STUDENT GUIDE

Painting the bones of your cat skull

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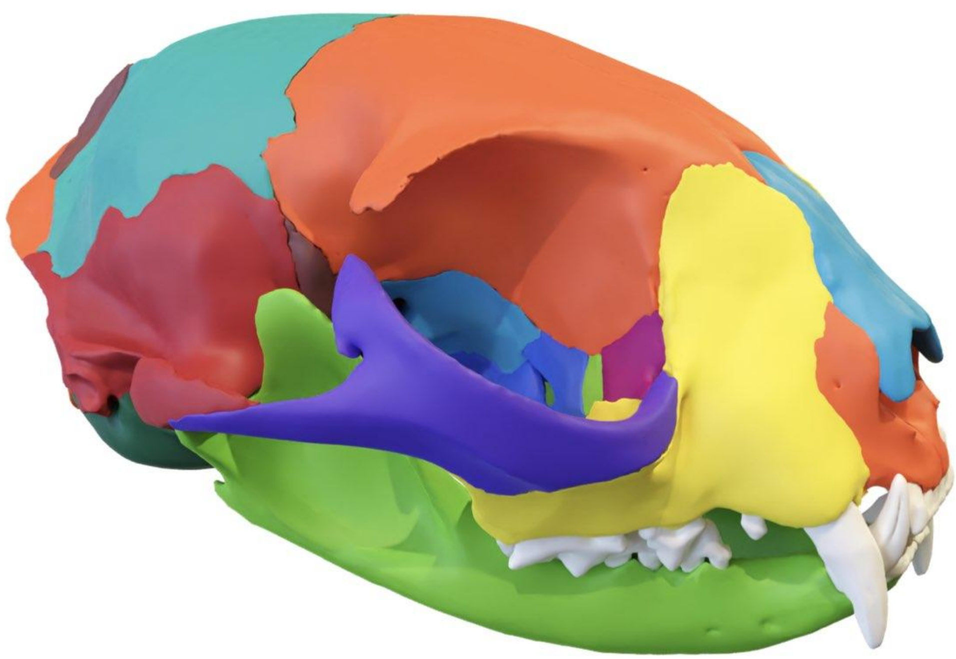


Description

In this module, you'll identify and "paint" (using markers) the bones of a model cat skull. In the process, you'll gain a better understanding of the bones' functional and developmental groupings, 3D shapes, and physical relationships.

Introduction

When it comes to learning the bones of the body, the head is the most challenging region. Vertebrates can have dozens of individually named bones in their head (cats have over two dozen!) with complex 3D shapes and borders that can be irregular and difficult to discern. Additionally, some structures we refer to as a “bone” are actually made of up multiple parts (called **ossification centers**), each of which may be referred to as a separate bone in another species. For example, the occipital bone in mammals is actually made up of three separate ossification centers (the supraoccipital, the basioccipital, and the exoccipital), which are referred to as separate bones in other vertebrate groups.

Often, the reason why bones are named as a group or individually is the presence or absence of **sutures**. During development of the skull bones form as individual ossification centers that are initially separated from one another like little islands. As these “islands” expand, their borders start to come into contact with one another and **suture lines** form between them. In some vertebrate groups (e.g., some mammals) most of these sutures are preserved into adulthood. In other groups (e.g., many birds) most sutures are obliterated by subsequent growth. When these suture lines are not preserved, what appears to be one “bone” may actually be several bones.

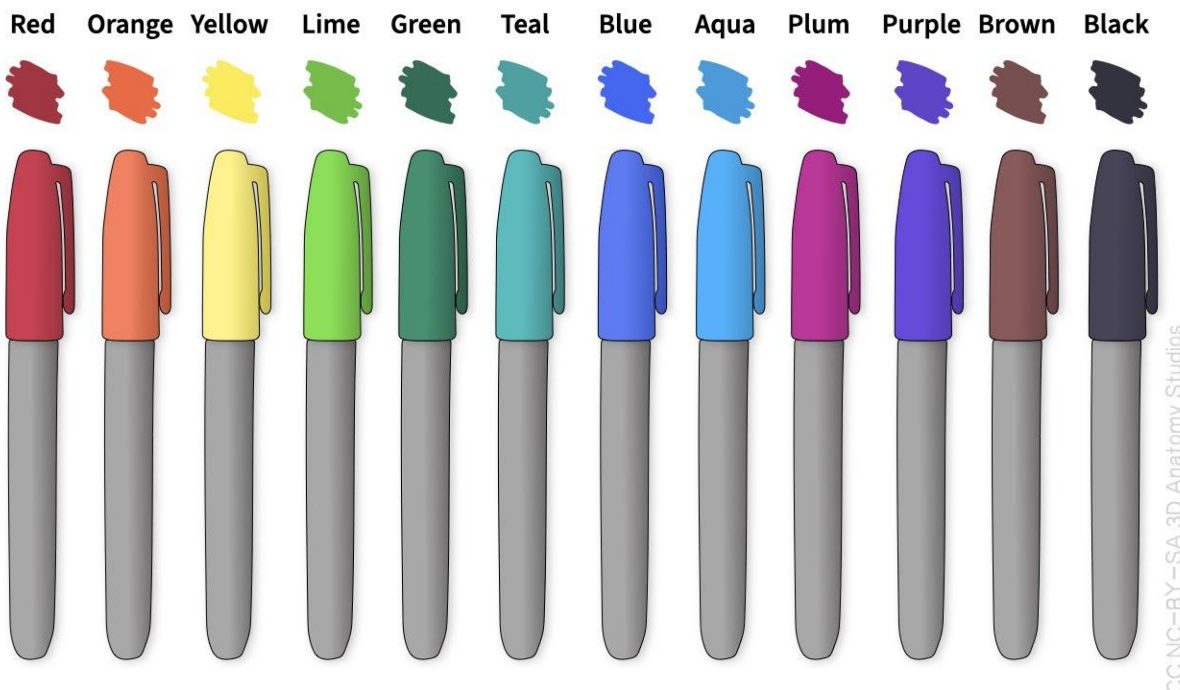
In this module, you will identify and “paint” (using permanent markers) each bone of your cat’s skull - like a 3D coloring book. Fortunately, in cats, most of the sutures among different bones are preserved into adulthood and visible on your model to help you identify each bone. Pay attention to these sutures as you color to keep from coloring “outside the lines.” The module is broken into three sections, following three traditional divisions of the vertebrate skull: the chondrocranium, the dermatocranium, and the splanchnocranium. After completing this module, you should be able to better identify the bones of the mammal skull, classify them into one of these three main divisions, and understand their 3D form, position, and physical relation to each other.

Cranium and **skull** are often used interchangeably in common language but in anatomy they have different meanings. “Cranium” usually refers to the bones of the head excluding the **mandible** or **lower jaw**, whereas “skull” refers to all of the bones of the head, including the lower jaw.

Materials needed

For this module, you'll need:

- The cat skull (cranium and mandible) from your kit
- **12 permanent markers**, each of a different color (you may be sharing a set). These may have come with your kit. The markers are not labeled so you may find the image below helpful to sort out which color is which.



- **OPTIONAL** Gloves
- **OPTIONAL** Paper towels
- **OPTIONAL** Ethyl or isopropyl alcohol

COLOR NOTE: Color scheme design

Given that there are only 12 colors available in the provided marker set and that there are more than 12 bones in the cat skull, you'll use the same color for more than one bone. The color coding has been designed so that no two neighboring bones have the same color.

CAUTION: Permanent markers

In this activity you'll be coloring in your cat skull using *permanent* markers. The markers can leave **permanent** stains on clothing or other materials so be careful when handling them. Also, you won't be able to erase and redo any markings so double check the reference images in this guide before using the marker to color in the bone.

Section 1. What are the bones of the cat chondrocranium?

The first major division of the vertebrate skull is the **chondrocranium** (or **neurocranium**). The bones of the chondrocranium help to encase the brain and other structures of the central nervous system. The chondrocranium is so named because all of these elements first develop as **cartilage** (*khondros* is Greek for 'cartilage'); in some vertebrates, these elements never actually ossify and remain as cartilage into adulthood. The process by which cartilage turns into bone is called **endochondral ossification**.

The chondrocranium bones are also the first to form in development and are generally deeper inside the skull. For this reason, you can think of these bones like the skull's foundation, onto which everything else is built. In cats, the chondrocranium includes six bones (or parts of bones): the occipital bone, the basisphenoid bone, the presphenoid bone, the orbitosphenoid bone, the petrous part of the temporal bone, and the non-turbinate part of the ethmoid bone.

BUILD NOTE: Painting tips

Follow these tips to paint your skull faster and end up with a better result!

1. **Follow the coloring order in this guide.** You'll notice that your markers sometimes bleed across the borders of a bone into neighboring bones. Don't worry, you won't see much of this bleeding once your skull is fully colored in. The coloring order in this guide has been designed to proceed from lighter to darker colors so that:
    a. The darker colors will cover up any prior bleeding of the lighter colors
    b. The lighter colors will lessen bleeding by the darker colors (if a bone is already colored in with marker, the marker ink on the surface tends to block bleeding into the bone)
    c. If you make mistakes at the start, the darker colors will cover these mistakes

2. **Look for the suture lines** to help you trace the border of the bone.

3. **Color the edge of the bone first (carefully)** so you can then quickly fill in the interior of the bone without going outside the edge of the bone.

4. **(Optional) Keep the marker tip clean** by occasionally wiping the marker tip on a paper towel. After using the marker for a while, the tip can start to release small threads making it difficult to color precisely. Wiping the tip will help remove these loose threads and preserve a clean tip.

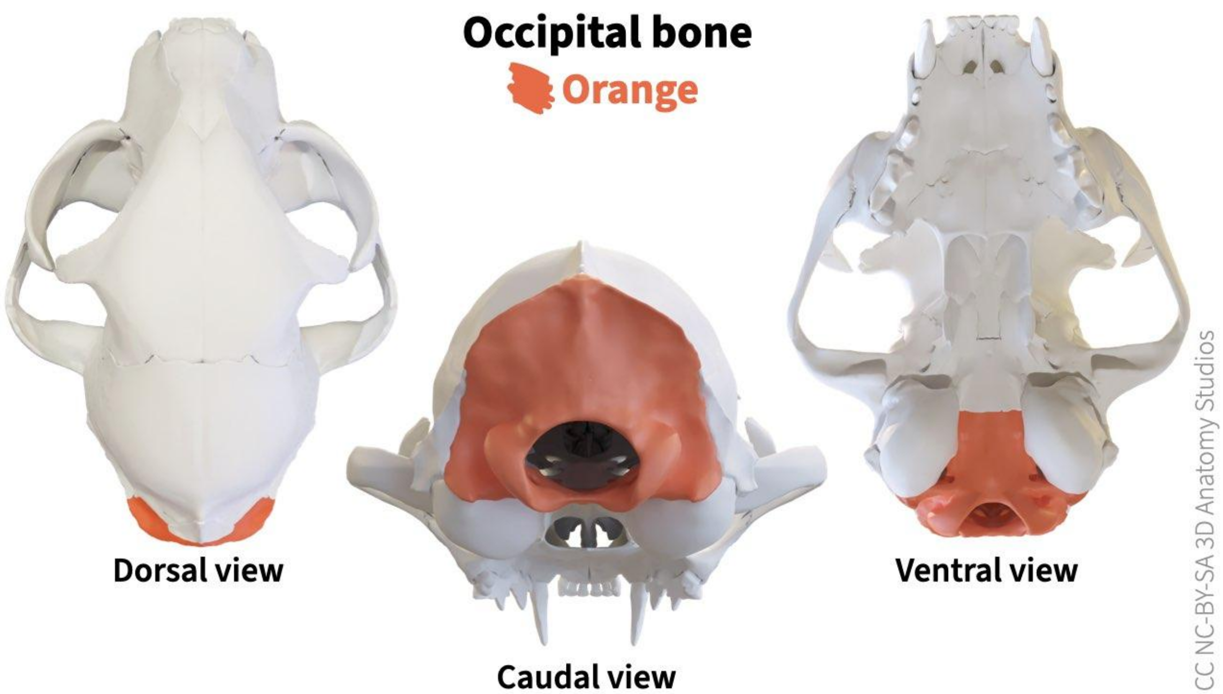
5. **(Optional) Use gloves** to keep from getting permanent marker on your hands. The permanent marker dries almost instantly but some can come off onto your hands.

6. **(Optional) Use ethyl or iIsopropyl alcohol to clean** marker off your hands, gloves, or your skull. Cut a piece of paper towel into small pieces, soak each piece of towel in alcohol, and use to wipe. You can even use this to correct *isolated* coloring mistakes. However, if you use alcohol to remove marker from your skull, be careful: the alcohol easily spreads and dissolves any ink nearby, potentially causing a larger mess than a small coloring mistake. Also, the alcohol doesn't *entirely* remove the marker from the skull; it removes enough that you can color back over the cleaned area and the previous color will not be easily visible.

Occipital bone

The **occipital bone** makes up the back of the skull, or **occiput** (from Latin for *ob-* 'against' + *caput* 'head). The most salient feature of the occipital bone is the large opening for the spinal cord: the **foramen magnum** (Latin for 'big hole'). The spinal cord is an extension of the **central nervous system (CNS)** so you could say the CNS actually passes through the occipital bone.

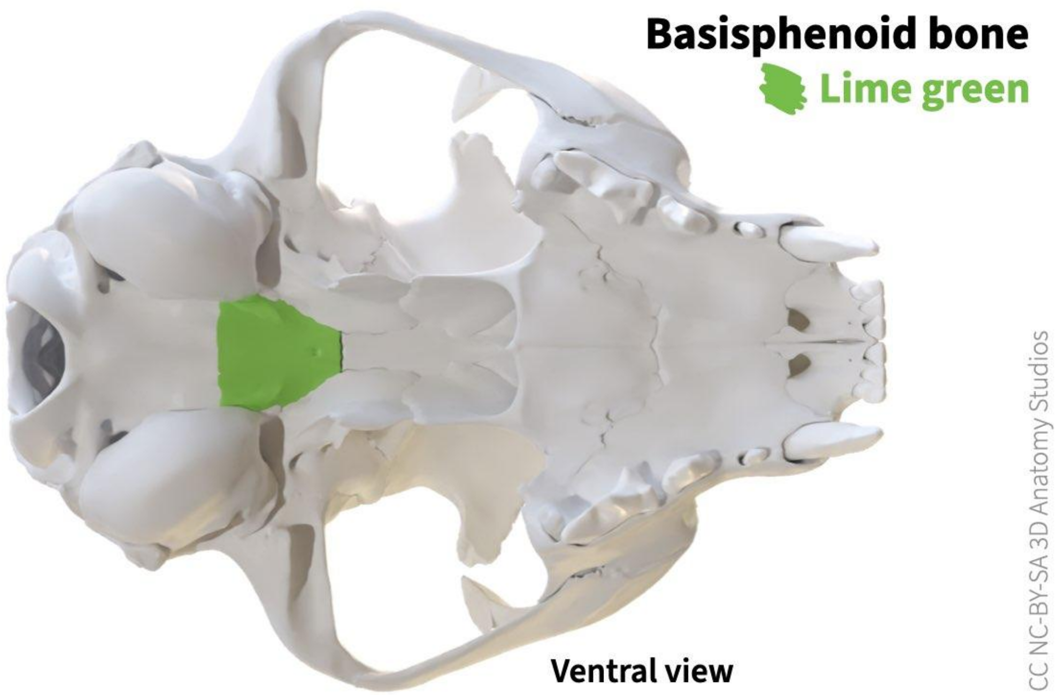
The occipital bone is actually made up of three chondrocranial bones (the **supraoccipital**, the **basioccipital**, and the **exoccipital**) plus one or more bones from the dermatocranium (discussed later in this module). Whereas in other vertebrates, the supraoccipital, basioccipital, and exoccipital can be visible as separate bones, in cats the suture lines fuse during development giving the impression of a single bone.



Use the image above to paint your cat's occipital bone **orange**.

Basisphenoid bone

Moving rostrally from the occipital bone, the next bone of the chondrocranium that you'll color in is the **basisphenoid bone**. The basisphenoid is one of several bones that makes up the **sphenoid bone** (sphenoid comes from the Greek word for 'wedge' because of its wedge-like shape). Like the occipital bone, the sphenoid bone is a composite bone made up of multiple constituent bones. However, these constituent bones are from all three divisions of the skull, not just two. So you'll see the sphenoid mentioned in each section of this module.

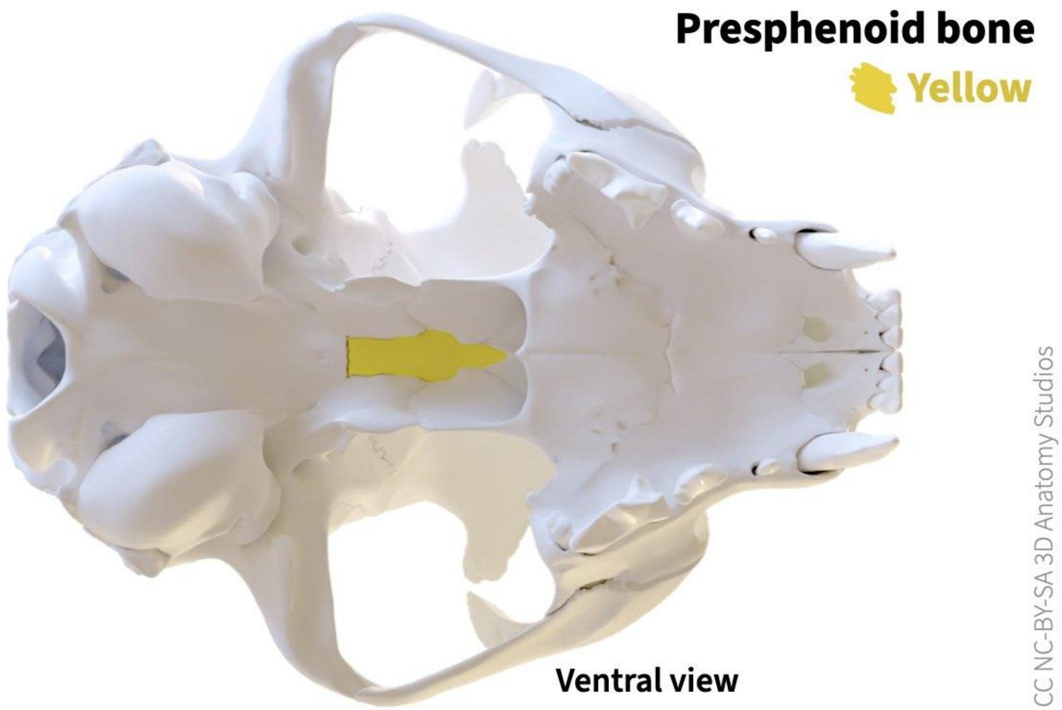


Paint your cat's basisphenoid **lime green**. Unlike the occipital bone, the suture lines among the bones of the sphenoid are still visible in the adult. Use these to help you find the borders of the basisphenoid.

Once you've painted the basisphenoid completely, paint over it **a second time** - this will help to reduce bleeding into this bone later.

Presphenoid bone

Continuing rostrally from the basisphenoid, you'll find another bone of the sphenoid: the **presphenoid bone**. It's long, narrow, and, like the basisphenoid, lies in the midline of the skull as shown in the image below.

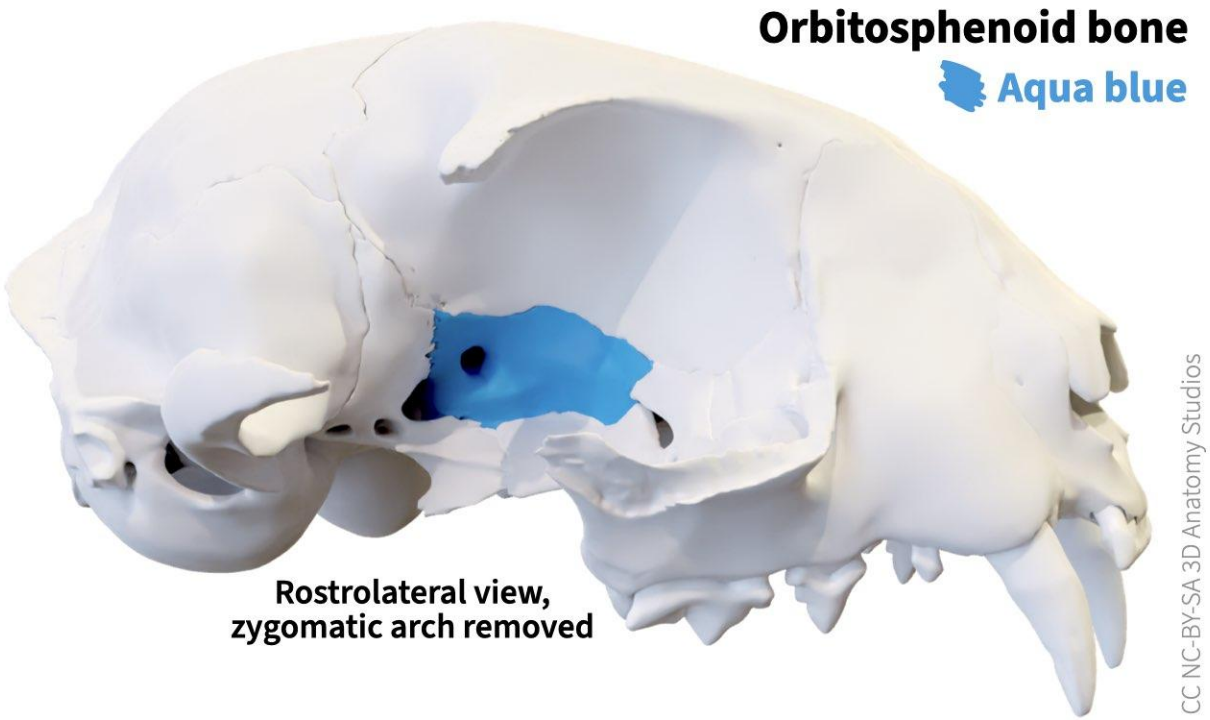


Paint your cat's presphenoid **yellow**. Remember to use the suture lines to help you!

Once you've painted the presphenoid completely, paint over it **a second time** - this will help to reduce bleeding into this bone later.

Orbitosphenoid bone

The last **chondrocranial** portion of the sphenoid bone in mammals is the **orbitosphenoid**. Unlike the basisphenoid and presphenoid, this bone is not at the midline but is separated into left and right parts, which help to make up part of the orbit (thus its name).
The right orbitosphenoid is shown in the image below.



It might not seem like the orbitosphenoid is continuous with the previous two sphenoid bones, but it is. The sphenoid is one continuous bone but some parts are covered externally by other bones, which can make it seem like separate elements.

Note the hole passing through the orbitosphenoid - that is the **optic foramen**. The **optic nerve (cranial nerve II or CN II)** passes through the optic foramen to carry visual signals from the eye to the brain. This relationship between the optic foramen and the orbitosphenoid is highly conserved across vertebrates. Recall that the chondrocranium helps to encase the brain. The optic nerve is actually an extension of the brain (i.e., it is part of the central nervous system) rather than a separate nerve. This conserved and close relationship between the orbitosphenoid and optic nerve reflects that close chondrocranium-brain relationship.

Paint your cat's left and right orbitosphenoids **aqua**.

Temporal bone (petrous part)

Like the sphenoid bone, the **temporal bone** is made up of multiple composite bones from various divisions of the skull, including the chondrocranium. The chondrocranial component of the temporal bone in mammals is called the **petrous (or petrosal) part of the temporal bone**. This part is formed from two bones, called the prootic and opisthotic in other vertebrate groups.

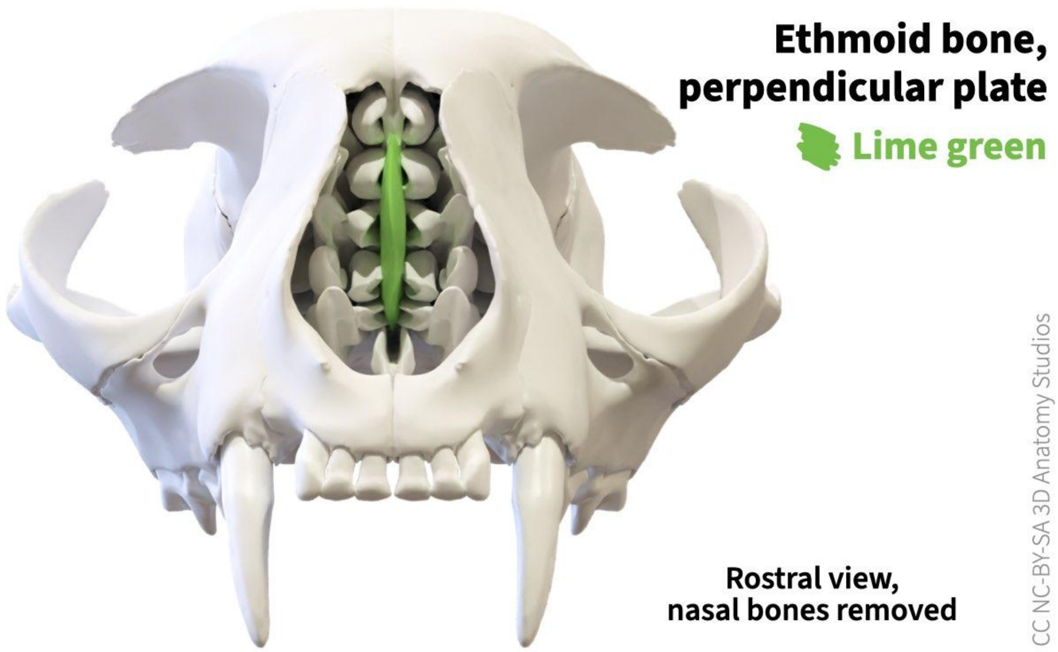
The name 'petrous,' from the Latin *petra* or 'rock,' derives from the fact that it is one of the densest bones in mammals. This high density is functional: the petrosal part of the temporal bone encases the **inner ear** (the **semicircular canals** and **cochlea**) and its density helps to insulate the sensitive nerves of the inner ear from external vibrations. Just as for the optic nerve, note the close relationship between the chondrocranium and special sense organs of the brain.

The petrous part of the temporal bone is not visible externally so you won't be able to paint this bone on your cat's skull.

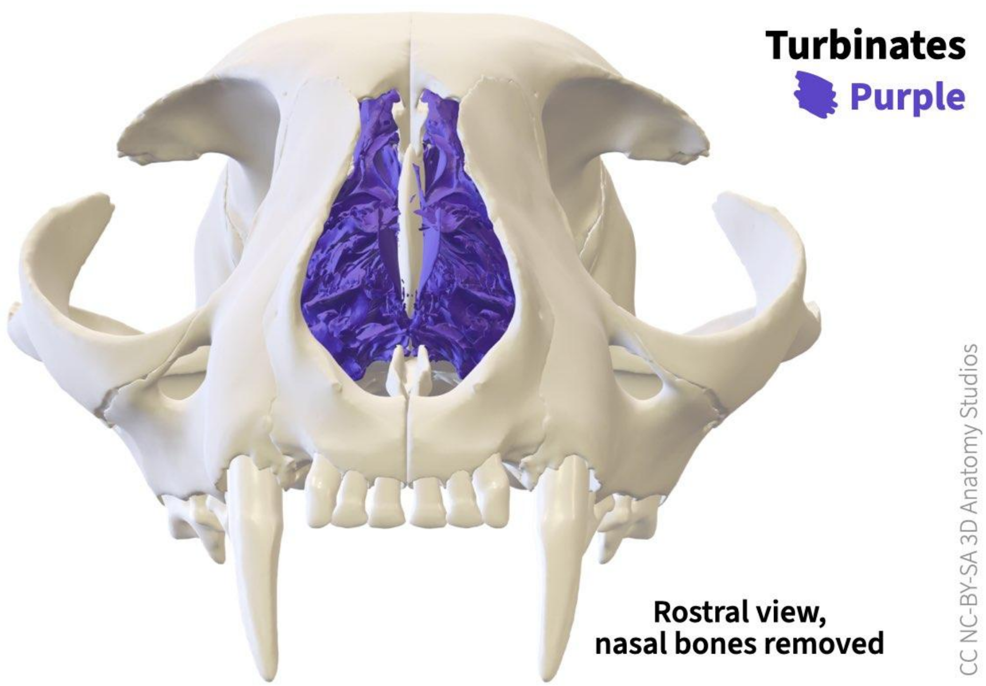
Ethmoid bone

The last and most rostral bone of the chondrocranium in your cat skull is the **ethmoid bone**. Just as the orbitosphenoid is closely related to optic nerve (CN II) and vision, the ethmoid is closely related to the **olfactory nerve (CN I)** and **olfaction**, or the sense of smell. The olfactory nerve (CN I) is also an extension of the brain or CNS, like CN II, again reinforcing the close relationship between the chondrocranium and brain.

The ethmoid forms the **cribriform plate**, a plate with several small **foramina** (plural form of foramen, meaning 'holes') through which the olfactory nerves pass to send sensory information from the nose to the brain. This is where the ethmoid gets its name: ethmoid comes from the Greek *ethmos*, meaning 'a sieve.' The ethmoid also forms other structures related to the nose and orbit. It forms part of the vertical plate that helps make up the midline wall separating the left and right nasal cavity as shown in the following image. The following images are for conceptualization only; you won't be able to paint these structures since they are too far inside the skull.

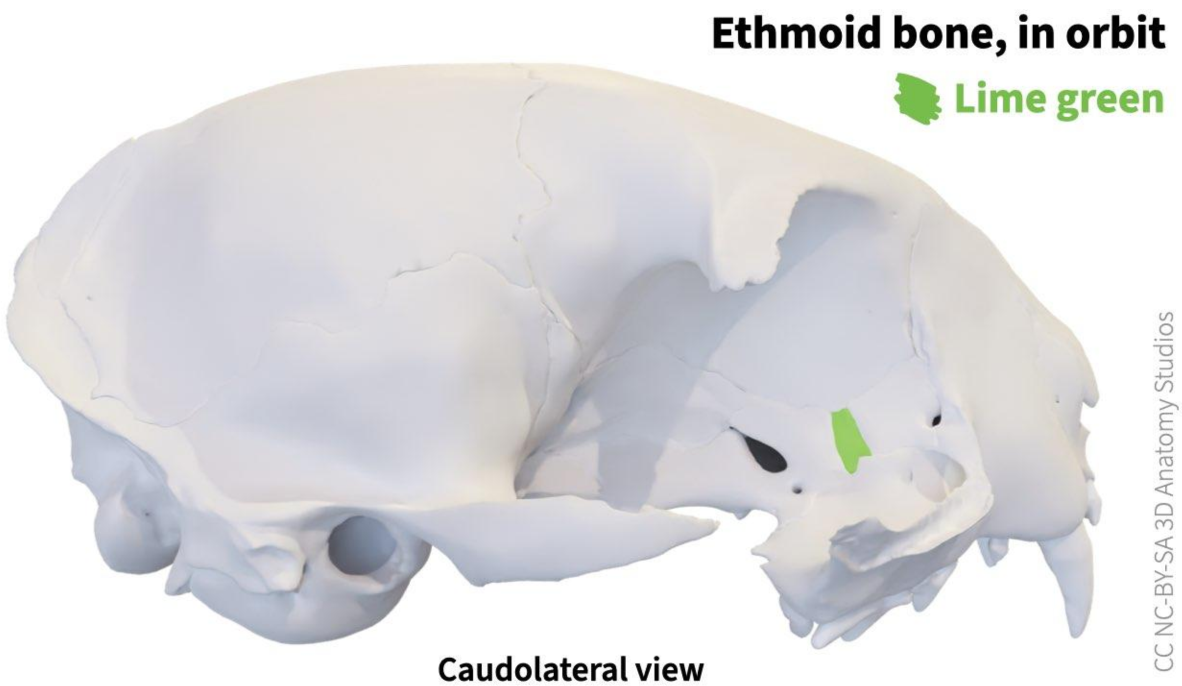


And the ethmoid forms part of the **turbinates**, which are paper-thin and tightly packed scroll-like bones in the nasal cavity (the nasal and maxillary bones can also contribute to the turbinates). The image below shows what these structures look like in a real cat (the turbinates in your cat skull model are thickened and simplified so that they can be 3D printed).



The turbinates are covered in a **mucosal** surface that is an important site for respiratory temperature regulation (cooling hot air in warm weather and heating cold air in cool weather) and for olfaction. The highly convoluted structure of the turbinates increases the mucosal surface area available for these functions.

Lastly, the ethmoid also helps to form part of the orbit. In your cat skull, the ethmoid forms just a small part of the orbit, peeking out between other bones.



Paint the small bit of ethmoid in your cat's left and right orbit **lime green**.

Once you've painted the ethmoid completely, paint over it **a second time** - this will help to reduce bleeding into this bone later.

Section 2. What are the bones of the cat dermatocranium?

The next major division of the vertebrate skull is the **dermatocranium**. The 'dermato-' in the name, rather than 'chondro-' is a clue that these bones have a different type of ossification and some relation to skin (*derma* is Greek for 'skin'). All of the bones of the dermatocranium develop directly from connective tissue rather than first forming as cartilage, a process called **intramembranous ossification**. And because the connective tissue in which these bones form tends to be close to the surface, it's as if these bones were forming directly in the skin. For this reason, bones that develop via intramembranous ossification are often called **dermal bones**.

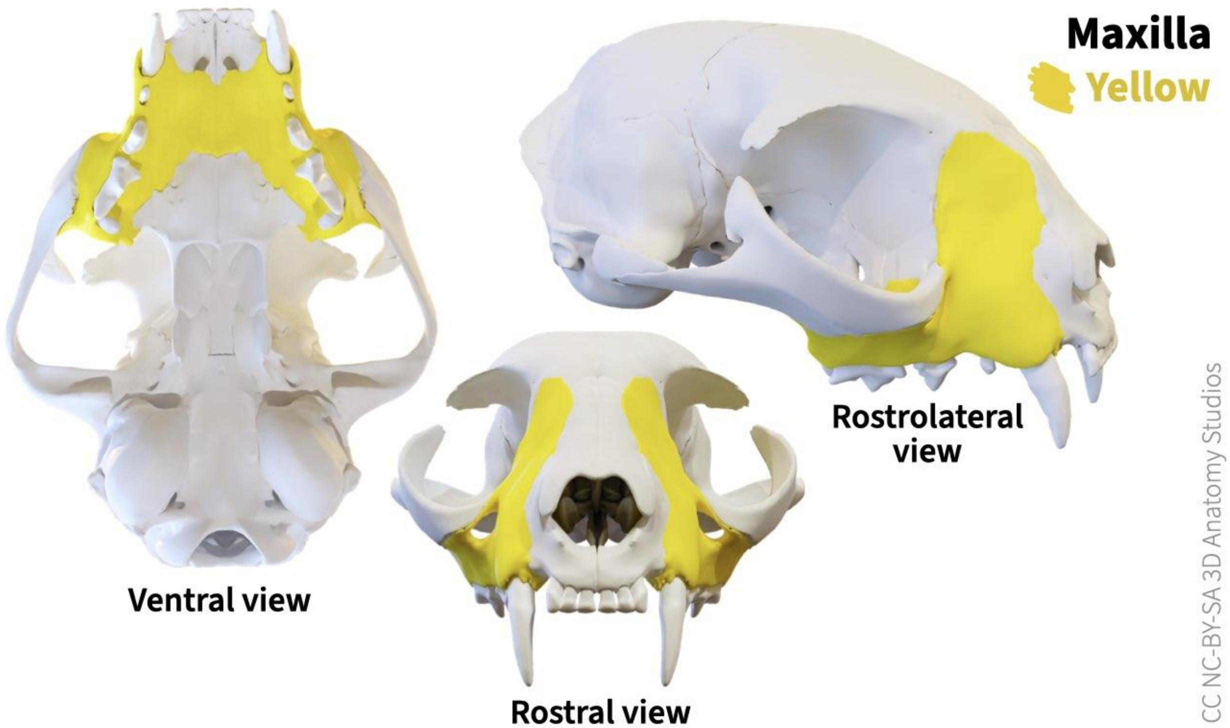
As opposed to the deep, internal bones of the chondrocranium, the bones of the dermatocranium tend to be more superficial. If the chondrocranium is the internal foundation of the skull, the dermatocranium generally functions more like the outer covering.

Importantly, some bones (or parts of bones) of the skull develop as dermal bones but are part of the third division (the splanchnocranium, or gill arch-derived bones- explored in the third section of this module). So, while all of the bones of the dermatocranium are dermal bones, the converse is not true: not all dermal bones are part of the dermatocranium. Thus, a more precise definition of the dermatocranium would be: all of the dermal bones of the skull that are not derived from the gill arches.

The bones of the dermatocranium can be subdivided into six "series" (listed in the same order as presented in this guide): facial, vault, temporal, orbital, palatal, and mandibular. These groupings are based on their approximate location in the skull - they have no relation to the bones' development or origins.

Maxilla

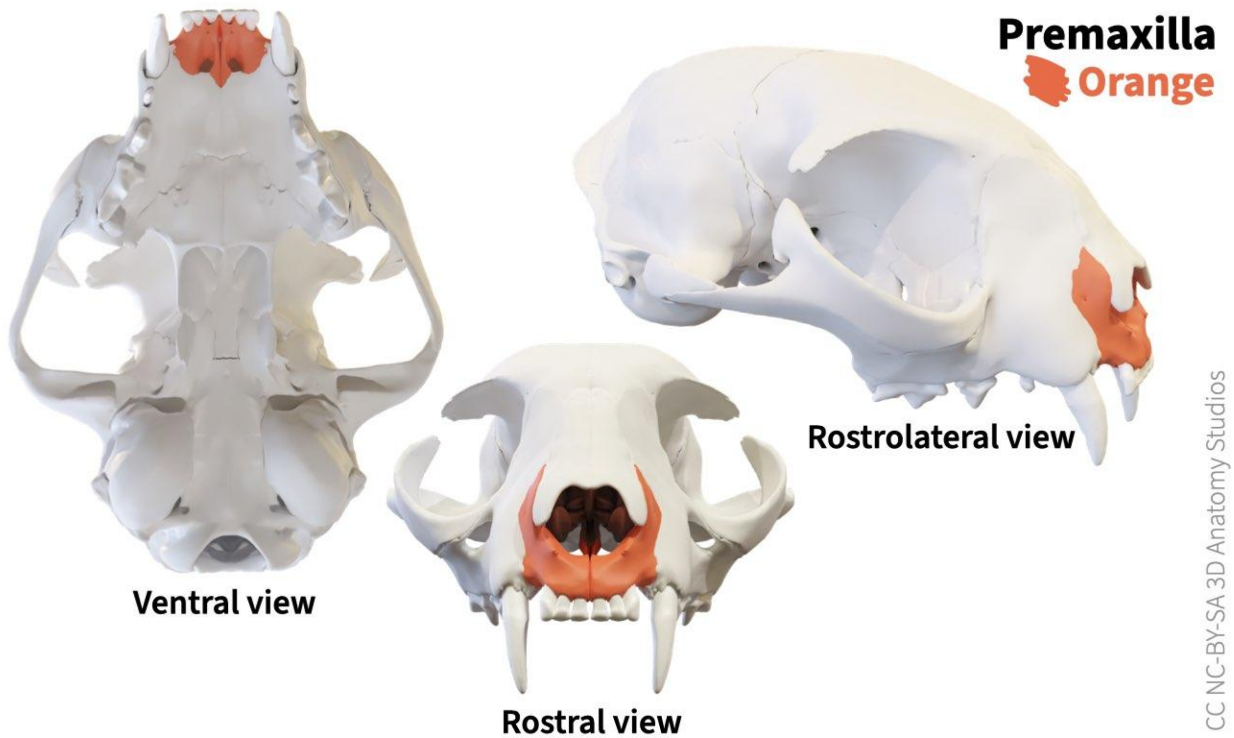
The first series of the dermatocranium is the **facial series**. These bones form the rostral most part of the cranium. The first of these is the **maxilla** or **maxillary bone**. The maxilla is notable for being one of the two bones in mammals that hold the upper teeth ('maxilla' comes from the Latin word for 'jaw'). Specifically, the maxilla holds the upper canines, premolars, and molars. The maxilla also forms parts of the turbinates, along with the ethmoid and nasal bones.



Paint your cat's left and right maxillae (plural of maxilla) **yellow**.

Premaxilla

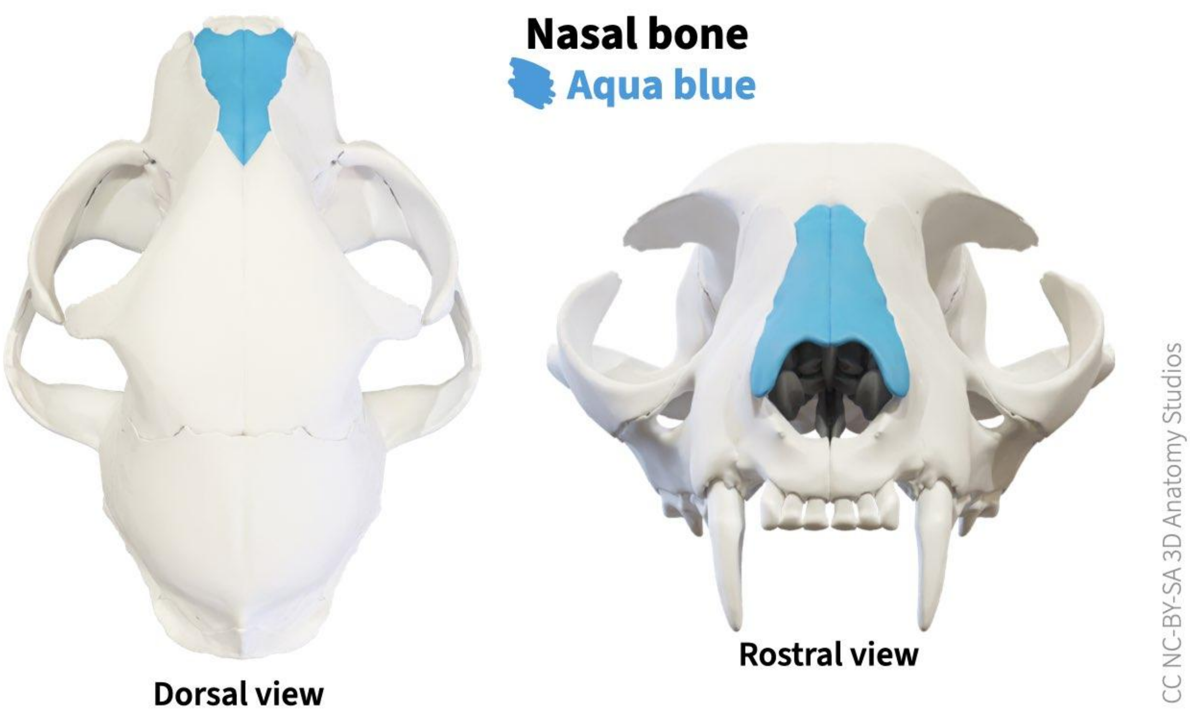
The second bone of the dermatocranium facial series and the other tooth bearing bone of the upper jaw in mammals is the **premaxilla** or **premaxillary bone**. The premaxilla is immediately rostral to the maxilla and holds the incisors.



Paint your cat's left and right premaxillae (plural of premaxilla) **orange**.

Nasal bone

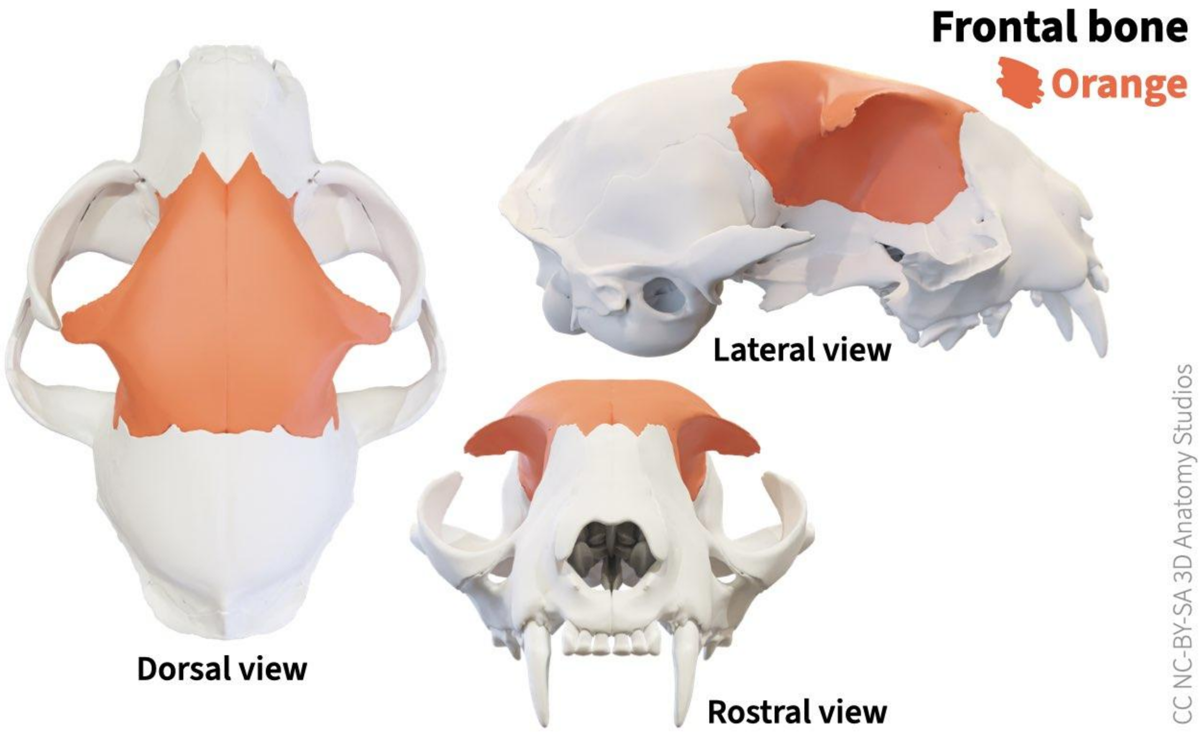
The last of the dermatocranium facial series bones is the **nasal bone**. This flat, narrow bone immediately superior to the premaxilla forms (as the name suggests) most of the bony portion of the nose (the other portion being formed by cartilage). In some mammals, the nasal also contributes a small part to the turbinates. If you look inside the nasal opening, you can see part of the ethmoid bone and turbinates.



Paint your cat's left and right nasal bones **aqua**.

Frontal bone

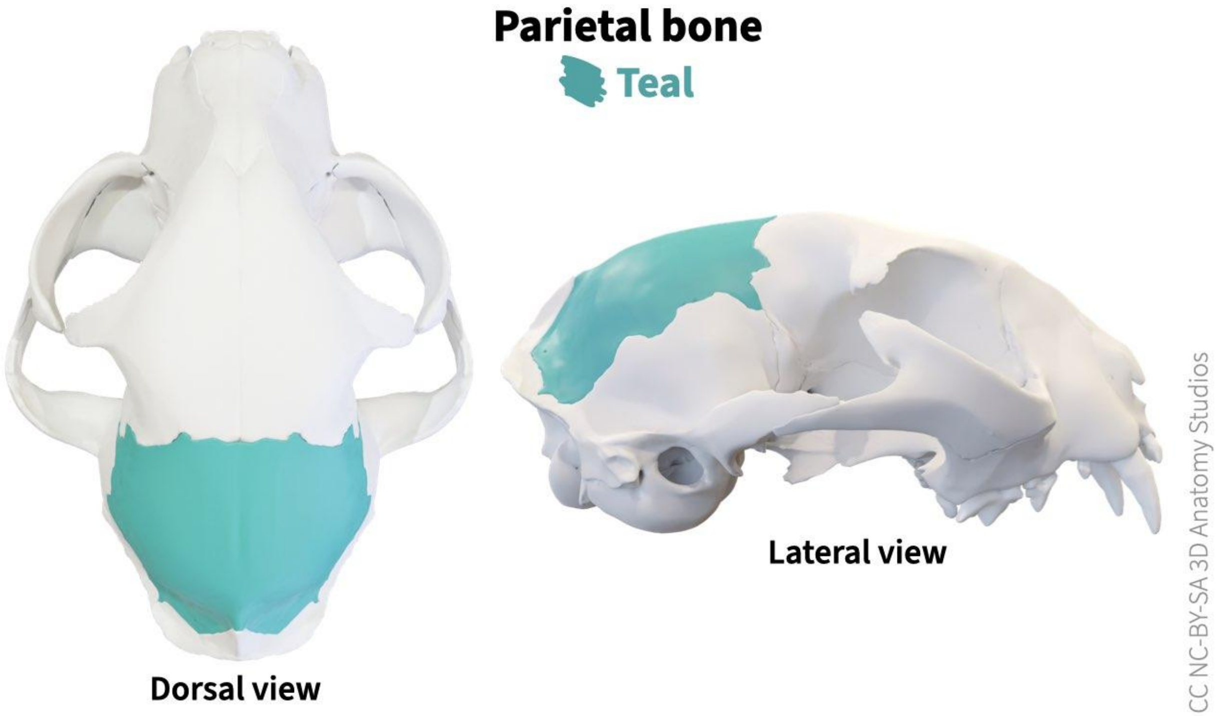
The next series of the dermatocranium is the **vault series**. The bones of the vault series form most of the roof of the cranium (think of 'vault' as in a vaulted ceiling, with these bones forming the "ceiling" of the cranium). The first of these is the **frontal bone**, so named because it is generally the bone of the forehead (frontal comes from the Latin *frons*, meaning 'forehead').



Paint your cat's left and right frontal bones **orange**.

Parietal bone

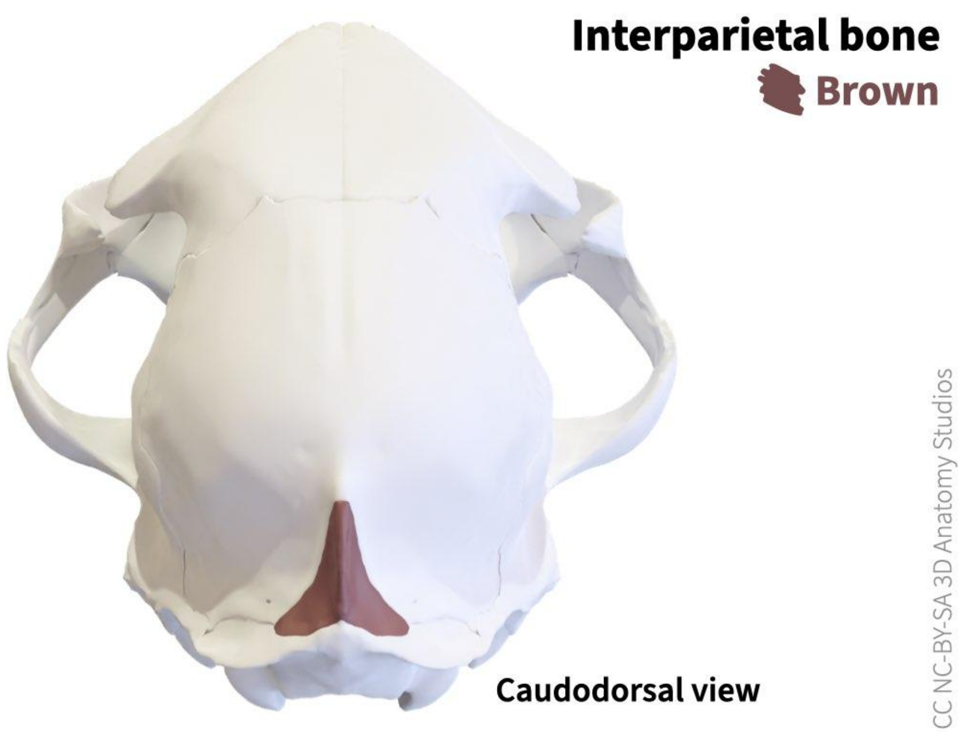
The second bone of the dermatocranium vault series is the **parietal bone**. Immediately caudal to the frontals, the parietals form the caudal roof and walls of the cranium (parietal comes from the Latin *paries*, meaning 'wall').



Paint your cat's left and right parietal bones **teal**.

Interparietal bone

The last of the dermatocranium vault series is the **interparietal bone**. This bone, located between the parietal and previously covered occipital bones, makes up part of the occipital bone (along with its other chondrocranial constituents). The interparietal is **homologous** with (i.e., it evolved from the same precursory structure as) the postparietal of other vertebrates (and maybe also the tabular bone) and is not present in all mammals (humans, for example, lack an interparietal bone).

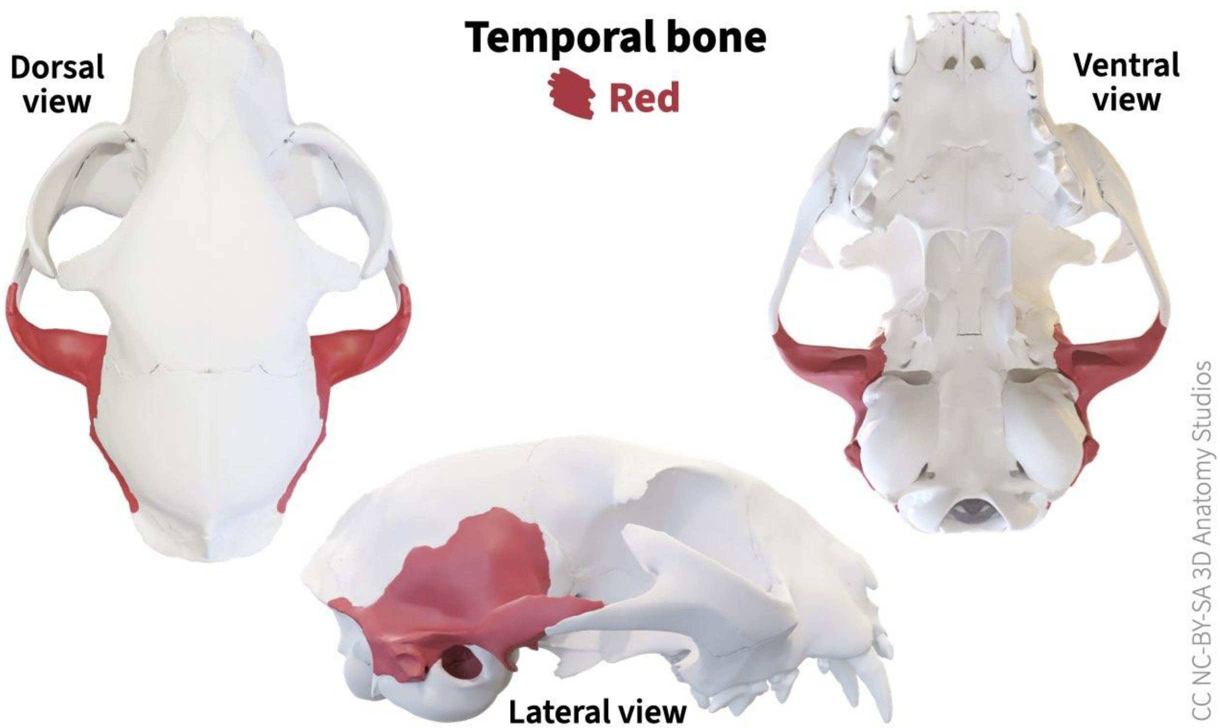


Paint your cat's interparietal bone **brown**.

Temporal bone (squamosal and zygomatic parts)

The next dermatocranium "series" is really all about one bone: the **temporal bone**. Like the sphenoid bone, the temporal bone is a composite bone made of bones from each of the three divisions of the skull. You're already familiar with the petrous part of the temporal bone (the chondrocranium component), which is not visible externally. However, the dermatocranium components are visible externally and these are the **squamous part** and **zygomatic part**.

Located near the temple of the head (as suggested by the bone's name), the squamous part forms a large portion of the lateral wall of the cranium and the zygomatic part forms the caudal portion of the zygomatic arch. These parts of the temporal bone also make up the **external acoustic meatus**, the hole of the "outer ear."

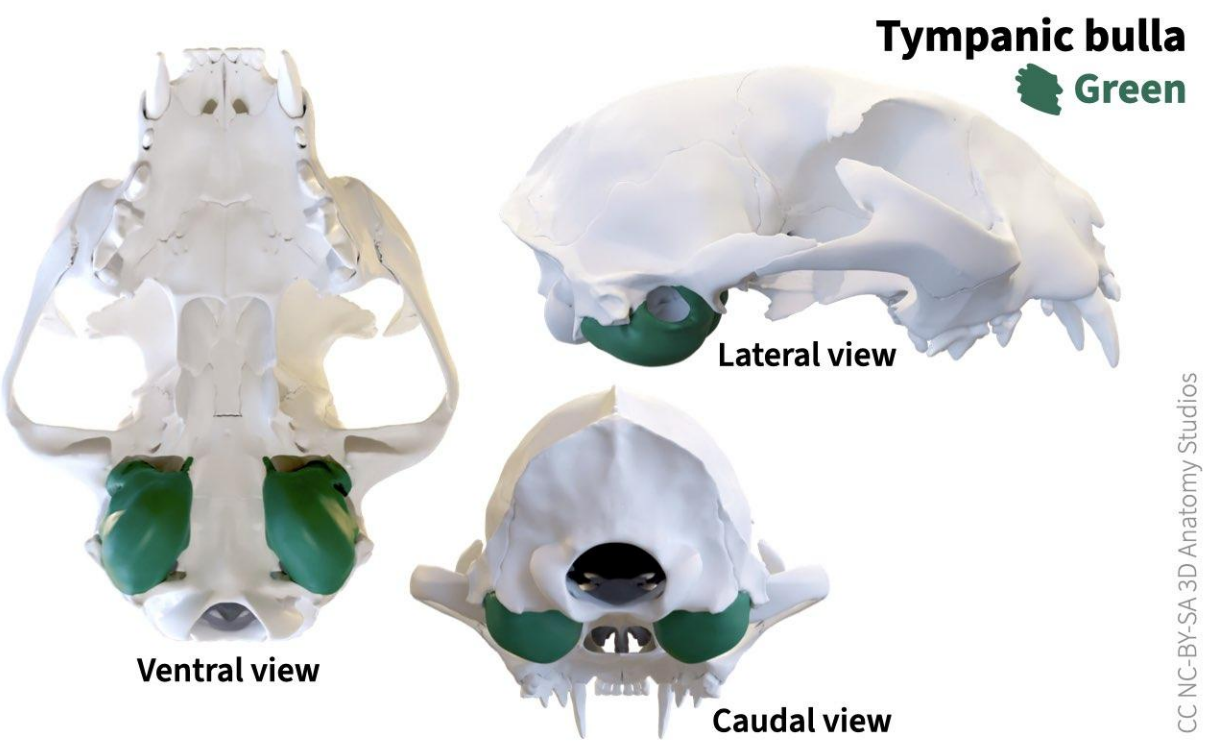


Paint the squamosal and zygomatic parts of your cat's left and right temporal bones **red**.

Tympanic bulla

Closely associated with the temporal bone and external acoustic meatus is a round and smooth bone called the tympanic bulla (‘tympanic’ denotes its association with the **tympanum** or eardrum and ‘bulla’ comes from the Latin word for ‘bubble’). This bone is sometimes included as the other bone of the dermatocranium temporal series.

This bone has rather complex origins: one portion is thought to derive from a dermal bone called the **angular bone** in other vertebrates (a bone that in other vertebrates forms part of the mandible) while another portion is thought to develop by endochondral ossification with no known homologue outside of mammals.[1] Tympanic bullae (the plural form of ‘bulla’) are only found in some mammals; humans, for example, do not have a tympanic bulla.

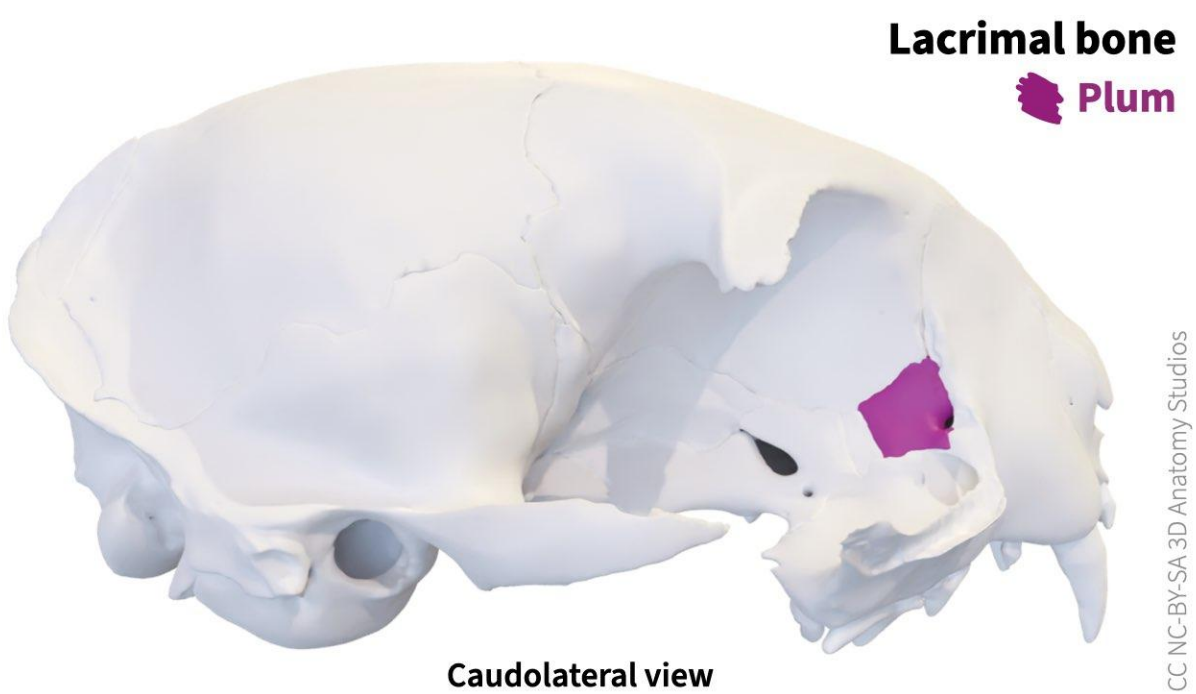


Paint your cat’s left and right tympanic bullae **green**.

[1] Source and confirmation needed.

Lacrimal bone

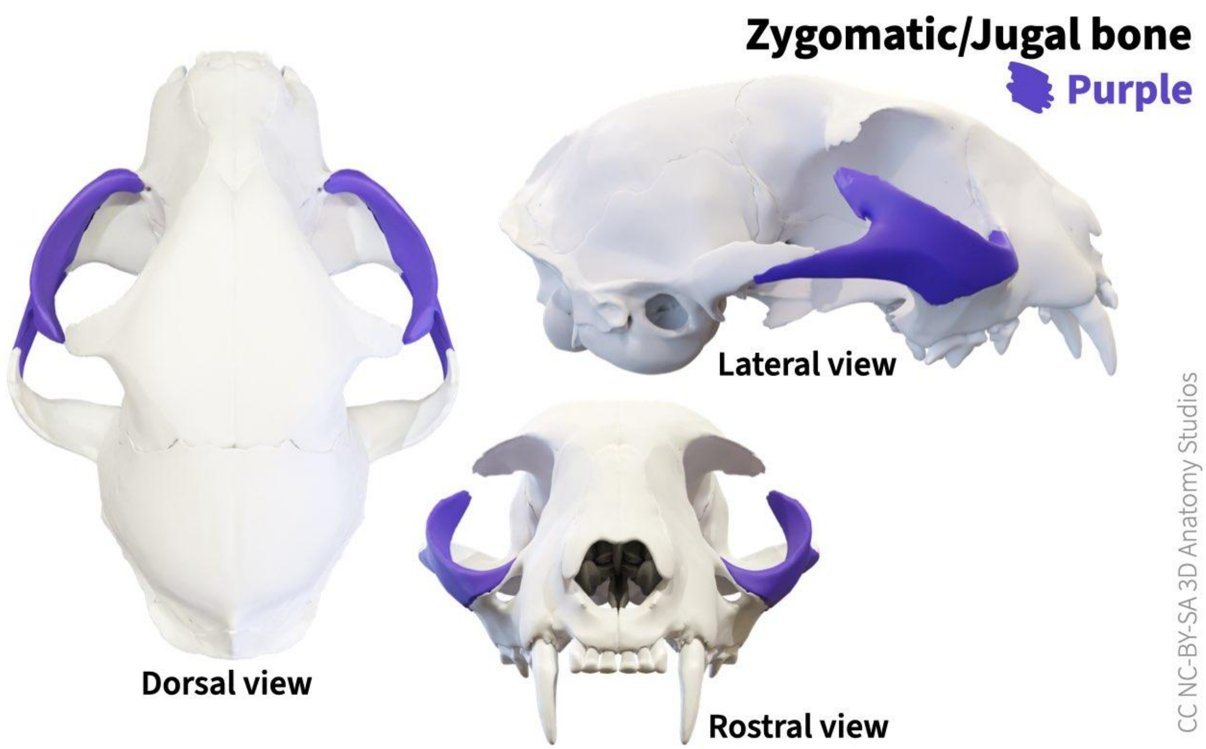
The next dermatocranium series is the orbital series. These are not the only dermatocranium elements that form the orbit (e.g., the frontal and maxillary bones also form part of the orbit), they are just the only two bones that are primarily associated with the orbit. The first is the **lacrimal bone**. This bone forms part of the medial wall of the orbit but it also has a foramen (located between the maxilla and lacrimal bone) that opens into the **nasolacrimal duct**, a duct that connects the orbit to the nasal cavity. This duct allows tears from the eye to drain into the nasal cavity and gives the lacrimal bone its name (*lacrima* means 'tear' in Latin).



Paint your cat's left and right lacrimal bones **plum**.

Zygomatic/Jugal

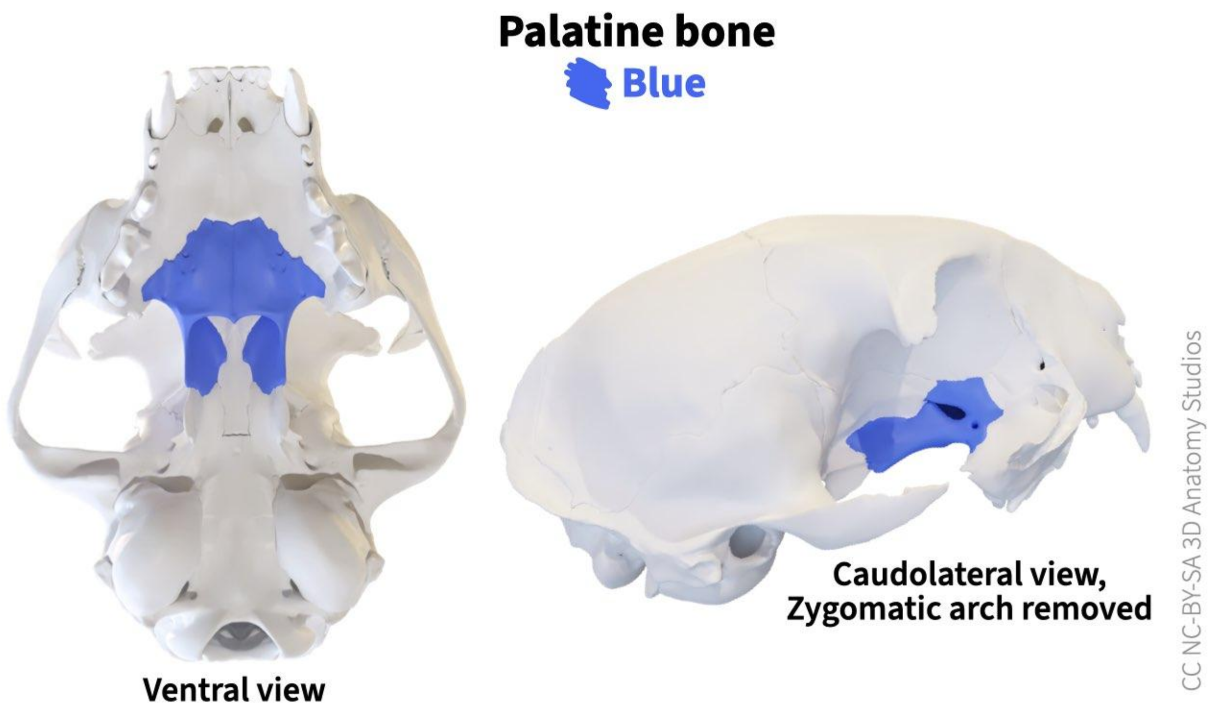
The other dermatocranium bone in the orbital series is the **zygomatic** or **jugal bone**. This bone forms most of the zygomatic arch, connecting with the maxillary bone rostrally and the temporal bone caudally. It was named based on its resemblance to a yoke, a wooden crosspiece fastened over the necks of two animals to pull a cart. Both names have the same original meaning, they're just derived from different languages: *jugum* (the source for 'jugal') means 'yoke' in Latin and *zugon* (the source for 'zygomatic') means 'yoke' in Greek.



Paint your cat's left and right zygomatic bones **purple**.

Palatine bone

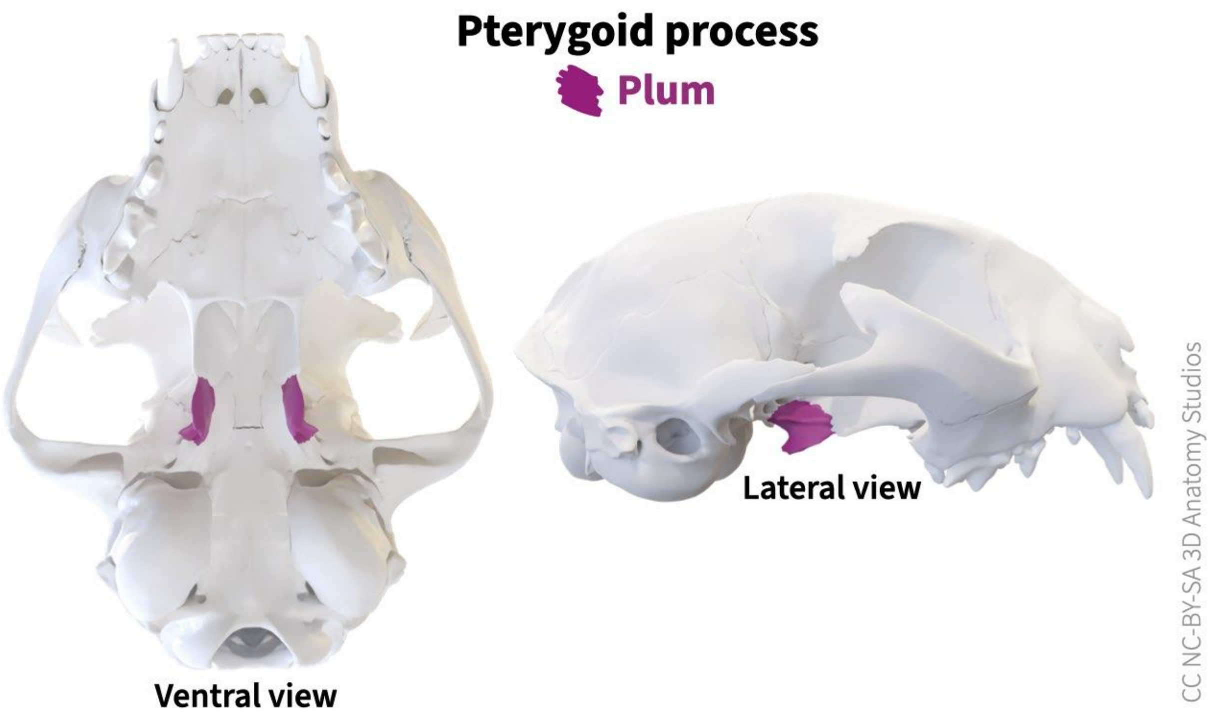
The next dermatocranium series is the palatal series, so named because of their association with the palate. The first of these is the **palatine bone**. In mammals, the premaxilla, maxilla, and palatine bones evolved to form a **secondary palate**, which separates the nasal and oral cavities forming the **choana** or **internal nares**. The palatine bone is the most caudal of these.



Paint your cat's palatine bone **blue**.

Pterygoid bone/process

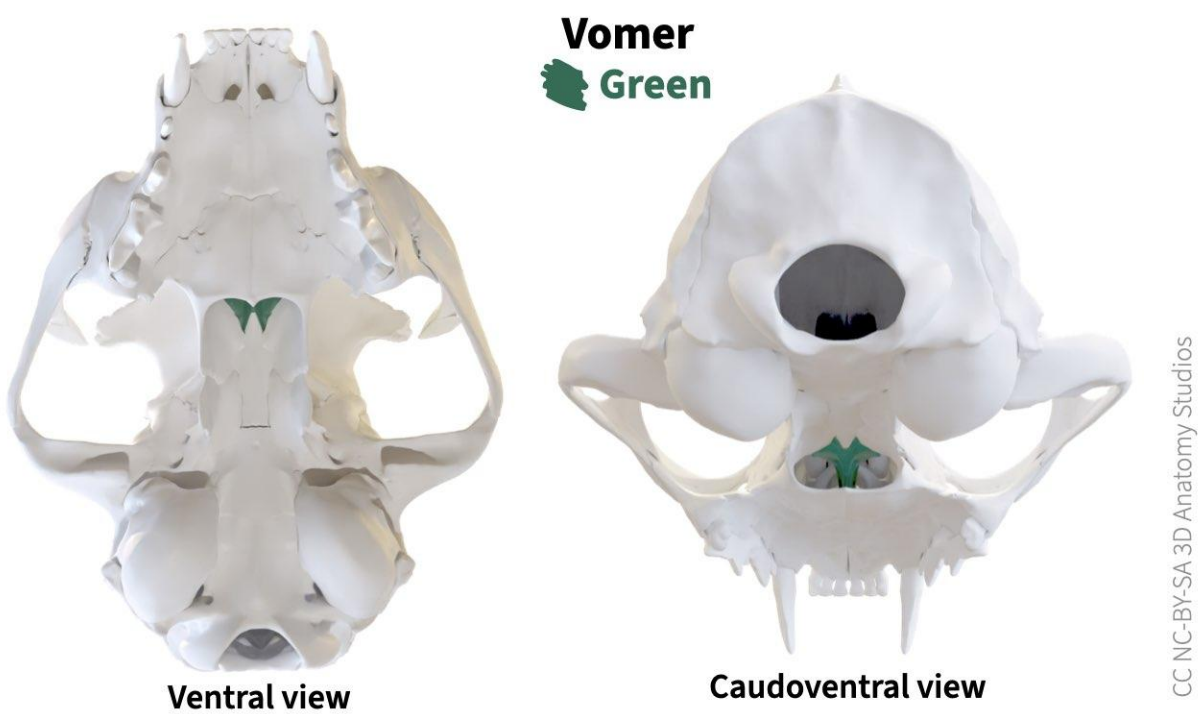
Remember the sphenoid bone and how it had contributions from all three divisions of the skull? The second bone of the palatal series, the **pterygoid**, is the dermatocranium component of the sphenoid bone. This bone may be called a bone or a process, depending on the vertebrate group; in mammals, it's called the **pterygoid process**. The difference is not really important, it just has to do with its relative size and position. The name of the bone comes from its flat, wing-like shape (*pteron* is Greek for 'wing', the same derivation as for pterosaur or pterodactyl).



Paint your cat's pterygoid processes bone **plum**.

Vomer bone

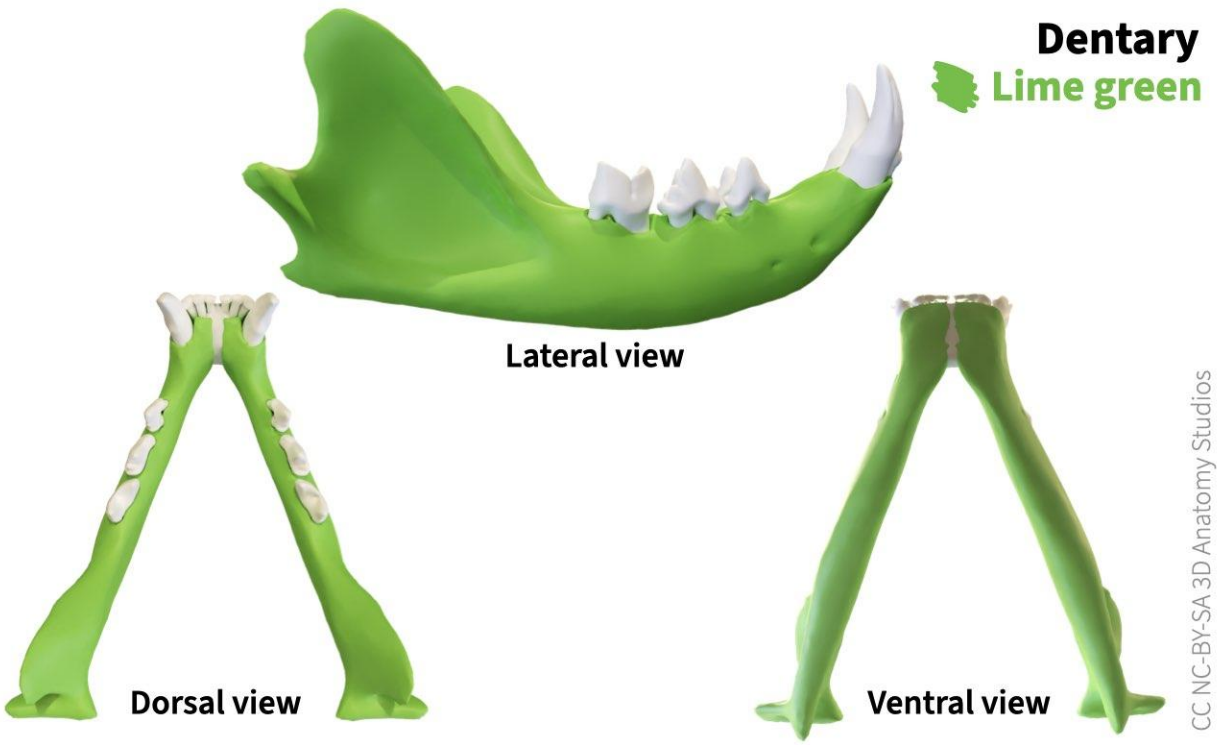
The last bone of the dermatocranium palatal series is the **vomer**. It was named based on its resemblance to a plowshare, the main cutting blade of a plow ('vomer' means plowshare in Latin). The vomer is a long, narrow bone that is associated with the **primary palate** (the palate dorsal to the secondary palate) and it is largely obscured from view externally by the palatine and maxilla. You can see a bit of the bone peeking out from the choana.



Paint your cat's vomer **green**. You'll only be able to paint the caudalmost portion of the vomer.

Dentary bone

Now that you've colored in 18 different bones of your cat cranium, you might be wondering if the mandible is also composed of several different bones. In many vertebrate groups, this is the case and the mandible is made of several dermatocranium elements referred to as the mandibular series. But in mammals, it's surprisingly simple: the mandible is composed of a single dermatocranium bone, the **dentary**. It derives its name from the fact that in vertebrates with multiple mandibular bones, it is the dentary that bears the teeth (*dens* means 'tooth' in Latin). Note that "mandible" is just a name for the entire structure (like cranium), not the name of a bone.



Paint your cat's dentary bone **lime green**.

Section 3. What are the bones of the cat splanchnocranium?

The last major division of the vertebrate skull is the **splanchnocranium**, also known as the **viscerocranium**. This division includes all of the bones of the skull that are derived from the **gill arches**. The name for this division derives from the association between the gill arches and the gut ('viscero-' comes from the Latin *viscera*, meaning 'entrails' or 'intestines' and 'splancho-' comes from the Greek *splankhna*, also meaning 'entrails'). The gill arches give rise to the structures of the jaw, oral cavity, pharynx, and branchial apparatus (gills) – all structures constituting the rostralmost portion of the gut. Although the gill arches have evolved in some vertebrate lineages to form structures not related directly to the gut (e.g., the middle ear bones), the names splanchnocranium and viscerocranium simply reflect this earliest association.

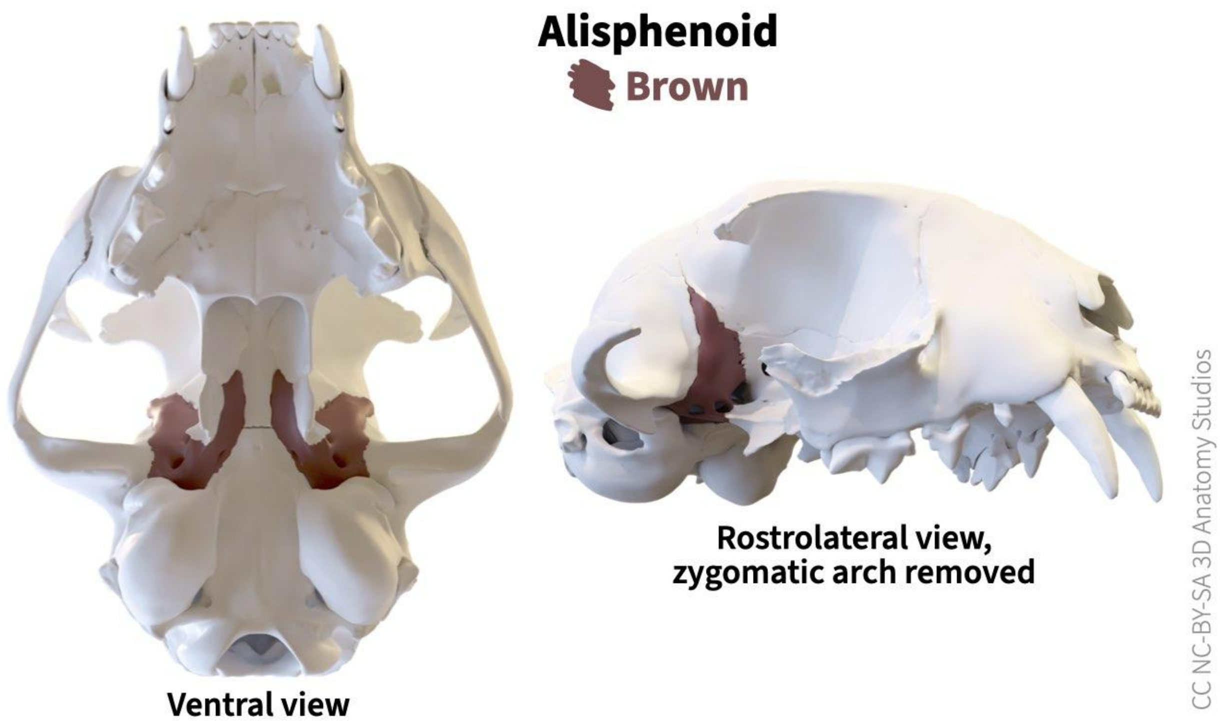
Vertebrates develop with a total of seven gill arches (typically referred to by Roman numerals, I, II, III, etc.) and in vertebrates with a full set of gills, the anatomical structures resulting from each arch into adulthood is fairly clear. However, even in vertebrates without gills, such as mammals, the gill arches are still a fundamental organizing principle of head and neck development. Associations between the muscles, nerves, and bones of each gill arch persist across the deep evolutionary history of vertebrates. By learning these associations, the complex structures of the head will make more sense and it will also be easier for you to remember the names and relationships among these structures.

In this module, we'll only cover structures derived from the first three gill arches. In the following steps, you'll color in each of these splanchnocranium elements sequentially (i.e., gill arches I, II, and then III).

Alisphenoid bone (Gill arch I)

As mentioned in the introduction to this section, the gill arches have associations with particular nerves, muscles, and bones that persist through vertebrate evolution. The **first gill arch** is also referred to as the **mandibular arch** because of its persistent association with the rostralmost oral jaws and associated muscles and nerves. In particular, the first gill arch is associated with the **trigeminal cranial nerve (CN V)**, which innervates the muscles, skin, and mucosa associated with the oral jaws (among other innervation targets).

The last remaining part of the sphenoid bone, the **alisphenoid**, is another splanchnocranium element derived from the first gill arch. The 'ali-' prefix is derived from the wing-like shape of this bone (*ala* is Latin for 'wing'). Consistent with the first gill arch's association with CN V, the alisphenoid sits at the base of the cranium near the articulation with the oral jaws and has foramina for branches of the trigeminal nerve (CN V), among other nerves.



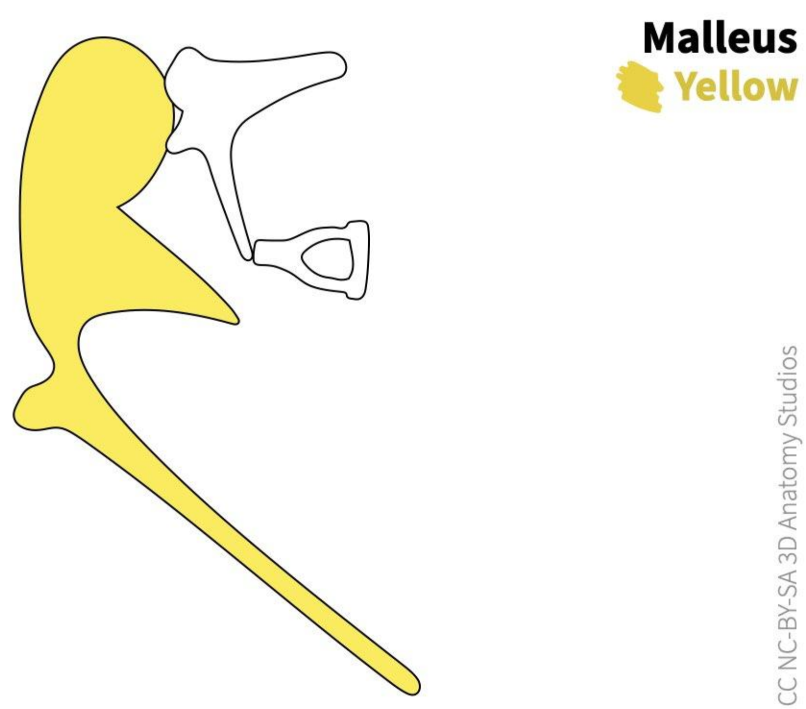
Paint your cat's left and right alisphenoids **brown**. Note that now all of the elements of the sphenoid are connected: the basisphenoid, presphenoid, orbitosphenoid, pterygoid process, and alisphenoid.

Meckel's cartilage (Gill arch I)

Meckel's cartilage is another splanchnocranium element derived from the first gill arch that persists throughout development in some vertebrates to form the mandible or lower jaw (e.g., sharks). However, in most vertebrate lineages, including mammals, it's resorbed during development and replaced by one or more bones that form the mandible instead (e.g., the dentary). Since Meckel's cartilage does not form any structures that persist into adulthood in cats, there's nothing to color in for this element.

Malleus bone (Gill arch I)

A key event in mammalian evolution was the transformation of gill arch-derived jaw bones into the bones of the middle ear. The most external of these middle ear bones, derived from the first gill arch, is the **malleus** (Latin for 'hammer', as in 'mallet'). The malleus is homologous with the **articular** of non-mammalian vertebrates, which, when present, forms part of the lower jaw at its articulation (thus its name) with the cranium.

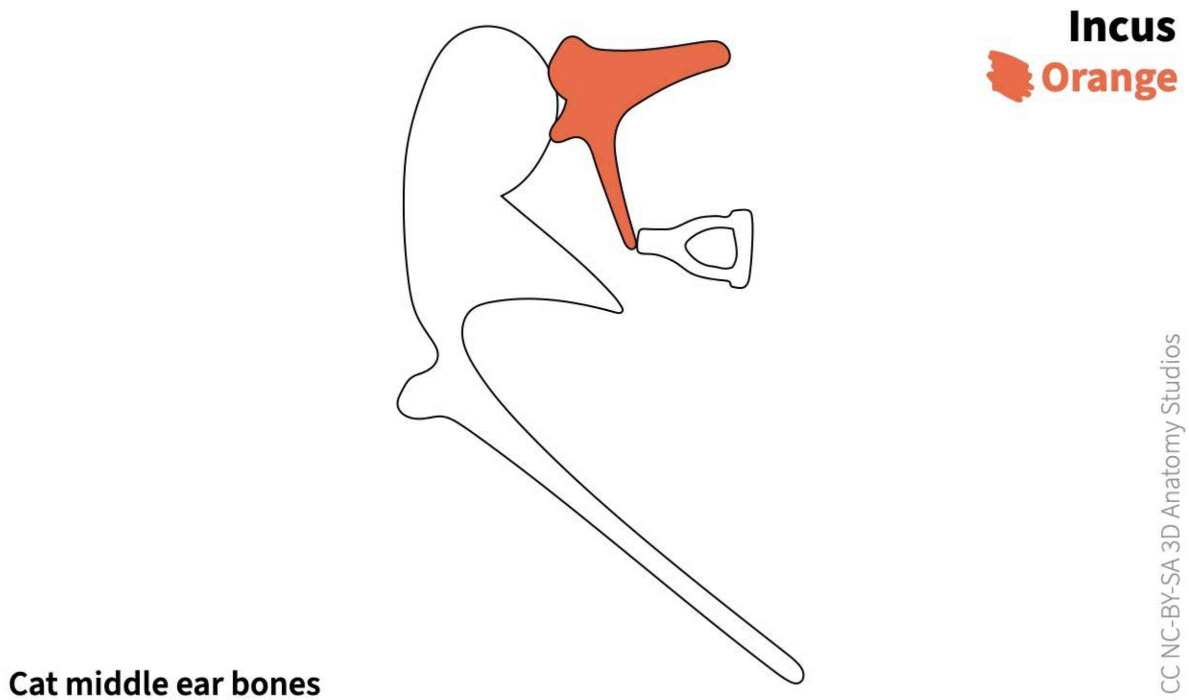


Cat middle ear bones

Color the malleus **yellow**. The bones of the middle ear are also too thin to be included in your kit as a 3D print so they are included in your kit as a print-out on paper.

Incus bone (Gill arch I)

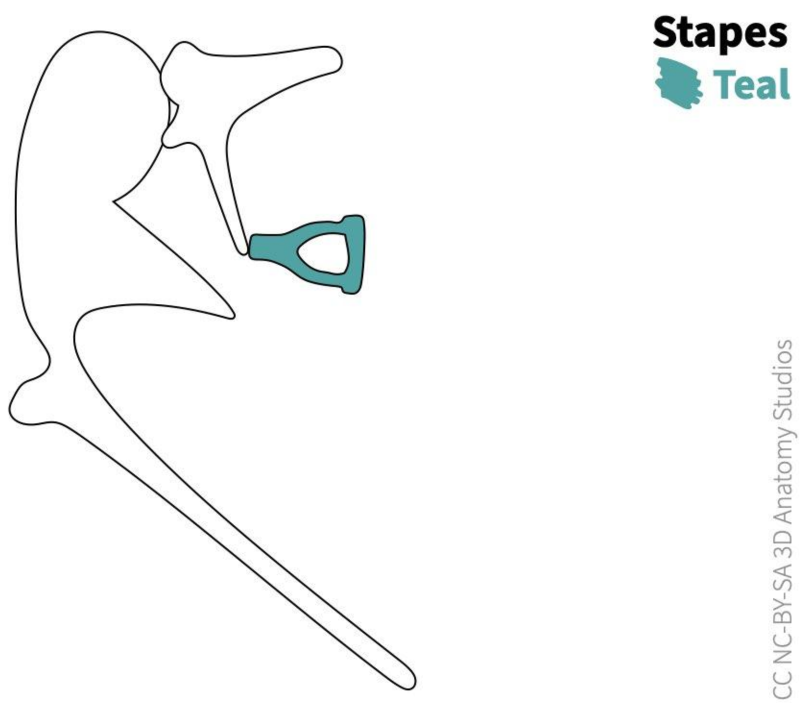
The second middle ear bone, also derived from the first gill arch, is the **incus**, named for its anvil-like shape (*incus* is Latin for 'anvil'). The incus is homologous with the **quadrate bone** of non-mammalian vertebrates, which, when present, is the part of the cranium that articulates with the articular bone.



Color the printed incus in **orange**.

Stapes bone (Gill arch II)

The last middle ear bone, derived from the second gill arch, is the **stapes** (its name derived from the Latin for 'stirrup'). The stapes is homologous with the **hyomandibula bone** or the stapes and **extracolumella** bones of other vertebrates. Ancestrally, the hyomandibula articulated with the quadrate, forming something like a second jaw joint between the quadrate and chondrocranium; this function persists in many living vertebrates. In other vertebrate lineages (e.g., birds, amphibians), the hyomandibula has undergone its own radical transformation into a middle ear bone, entirely different and independent of the transformation that occurred in mammals.



Cat middle ear bones

Color the printed stapes in **teal**.

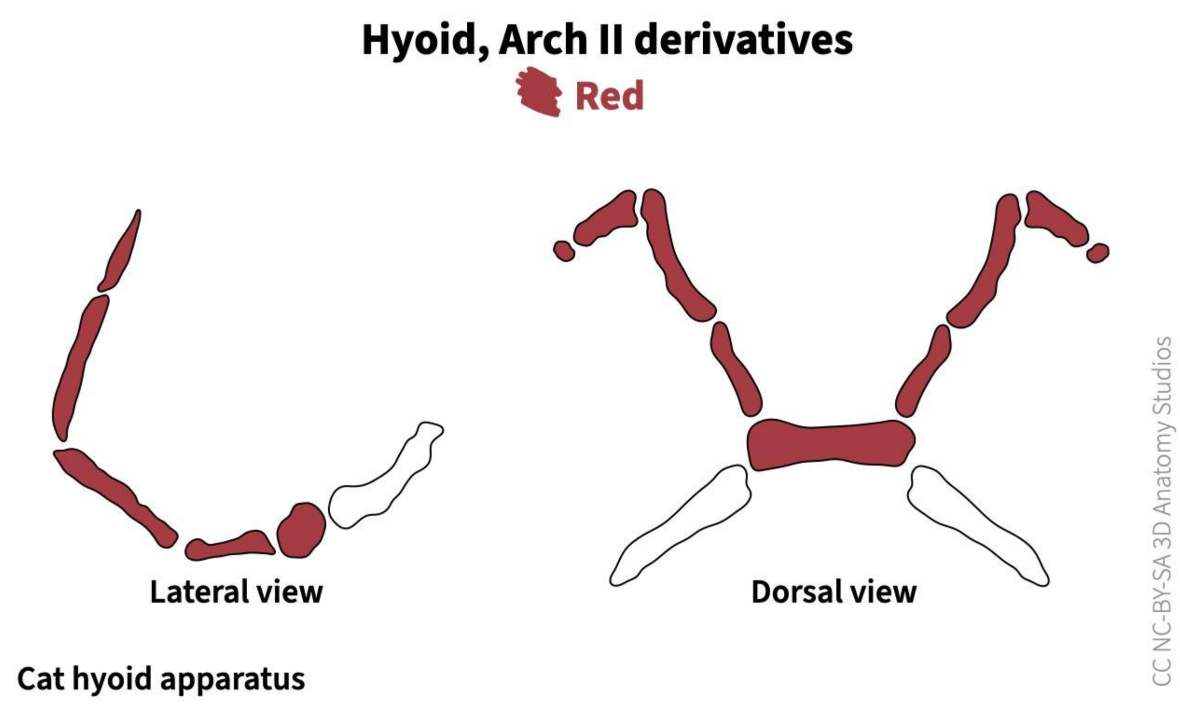
Consider how despite the radical transformation of size, shape, location, and function of the malleus, incus, and stapes, these bones retain the same sequence and pattern of articulation as their homologues in other vertebrates (articular, quadrate, and hyomandibula) – an example of how knowing the gill arch derivatives and their homologies helps to make sense of otherwise complex and seemingly arbitrary anatomy.

Hyoid apparatus (Gill arch II & III)

In early vertebrates, the second gill arch, also known as the **hyoid arch**, was a robust U-shaped set of bones caudal to the mandibular arch that supported the throat and connected the oral jaws to the **pectoral girdle** (‘hyoid’ comes from the Greek for ‘upsilon-shaped’). This basic form and function of the hyoid arch persists in most vertebrates today, with reductions of the bony elements in some lineages, such as mammals. Additionally, in vertebrates that evolved a highly mobile tongue, the hyoid evolved a new association with the musculature of the tongue.

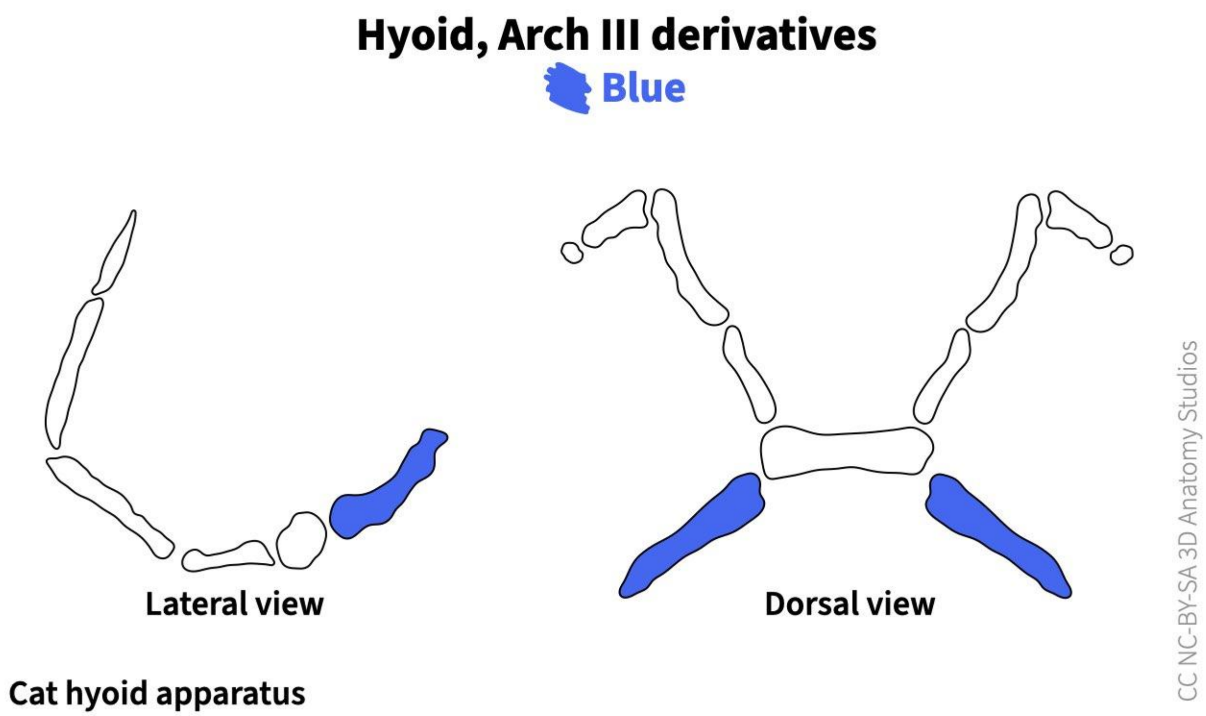
In mammals, the **hyoid apparatus** (the set of all hyoid bones) functions as a skeletal attachment site for muscles that depress the lower jaw, muscles connecting to the pectoral girdle (sometimes more vestigial than functional), and the external muscles of the tongue. Your cat’s hyoid bones are too small and thin to be included as 3D prints so they are printed on paper instead; find the folded card with the hyoid printed on it.

The hyoid apparatus in mammals is composed of bones from the second and third gill arches. Despite the evolutionary changes, you can still see the U-shaped form in bones derived from the second (hyoid) arch, shown in red in the image below.



Color the second arch elements of the hyoid in **red**.

The remaining bones of the cat hyoid apparatus are derived from the **third gill arch**. In vertebrates with gills, the third gill arch forms the first arch of the actual gills or branchial apparatus.



Color the third arch elements of the hyoid in **blue** using the image above.

Pulling it all together

Learning the bones of the vertebrate skull is complicated. However, there are patterns that will help you! By pulling together information about those bones from different sources, you can build a robust set of cues that can help you recognize those patterns and better remember the bones.

Firstly, knowing the close associations between divisions of bones and the types of structures that pass through them can help you remember bones based on their position and foramina. Like how the relationship between the chondrocranium and CNS explains the associations of: the olfactory nerve, cribriform plate, and ethmoid; the optic nerve, optic foramen, and orbitosphenoid; and the spinal cord, foramen magnum, and occipital. Or the association of the nasolacrimal duct and lacrimal bone.

Secondly, use the names of their bones and their derivations to maximal advantage. You don't have to know Greek or Latin for these derivations to be useful – use what you know. For example, think of the frontal bone as "the forehead bone," the pterygoid as "the palatal wings," the temporal bone as the "temple bone," the malleus as "the hammer bone," the dentary as "the toothed bone," etc.

Lastly, take the time to learn the gill arches and their derivatives. If you're learning the anatomy of other vertebrates, knowing the gill arches and their associated bones, muscles, and nerves can be enormously helpful. For example, it can help in recognizing that the articular, quadrate, and hyomandibula and the malleus, incus, and stapes are the same bones, with the same gill arch derivation, connectivity, and sequence – just modified by evolution to different sizes, shapes, and functions.

The more cues like these that you can pull together, the more likely you are to remember the bones of the skull. And the better you remember the bones of the skull, the stronger foundation you'll have for learning the muscles, nerves, and other soft tissues supported by and integrated with that skeletal foundation.