fontanels. Progressive closure of these fontanels and morphological changes in skull sutures result in the anatomical and morphological changes noted in the pediatric skull in different age groups ***(D'Antoni et al., 2017).*** Abnormalities in the timing of ossification of different fontanels and sutures lead to premature closure and abnormally shaped skull. These abnormalities may also impair normal development of the brain.

The bony plates of skull vault mature gradually during first year of postnatal life into two tables, an outer one and an inner one, both formed of compact bones with a layer of cancellous diploë separating the two compact bone plates ***(Tubbs et al., 2012).***

Bones of the Skull

The infants calvarium (**Figure 1**) is made of both parietal bones, most of the frontal bone, the squamous part of both temporal bones, parts of the sphenoid bone and the squamous part of the occipital bone ***(Tubbs et al., 2012).*** The skull base is formed by parts of the sphenoid, temporal and occipital bones. These bones are connected together with skull sutures and fontanels. The facial skeleton is formed by the paired nasal bones, palatine bones, lacrimal bones, zygomatic bones, maxillae, inferior nasal conchae and the unpaired vomer ***(Glass et al., 2004).***

The frontal bone can be divided into two segments, a vertically oriented segmented (squama) which has an internal and external surfaces, and a horizontally oriented segment (orbital) which has a superior and inferior surfaces ***(Imajo et al., 2018).*** The frontal bone is connected with twelve skull bones. The frontal bone is connected superiorly with both parietal bones at the coronal suture.

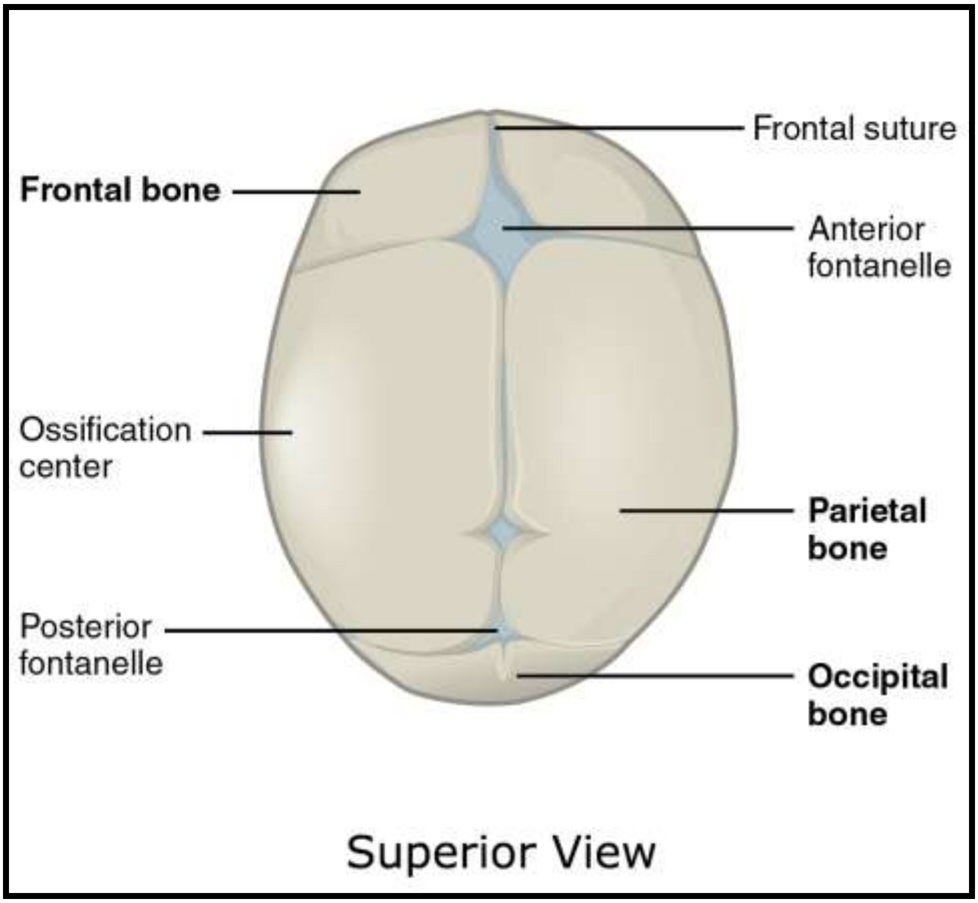

Figure (1): Skull Anatomy, superior view, courtesy of OpenStax College, Radiopaedia.org, rID: 42758

The parietal bones (**Figure 2)** are pair of quadrangular calvarial bones found on the lateral sides and the roof of the cranium. The parietal bone has an external and an internal surfaces.

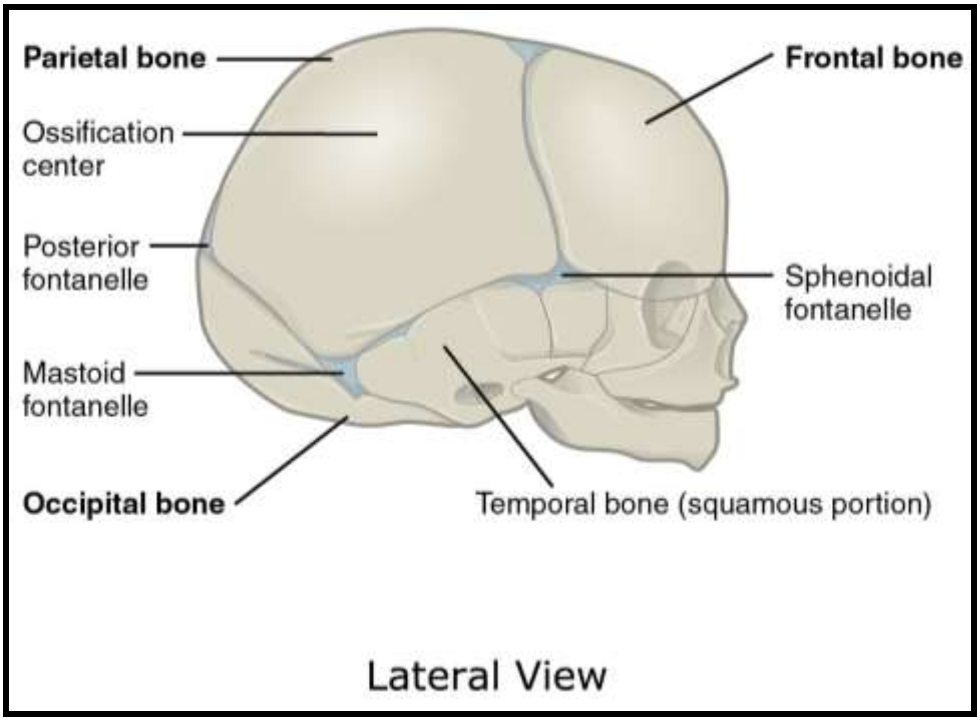

Figure (2): Skull anatomy, lateral view, courtesy of OpenStax College, Radiopaedia.org, rID: 42758

The temporal bones are located on the lateral aspects of the skull and the skull base. It is divided into five segments: squamous part, mastoid part, petrous part, tympanic part and styloid process.

The occipital bone is a trapezoidal shaped skull bone present at the posteroinferior part of the skull vault. The foramen magnum is situated within the occipital bone at the base of the skull. It articulates with the first cervical vertebra at the atlanto-occipital joint. The occipital bone is divided into four parts, squamous part, basilar part (also called the basiocciput), and two lateral or jugular parts ***(Idriz et al., 2015).***

Fontanels

There are usually six fontanels in the human skull: the anterior and posterior fontanels, which are located at the mid sagittal plane on the skull vault, and the anterolateral (sphenoidal) and posterolateral (mastoid) fontanels, which are present laterally on both sides of the skull. The parietal bone contributes in the formation of all fontanels because of its central location in the skull vault ***(Patel et al., 1994).*** Minimal pulsations may be evident normally on skull fontanels.

The AF is a curved rhomboid or diamond shaped, noncalcified, soft fibrous membrane located in the most superior part of the vault of the skull. It is situated at the confluence of the coronal, sagittal, and metopic sutures in neonates and infants in between the two frontal bones and the two parietal bones of the skull ***(Moffett and Aldridge, 2014).*** It is the widest fontanel and measures about 2.1 cm in diameter ***(D'Antoni et al., 2017).***

In some infants, the AF may initially increase in size in the first few months of life. The anterior fontanel closes progressively with increasing age as the infant's brain and skull develops, due to the gradual ossification of the bones surrounding it. The AF becomes completely closed at variable age ranging from 3 to 24 months ***(Adeyemo and Omotade, 1999).*** The AF closes at 1 year in about 40% of children, the median age of closure of the AF is 13.8 months and it closes earlier in boys than girls ***(D'Antoni et al., 2017).***

The posterior fontanel (PF) is more or less triangular in shape. The PF is situated at the junction of the occipital bone with the two parietal bones ***(Idriz et al., 2015).*** It persists until approximately 2-3 months after birth, after which it is known as the lambda. It can be used as an acoustic window for performing transcranial US to improve visualization of the posterior cranial fossa and dependently layering intraventricular hemorrhage.

The mastoid or posterolateral fontanels are present on both side of the skull at the confluence of the parietotemporal, occipitomastoid, and lambdoid sutures. The mastoid fontanel is usually closed after age of 2 years. The asterion is located at the site of the closed mastoid fontanel. The mastoid fontanel is frequently used as an acoustic window to the posterior cranial fossa during transcranial US ***(McKinney, 2017).***

The mastoid fontanel with the neighboring non fused squamosal and occipitomastoid sutures can be mistaken for a diastatic skull fracture during interpretation of head CT of an infant in the setting of trauma **(Figure 3)**. This is more pronounced if the infants head was positioned in an oblique orientation inside the CT gantry during image acquisition ***(McKinney, 2017).***

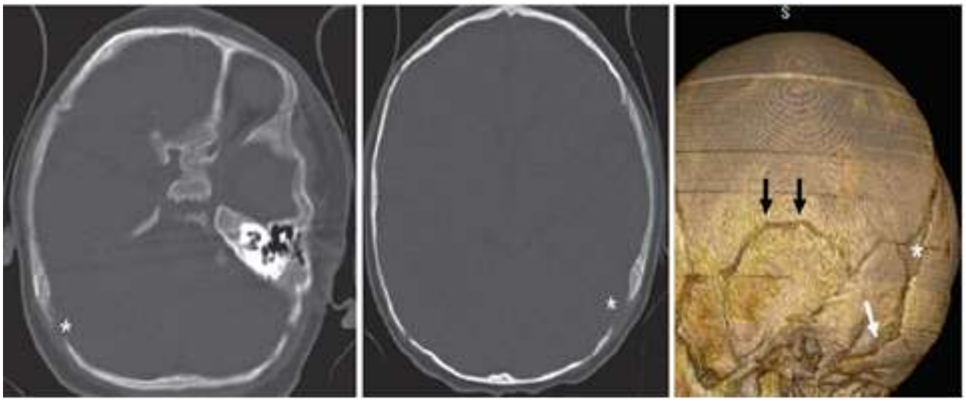

Figure (3): Mastoid fontanel initially misdiagnosed as a diastatic fracture in an infant. The patient was positioned obliquely during scanning. The left mastoid fontanel (white asterisks). White arrow indicates occipitomastoid suture; black arrows indicate squamosal suture ***(McKinney, 2017)***

Sutures

The complex nature of the pediatric skull anatomy makes recalling of normal sutural appearance difficult for most emergency radiologists. This complexity originates from the inconsistent and continuously changing appearances of skull sutures and fontanels over the normal developmental time span, especially during infancy and early childhood. Good knowledge of the normal anatomical evolution of skull sutures, synchondroses and fontanels is fundamental for correct interpretation of multidetector computed tomographic (CT) images of the pediatric skull ***(McKinney, 2017).***

Skull sutures closure is variable but usually begins in early childhood and is completely achieved at the third decade ***(Tubbs et al., 2012).*** Adult skull sutures are strong and capable of absorbing shock resulting from trauma, unlike the infant skull suture, which are considerably weaker ***(Margulies and Thibault, 2000).***

The main sutures of the calvarium are the coronal, sagittal, lambdoid and squamosal sutures. They are found in all pediatric patients and persist into adulthood. The normal anatomical appearance of these sutures is familiar to most radiologists, as they are commonly identified at head CTs of adult patients. The problem stems from the fact that these sutures fuse at different ages, and may vary from individual to another.

Coronal suture lies anteriorly and transversely at the junction between the frontal and the two parietal bones. Its measures around 2.5 mm at birth and narrows progressively to 1.3 mm after the first month of post natal life ***(Mitchell et al., 2011).*** The coronal suture is usually fused around 24 years of age. Early closure of the coronal suture may result in craniosynostosis and cranial distortion as in case of plagiocephaly ***(Glass et al., 2004).***

The frontozygomatic suture or the zygomaticofrontal suture is the articulation between the frontal process of the zygomatic bone and the zygomatic process of the frontal bone. Both nasal bones articulate with the frontal bone at the