SKULL FRACTURES
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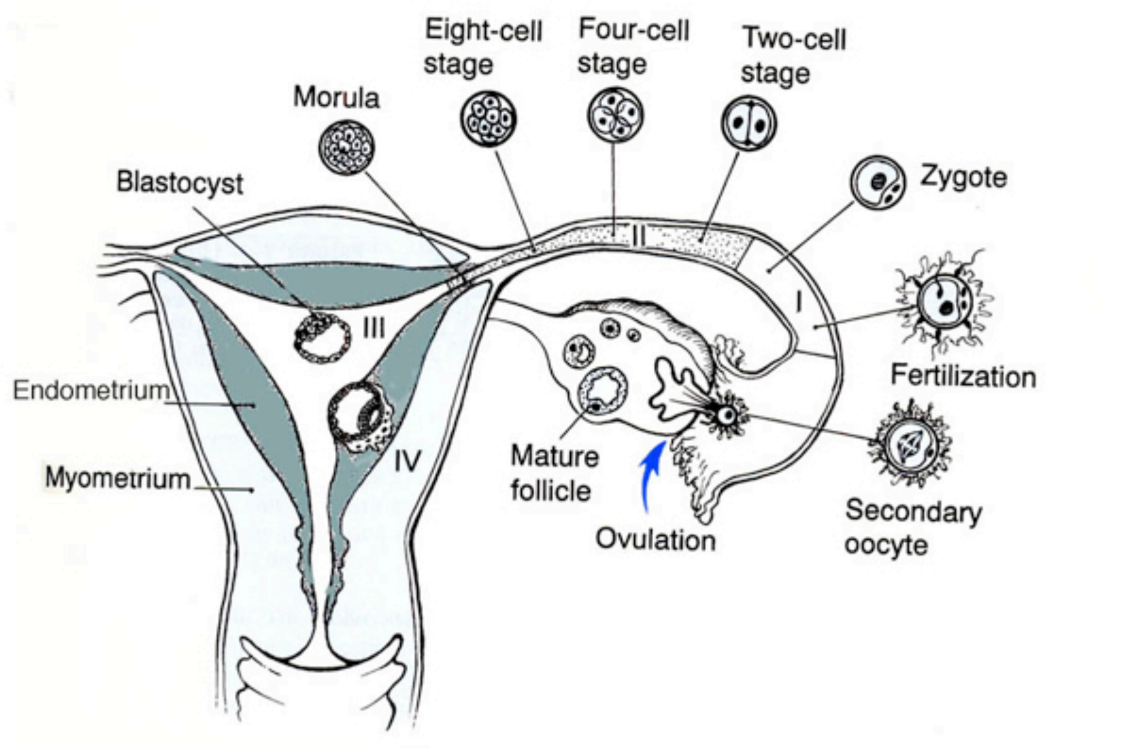
General Information

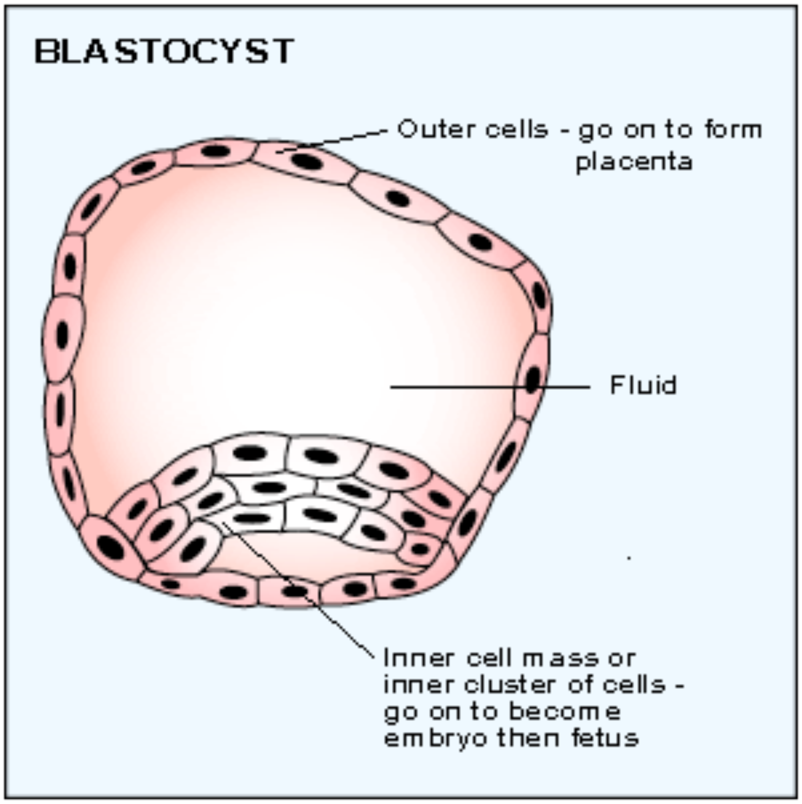
There are several types of skull fractures, which include linear skull fractures, depressed skull fractures, comminuted and multiple skull fractures, expressed skull fractures, contracoup fractures, ping pong fractures (pond fractures), birth fractures, infant skull fractures, diastatic fractures, and growing skull fractures. If the scalp is lacerated over a fracture, it is considered an open or compound fracture. Although skull fractures are indicators of serious potential injury, they in of themselves often do not cause a serious problem; the prognosis is more dependent on the nature and severity of the injury to the brain than on the severity of the injury to the skull. Before proceeding with a discussion of the various types of skull fractures, I believe it is important that we have a fundamental understanding of how the skull forms embryologically.

Embryological Development of the Skull

The origin of the bones of the calvarium (top of your head) and the base of the skull can be traced back to the first two weeks of human development, which is referred to as the pre-embryonic period.



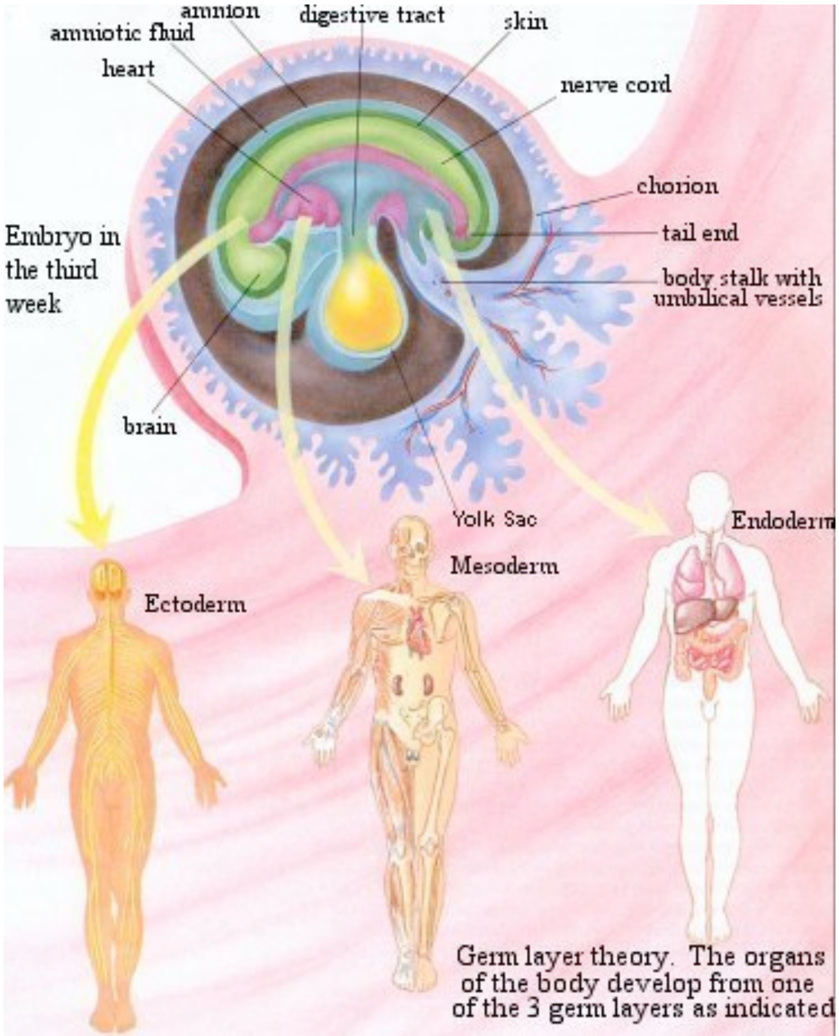
The pre-embryonic period begins with fertilization of the egg. Following fertilization, the cell divides over the next 4 to 5 days to form a cluster of cells, which is referred to as a blastocyst. The blastocyst consist of a hallow sphere, which contains an inner cell mass and an outer layer of cells. It is from the inner cell mass



that the embryo develops. Approximately one week after fertilization the blastocyst attaches itself to the uterus. Around the ninth day after fertilization the blastocyst consist of about 20 cells. It is at this point there is a restructuring and differentiation of these cells, which continues over the next 5 days culminating in the formation of an embryo, thus the first two weeks of development is referred to as the pre-embryonic period.

Technically, the embryonic period extends from the 14^{th} day of development until the eighth month of pregnancy. It is after the eighth month the developed embryo is referred to as a fetus.

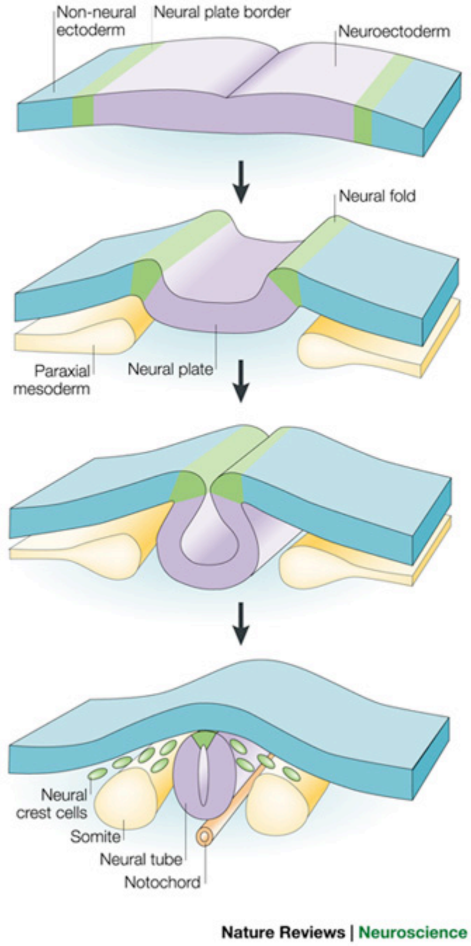
It is during the pre-embryonic period that the cells, which ultimately give rise to the various structures of the body, differentiate into three germ layers, the ectoderm, mesoderm and endoderm.



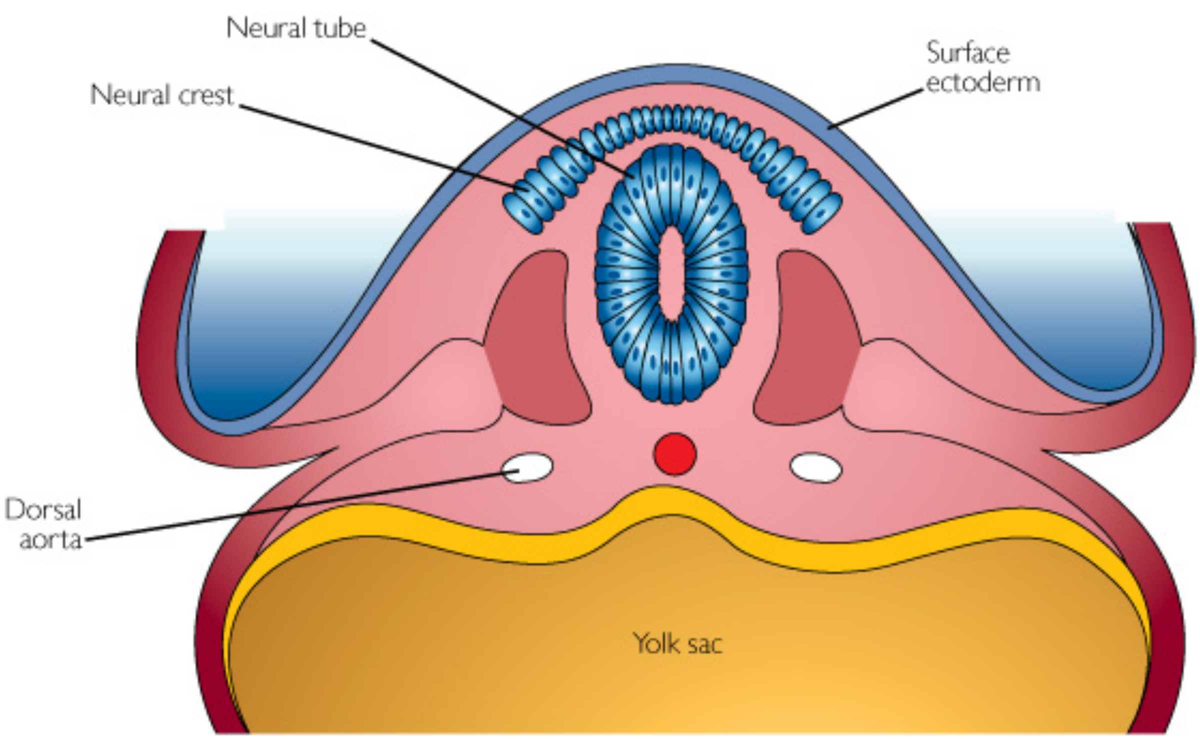
The ectoderm forms all nerve and some epithelial tissue; the mesoderm forms all connective, muscle and some epithelial tissue and the endoderm forms some of the epithelial tissue.

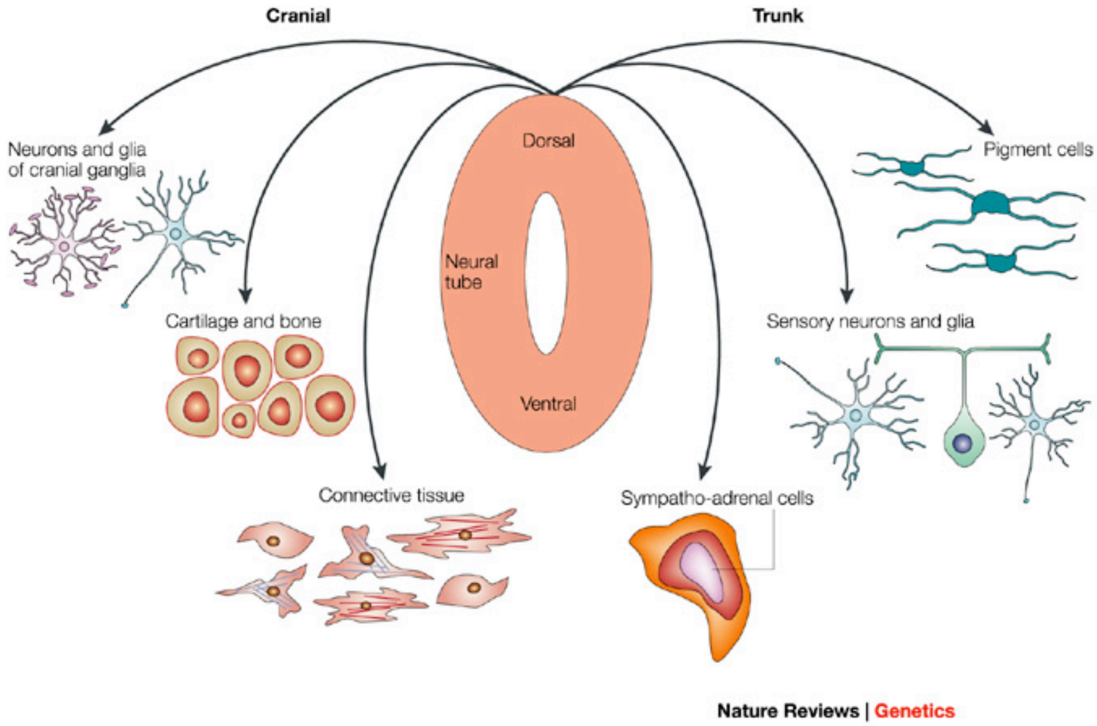
The development of the calvarium and base of the skull involves two of the germ layers, the ectoderm and mesoderm. By the end of the third week, the ectoderm differentiates into the neuroectoderm and epidermis. The epidermis covers the outside of the body. The neuroectoderm forms the neural tube, which gives rise to the brain and spinal cord and the neural crest.

The neural crest due to is importance is sometimes referred to as the fourth germ layer. It gives rise to neurons and glia of the autonomic nervous system, some skeletal elements, tendons and smooth muscle; chondrocytes, osteocytes, melanocytes, chromaffin cells, and supporting cells and hormone producing cells in certain organs.



The neural crest is divided into several categories, cranial, trunk and cardiac, the latter of which is in reality a subcategory of the cranial.



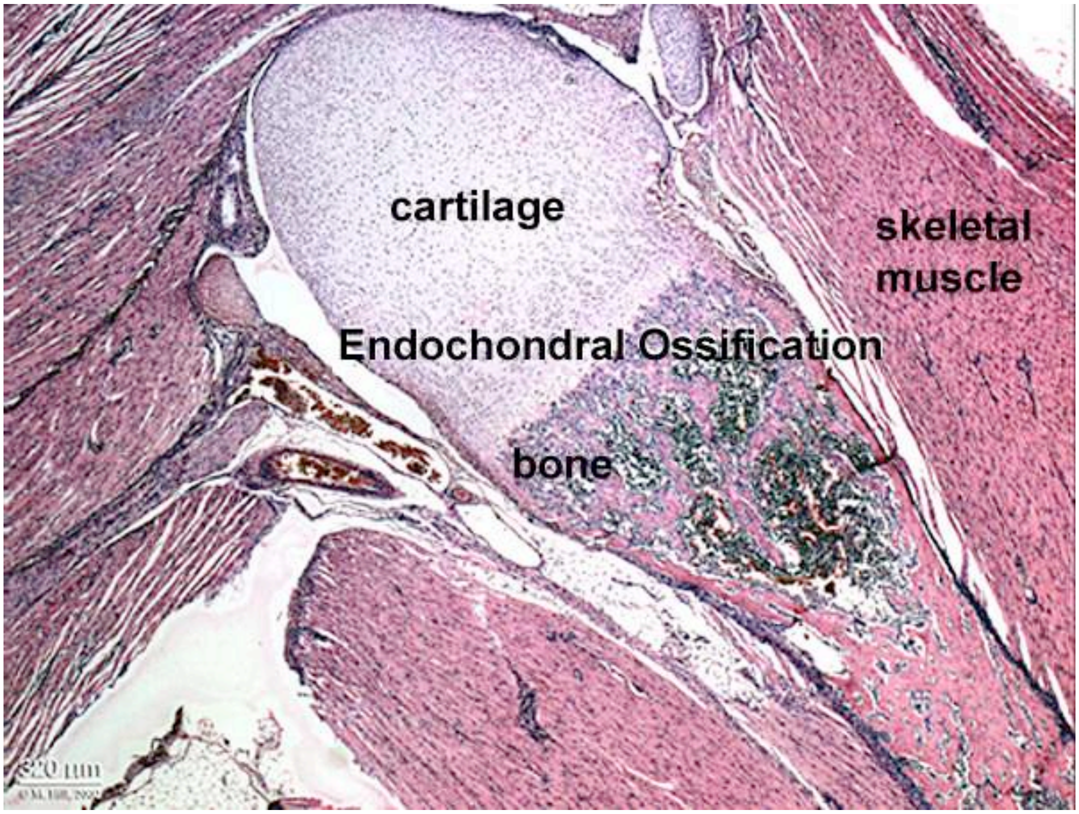


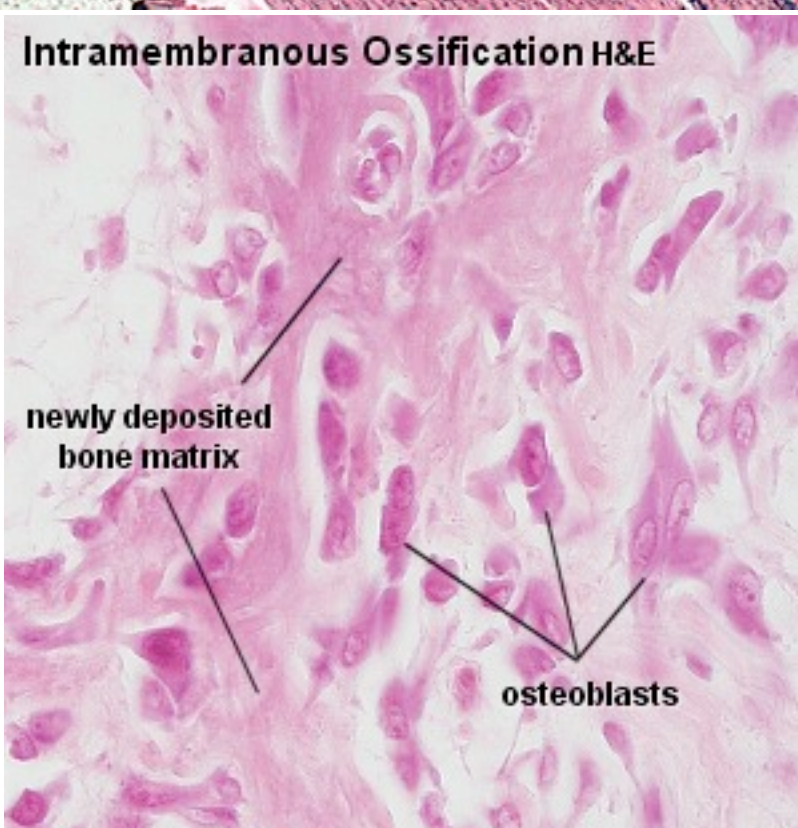
The mesoderm is also divided into regions, which are named relative to the embryo's midline, chordamesoderm (axial mesoderm), paraxial mesoderm, intermediate mesoderm and lateral plate mesoderm. As the head continues to develop cells from the neural crest and lateral plate mesoderm migrate to form the pharyngeal arches. Within these pharyngeal arches the cells of the cranial neural crest and lateral plate mesoderm form the bones of the jaw and portions of the base of the skull, which is referred to as the splanchocranium (viscerocranium). The cranial neural crest cells also give rise to the bones of the calvarium, which is part of the neurocranium.

The actual formation of the bones of the calvarium, also referred to as the cranial vault, and the base of the skull is through a process called ossification.

There are two types of ossification: endochondral and intramembranous.

Endochhondral ossification is a process of bone formation that begins with (endo) cartilage (chondral). Bone is derived from specialized mesodermal cells called mesenchyme. In endochondral ossification these mesenchymal cells first form cartilaginous centers, within the developing embryo beginning in the fifth week of gestational development. These cartilaginous structures are then transformed into bone through osteoblast, which migrate into these cartilaginous centers. Another cell, which migrates into these cartilaginous centers are osteoclast, which in contradistinction to osteoblasts, which form bone, breakdown bone formed by the osteoblasts. The osteoclasts and osteoblasts work in conjunction throughout the development of the calvarium, base of skull and face to modify the shape of each individual bone. The ossification of these cartilaginous centers of the facial bones begins around the third month of gestation.



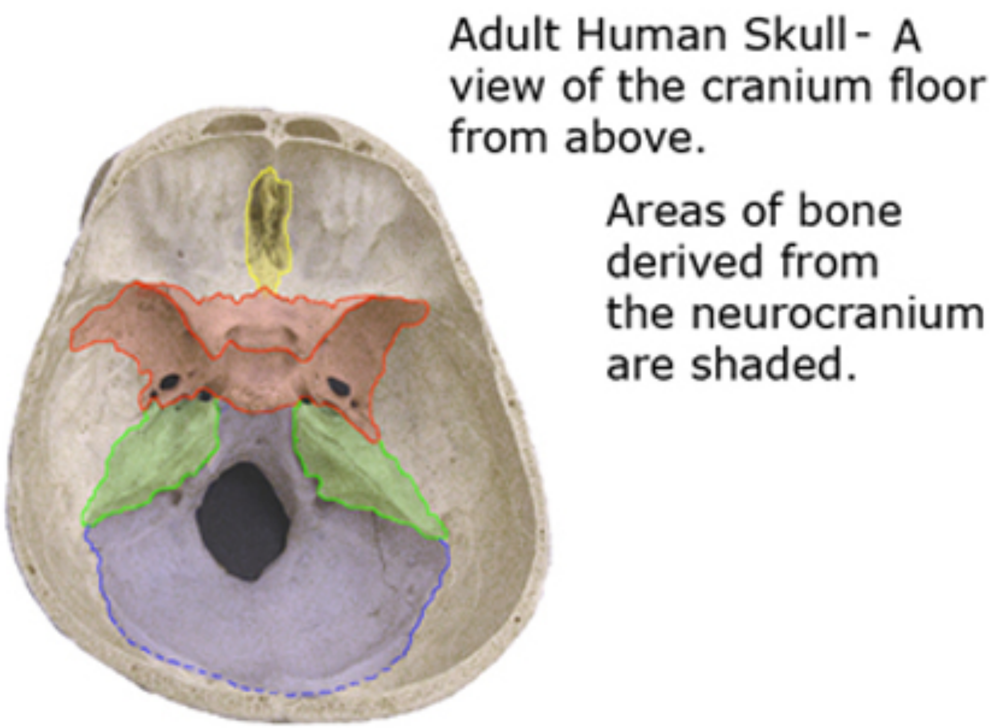


Intramembranous ossification is a direct form of bone formation in that bone is formed directly without going through a cartilaginous stage. The cells that ultimately will form bone are derived from specialized mesodermal cells that form membranous sheets. It is within these sheets that foci of the specialized mesodermal cells form osteoblasts and osteoclasts.

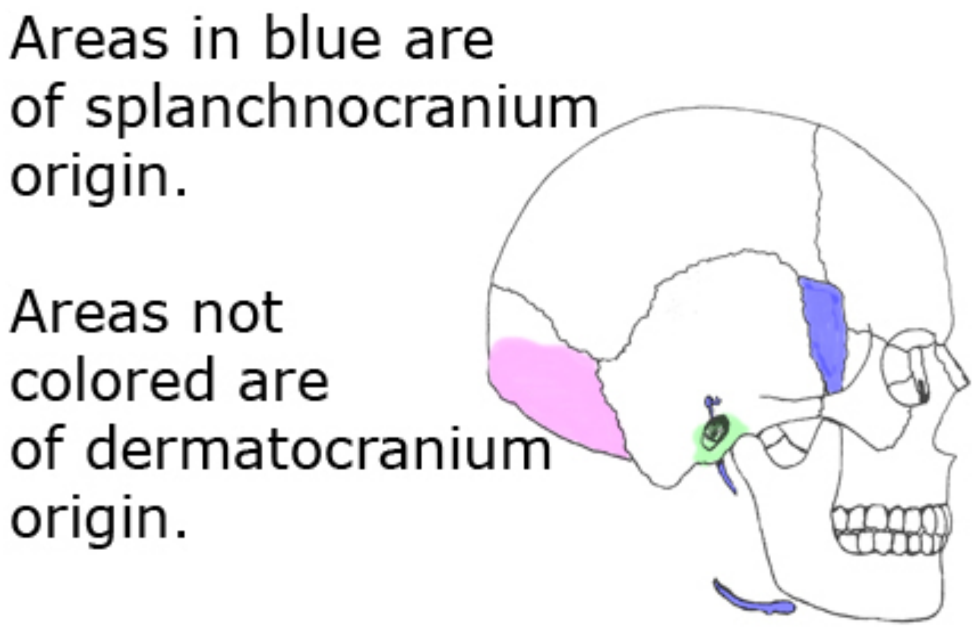
Bones Forming the Cranial Vault and Base of Skull

The bones of the complete skull (calvarium and base of skull and face) are formed through both intramembranous and endochondrial ossification with intervening flexible fibrous sutures. The flexible fibrous sutures between the developing bones of the calvarium allow the head to be compressed and thus pass through the birth canal as well as for postnatal growth.

The human skull develops from three separate sets of bone forming tissues: The neurocranium, splanchnocranium,and dermatocranium groups. In embryonic development, both the nerocranium and splanchnocranium groups begin as cartilage. As embrologic development proceeds these cartilages are converted to

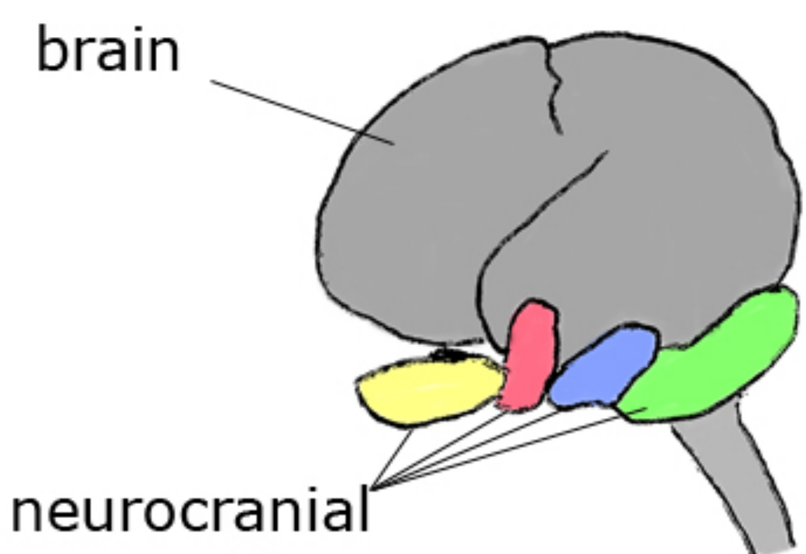


bone through endochondral bone formation. In contradistinction to the neurocranium and splanchnocranium, the dermatocranium evolves as fibrous membranes, which later in embryological development are converted to bone through intramembranous, or direct, bone formation.



NEUROCRANIUM

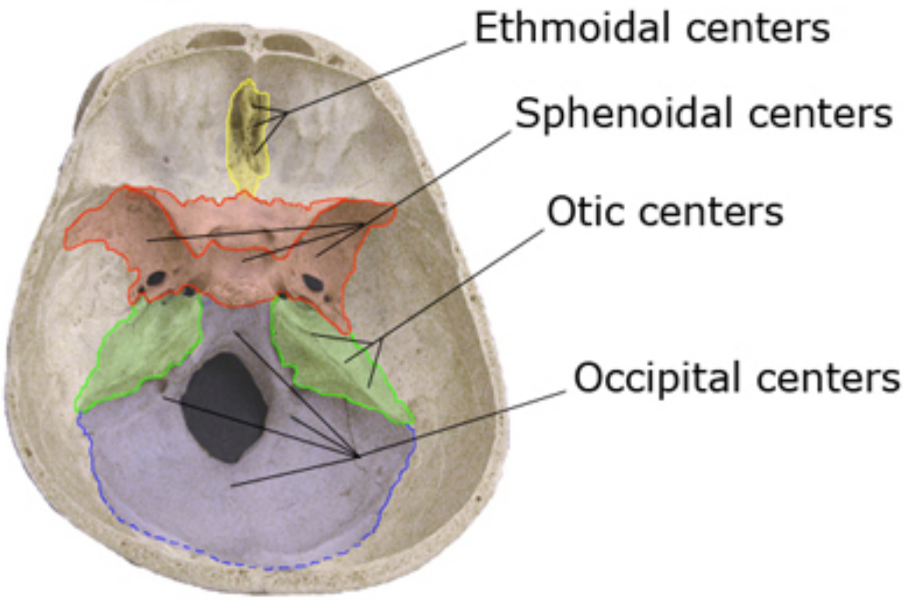
The neurocranium is a region of the head which forms from cartilages that develop around the floor of the brain just anterior to the notochord. The image below gives you the approximate locations of the neurocranium cartilages in human fetal



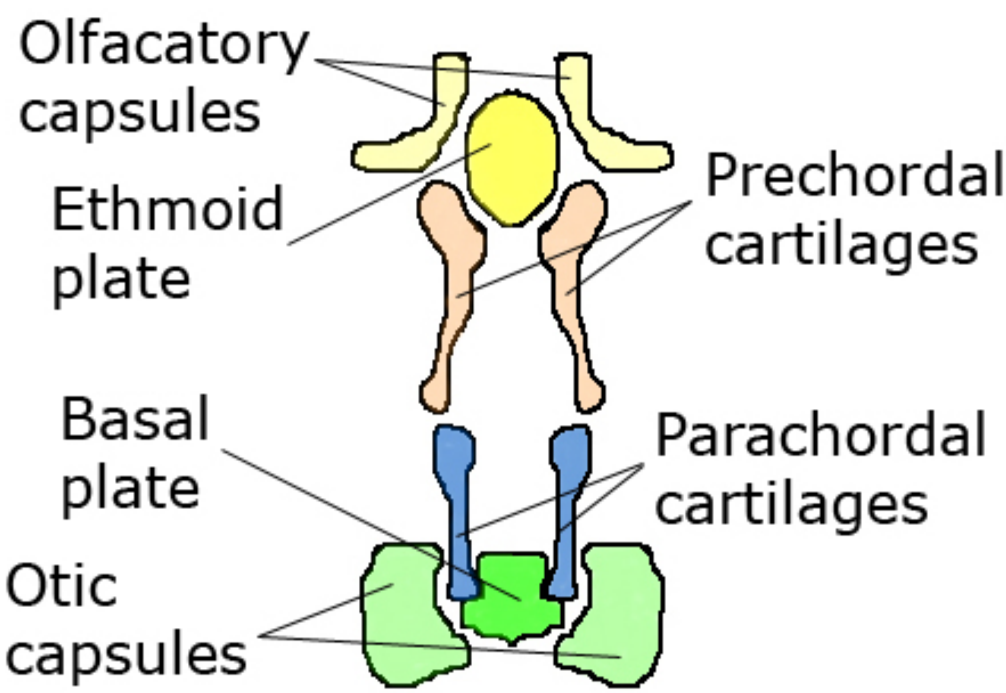
development.

These neurocranial bones become tightly fused with dermatocranial and splanchnocranial parts in the fully developed skull.

Neurocranial ossification regions as seen in the floor of the adult cranium when viewed from above.



The neurocranial elements begin as disconnected embryonic cartilages. One pair of cartilages lies ventral and lateral to the posterior brain region. These are the

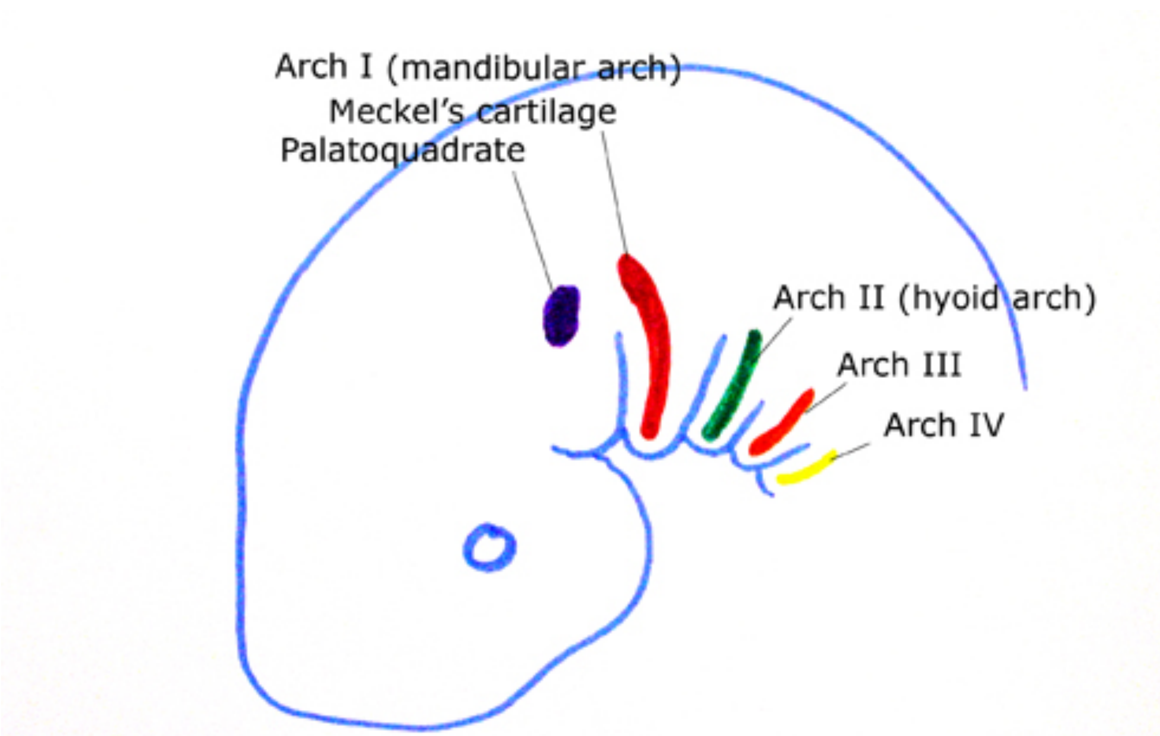


parachordal cartilages. Another pair of cartilages, the prechordal cartilages, lies ventral and lateral to the brain just anterior to the parachordals.

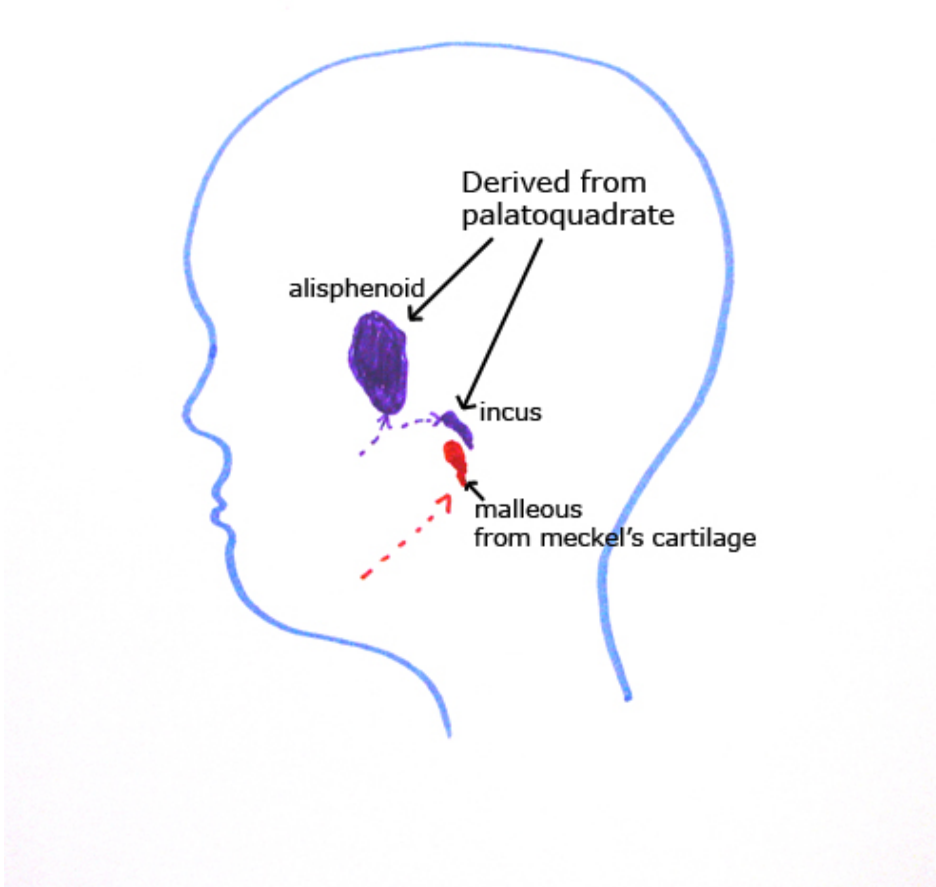
The prechordals become connected to the median ethmoid cartilage near the anterior end of the developing brain, and the parachordal cartilages become connected to the basal plate cartilage near the posterior end of the brain. These six cartilages form a supportive base at the perimeter of the developing brain. In addition to this supportive base, additional cartilages begin development around the paired internal ear structures and the olfactory organs. These become the otic capsules and olfactory capsules, respectively. In most species all of these cartilages become fused or tightly connected into all or part of the brain case during skull formation. In the human these elements become the ethmoid bone, part of the sphenoid bone, part of the temporal bones, and part of the occipital bone.

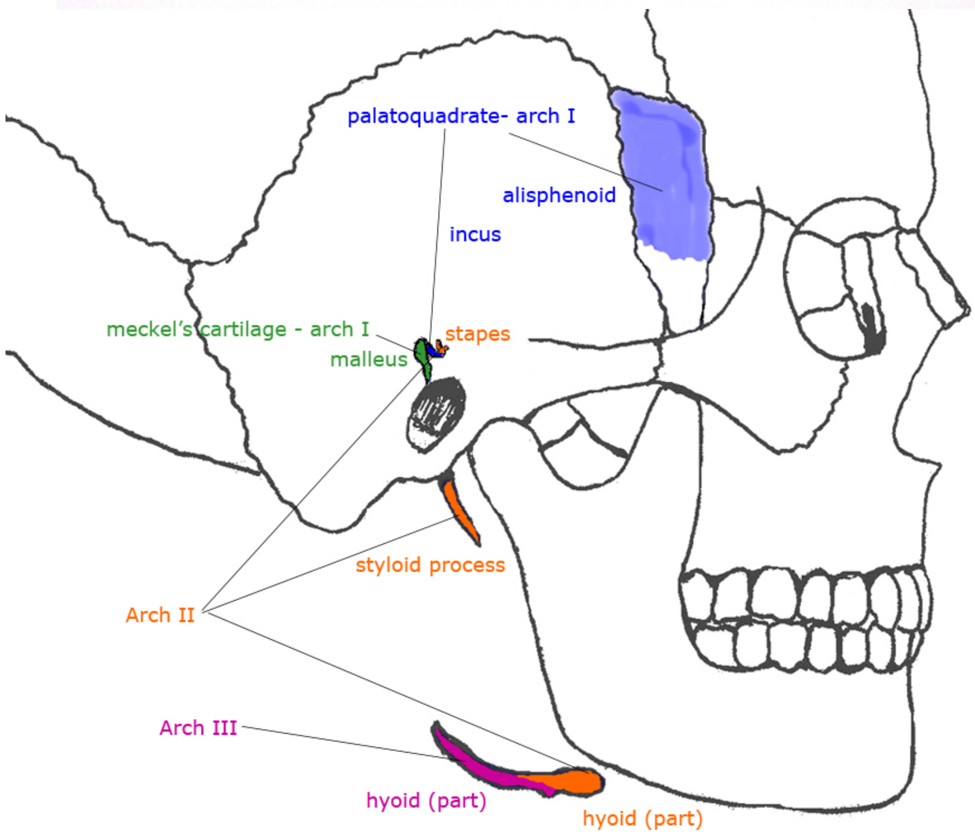
THE SPLANCHNOCRANIUM

The splanchnocranium, or visceral skeleton, has its embryonic origins in the visceral arches that surround the early pharyngeal tube. The skeletal elements begin as



cartilages. The cartilages of the first arch are the palatoquadrate of the upper jaw, and the Meckel's cartilage of the lower jaw.





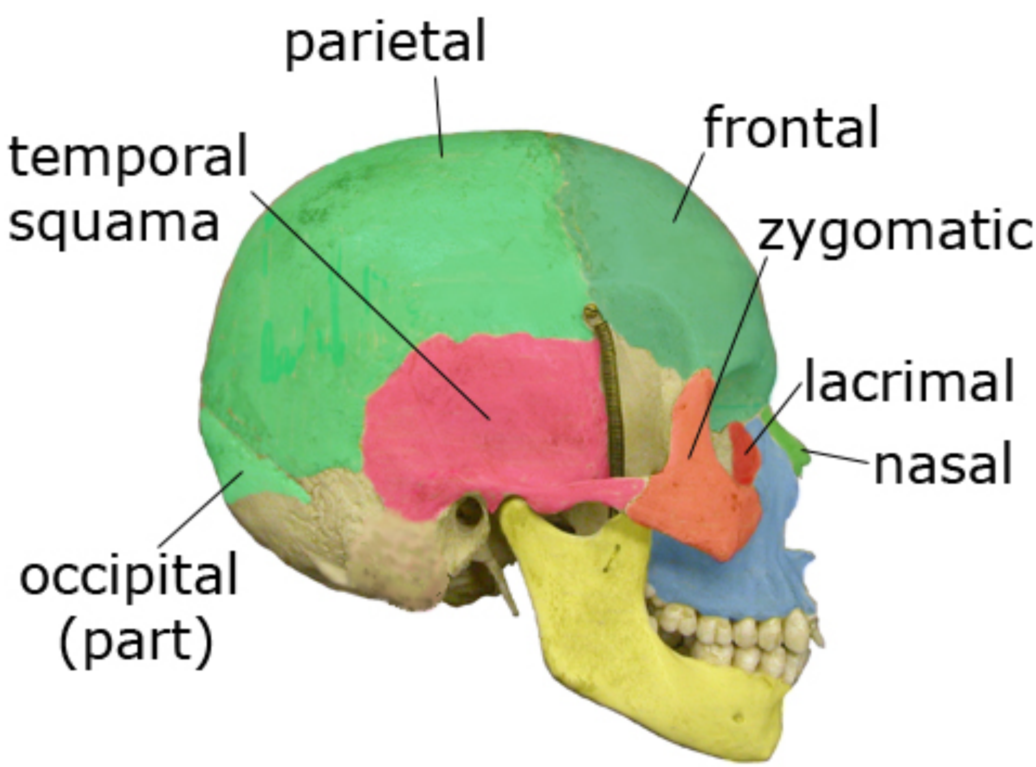
In the human skeleton remnants of the palatoquadrate become a lateral part of the sphenoid bone and the incus of the middle ear. A remnant of Meckel's cartilage becomes the malleus bone of the middle ear. Remnants of the cartilages from the second visceral arch become the stapes of the middle ear, the styloid process of the temporal bone, and a portion of the hyoid bone.

Other cartilages from the 3rd, fourth, and 5th visceral arches become parts of the hyoid bone and the larynx, but do not become part of the skull.

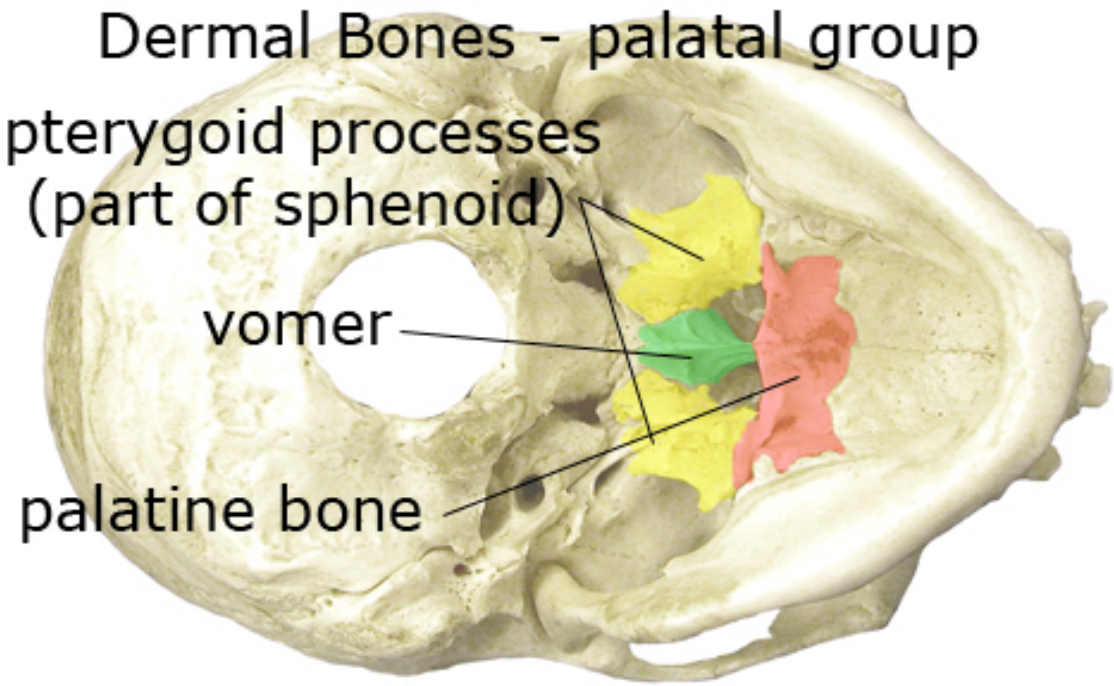
THE DERMATOCRANIUM

The drmatocranium is that portion of the skull which develops from dermal bone. The dermatocranial regions include the dermal bones of the cranial roof, the dermal bones of the primary palate, the dermal bones of the upper jaw, and the dermal bones of the lower jaw. In the human skull the dermal bones regions include the following:

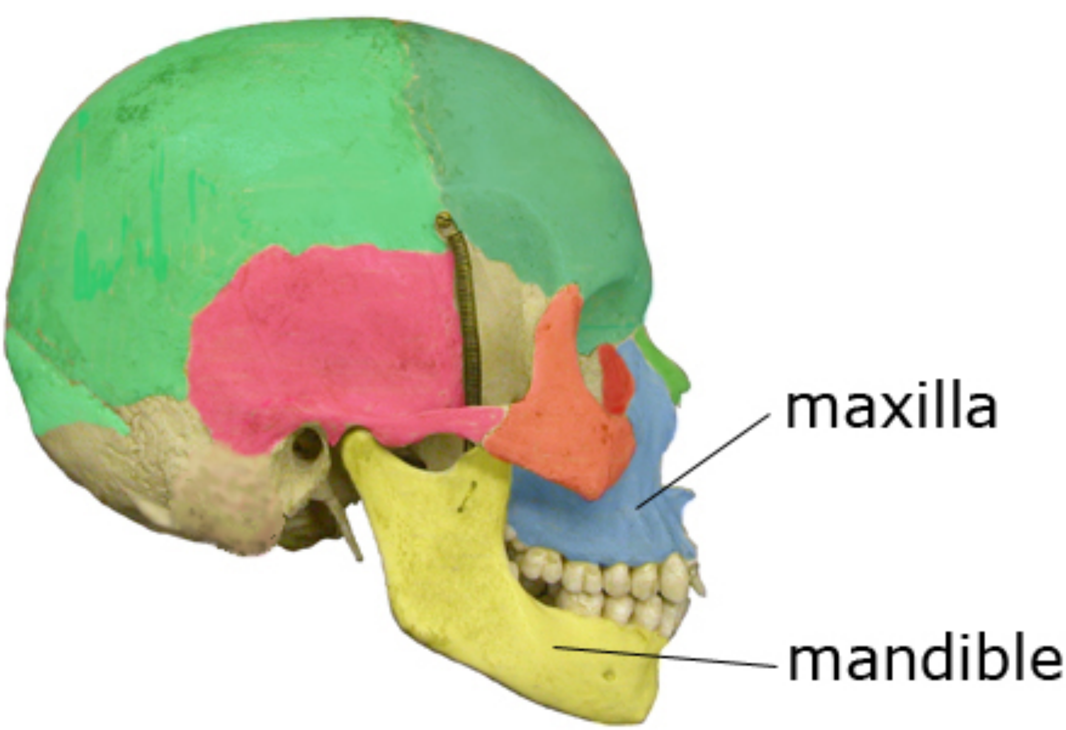
The cranial roof group: nasal, frontal, parietal, occipital (part), temporal (part), zygomatic, and lacrimal.



The primary palate group: vomer, palatine, pterygoid and part of the sphenoid.



The upper jaw: maxilla.



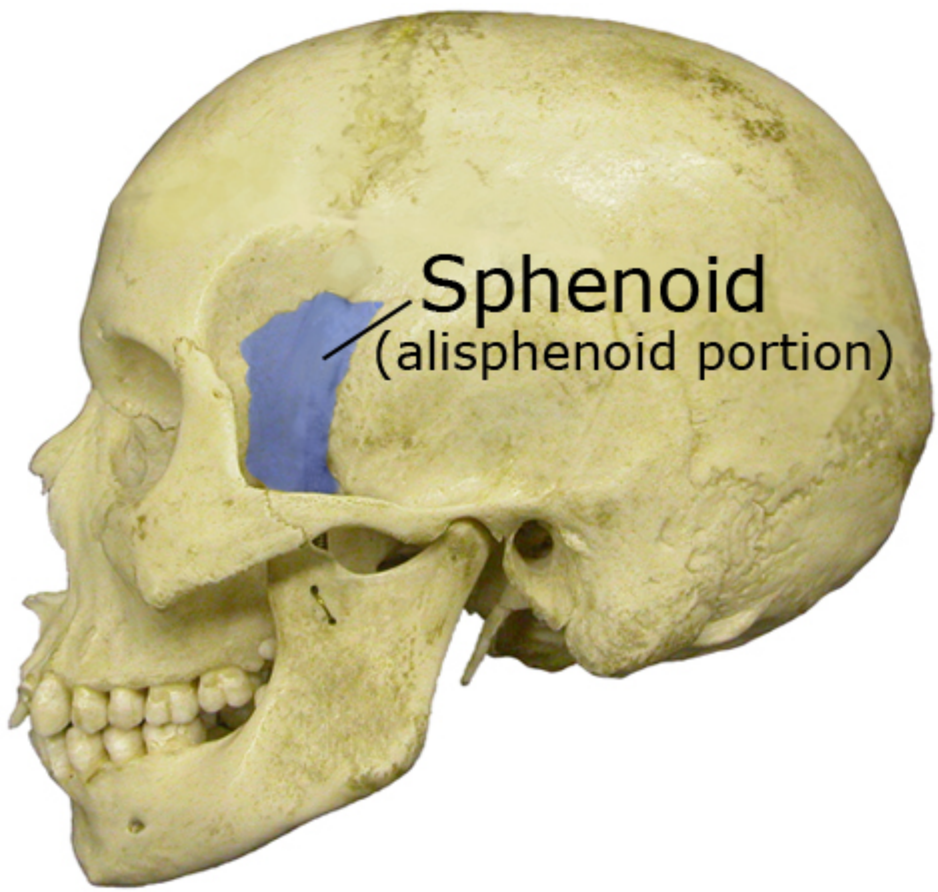
The lower jaw: manidble.

SKULL BONES FORMED FROM BOTH ENDOCHONDRIAL AND INTRAMEMBRANOUS OSSIFICATION

SPHENOID BONE

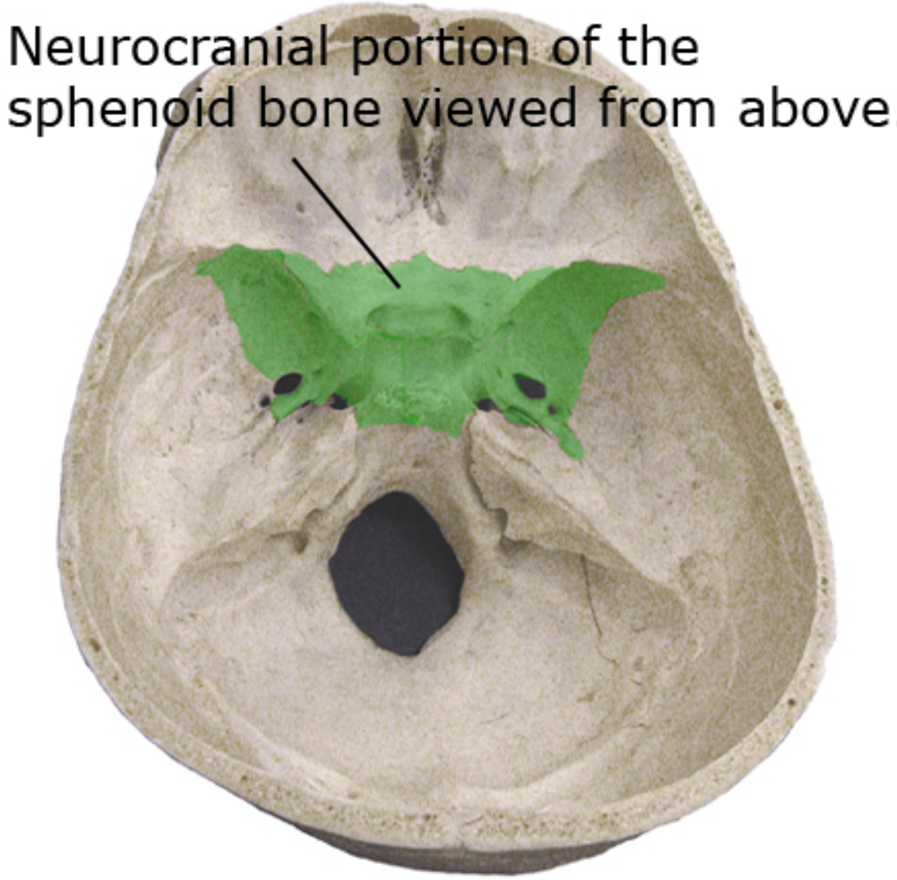
In the adult human skull the sphenoid gives the appearance of being a single piece, it is actually the result of fusion of several separate bones.

When you look at the lateral aspect of the human skull you will note the squamosal portion of the sphenoid bone (alisphenoid). This portion of the sphenoid is derived

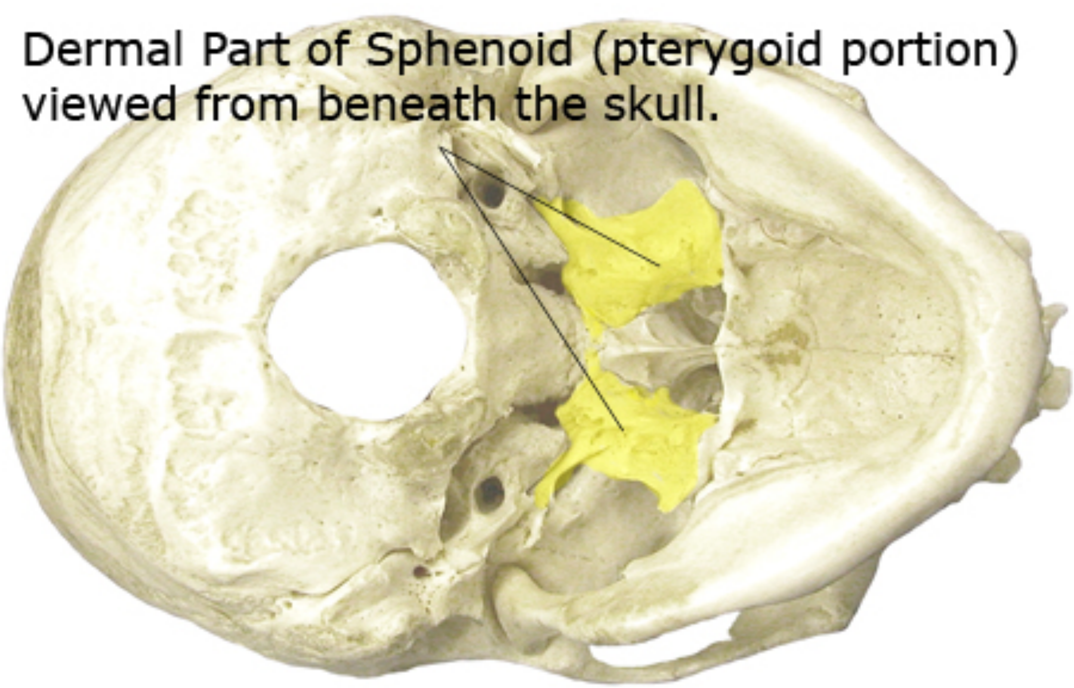


from the palatoquadrate, thus it evolved from the first visceral arch and forms through endochondrial ossification.

The central portion of the sphenoid, which include that portion that encloses the sphenoid sinus, forms the posterior lateral wall of the orbit, the sella turcica, and the



greater and lesser wings of the sphenoid bone. The central portion of the sphenoid is of neurocranial origin and thus forms also from endochondrial ossification.

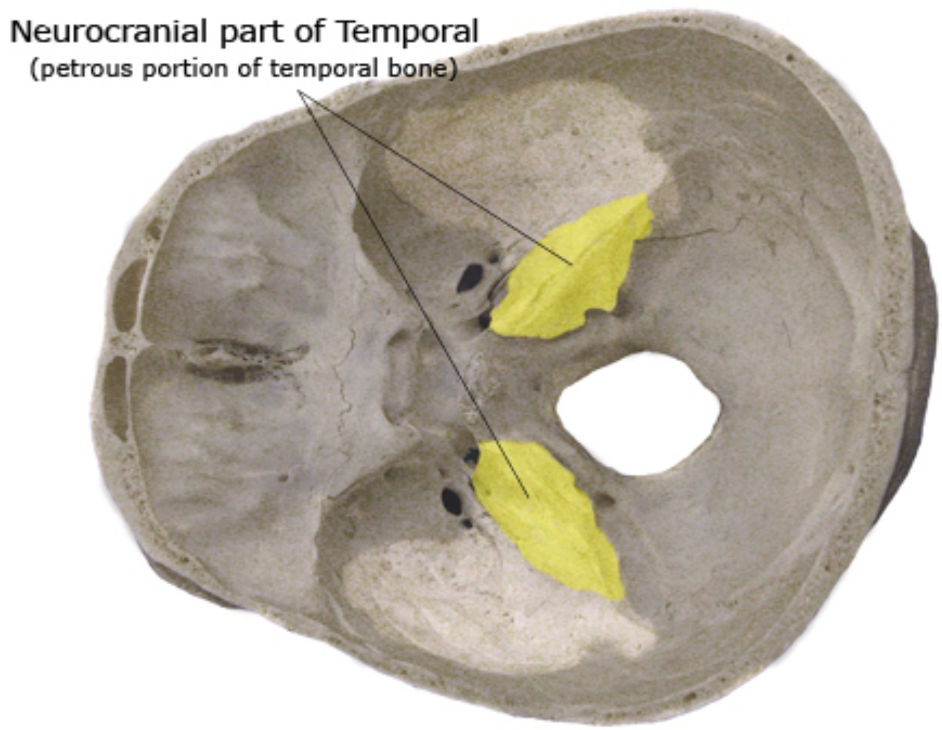


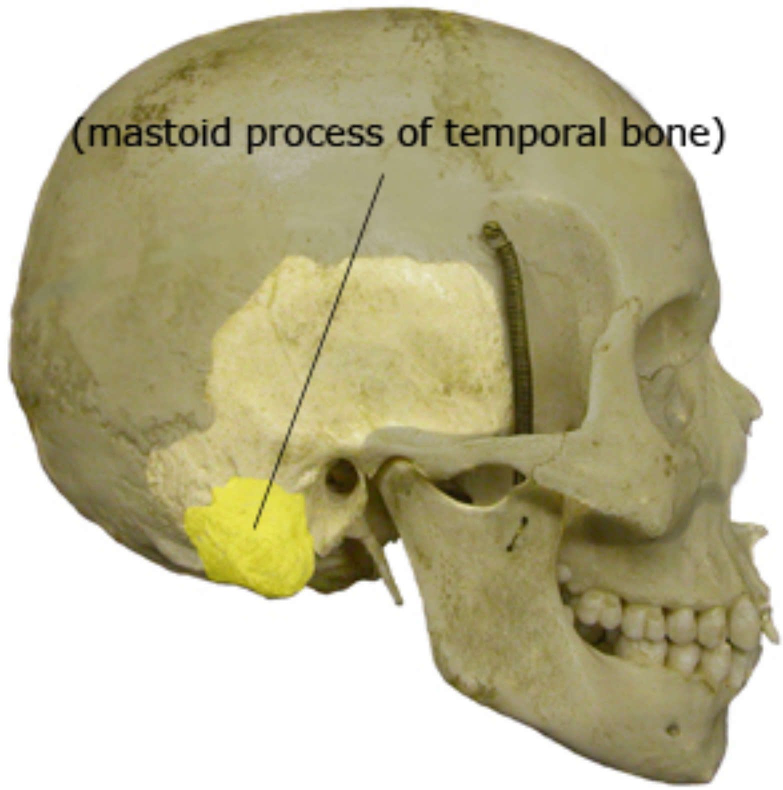
The ventral portions of the sphenoid, which are derived from dermal bone, include the pterygoid processes. These structures lie to either side of the vomer and extend lateral to the internal nares and the palatine. Since the pterygoid processes are derived from dermal bone they form by intramembranous ossification.

TEMPORAL BONE

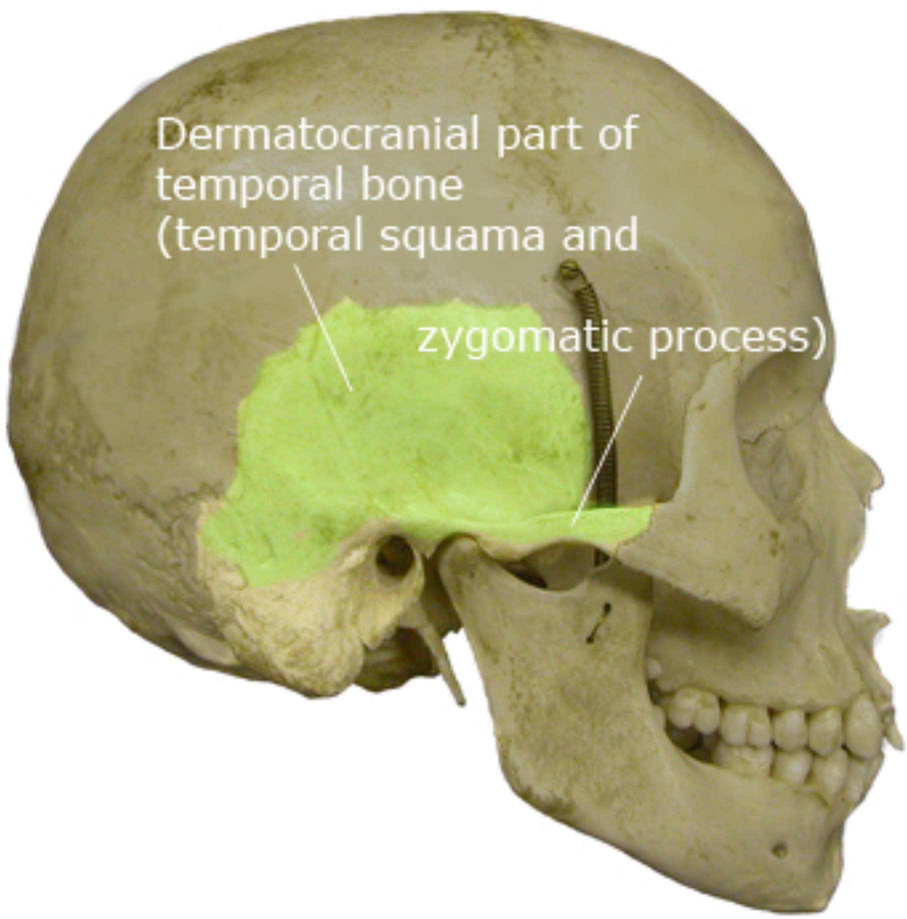
The temporal bone is another example of a bone, which forms through a fusion of several separate embryonic bone forming tissues. The temporal bone includes the following components:

The neurocranial component consists of the petrous portion and the mastoid process.

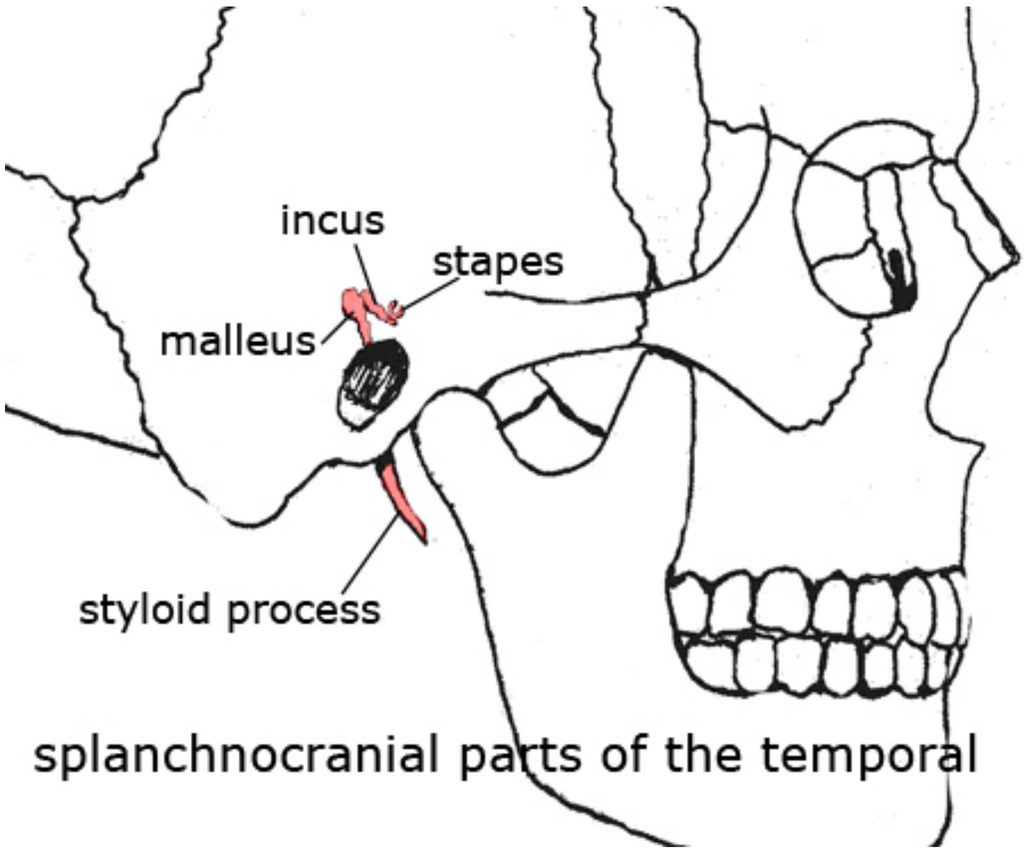




These are formed by endochondrial ossification.

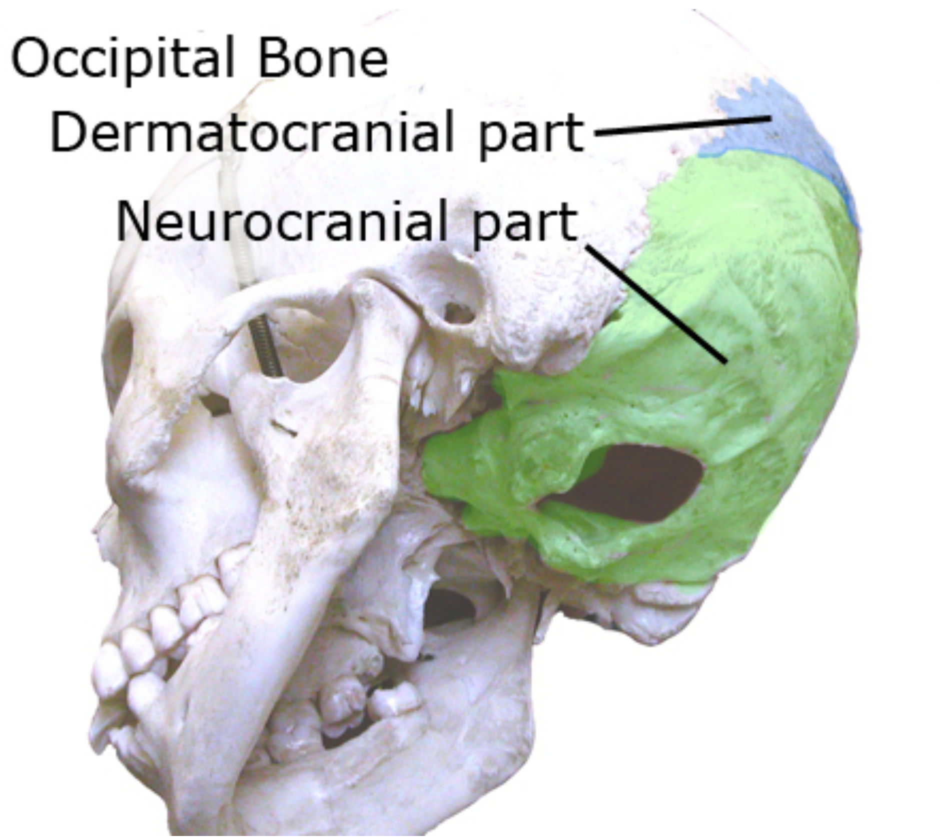


The dermatocranial portion consist of the squamous portion of the temporal bone. These are formed by intramembranous ossification.
The splanchnocranium portion consists of the malleus, incus, stapes and styloid process. These are formed by endochondrial ossification.

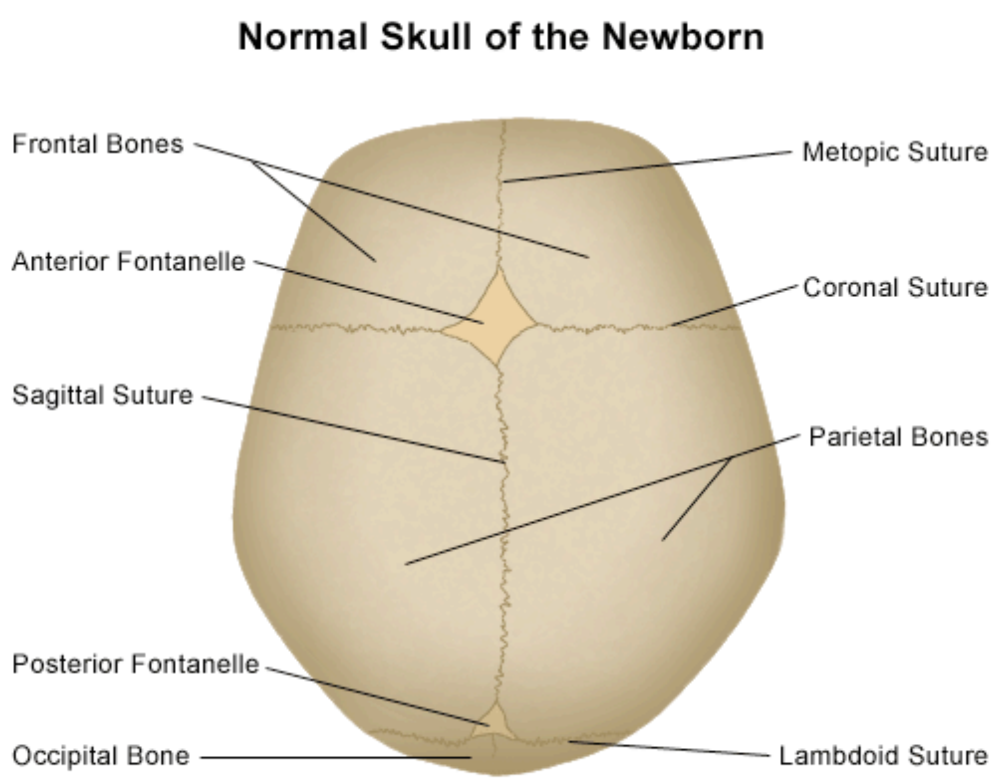


OCCIPITAL BONE

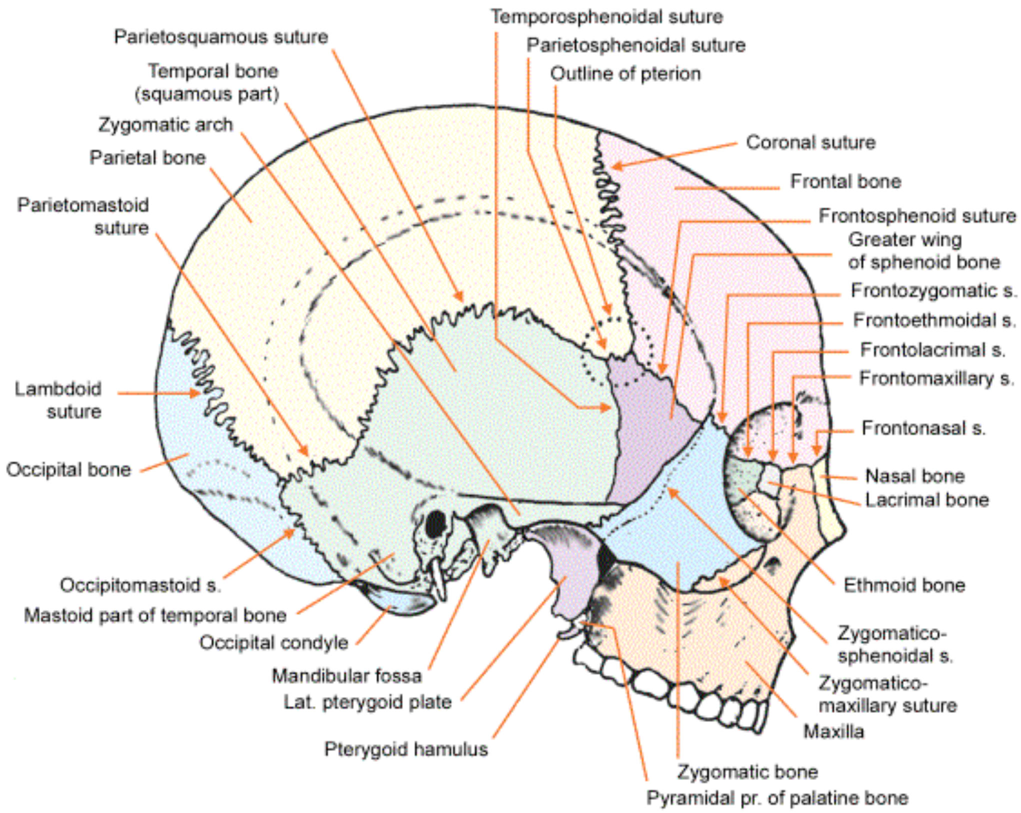
The occipital bone has both neurocranial and dermatocranial components. Most of the occipital bone is neurocranial in origin, including the area anterior to the foramen magnum, the occipital condyles and a broad area, which both surrounds and is posterior to the foramen magnum.
Only a small area of the occipital bone is derived from dermal bone. This area lies between that portion of the neurocranial bone posterior to the foramen magnum and the parietal bones. You can also see irregular small bones called Wormian bones, which lie within the lambdoidal sutures and lambda and are derived from dermal bone.


Occipital Bone
Dermatocranial part
Neurocranial part

SUTURES


Normal Skull of the Newborn
Frontal Bones
Metopic Suture
Anterior Fontanelle
Coronal Suture
Sagittal Suture
Parietal Bones
Posterior Fontanelle
Occipital Bone
Lambdoid Suture

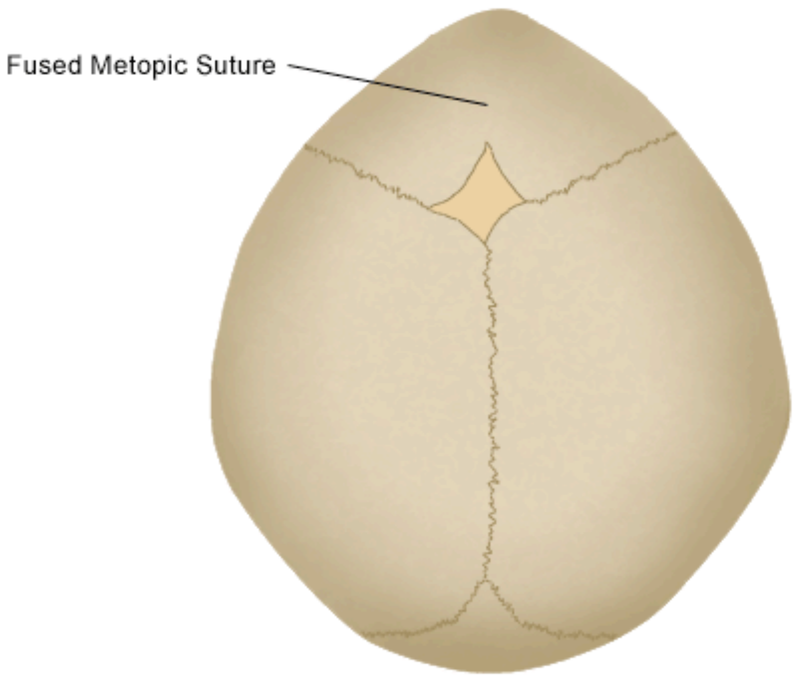
The five principle sutures of the calvarium are the coronal suture, which is between the frontal and parietal bones; the lambdoidal suture, which is between the parietal, temporal and occipital bones; the sagittal suture, which occurs in the midline



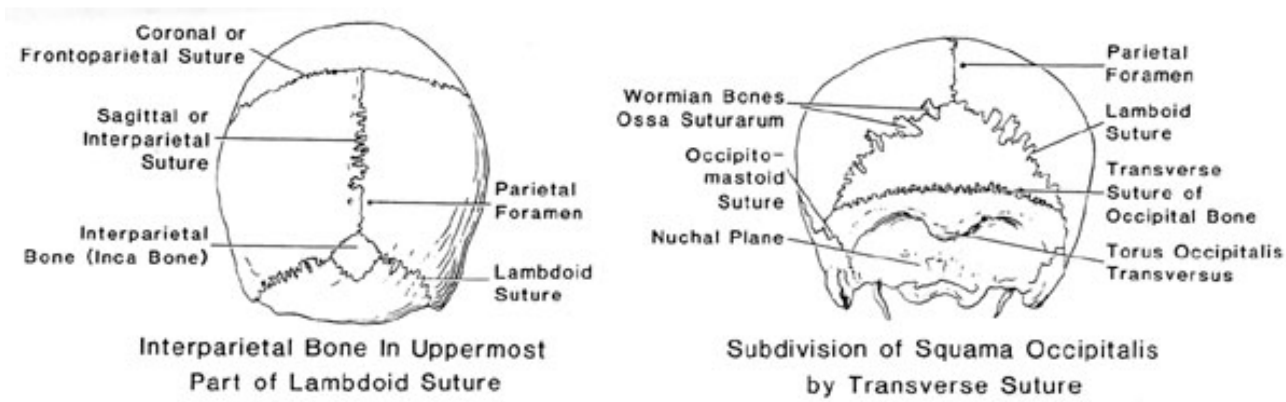
between the parietal bones and the squamosal sutures, which are between the parietal and the temporal bones. In addition to these five principal sutures, both the frontal and occipital bones may show additional sutures, the metopic (frontal) suture and the mendosal suture or sutures.

Within the midline of the frontal bone you may see the metopic suture, which begins normally at the root of the nose and runs superiorly to meet the sagittal suture. This normally begins to fuse at 3 months of age and is completed by 2 to 6 years. In 10 % of the population it remains open until adulthood. Typically in these cases the frontal sinuses are absent or hypoplastic. If the metopic suture is not present at birth, a condition called craniosynostosis, it will give rise to a keel-shaped deformity of the skull called “trigonocephaly.”

Trigonocephaly



If there is a defect in the ossification of the occipital bone it can give rise to an

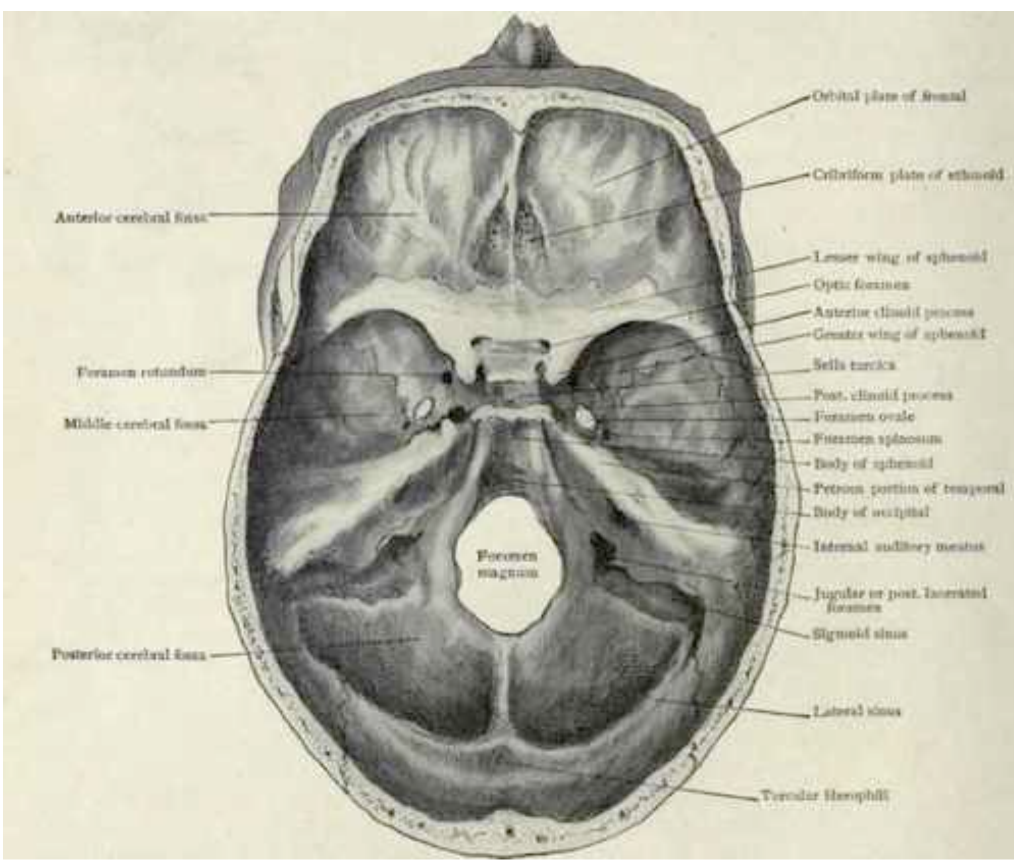


accessory suture or sutures called the mendosal suture and the transverse suture of the occipital calvarium. The mendosal suture typically runs close to the superior nuchal line, arising from the medial portion of the lambdoidal suture. The mendosal suture generally runs medial and horizontally. In one study they were found in 16% of adult skulls. Of these 16%, 12% had these sutures bilaterally and 4% where on the right side only. Typically their length varies between 0.8 to 1.4 cm., average 1.1 cm. The mendosal suture or sutures generally close within a few days of birth.

The sutures of the calvarium and base of skull typically close clinically between 6 and 12 months of age, but do not ossify completely until after 30 years of age.

As alluded to above, premature fusion of the cranial sutures will result in a condition called craniosynostosis, which manifest by producing an abnormal shaped skull, blindness and mental retardation. The type of craniosynostosis is determined by which suture fuses prematurely (oxycephaly-tower skull is due to premature closure of the coronal suture, etc.).

The skull vault is composed of both cortical bone (compact bone) and cancellous bone (diploe). The cortical bone forms the hard external surface (lamina externa) and internal surface (lamina interna). Between these two layers of compact bone is the softer spongy bone, which is referred to as cancellous bone. The lamina externa measures approximately 1.5 mm in thickness and the lamina interna 0.5 mm. An important point to remember is the diploe does not form where the skull is covered with muscle, i.e., squamosal portions of the temporal bone and the adjacent parietal bone; hence the bones in this region are thin and easily fractured. The diploic skull does not become evident until approximately 1 year of age.



The skull is also prone to fracture in the region of the sphenoid sinus, foramen magnum, petrous portions of the temporal bone, and the inner parts of the sphenoid wings at the base of the skull. The bones of the middle fossa are also prone to fracture, not only because they are thin, but also because they contain multiple foramina, which constitute weak points in the structure of the bone. Other bones that are prone to fracture are the cribiform plate and the orbital plates of the frontal bone, which form the roof of the orbits, and that portion of the skull between the mastoid and dural sinuses in the posterior cranial fossa.

Another important point to remember in considering the evolution of fractures of the skull is the thickness of the bone. The thickness of the skull not only varies according to anatomic location, but it also varies depending on age, race and sex. There is a rapid increase in skull thickness during the first two decades of life, followed by a small uniform increase reaching a peak in the 5^{th} and 6^{th} decades. The sex differences are variable, but in certain age groups the females in both whites and blacks have significantly thicker parietal and occipital bones than their male counterpart. The frontal bone is thicker in the white male than in the black, and the parieto-occipital is thicker in blacks than in whites.

The biomechanics of the adult skull is not attained until puberty, although from a pragmatic standpoint by age 5 or 6 the differences between the child's skull and the adult are comparatively small. The tensile strength of the adult skull averages about 10,150 psi, whereas the compressive strength ranges from 5,000 to more than 31,000 psi depending on what part of the skull is being measured.

Tensile strength is the maximum point of the stress-strain curve or if you will that point, in which the material being measured fails, otherwise referred to as ultimate strength. For a long bone this is 130 MPa. In contradistinction to this, the point at which a long bone reaches it maximum elastic deformation prior to fracturing is 104-121 MPa.

Compressive strength is the capacity of a material to withstand axial directed pushing forces. When the limit of compressive strength is reached, materials are crushed.

What is important to understand is the anatomic structure of the skull has important implications in its ability to handle impacts to the head. From an engineering standpoint the sandwich type construction of the bones of the skull allows for a relatively lightweight structure to have substantive strength in resisting bending and shear stresses. The lamina externa and interna provide for bending and shear strength, whereas the cancellous bone, due to its spongy character, allows for dissipation and absorption of energy. If you will, the anatomic structure of the skull is very much analogous to that of the wings of an aircraft.

The curved nature of the calvarium allows for dissipation of the impact force to be rapidly and evenly distributed across the bones of the skull. The fused sutures of the adult skull also play a substantive role in the dissipation and absorption of impact force through the interdigitation nature of the sutures, which because of the interdigitation provide a much larger surface area for dissipation and absorption of energy between the various bones forming the calvarium. Another way of looking at this is the external and internal lamina provides more for dissipation of the energy of the impact force, whereas the sutures provide more for absorption of this energy. In contrast to the fused nature of the sutures of the adult skull, the sutures of the infant skull are membranous and thus cannot dissipate or absorb the energy of impact force as well as the adult skull. This point is emphasized in experiments in which infant cadaver heads showed little difference in skull stiffness between anterior-posterior and lateral loading. In contrast, adult skulls showed a 50% greater anterior-posterior stiffness as compared to side-to-side (lateral loading) stiffness. Thus, although the compliance of the immature skull allows for greater deformation during vaginal delivery, it does not allow for the degree of dissipation and absorption of impact force as is seen in the mature skull.

Biomechanics of Fractures

How a fracture of the skull manifest itself is depended upon the anatomic location of the impact force, the intensity of the impact force and the surface area delivering the impact force. As previously discussed the individual skull bones show variation in their ability to tolerate impact force and thus sustain a fracture, as well as variation between the tolerance of an immature skull's to impact force as compared to an adult skull. A term which describes these differences mathematically is "elastic modulus, or modulus of elasticity."

Elastic modulus is a mathematical description of an objects' tendency to undergo non-permanent elastic deformation when force is applied to it. The elastic modulus is defined by the following formula:

$$\lambda \overset{\text{def}}{=} \frac{\text{stress}}{\text{strain}}$$

Where λ (lambda) is the elastic modulus; stress is the force causing the deformation divided by the area to which the force is applied; and strain is the ratio of the change caused by stress to the original state of the object. Typically stress is measured in Pascals, with strain being a unitless ratio, which results in λ being measured in Pascals. A Pascal is a measure of force per unit area, defined as one Newton per square meter. The elastic modulus for various materials are as follows:

Another way of expressing the elastic modulus is the stress required to cause an object to double in length. Leestma points out that the elastic modulus for neonatal skulls is less than 1,000 MPa (mega-Pascals), but from 6 months to 20 months it ranges between 3,000 to nearly 4,000 MPa. In the adult, the elastic modulus can reach as high as 10,000 MPa.

There is another term, which is instrumental in explaining the biomechanics of skull fractures, called "skull buttresses." Le Count and Apfelbach originally developed the concept behind this term; they published this concept in a paper "Pathological anatomy of traumatic fractures of the cranial bones and concomitant brain injuries," in 1920. Le Count and Apfelbach's concept was expanded by Gurdjian et al in a paper entitled, "Observation on prediction of fracture site, Head Injury," published in 1953. In essence what this concept states is there are linear areas within the skull, which pass from the base of the skull to the vertex, which have greater structural integrity than other areas. Thus, when impact force is applied in line with a skull buttress, the force or energy of the impact is directed upward toward the vertex. Consequently, if a fracture is produced it will follow the buttress; typically fractures do not cross buttresses. The primary buttresses are those, which extend from the orbital rim upward, from the junction of the zygomatic arch and temporal-sphenoid bone upward, from the mastoid bone upward, and from the occipital bone upward. Impacts to the frontal and occipital ones tend to pass vertically, whereas lateral

impacts tend to run horizontally or obliquely.

There are a number of other fundamental concepts of the biomechanics of fractures you need to be cognizant of. When impact force is applied to the skull over a small surface area, there will be a brief distortion of the underlying bone, such that the bone at the impact site bends inward. This is immediately followed by the bending of the bone outward at the periphery of the impact site, due to the dissipation and absorption of the impact force. If the stress force (elastic modulus) causing the deformation exceeds the allowable stress/strain of the impacted bone a fracture will develop initially at the inner lamina of the impact bone, which often extends vertically to the external lamina of the cortical bone. Virtually simultaneously, if the stress/strain of the bone at the periphery of the impact site is exceeded, you will see another fracture, which because of the direction of the energy of the impact force, will commence in the external lamina and proceed vertically downward often producing a fracture of the inner lamina. The biomechanics of this type of fracturing is often referred to as 'struck hoop' analogy.

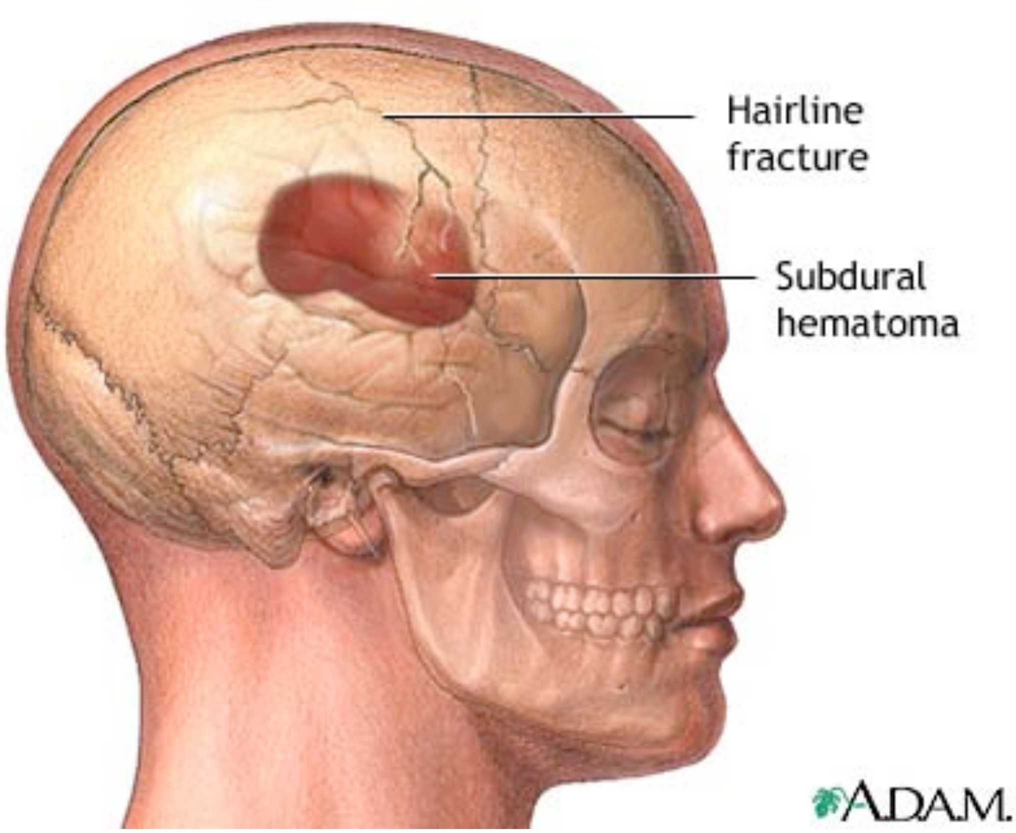
If the impact force is substantive, a depressed comminuted fracture will result.

When the impact force is delivered over a wider surface area of the skull the deformity of the skull is typically less than that arising from an impact force applied to the skull over a small surface area. However, if the force applied is such that it overcomes the stress/strain of the impacted bone than fractures will occur. These fractures may occur in an area removed from the impact site, i.e., blow to the vertex of frontal calvarium producing fractures in the orbital plate of the frontal bone. The fracture may originate from the area removed from the point of impact and travel toward the impact site, i.e., fracture of the parietal eminence, which travels toward the impact site of the frontal bone anterior to bregma.

Gurdjian performed an experiment in which he demonstrated stress lines in the cranium from impact forces not sufficient to induce fractures. When he increased the impact force, fractures developed in the same areas of the cranium that showed stress lines.

There are areas of the skull, which when they sustain sufficient impact force to overcome the stress/strain of that particular bone will produce fractures in specific areas of the skull. As an example, an impact force applied to the squamosal portion of the temporal bone or the parietal-temporal area will give rise to a fracture, which travel obliquely downward into the temporal area (petrous portion of the temporal bone). Such impact force, as discussed above, can also produce horizontal fractures, which pass across the superior aspect of the squamosal portion of the temporal bone into the parietal bone. If the impact force is substantive the oblique fracture can also travel superiorly through the sagittal suture into the contralateral parietal and sometimes into the squamosal portion of the temporal bone.

A substantive impact force delivered to the vertex of the skull or the side of the skull can give rise to a fracture which travels downward through the squamosal portion of the temporal bone into the petrous portion of the temporal bone either ending in the hypophyseal fossa (sell turcica) or extending onward into the opposite petrous



portion of the temporal bone producing a horizontal hinge fracture. The hinge fracture is so named because it separates the base of the skull into two halves. What is of interest is that these fractures typically do not begin at the actual impact site, unless the impact site shows a depressed skull fracture.

Impact force applied to the squamosal portion of the frontal bone generally gives rise to a linear fracture which travels vertically downward passing through the superior orbital margin where it turns to run posteriorly (backward) through the orbital plate of the frontal bone, either ending there or in the body of the sphenoid bone or it will turn medially ending in the cribiform plate of the ethmoid bone.

Impact force to the occipital calvarium typically produces a fracture, which passes downward either vertically or obliquely ending immediately adjacent to the posterior midline or at the edge of the foramen magnum. Also, the contracoup force generated by the impact force to the occipital calvarium, typically due to a fall, will induce fractures to the orbital plates of the frontal bones.

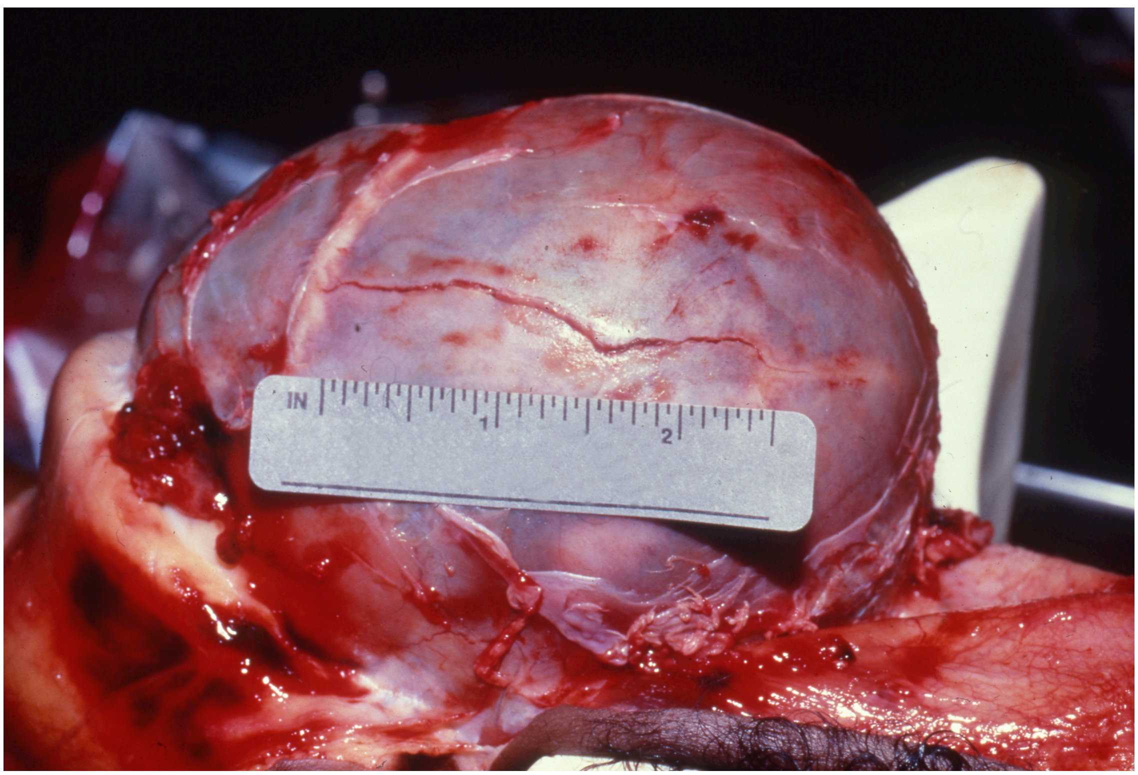
If the impact force is particularly severe and delivered over a finite surface area, such as that induced by the head of a hammer, it will produce a depressed fracture, the conformation of which is analogous to the head of the hammer. Remember, if the head of the hammer strikes the skull at an angle, it will only produce a semicircular depression. However, this semicircular depression will conform to part of the circumference surface area of the hammerhead. These features will be demonstrated later in this article.

Lastly, if you have multiple fractures of the skull, which have come about by multiple blows to the head the sequence of these fractures (the order in which they occurred) can be determined by 'Puppe's rule,' which simply stated means the later fracture will not cross the earlier fracture line. 'Puppe's rule' can also be used to determine the sequence of gunshot wounds of the skull.

TYPES OF FRACTURES

Linear Skull Fractures

Linear fractures constitute approximately 70% of all skull fractures in adults and



90% in children. They are generally the result of the head being struck by a broad flat object or striking such a surface such as a concrete pavement. They occur both over the convexity of the calvarium as well as the base of the skull. These fractures take their origin typically from the point of out bending, which is at the most peripheral margin of the impact site, extending toward the impact site as well as toward areas of weakness including foramina and may in fact cross them. They typically appear as a straight-line fracture, which may be confined to the vertex or base of the skull or both. They may involve only the external lamina or internal lamina or both, i.e., full thickness. If the impact force is especially severe you may see additional linear fractures at secondary and tertiary stress areas. Also, if the force is especially severe you may see linear fractures radiating outward toward the periphery.

Linear fractures of the occipital calvarium are usually due to falls with the back of the head striking the floor, pavement or sidewalk. Examination of the scalp overlying the occipital region may show a contusion, abrasion or laceration or any combination of these on the external surface. If however, the person has abundant hair, such evidence of blunt force trauma may not be evident on your external examination, however, hemorrhage into the soft tissue or lacerations may be evident on examination of the inner surface of the scalp upon its reflection. It is also important to understand that these lesions of the scalp do not occur in all fractures of the skull. Fractures of the occipital calvarium may run vertically toward the lambdoidal suture or lambda or inferiorly toward the foramen magnum, either ending there or within the posterior fossa or continue anteriorly into the middle fossa, ending there or extending further anteriorly through the greater and lesser wings of the sphenoid bone, ending in the orbital plate of the frontal bone (anterior fossa).

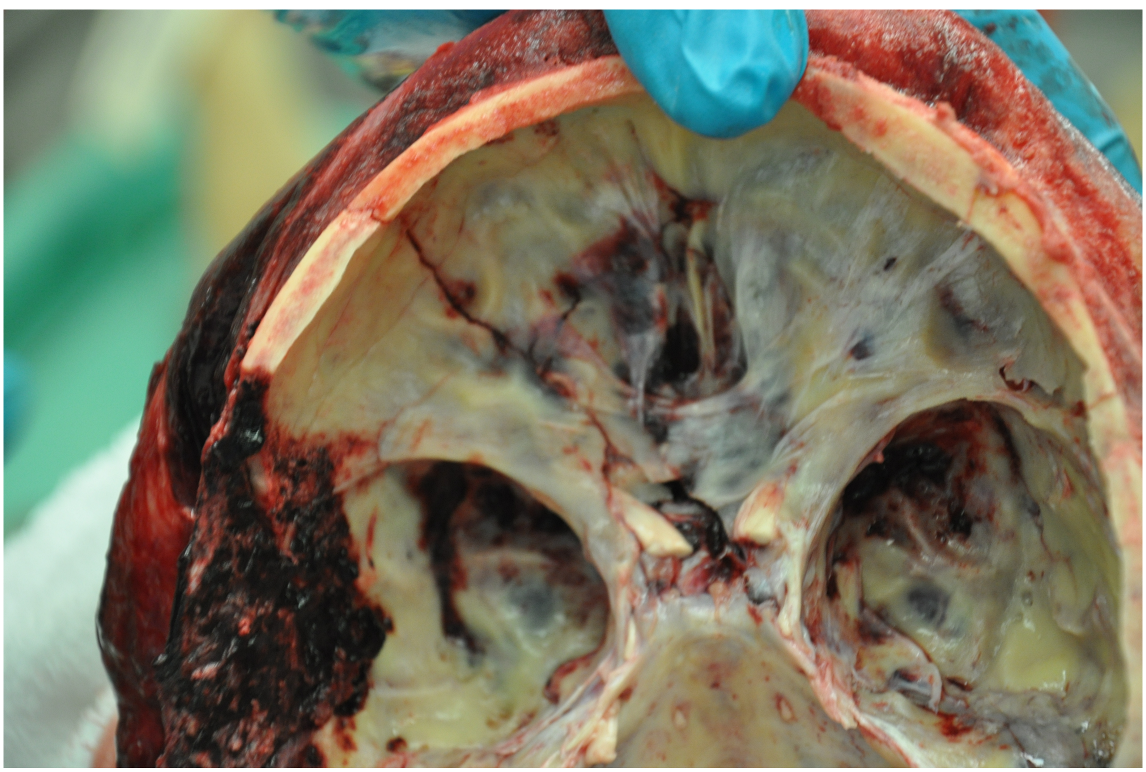
Fractures of the orbital plate of the frontal bones may occur in absence of fractures involving the floor of the middle fossa; such fractures are the result of accelerated falls onto the back of the head, which can give rise to contracoup injury to the temporal poles, the inferior aspect of the temporal lobes, the inferior aspect of the frontal lobes and the frontal poles in any combination, as well as contracoup fractures of the orbital plates of the frontal bone. A linear fracture of the occipital calvarium may extend horizontally toward one or both petrous portions of the temporal bone traveling often parallel to the transverse sinus or obliquely.

which is commonly associated with raccoon eyes.

Recognizing raccoon eyes

It's usually easy to differentiate raccoon eyes from the "black eye" associated with facial trauma. Raccoon eyes (shown below) are always bilateral. They develop 2 to 3 days after a closed-head injury that results in a basilar skull fracture. In contrast, the periorbital ecchymosis that occurs with facial trauma can affect one eye or both. It usually develops within hours of injury.

Battle's sign manifested by bruising over the mastoid process.The picture below is



that of a fracture of the orbital plate of the left frontal bone, which is commonly associated with raccoon eyes.

Linear fractures of the squamosal portion of the temporal bone are quite common due to its thinness. They may be the result of a blow or fall. The primary concern of fractures involving the squamosal portion of the temporal bone is laceration of a branch of the middle meningeal artery followed by the development of an epidural hematoma.

Blows to or falls on to the face can give rise to linear fractures of the squamosal portions of the frontal bone (that portion of the frontal bone responsible for your forehead). They are often associated with contusions, abrasions and or lacerations to the face or forehead. You may see periorbital ecchymoses, Raccoon eyes, although classically Raccoon eyes and Battle's sign suggest a basilar skull fracture.

Raccoon eyes is a purplish discoloration around the eyes due to a fracture of the orbital plate of the frontal bone.

Battle's sign (mastoid ecchymosis) is an indication of fracture of the base of the posterior portion of the skull. Battle's sign consist of bruising over the mastoid process, as a result of extravasation of blood along the path of he posterior auricular artery. The sign is named after William Henry Battle (1855 - 1936) who was an English surgeon and teacher.

Fractures of the squamosal portion of the frontal bones are most commonly vertical, usually extending toward the coronal suture or to run inferiorly extending into the base of the skull. In those fractures, which extend into the coronal suture or sagittal suture, they may induce a fracture within these sutures causing them to expand. This is especially true in children and young adults, in which a linear fracture enters a suture line, giving rise to a diastatic fracture, which in essence is a separation of a suture or sutures. When they extend inferiorly, they may extend through the supraorbital margin and then turn posteriorly into the orbital plate of the frontal bone, either ending there or continuing into the lesser or greater wing or body of the sphenoid bone. They may also extend directly inferiorly through the bones of the orbit, through the lacrimal bone and end in the maxilla or the hard palate (palatine process of the maxilla) and the horizontal plate of the palatine bone.

Sometimes it can be difficult to determine the difference between a skull fracture and a suture. This is especially true if you do not have a firm grasp of anatomy. The difference between skull fractures and sutures are as follows:

Fractures	**Sutures**
Greater than 3 mm in width	Less than 2 mm in width
Widest at the center and narrow at the ends	Same width throughout
Runs through both the outer and the inner lamina of bone, hence appears darker	Lighter on X-rays compared with fracture lines
Usually over temporoparietal area	At specific anatomic sites
Usually runs in a straight line	Does not run in a straight line
Angular turns	Curvaceous

The clinical effect of a simple linear skull fracture is usually minimal in that it typically does not give rise to an underlying contusion, maceration or laceration to the underlying brain. However, should the linear fracture travel through a groove for a branch of the middle meningeal artery, it can give rise to an epidural hematoma and its consequences. Also, if the fracture passes through a foramina it may damage a cranial nerve giving rise to neurologic sequelae or a blood vessel giving rise to hemorrhage. If the fracture enters a sinus cavity it can give rise to leakage of cerebral spinal fluid (CSF) in the form of rhinorrhea or otorrhea and possibly infection. A glucose oxidase tape can be used to differentiate between rhinorrhea due to natural causes verses that due to CSF as the result of trauma, however, the glucose oxidase test is not very specific. A far more sensitive test for the detection of CSF either in rhinorrhea or otorrhea is looking for Beta-2-Transferin, which is almost a specific marker for CSF.

At the time of autopsy, simple linear fractures, especially if they do not involve both the inner and outer lamina can be difficult to ascertain. In light of this it is important that you examine both surfaces, most especially if there is an indication of blunt force trauma to the head.

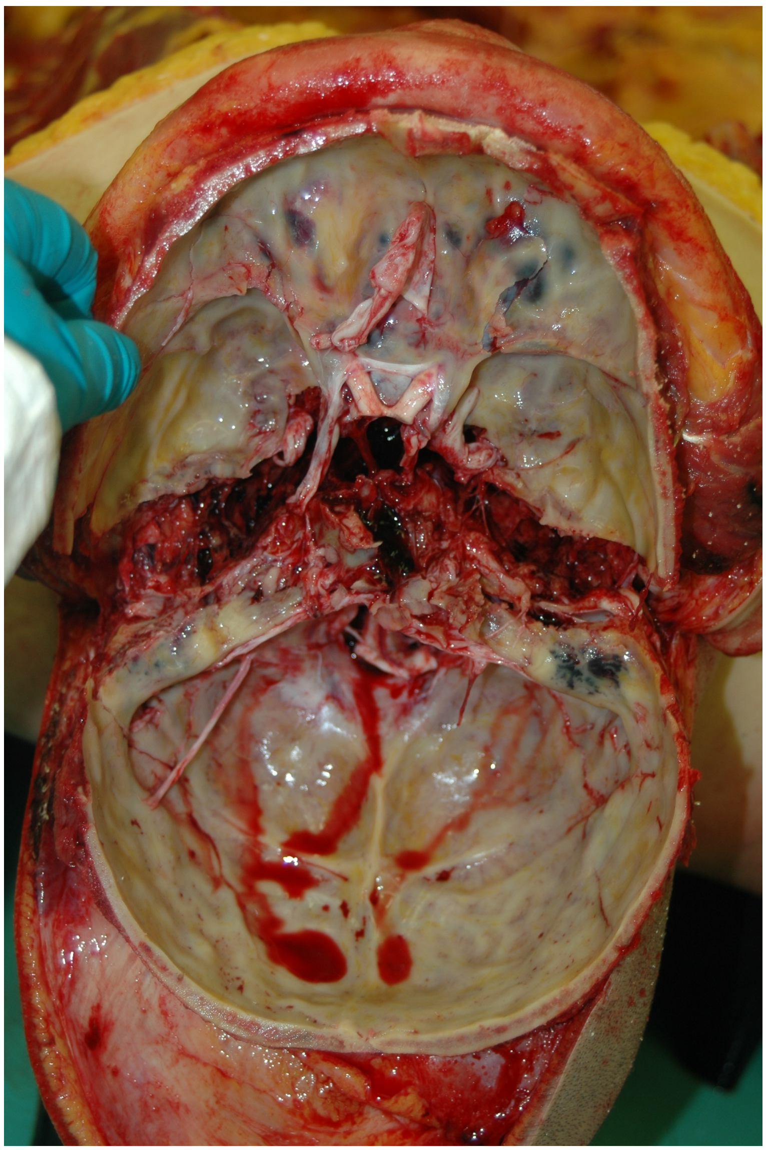
Healing of Skull Fractures

Linear fractures, as is true of all fractures heal overtime, however radiographically these fractures are visible for months. Immediately after the fracture there is bleeding into the fracture site. The origin of the bleeding is from the marrow at the site of the fracture, the lacerated dura, the periosteum of the external and internal lamina, as well as the superficial vessels on the surface of the underlying brain. This is followed within a few hours by necrosis of the traumatized bone at the edges of the fracture site. The resulting hematoma begins to organize with the infiltration or fibroblast. The repair of the fracture begins in the periosteum of both the external and internal lamina. The process of repair begins with the deposition of fibroblastic tissue within the fracture interspersed among the blood vessels forming granulation tissue. The deposition of the fibroblastic tissue gives rise grossly to the formation of a lip along the edge of the skull fracture. This becomes visible within about two weeks of the origin of the skull fracture.

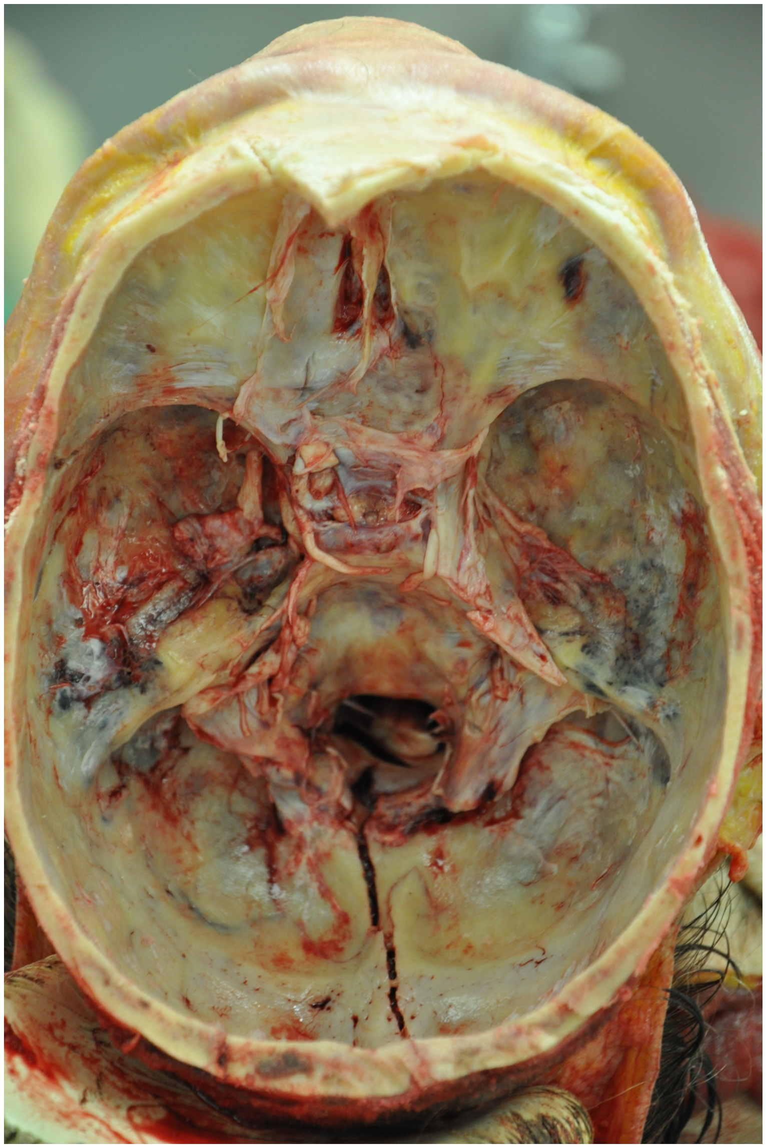
The periosteal cells than give rise to chondroblast and osteoblast. The chondroblasts form hyaline cartilage and the osteblasts form woven bone. Both the hyaline cartilage and woven bone form a bridge through the fracture. This is followed by the replacement of the hyaline cartilage and woven bone with lamellar bone. Substitution of the woven bone with lamellar bone precedes the substitution of the hyaline cartilage with lamellar bone. Vascular channels and osteoblasts, which gives rise to new lamellar bone in the form of trabecular bone, then penetrate this mineralized matrix. Eventually all of the hyaline cartilage and woven bone are replaced by trabecular bone. The trabecular bone then undergoes a remodeling process, which culminates with the replacement of the trabecular bone by compact bone. The replacement of the trabecular bone occurs through a resorption process by osteoclasts, which create shallow depression in the trabecular bone referred to as Howship's lacunae. Osteoblasts than line these depressions forming compact bone. Howship's lacunae are named after John Howship (1781 to 1841), a British anatomist. He was a surgeon at St. George's and Charing Cross hospital in London. In 1820 he published a treatise on the natural and pathological anatomy of bones. In this work he described the bone pits or shallow depressions in trabecular bone.

Fractures of the Base of the Skull

Fractures of the base of the skull can occur in several forms from simple linear fractures as discussed above to more complex fractures. Although, a fracture of the base of the skull can occur from a blow anywhere on the head; most occur as the result of impact force to the occiput, sides of the head, or front of the head. Typically where a basilar skull fracture occurs is determined by the direction of the impact force. As an example, lateral impact forces produce side-to-side fractures and axial



Transverse basilar skull fracture due to lateral impact force provided by the Rhode Island Office of State Medical Examiners impacts (impact force to occiput or squamosal portion of the frontal bone) produce axial fractures. To put this in another way, basilar skull fractures originate from two locations, the temporal region (lateral impacts) and the occipital condylar region (axial impacts).



Occipital linear fracture due to axial impact (occipital impact) provided by the Rhode Island Office of State Medical Examiners.

The temporal fractures are divided into three subtypes: longitudinal, transverse, and mixed. Of these the longitudinal is the most common representing between 70 to 90% of the temporal fractures. These fractures extend from the squamosal portion of the temporal bone through the superior wall of the external auditory canal and the tegmen tympani. It may extend either anterior or posterior to the cochlea and labyrinthine capsule, ending in the middle cranial fossa near the foramen spinosum or in the mastoid air sinuses. Transverse fractures, which represent 5 to 30% of temporal fractures, originate at the foramen magnum, extending to the cochlea and labyrinth, ending in the middle cranial fossa. Mixed fractures simply represent a combination of both longitudinal and transverse fractures.

Occipital condylar fractures are the result of a substantive impact force, giving rise to high-energy transfer with axial compression, lateral bending, and sometimes rotational force, which injures the alar ligament. Occipital condylar fractures are divided into three subtypes: Type I, Type II and Type III.

Type I is due to axial compression giving rise to a comminuted fracture of the occipital condylar region. This fracture is stable.

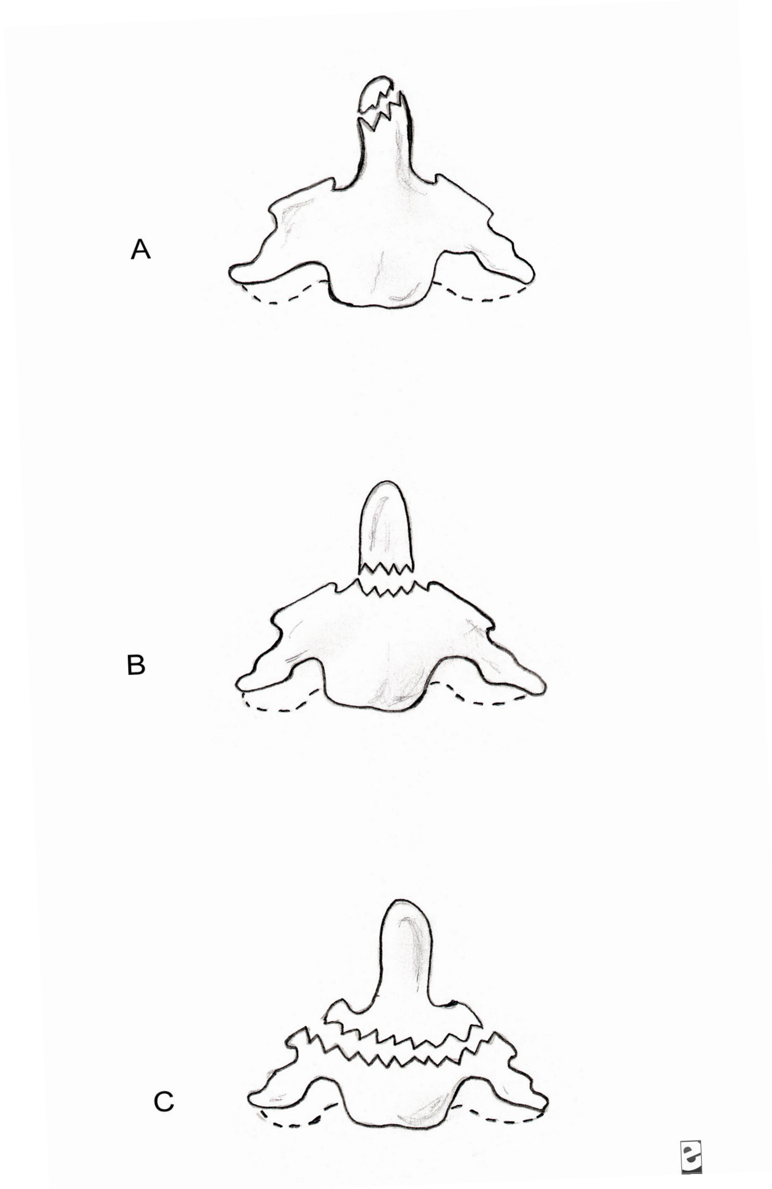
Type II is also due to axial compression as the result of an impact force, which is more severe that that producing Type I, the result of which is more extensive fracturing of the basioccipital region. This fracture is also stable due to the preservation of the alar ligament and tectorial membrane.

The alar ligaments connect the sides of the dens (on the axis, or the second cervical vertebra) to tubercles on the medial side of the occipital condyle. They are short, tough, fibrous cords that attach the skull to C2 vertebra (via the dens) and function to check side-to-side movements of the head when it is turned.

The tectorial membrane is firmly attached to the base of the skull and the body of the axis, but not to the posterior aspect of the dens (the odontoid process). The tectorial membrane prevents the odontoid process from moving posteriorly into the cervical canal, thus compressing the cervical spinal cord as well as limiting movement of the craniocervical junction. Something you need to keep in mind is a complete or partial tear of the tectoral membrane is invariably an associated injury with an odontoid fracture from hyperflexion of the neck.

Type III fracture is an avulsion fracture of the insertion site of the alar ligaments.

In the the illustration below, A represents a Type I odontoid fracture, which is due to an avulsion of the tip of the dens at the insertion of the alar ligaments. B represents



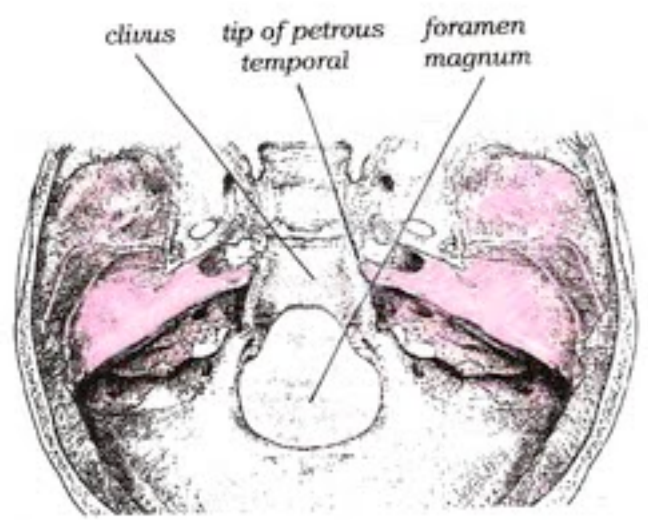
a Type II fracture, which occur at the base of the dens and are the most common odontoid fractrues. C represents a Type III fracture in which the fracture line extends into the body of the axis.

Whether there is stability of the occipitoatlantal articulations is entirely dependent on the integrity of both the alar ligaments and the tectorial membrane. Type III fractures are unstable only if the cephalic extent of the posterior longitudinal ligament, the tectorial membrane, is disrupted. In many respects a Type III occipital condylar fracture (OCF) falls within the spectrum of atlantooccipital dissociation injuries (AOIs).

An important point to remember is that it is not possible to directly assess the integrity of the alar ligaments or tectorial membrane. However, the biomechanical stability of these structures can be inferred through radiographically monitored dynamic or “stress” testing. Through flexion-extension, a change in the dens-basion distance greater than 2 mm defines C0-C1 instability. Although MRI imaging can be used to help determine the integrity of the tectorial membrane and alar ligaments, its reliability has yet to be determined.

The majority of OCFs as well as atlantooccipital dissociation (AOD) injuries are due to high speed vehicular collisions due to forceful hyperextension, hyperflexion, distraction, or rotation. The other point to remember is that although the majority of AODs result from purely ligamentous disruptions of the alar ligaments and tectorial membrane, a substantial number do have associate Type III OCFs. Also, both AODs and OCFs are commonly associated with closed head injury and cranial nerve injury.

There is another fracture of the base of the skull, which you need to be cognizant of and that is a fracture of the clivus. These fractures are typically the result of



substantive impact force, which is seen in motor vehicular accidents, falls and pedestrians struck by a motor vehicle. There are three types of clivus fractures: 1. longitudinal, which is a fracture that extends from the tuberculum sella to the foramen magnum; 2. transverse, which typically occurs near the spheno-occipital synchondrosis, in essence extending from one carotid canal to the other; and 3.

oblique, which extends from the dorsum sella to the contralateral petroclival fissure.

The mechanical forces believed to be responsible for these fractures are due primarily to the outbending forces produced by a substantive focal impact force, the kinetic energy of which exceeds the elastic capacity of the skull. Generally the impact forces are those associated with lateral crushing injury. An example would be an anterolateral impact that passes through the lateral aspect of the orbit or sphenoid wing. Another example would be a posterolateral impact that is transmitted through the petrous portion of the temporal bone. Such impact forces typically give rise to a transverse or oblique fracture of the clivus. Longitudinal fractures are usually the result of an occipital impact force or as the result of an axial impact force, which results in the clivus getting caught between the vertebral column and the petrous portions of the temporal bones.

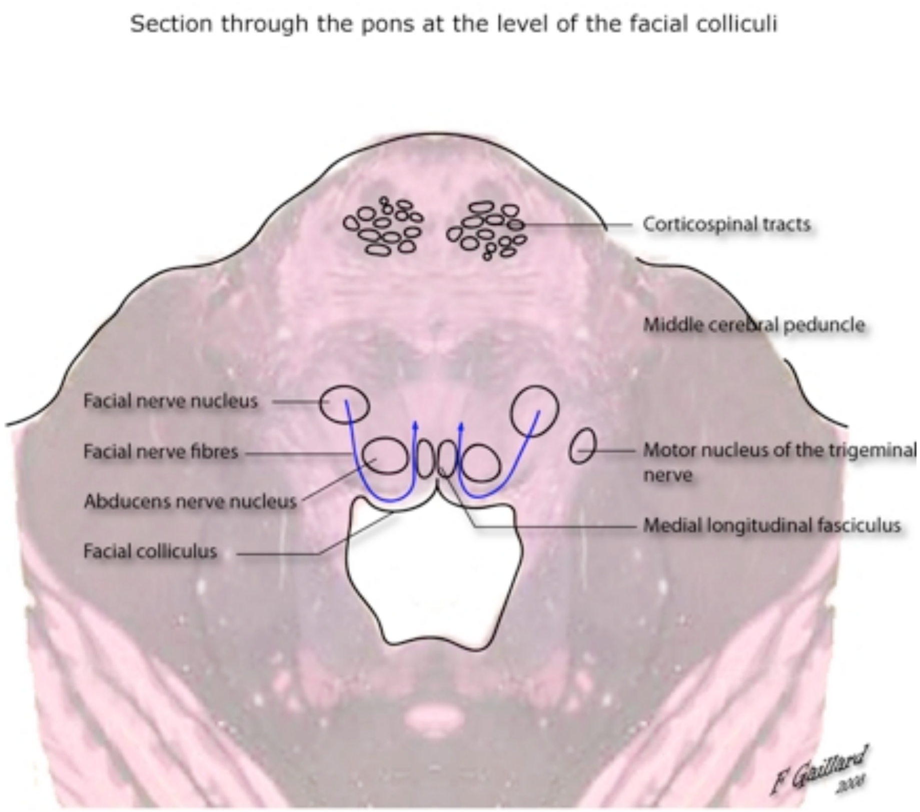
All of these fractures are associated with severe or moderate head injuries that clinically are typically associated with unfavorable outcomes, such as multiple cranial nerve palsies, CSF leaks, diabetes insipidus and oculo-hematomas. Of these three fractures, the longitudinal carries the worse prognosis, especially when it involves the vertebrobasilar system, as for example a vertebrobasilar artery occlusion due to trapping of the basilar artery in the fracture or the development of a traumatic aneurysm of the posterior circulation.

Longitudinal fractures have also been associated with bilateral internuclear ophthalmoplegia manifested by divergent strabismus without evidence of other

Fig 1. Divergent strabismus without other cranial nerves abnormalities.

cranial nerve involvement. The underlying mechanism for this rare complication of blunt force trauma to the head is the evolution of a longitudinal fracture of the clivus with the transmission of the kinetic energy responsible for the fracture into the brainstem, specifically the medial longitudinal fasciculus (MLF).

The MLF consist of a pair of crossed fiber tracts, one on each side of the brainstem.



These bundles of axons are situated near the midline of the brainstem and are composed of both ascending and descending fibers that arise from a number of sources and terminate in different areas. It extends from the medulla oblongata of the brainstem, through the pons, terminating in the midbrain of the rostral brainstem. In the midbrain and rostral pons it is located ventral to the cerebral aqueduct. In the caudal pons and rostral medulla oblongata it is located near the floor of the fourth ventricle, again running close to the midline of the brainstem.

The MLF's joins cranial nerves III (oculomotor nerve), IV (trochlear nerve) and VI (abducens nerve) together, and integrates movements directed by the gaze centers (frontal eye field) and information about head movement (from cranial nerve VIII). It is an integral component of saccadic eye movements as well as vestibulo-ocular and optokinetic reflexes. The vestibulo-ocular reflex stabilizes images on the retina during head movement by producing an eye movement in the direction opposite to head movement, thus preserving the image on the center of the visual field. The optokinetic refles allows the eye to follow objects in motion when the head remains stationary. This reflex develops at about 6 months of age.   The MLF also carries the descending tectospinal tract and medial vestibulospinal tracts into the cervical spinal cord, and innervates some muscles of the neck and upper limbs. Lesions of the MLF produce internuclear ophthalmoplegia.

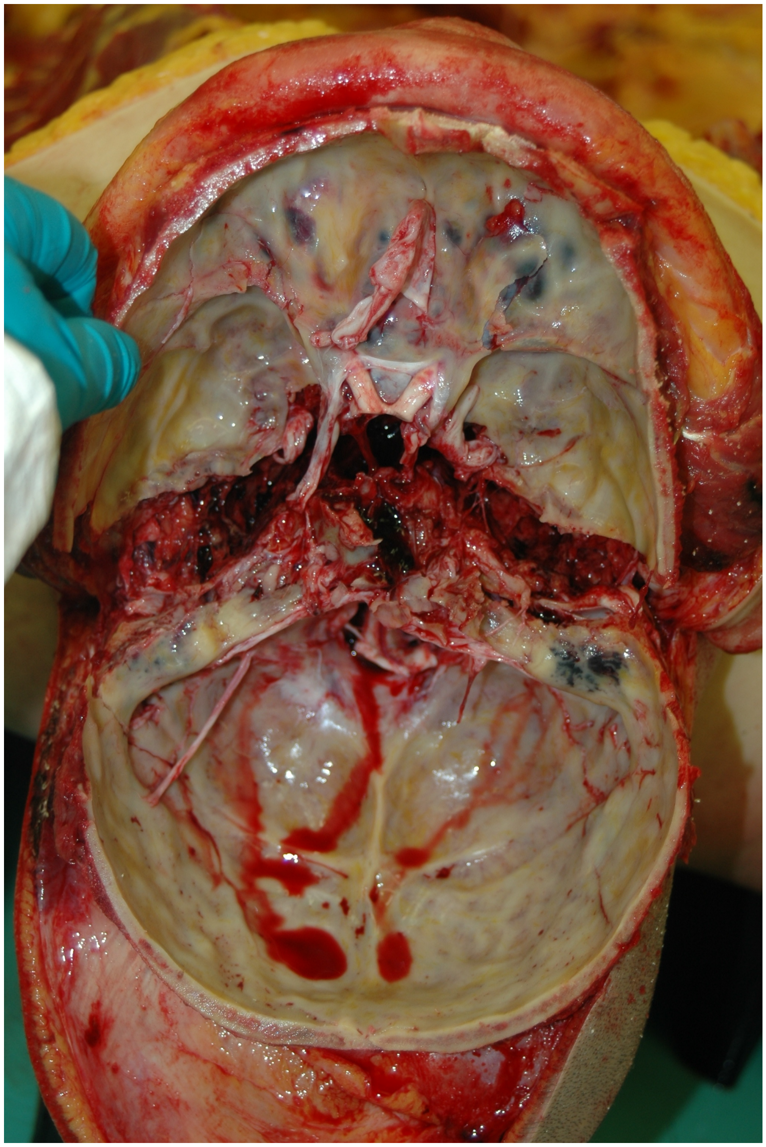
Fractures of the clivus are not the only cause for injury to the MLF. The MLF can also be injured as the result of mass effect giving rise to herniation.

The involvement of the MLF in these lesions is due primarily to its periventricular location within the midbrain and pons. The shearing forces generated by blunt force trauma giving rise to the transmission of kinetic energy into the brainstem are accentuated near the ventricular system. This concentration of kinetic energy within the brainstem results in nerve fibers being stretched and torn, especially in the periventricular location as well as in the gray-white matter transition zone.

There is also possibly another explanation for injury to the MLF and that is temporary downward displacement of the brainstem due to the transmission of kinetic energy generated in the supratentorial space. The posterior portion of the brainstem is especially susceptible to displacement than the anterior portion because the latter is maintained fixed by the small perforators of the basilar artery. Also, the downward displacement of the brainstem may stretch the basilar artery perforating branches resulting in ischemia of the MLF, which is located in the vascular watershed zone of these arteries.

Transverse or oblique fractures are typically associated with cranial nerve palsies due to the close proximity of the cavernous sinus, the carotid canals and the cranial nerves III through VI. In one study, injuries to these nerves occurred in 66.6% of patients with fractures of the clivus.

Hinge fractures of the base of the skull generally extend from one side to the



Transverse basilar skull fracture separating the anterior portion of the base of the skull from the posterior, provided by the Rhode Island Office of State Medical Examiners

opposite giving rise to separation of the floor of the skull into an anterior and posterior parts. In the classic hinge fracture, the fracture extends from the lateral most aspect of the petrous portion of the temporal bone, through the sella turcica to the lateral most aspect of the opposite petrous portion of the temporal bone. This type of hinge fracture is called Type I. There are three types of hinge fractures: Type I, coronal; Type II, front to back, extending through the sella, and Type III, coronal, but not through the sella. Type I is the most common and are generally due to impact on the side of the head or the tip of the chin. Hinge fractures in general are most commonly seen in motor vehicular accidents including air bag deployment. Hinge fractures can also be the result of falls from a height with the initial impact being to the top of the head or by a severe blow to the top of the head. Front to back hinge fractures are due to axial impacts to the base of the skull. This type of fracture occurs when there is a high-energy impact to the occipital portion of the skull, which drives the front of the head into a hard surface. An example would be a pedestrian struck by a motor vehicle in the occipital region of the head and driving the head forward such that the front of the head strikes a poll, another vehicle, the roadway or sidewalk. The primary impact site, the occipital calvarium, often shows a depressed comminuted fracture, sometimes with a mosaic pattern (to be described), often terminating within the foramen magnum. The impact of the front of the head onto a firm surface, referred to as a secondary impact, will induce a fracture of the squamosal portion of the frontal bone, which also may extend into the base of the skull, terminating within the foramen magnum. The termination of both the primary and secondary impact fractures in the foramen magnum creates the 'front-to-back' hinge fracture. In reality, both hinge fractures and ring fractures (to be described next) can be produced by impacts anywhere on the circumference of the head.

Another point to remember is that blows to the mandible can give rise to fractures of the base of the skull. In such circumstances the mandibular condyles are driven upward through the temporal-mandibular joint, being driven into the middle cranial fossa, giving rise to contusions, macerations and or laceration of the inferior surface of the temporal lobes.

There is another fracture of the base of the skull, which is of a particular interest and that is the 'ring fracture.' These fractures occur within the posterior fossa and hence come under the broad heading of basilar skull fractures. They are represented by a circumferential fracture, which encircles the foramen magnum. They are the result of either a fall from a substantive distance or the person jumps or falls from a height, landing on their feet or buttocks. In the former scenario, the kinetic energy travels up through the lower extremities, into the pelvis, up through the vertebral column, driving the upper cervical vertebrae into the base of the skull in the region of the foramen magnum, thus inducing a ring fracture. In the latter scenario the kinetic energy begins at the level of the pelvis, traveling in the same direction as the first scenario. A ring fracture can also be produced by a fall or a crushing blow to the top of the head, which results in the base of the skull being driven into the upper cervical vertebrae.

It is very important in all of these scenarios that the cervical vertebra be inspected as well as the thoracic and lumbar vertebrae, pelvic bones and bones of the lower extremities be inspected. To aid you in your examination, it is a good idea to x-ray the head, neck, chest, abdomen and lower extremities.

Ring fracture provided by Dr. Catanese

Before leaving this subject, I need to make you aware of another scenario, although rare, which can give rise to a ring fracture. Violent hyperflexion/hyperextension of the neck can produce a ring fracture. Such fractures are believed to be due to the considerable strength of the ligamentous attachments between the base of the skull and the cervical vertebra.

Complications of Basilar Skull Fractures

The complications, which can be seen with basilar skull fractures are laceration or trauma to cranial nerves in their foramina; damage to arteries or venous sinuses at the base; opening of a paranasal sinus giving rise to leakage of CSF with the possibility of developing an infection; laceration of the pituitary stalk; fracture through the inner ear structures; explosion or implosion of orbital contents; and contusions, maceration and or lacerations of the inferior surface of the cerebral and cerebellar hemispheres. Trauma, which frequently gives rise to basilar skull fractures also cause epidural, subdural and subarachnoid hemorrhage and not uncommonly intermediary contusions (intraparenchymal contusions) and diffuse axonal injury.

Patients with fractures of the petrous temporal bone often present with CSF otorrhea and bruising over the mastoids (skin behind the ear lobes), i.e., Battle's sign. Fractures of the orbital plates of the frontal bones (anterior cranial fossa fractures) can present with CSF rhinorrhea and bruising around the eyes, i.e., Raccoon eyes. Whether loss of consciousness occurs and its degree, as determined by the Glasgow Coma Score, will be dependent on the degree of parenchymal injury (diffuse axonal injury, intermediary contusions, etc.).

Longitudinal temporal bone fractures result in ossicular chain disruption and conductive deafness of greater than 30 dB that last longer than 6 to 7 weeks. Temporary deafness that resolves in less than 3 weeks is due to hemotympanum and mucosal edema in the middle ear fossa. Facial palsy, nystagmus, and facial numbness are secondary to involvement of the VII, VI, and V cranial nerves, respectively. Transverse temporal bone fractures, which involve the VIII cranial nerve and the labyrinth, result in nystagmus, ataxia, and permanent neural hearing loss.

Illustration of Battle's sign provided by Dr. Charles Catanese

Occipital condylar fracture is a very rare and serious injury. Most of the patients with occipital condylar fracture, especially with Type III, are in a coma and have other associated cervical spinal injuries as previously discussed. These patients may also present with other lower cranial nerve injuries and hemiplegia or quadriplegia. Vemet syndrome or jugular foramen syndrome is due to a basilar skull fracture, with involvement of cranial nerves IX, X, and XI; patients present with difficulty in phonation and aspiration and ipsilateral motor paralysis of the vocal cord, soft palate (curtain sign), superior pharyngeal constrictor, sternocleidomastoid, and trapezius.

Collet-Secard syndrome on a rare occasion can be produced by occipital condylar fracture with unilateral IX, X, XI, and XII cranial nerve involvement. Clinically these patients can present with difficulty in swallowing, weakness of a shoulder, unilateral vocal cord paralysis, and unilateral absence of a gag reflex. Most patients who sustain an occipital condyle fracture with lower cranial nerve damage usually die virtually instantaneously.

Types of Impact Force Giving Rise to Basilar Skull Fractures

The types of force that often give rise to basilar skull fractures are those sustained when a person falls backward striking the back of the head on a hard surface, falling down the stairs, blows to the head with objects like a baseball bat, iron pipe, bricks, and "2 by 4's." They are also often seen with falls from substantive heights. As previously pointed out, basilar skull fractures are also commonly seen in motor vehicular accidents, especially pedestrians struck by motor vehicles in which there is sudden hyperextension of the neck. In these cases it is not uncommon to see pontomidbrain and or pontomedullary lacerations often associated with compression of the cervical spinal cord at the level of C4-C6 along with extensive fractures involving the posterior fossa.

As is true of all skull fractures, whether they involve the calvarium or base of the skull, they should be documented not only in the written portion of the autopsy report, but placed on anatomic drawings of the skull, as well as photographed.

Depressed Skull Fractures

These fractures are typically produced by massive objects moving slowly or objects with a small surface area such as the head of a hammer. The resulting injury seen is dependent on the kinetic energy delivered by the impact force and the surface area of the object delivering the impact force. If the impact force is not especially severe you may only see an indentation on the external lamina. As the severity of the force increases, you may only see a circular depressed fracture involving the external lamina. As the force increases the circular depressed fracture may include the entire thickness of the diploe. When the impact force is particularly severe the depressed fracture can be comminuted with the punched out area of bone being driven through the underlying dura giving rise to epidural and or subdural hemorrhages,

Depressed Skull Fractures, Outside Surface of Calvarium, provided by Dr. Catanese

Inner surface of Depressed Skull Fractures of the Calvarium provided by Dr. Catanese

This hammer produced the illustrated depressed skull fractures provided by Dr. Catanese.

contusions, macerations and or lacerations of the underlying brain. It is important to remember that the underlying causation is due to an impact force being delivered over a well-defined finite area, often having the shape of the impacting object. If the impact force was delivered more at a tangential angle, than the depressed fracture will have a wedge shape. What also can be helpful in determining the nature of the impacting object is careful examination of the scalp. Impacting objects commonly associated with depressed fractures are baseball bats, bricks, hammers, or falls from a height, such as a headfirst plunge into shallow water in a swimming pool. The morbidity and mortality of depressed fractures is much greater than almost any other type of fracture.

Depressed Fractures Induced by Substantive Sharp Edged Instrument

Depressed fractures produced by sharp edged instruments, such as by swords, machetes, axes and similar objects produce a very characteristic depressed fracture. An impact with one of these heavy cutting instruments produce a cut through the bone in which one edge has a clean sharp appearance often with a glassy surface. The opposite edge is often irregular. The irregular edge is believed to be due to the withdrawal of the sharp edged object from the skull, not uncommonly at a slightly different angle.

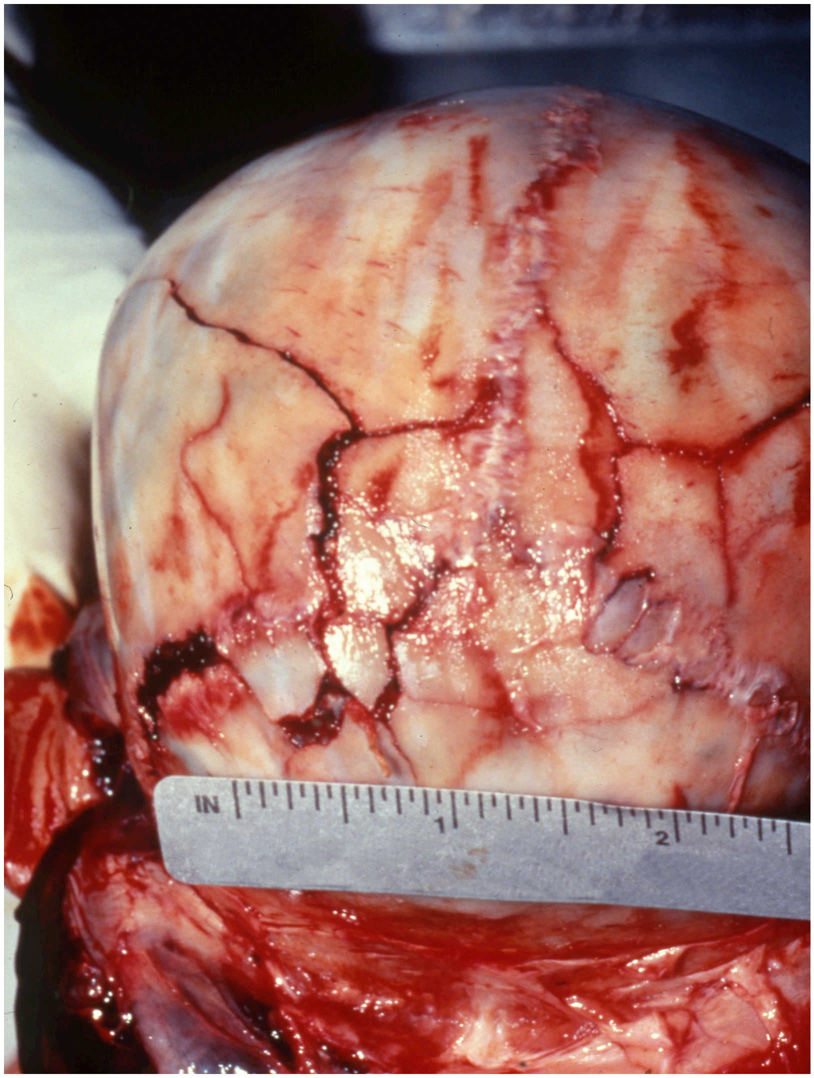
The above picture was provided by the Rhode Island Office of State Medical Examiners

The above picture was provided by the Rhode Island Office of State Medical Examiners

Comminuted and Multiple Fractures

Comminuted fractures may be simple or quite complex in that there may be multiple comminuted fractures, some of which may show shattering or fragmentation of the skull with the fragments being separated and often overriding each other.

These fractures are produced in the same manner as depressed skull fractures, often by massive objects in which a very finite area of that object impacts the skull over a small surface area at low velocity. The fractures usually occur at the site of the impact but often show wide areas of fragmentation, often with fragments that do not rebound. These fractures are commonly produced by repeated blows to the head with the head of a hammer, which not only shatters the skull but also results in an open cranial wound. The morbidity and mortality associated with these fractures is quite high.



The above illustration of comminuted and multiple fractures was provided by Dr. Catanese.

Comminuted and Multiple Fractures due to Static Load

These fractures are somewhat unique in that in contradistinction to the usual comminuted fractures and depressed fractures, where there is associated injury to the brain; in these fractures there is little damage to the brain. This is especially true in infants who may or may not display immediate neurologic symptoms. If brain damage does occur it is due to the bone fragments being driven into the underlying brain. These fractures occur when the head is stationary, the person is prone or supine, with the head resting on a firm surface, thus the head upon being struck cannot move, hence the brain does not undergo acceleration-deceleration. The kinetic energy of the impact force is absorbed and dissipated by the skull. This type of fracture is often seen in a person who is prone or supine and is struck about the head with a baseball bat, brick, pipe, nightstick, etc. These individuals will often show crushing injury to the face in addition to the skull fractures along with open cranial injuries in which part or the brain is avulsed.

Mosaic Fractures (Spider's web fractures)

These fractures are really a subtype of depressed comminuted fractures with linear fractures radiating from the central depressed area. Often these are intercepting fractures running perpendicular to the linear radiating fractures emanating from the central depressed area, thus giving the appearance of a spider's web. Sometimes there is no actual central depressed area, only linear fractures emanating from a central point. Also, due to the spider's web pattern, you may see sections of free-floating bone. The radiating arms of these fractures may extend into the base of the skull or intersect with other fractures induced by additional impacts to the skull. The underlying causation of these fractures is typically due to high-energy impact at high velocity such as a person being struck in the back of the head by a side view mirror of a moving vehicle, or a projecting part of a bumper of such vehicle. They can also be produced in a fall from a height in which the person's head strikes a firm object with a narrow surface area. They typically are not seen in accelerated falls such as that induced by a person struck in the face by a fist or firm object, such as a nightstick, unless the person's head strikes a firm pointed object, such as the coroner of a coffee table.

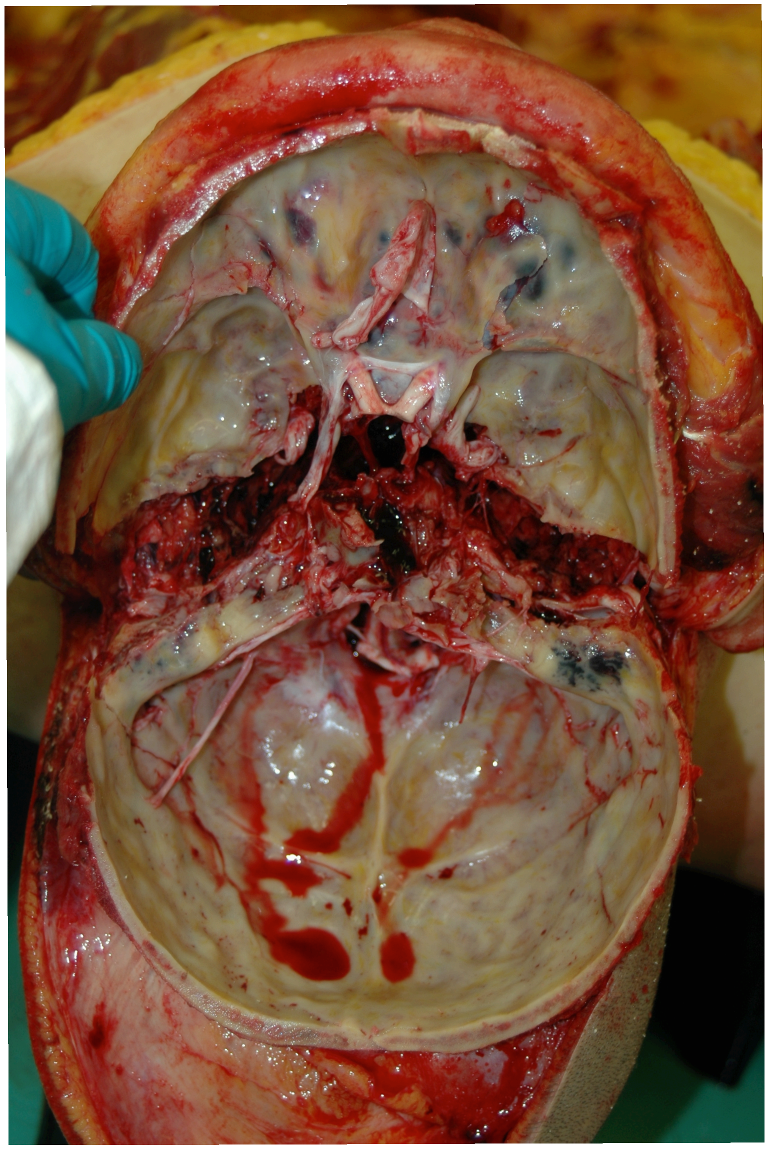
Expressed Skull Fractures

This is an example of an expressed fracture provided by Dr. Catanese

These are massive fractures involving fragmentation or shattering of the skull in which fragments of the skull come to lay outside the normal curvature of the calvarium in the pericranial tissues, in the orbit, sinuses or physically outside the head. Motor vehicular accidents, missiles or explosions, such as that produced by improvised explosive devices (IED), typically produce these fractures. Such injuries are not always fatal, especially in the case of those produced by missiles or explosions, due to the fact that although the skull is crushed, the head however, was not accelerated, thus the kinetic energy of the explosion was not transmitted through or dissipated within the brain, but rather was absorbed and dissipated by the skull.

Contracoup Fractures (Transmitted Fractures)

Fractures that are classically representative of contracoup fractures (transmitted fractures) are those of the orbital plates of the frontal bones and the cribiform plate of the ethmoid bone. Other anatomic sites for these fractures are portions of bones adjacent to sinuses (pneumatized spaces, i.e., air containing spaces within bone), such as the lacrimal, sphenoid and frontal bones. They typically manifest themselves as simple linear fractures, however, they can also be more complex. These fractures occur as the result of pressure differentials, such as between the intracranial orbital surface and the intraorbital space as arises in falls in which the back of the head strikes a hard surface, or as induced by a substantive blow to not only the back of the head, but any portion there of. These fractures come about through the developing negative pressure (suction forces) within the frontal region due to the differential movements of the brain versus the skull induced by the back of the head striking a hard surface or a heavy blow to the head giving rise to implosion of the thin and thus weak orbital plates of the frontal bone. These fractures can also be produced by missiles entering the cranial vault giving rise to immediate positive pressure followed by immediate negative pressure, thus causing the thin orbital plates of the frontal bone to expand into the orbits followed by immediate contraction and extension into the cranial vault.



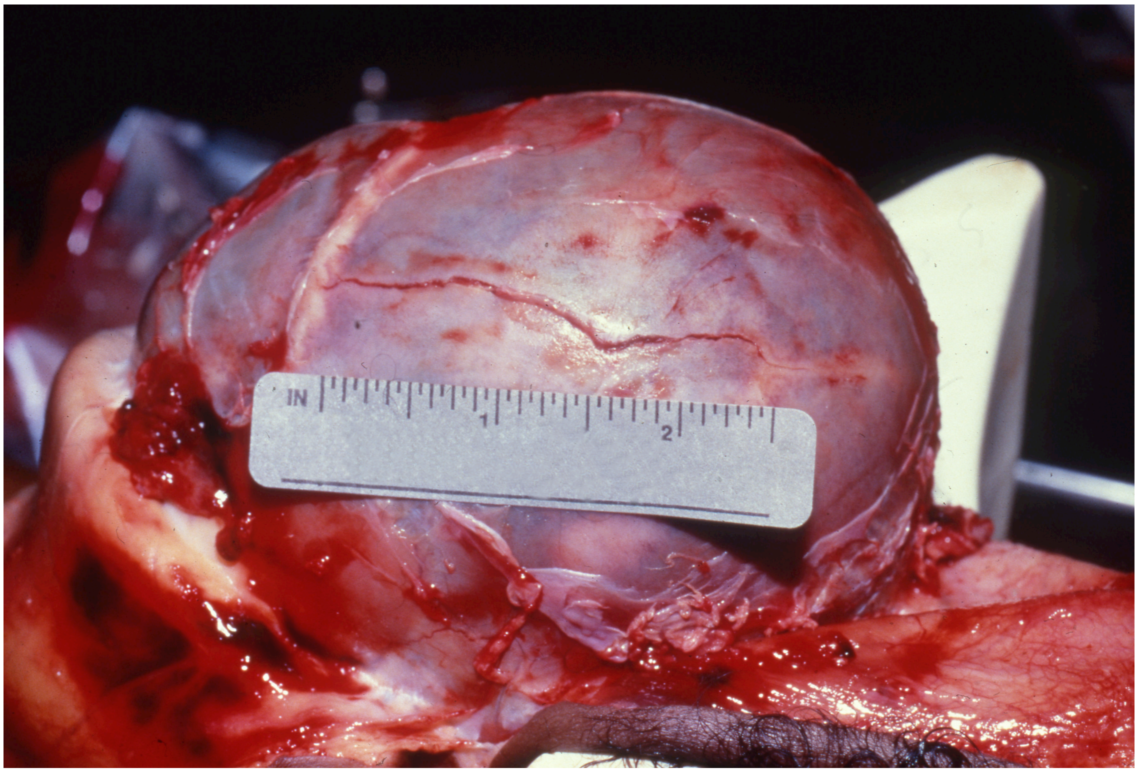
Contracoup fracture of the right orbital plate of frontal bone accompanied by a transverse basilar skull fracture, RI Office of State Medical Examiners

Ping-Pong Fractures (Pond Fractures)

These are shallow depressions in the outer lamina of the skull, often assuming the configuration of the impact object. They typically occur during the first few months of life due to the fact the infant's skulls are very pliable. These depressions may not actually show a fracture. They were first described in a newborn whose head was impinging against the mother's sacral promontory during uterine contractions. The application of forceps can also cause this injury. Typically they are caused by a fall, such as an infant being dropped while being held, with the head striking the edge of a hard object, like the corner of a coffee table.

Birth Fractures

Skull fractures can occur as the result of use of forceps or vacuum extraction during delivery. Most are uncomplicated linear fractures of the parietal calvarium, however



Simple linear skull fracture provided by Dr. Catanese

more complex, including depressed fractures can also be seen. The latter may be associated with, epidural and or subdural hemorrhage, subarachnoid hemorrhage and rarely parenchymal injury.

These fractures may be associated with a cephalohematoma, however, cephalohematomas can occur without skull fractures. A cephalohematoma is due to bleeding beneath the periosteum of the external lamina and as such it does not cross suture lines. These hematomas can result from forceful deliveries such as the head is forced forward during a natural birth or due to the application of forceps or the use of vacuum extraction.

There is another lesion involving the newborns scalp, which you need to be cognizant of and that is caput succedaneum. Caput succedaneum typically occurs during vaginal delivery or as the result of vacuum extraction. It represents itself as a soft tissue swelling of the scalp, which can be diffuse, crossing the midline and suture lines and is associated with head molding. It is due to serosanguineous fluid deposition within the soft tissue of the scalp. These lesions generally do not cause complications and usually resolves in 2 weeks.

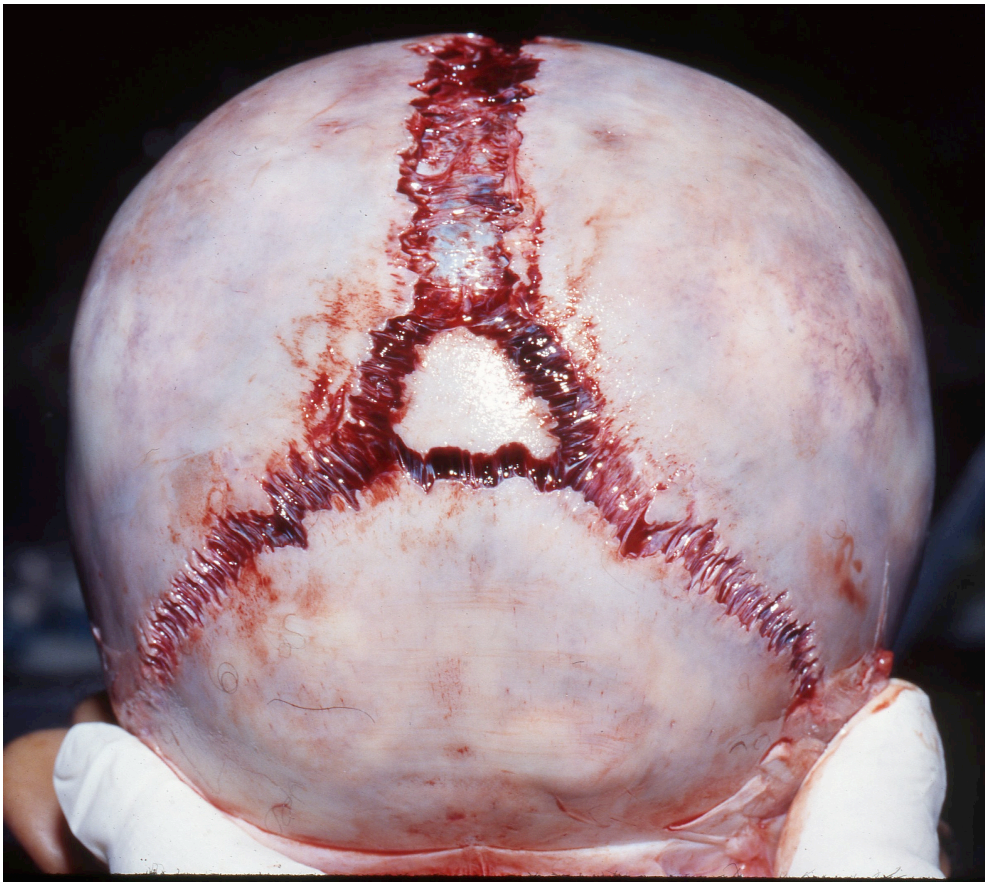
Fractures of Infant Skulls

Hitherto fore it was commonly thought that fractures of the infant skulls rarely were caused by falls of short distance. If such a fracture did occur it was typically a simple linear fracture with no neurologic complications. It had also been taught that should you see a gaping linear fracture or a more complex fracture with or without depression associated with neurologic symptoms, this was virtually pathognomonic of child abuse unless proven otherwise, such as a clearly defined accident had been witnessed. However, there is now an accumulated body of literature, which has clearly demonstrated short distance falls involving infants can produce both uncomplicated linear fractures as well as complex skull fractures with subdural hemorrhages and injuries to the brain parenchyma. These injuries may not manifest themselves immediately, some may require hours, days or weeks.

Some of the most important work done to help our understanding of the pathogenesis of fractures of infant skulls was that of Weber (Experimental Studies of Skull Fractures in Infants, Z. Rechtsmed 1984; 92:87-94; Biomechanical Fragility of the Infant Skull, Z. Rechtsmed 1985; 94: 93-101; Predilection sites of Infantile Skull Fractures following Blunt Force, Z. Rechtsmed 1987; 98: 81-93). In a series of experiments involving horizontal drops of fifty infant cadavers from approximately 32 inches on to a variety of floors, including padded and unpadded, resulted in both simple and complex skull fractures when the drops were onto hard flooring. These fractures occurred in newborns to infants of age 8 months.

Weber made an important observation, noting that these fractures typically occurred in bone varying in thickness between 0.1 to 0.4 mm and without diploe.

Diastatic Fractures



Diastatic fracture provided by Dr. Catanese

These are fractures, which involve the separation of one or more cranial bone sutures. They are most often seen in children and are commonly associated with epidural hematomas, lacerations of the dura caused by the edges of the fracture and severe brain injury. They typically are due to large impacts to the head as the result of blows, falls, bodily swinging the child by the legs with their head striking a wall or hard object.

Growing Skull Fractures

Most skull fractures involving children heal rapidly and without complication. However, in approximately 1.2 to 1.6% a growing skull fracture may develop. John

Hopkins first recognized this potential complication of skull fractures in 1816. GSFs are referred to as a leptomengeal cyst, posttraumatic meningocele, cerebrocranial erosion, cephalohydrocele, meningocele and spuria. The majority of GSFs occur during the first 3 years of life, rarely being seen after 8 years of age, although some have been described in patients in their 60s. It is believed that the reason they tend to be seen during the first three years of life is due to the rapid growth of the brain during this period.

One of the essential components of the genesis of GSFs is the laceration of the underlying dura. Other components, which play a roll in the pathogenesis of a GSF is a growing brain, hydrocephalis, herniation of cerebral tissue or CSF into the fracture, formation of a leptomeningeal cyst, which represents entrapment of the arachnoid in a fracture. All of these anatomic deviations will prevent healing of the fracture margins, thus leading to expansion of the fracture and not uncommonly a palpable mass.

Linear fractures are most commonly associated with GSFs, while depressed skull fractures are not. A linear fracture with a separation of greater than 4 mm may be considered at risk of developing a GSF. Beneath the GSF is evidence of focal brain injury in the form of a contusion, maceration and or laceration.

A GSF manifest itself clinically as a progressively enlarging pulsatile mass or as an enlarging, sunken palpable cranial defect. It may not become evident until several months after the initiation of the fracture, once presenting, gradually enlarging over months. GSFs are commonly associated with neurological complications, such as seizures, hemiparesis and psychomotor retardation. Whatever neurocomplication they develop progressively gets worse overtime. Thus, it is important to examine children with skull fractures 4 to 6 weeks following the injury to make certain that proper healing is taking place.

The most common location for GSFs is the convexity of the calvarium, most notably, the parietal bone, however, they can also occur at the base of the skull.

CT is the favored radiological study for determining GSFs. There are three types of GSF, Type I through Type III. Type I is a GSF with a leptomeningeal cyst, which can herniated not only into the fracture line, but through it into the subgaleal space.

Type II shows a GSF with underlying traumatic brain injury, including a healed injury (evidence only of gliosis). Type III GSF contains a porencephalic cyst.
The term "porencephaly" is typically restricted to circumscribed hemispheric defects that had occurred ***in utero*** or before the adult features of the hemisphere were fully developed. The developmental origin of the lesions is evident from the smooth walls with minimal scarring, and from developmental disturbances in the architecture of the adjoining cortex. These lesions need to be differentiated from encephaloclastic lesions, which have their onset during the terminal phase of pregnancy or postnatal life. Typically these lesions come about as the result of destruction of existing cortical tissue without altering cortical architecture, except in terms of atrophy or scarring, and in forming irregular defects with shaggy, rough walls.

Although CT is preferred to denote skull fractures, MRI is preferred for the determination of the severity of dural lacerations.

Early surgical correction is recommended.