A Proposal for the Anatomy of Mermaids

by
Bethany Betancourt

A thesis presented to the Honors College of Middle Tennessee State University in partial fulfillment of the requirements for graduation from the University Honors College.

Spring 2020

A Proposal for the Anatomy of Mermaids

by Bethany Betancourt

APPROVED:

____

Dr. R. Stephen Howard
Biology

____

Dr. Dennis Mullen, Interim Chair
Biology

____

Dr. Rebekka King
Philosophy and Religious Studies

____

Dr. John R. Vile, Dean
University Honors College

ABSTRACT

Mermaids are creatures featured in mythologies around the world. They are typically depicted as having a human torso (usually that of a female) and the tail of a fish. My objective was to craft a depiction of their anatomy and physiology through the lens of evolutionary biology, a task which was accomplished by researching the biology of existing marine mammals and of humans. My research suggests that a mermaid-like animal would likely have evolved a streamlined body form and adaptations that optimize their ability to thermoregulate in cold ocean waters. Such adaptations might include a thick layer of fat and shortened limbs. My hypothesis, of course, assumes that the necessary conditions for the evolution of a mermaid-like species existed in ancient ancestral populations.

Table of Contents

INTRODUCTION

For millennia, humans have employed storytelling as a means of entertainment, of imparting knowledge, and explaining the mysteries of the natural world. Countless tales have arisen for the purpose of explaining such phenomena, and due to the nature of storytelling, the content has been altered to fit different cultures and time periods. As technology and scientific observation have advanced through the years, many previously unexplained phenomena have become better understood and are no longer attributed to the fantastical speculations of the imagination. However, stories continue to enchant and entertain and are an important component of the human experience.

Among these are various legends from around the world pertaining to creatures commonly known as mermaids. In popular culture, mermaids are described as having the head and torso of a human, and the tail of a fish (Augustyn 2019). Descriptions beyond this vary depending on which culture a story originates. Naturally, such stories do not consider current biological knowledge in their telling, and inherently require of the listener a suspension of realism. While this is an inherent facet of storytelling, it can also be entertaining to consider mythological creatures, such as mermaids, from a biological standpoint and imagine the possibility that such life forms could have originated from evolutionary processes.

EVOLUTION

Before attempting to address the question posed here, it is important to have a basic understanding of evolution. In simple terms, evolution is defined as a change in gene frequencies of populations over time (Herron and Freeman 2014, p. 38). The ultimate source of genetic variation is mutation. Advantageous mutations can spread through populations as the result of natural selection, which can lead to adaptation over time. For example, imagine an environment that becomes colder over time. Species having genetic variation for fur length have the potential to evolve longer fur as an adaptation to a colder environment. Evolution by natural selection produces organisms with traits that confer an advantage in the environments they inhabit.

Biologists hypothesize all life evolved from a common ancestor, and a very large amount of evidence supports this idea. Life on earth emerged from the abiotic realm over the course of about one billion years, and eventually gave rise to the incredible variety of single- and multicellular organisms that exist today.

Patterns of human evolution are also germane to my central question. Humans today, *Homo sapiens*, evolved from ancient hominin species, and by the time *H. sapiens* appeared roughly 200,000 years ago, there were already other *Homo* species that co-existed or had gone extinct (Herron and Freeman 2014, p. 787). The current understanding of these hominin species is drawn from fossilized evidence and molecular data which has been pieced together like a puzzle to unravel the mystery of human evolution. Around two million years ago, the first *Homo* species appeared in Africa (Herron and Freeman 2014, p. 787). From then until now, there have been nine *Homo* species, including *H. sapiens*, that existed (Herron and Freeman 2014, p. 787). With the exception of *H. sapiens*, all of these species are now extinct. This project will follow the imaginary evolution of a species that would have arisen somewhere in this time period and that shared a recent terrestrial common ancestor with *H. sapiens*.

Consider now a creature with the torso and head of a human and the tail of a fish. How likely is it that such a creature, the classical mermaid, could have arisen by natural selection operating on some ancestral population? Fish are adapted to aquatic environments while humans live on land. Fish intake oxygen differently from humans, fish process nutrients differently from humans, and fish move differently from humans. Simply put, while both species have a common ancestor, the fish followed a very different evolutionary path from humans. Given this, a more easily imagined mermaid with human characteristics would have to have arisen more recently in geologic time. While both ideas are impossible, a mermaid that is an amalgam of parts of wholly different organisms is much less comprehensible than one envisioned as entirely mammalian.

Organisms do not choose to develop a trait because they anticipate that it will benefit them in their environment. Mutations are random, and whether they remain in a population is dependent upon whether or not they are favored by natural selection. This is important to acknowledge in this project as a disclaimer. This project is entirely the result of speculation and imagination drawing from existing scientific knowledge and is not an attempt to claim the existence of mermaids. The results also should not be seen as the only potential outcome when following a line of thought such as the one laid out in this paper. This is purely an exercise of the imagination, meant to engage scientific knowledge and curiosity in the consideration of a mythological creature.

MYTHOLOGY

Perhaps the most familiar example of the mermaid today is Ariel from Disney's *The Little Mermaid*, adapted from the Hans Christian Andersen tale of the same title. Also familiar are the European myths regarding mermaids, including those of the Ancient Greek siren and the Celtic merrows. When approaching the question of a hypothetical mermaid evolution, however, a brief preliminary discussion of the earliest mermaid lore must occur. Cultures around the world have legends regarding creatures or spirits relating to the water; for the purposes of this project, the discussion will be limited to the earliest recorded stories. The purpose of this is to establish an idea of the area in which mermaid mythology first began to arise, which will assist in the determination of a geographical range for the creature.

The first recorded stories speaking of mermaid type creatures arose in Ancient Mesopotamia, in the mythologies relating to the goddess Atargatis in the 1000s BCE (Rostovtzeff 1933). As people moved and cultures merged, Atargatis was introduced to other areas and took on different names, Ea and Derceto, and was sometimes merged with similar stories (Rostovtzeff 1933; Black, et al. 2014; Strong 1913). Common throughout her mythology is an association with fish and with the sea, to such a degree that she was often depicted as having the tail of a fish and the head of a human (Rostovtzeff 1933; Strong 1913). This is the same description given to mermaids today and establishes Ancient Mesopotamia as the beginning point in this project. More specifically, given the origin of the recorded stories about Atargatis, this endeavor begins where Syria is today.

GEOGRAPHIC RANGE AND HABITAT

Ancient Mesopotamia had contact with two large bodies of water: the Mediterranean Sea and the Persian Gulf. As was already mentioned earlier, Syria is the area in which the focus of this section rests. Therefore, given that the Mediterranean Sea is the water body bordering Syria, this is the water body in which this hypothetical species will exist (Boxer and Salah 2019).

As mentioned already, mermaid myths exist across the globe. In the context of this discussion, the hypothetical species would also be capable of expanding past the Mediterranean Sea, due to its connection with the Atlantic Ocean at the Strait of Gibraltar (Boxer and Salah 2019). The Mediterranean Sea is composed of three layers: the surface, intermediate, and deep layers (Boxer and Salah 2019). The surface layer is from 75 m to 300 m deep; the intermediate layer is from 300 m to 600 m deep, and the deep layer is from 600 m to the floor of the sea (Boxer and Salah 2019). Water flows out of the sea into the Atlantic Ocean through the Strait of Gibraltar in the deep layer, and water flows in through the same passage from the surface layer (Boxer and Salah 2019). Temperatures in the surface layer have a rather wide range depending on the season and location. Its highest mean temperature is recorded as 31°C in August in the Gulf of Sidya: its lowest mean temperature is recorded as 5°C in February in the north of the Adriatic Sea (Boxer and Salah 2019). Temperatures of the deep layer only range from 12.9°C to 13.1°C year-round (Boxer and Salah 2019). Salinity of the surface water ranges from 38 to 40 parts per thousand, and salinity of the deep water is roughly 38.4 parts per thousand (Boxer and Salah 2019).

RELEVANT SPECIES

To provide guidance regarding potential adaptations a mermaid could develop to survive in the environment of the Mediterranean Sea, the discussion will turn to existing mammals. These mammals have already undergone natural selection and evolution, specifically from previously terrestrial organisms, to thrive in the habitat provided by the Mediterranean Sea. This is an important detail given the assumptions that have been established regarding the evolution of this hypothetical mermaid; namely, that of it having derived from a close common ancestor of *H. sapiens*.

There are a handful of mammal species that spend most of their lifespans in the Mediterranean Sea (Notarbartolo di Sciara 2016; Coll, et al. 2010). According to Notarbartolo di Sciara, there are a total of twelve such species; these are the Mediterranean monk seal (*Monachus monachus*), the fin whale (*Balaenoptera physalus*), the sperm whale (*Physeter macrocephalus*), Cuvier's beaked whale (*Ziphius cavirostris*), the short-beaked common dolphin (*Delphinus delphis*), the long-finned pilot whale (*Globicephala melas*), Risso's dolphin (*Grampus griseus*), the killer whale (*Orcinus orca*), the striped dolphin (*Stenella coeruleoalba*), the rough-toothed dolphin (*Steno bredanensis*), the common bottlenose dolphin (*Tursiops truncatus*), and the harbor porpoise (*Phocoena phocoena*) (2016). Of these twelve species, eleven are cetaceans, and one, the Mediterranean monk seal, is a pinniped. According to a review by Coll et al., there are only nine species considered residents of the Mediterranean Sea; of these, only eight are cetaceans and one is a pinniped (2010). The following discussion will use these two groups, cetaceans and pinnipeds, as a real example of the transition of life from terrestrial to aquatic.

Cetacea is an order of mammals that is comprised of whales, dolphins, and porpoises (Thewissen, et al. 2009). Examples of all three are seen in the Mediterranean Sea. Cetaceans are known for their evolution from a terrestrial lifestyle to an aquatic lifestyle (Thewissen, et al. 2009). This transition between land and sea lasted over the course of about 20 million years (Thewissen, et al. 2009). Cetaceans evolved from terrestrial artiodactyls, or even-toed ungulates, which are believed to have looked like small deer (Thewissen, et al. 2009). The earliest known cetaceans are the pakicetidae, which are an extinct family of creatures that looked like a wolf with an elongated head and tail (Thewissen, et al. 2009). Pakicetids had eyes located at the top of the skull, like those of crocodiles, which would have allowed them to rest just under the surface of the water with only their eyes emerged to observe their surroundings (Thewissen, et al. 2009). At first glance, pakicetidae look nothing like extant cetaceans. They existed in a semi-aquatic habitat as opposed to the fully aquatic habitat in which extant cetaceans reside (Thewissen, et al. 2009). This drastic difference between ancient cetaceans and modern cetaceans is important to note as, in the case of cetaceans, the time spanning between the two totals roughly 20 million years. In the case of the hypothetical mermaid discussed in this paper, the distance between early hominins and the mermaid placed in present day totals at roughly 2 million years. This will be significant later when determining the extent to which features of the mermaid will have evolved, as they will not have had as much time as the cetaceans to execute a full transition from a terrestrial habitat to an aquatic one.

Pinnipeds are members of a clade of organisms belonging to the Order Carnivora ("Pinniped Evolution and Systematics" 2006). The pinniped clade includes the scientific families Odobenidae (walruses), Otariidae (eared seals), and Phocidae (earless seals) ("Pinniped Evolution and Systematics" 2006). The Mediterranean monk seal falls within the family Phocidae ("Pinniped Evolution and Systematics", 2006). There is some disagreement on whether the pinnipeds are a monophyletic group or a polyphyletic group ("Pinniped Evolution and Systematics" 2006). For it to be a monophyletic group, the three families would have a common ancestor that is not shared with another family; in this case, this would mean that Odobenidae, Otariidae, and Phocidae are more closely related to one another than to other families ("Pinniped Evolution and Systematics" 2006). If it were a polyphyletic group, the three families would not trace back to a single common ancestor. The disagreement lies in whether Phocidae is more closely related to Musteloidea, a family also within the Order Carnivora that includes animals like weasels and otters, than it is to the other pinniped families ("Pinniped Evolution and Systematics" 2006). This is mentioned here to emphasize the fact that the evolution of pinnipeds is not as well understood as that of cetaceans. However, it is known that they are closely related to Musteloidea, as well as to the family Ursidae (bears) ("Pinniped Evolution and Systematics" 2006). The earliest known pinnipedimorphs, Enaliarctos, emerged roughly 27-25 million years ago (mya), and the earliest pinniped lineage diverged from this around 19-15 mya ("Pinniped Evolution and Systematics" 2006). Compared to modern pinnipeds, pinnipedimorphs are inferred to have spent more time near the shore ("Pinniped Evolution and Systematics" 2006). While modern pinnipeds are not fully aquatic like the cetaceans are, and can spend time on the shore, this span between the pinnipedimorphs and early pinnipeds of roughly 10 million years can be considered the time taken to transition to an aquatic lifestyle ("Pinniped Evolution and Systematics"

2006). This is still far more than the 2 million years previously estimated between present day and the early hominins, so, as with the cetaceans, the pinnipeds likely underwent far more evolutionary changes than this proposed mermaid species.

RELEVANT ANATOMY

This section will first discuss the anatomy of the three types of creature already discussed, those being cetaceans, pinnipeds, and humans. In the case of cetaceans, there are a number of potential species to discuss and use as reference for this project; for simplicity's sake, the cetacean part of the discussion will be relatively broad, with any necessary specifics coming from *D. delphis*, the short-beaked common dolphin, and *P. phocoena*, the harbor porpoise. Of the species listed earlier, these two species are the closest in size to humans and will be best for comparisons. The only pinniped resident of the Mediterranean Sea is *M. monachus*, the Mediterranean monk seal, so the anatomy discussion for the pinnipeds will largely use *M. monachus* as a reference. *Homo sapiens* will be representing humans, as they are the only extant hominin species. After these anatomies are discussed, the discussion will draw inferences as to a potential mermaid anatomy. All anatomy discussions will be organized by systems, such as the musculoskeletal system or the nervous system. In the case of cetaceans and pinnipeds, the focus will rest on general adaptations that aid in survival in a marine environment. The human anatomy will provide a baseline, with posed adaptations as alterations upon the human body plan.

Cetacean Anatomy

The sensory system refers to the methods by which an organism intakes and processes external stimuli, such as light or sound (Mass and Supin 2007). In cetaceans, the eyes are typically hemispherical, with thickened sclera and corneas, and large ocular muscles (Mass and Supin 2007). The structures of the eye have evolved both to be more light-sensitive under low-light conditions and to protect the eye from mechanical damage caused by water temperature (Mass and Supin 2007). Cetacean eyes are also set on either side of the head, as opposed to on the front of the head (Mass and Supin 2007). All cetaceans lack an external ear lobe, or pinna (Ridgway 2000). Sometimes the ear is visible as a hole, but most of the ear is internal (Ridgway 2000). Auditory structures in cetaceans, particularly odontocetes (toothed whales) like *D. delphis* and *P. Phocoena*, are larger than their counterparts in humans (Ridgway 2000). Cetaceans have a higher ratio of hair cells than humans, indicating a higher auditory proficiency (Ridgway 2000). This increased size & sensitivity of the auditory structures allows for communication via echolocation (Ridgway 2000). The brains of cetaceans have evolved alongside the ears themselves to be specialized in the processing of auditory input (Ridgway 2000). This makes hearing the highest sense in cetaceans (Ridgway 2000).

The integumentary system refers to the skin, hair, and fat that serve as protection for the body from physical damage (Berta, et al. 2015). Cetaceans lack sweat glands and pelage hair, meaning that they are hairless (Berta, et al. 2015). In cetaceans, coloration of the skin is used either for camouflage, which conceals an organism from other creatures, or for communication with other organisms (Berta, et al. 2015). Cetaceans also have blubber, which aids in thermal regulation in cold environments (Hashimoto, et al. 2015).

Perhaps the most important system that will be discussed here is the skeletal system. The skeletal system maintains the structure of the body and provides a framework for the skeletal muscle. In cetaceans, the skeleton has been modified from that of a tetrapodal terrestrial ancestor. Modern cetaceans have an elongated skull, which allows room for the melon of the animal and aids in hydrodynamics (Cozzi, et al. 2010). The limbs of modern cetaceans are drastically different from those of their ancestors (Cozzi, et al. 2010). Cetaceans have flippers which are, like the elongated skull, useful in hydrodynamics; having a wide, flat flipper instead of the hooves of their ancestors or the individual digits on the hand of a human, allows cetaceans better control of their movement and speed underwater (Cozzi, et al. 2010). The arm bones in the flipper are shortened, and the finger bones are elongated (Cozzi, et al. 2010). Cetaceans have also mostly or entirely lost their hind limbs, with only some species retaining remnants of that part of the skeleton (Cozzi, et al. 2010). The vertebrae in cetaceans are especially important in locomotion (Cozzi, et al. 2010). Cetaceans propel their bodies by moving their tail and cartilaginous flukes, and precise movements in the spine give them better control over their movement (Cozzi, et al. 2010). The flukes of cetaceans are on the same plane as the flippers, as opposed to being perpendicular like the tails of fish (Galatius 2005). In general, the evolution of their musculoskeletal systems has resulted in cetaceans having a streamlined body that is well-equipped for underwater movement (Cozzi, et al. 2010; Galatius 2005).

The digestive system is what an organism uses to process food, extracting nutrients from what it eats and then expelling the leftover waste. This includes several organs, but most important to note here is the stomach. In cetaceans, the stomach is composed of multiple compartments, as opposed to only a single compartment in humans (Mead 2007; Horstmann 2018). This is similar to their terrestrial ancestors, and therefore did not evolve for the purpose of surviving life underwater (Mead 2007). Instead, it was an evolution that happened before the transition from land to water and, among marine mammals, is unique to the cetaceans due to their ancestry (Mead 2007).

The circulatory system is responsible for the transport of oxygen throughout the body and for the removal of carbon dioxide from the body. Like in other mammals, cetaceans have a four-chambered heart to pump blood, the blood gets oxygenated in the lungs and is sent throughout the body via a network of blood vessels (Soegaard, et al. 2012; Piscitelli-Doshkov, et al. 2013). Unlike other mammals, cetaceans have a higher blood volume to retain more oxygen (Soegaard, et al. 2012). This adaptation allows cetaceans to dive for multiple minutes at a time; having more oxygen stored in the body means more time that can be spent underwater before surfacing for another breath of air (Soegaard, et al. 2012; Piscitelli-Doshkov, et al. 2013). Cetaceans do not have gills to filter oxygen from the water like fish (Piscitelli-Doshkov, et al. 2013). They have lungs with the capacity to hold large volumes of air and empty to very low levels, allowing for longer dives (Piscitelli-Doshkov, et al. 2013). The actual length of time an organism can spend underwater and the frequency of surfacing varies by species (Piscitelli-Doshkov, et al. 2013). Species that deep dive have lungs that collapse to low air volumes, while those that remain closer to the surface, like *P. phocoena*, do not need that capability (Soegaard, et al. 2012). Cetaceans also have blowholes on the top of the head to breathe through, instead of nostrils like other mammals (Piscitelli-Doshkov, et al. 2013).

The nervous system is comprised of the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS is the brain and the spinal cord, and the PNS includes the nerves that branch off from the CNS and connect to the extremities of the body. In odontocetes, the brain is asymmetrical (Ridgway, et al. 2007). The blowhole is shifted slightly to the left side of the center of the head, and the right side of the brain is larger than the left (Ridgway, et al. 2007).

The urinary system functions to remove waste from the body and to regulate the blood. This includes the kidneys, ureters, bladder, and the urethra. In cetaceans, the kidneys are reniculate, or multi-lobed; this likely evolved due to the large size of the animals and their diving abilities (Ortiz 2001). They can produce urine of a slightly higher concentration than humans, but not to the degree as would be expected, as they have the “anatomical prerequisites” to produce a highly concentrated urine (Ortiz 2001).

The reproductive system in cetaceans is categorized into male and female systems. The male system has typical mammalian organs, including a pair of testes, a penis, and ductus deferens (Rommel, et al. 2007). As with the rest of the organ systems, modifications have been made to allow cetaceans to adapt to living underwater. The testes in cetaceans are internal, residing on the ventral side, or the underside, of the kidneys (Rommel, et al. 2007). The penis is retractable and does not have a bone (Rommel, et al. 2007). These adaptations aid in making the body more streamlined for faster swimming (Rommel, et al. 2007). There is no scrotum to aid in thermoregulation of the testes; instead, there are vascular structures that serve as countercurrent heat exchangers (Rommel, et al. 2007). The female reproductive system also has typical mammalian organs, those being the vagina, uterus, ovaries, and fallopian tubes (Rommel, et al. 2007). Cetaceans also have mammary slits located within the urogenital opening (Rommel, et al. 2007).

Pinniped Anatomy

As with the cetaceans, pinnipeds have eyes in a hemispherical shape (Mass and Supin 2007). The pinnipeds eyes, however, are located on the front of the cranium, and not on the sides (Mass and Supin 2007). Pinniped ears have either reduced pinnae or no pinnae (Pihlström 2008). Earless seals like *P. phocoena* have no pinnae (Pihlström 2008). This reduction or loss of external ear structures likely helps with streamlining the body and makes thermoregulation easier (Pihlström 2008). The nose varies among pinniped species; in the genera *Mirounga* (elephant seals) and *Cystophora* (hooded seals), the males have very large noses, but in other species, like *P. phocoena*, the nose is much less conspicuous (Pihlström 2008).

Pinnipeds have hair on their bodies, with individual hairs flattened rather than round like other mammals (Yochem and Stewart 2009). In phocids like *P. phocoena*, the hair consists of long, thick guard hairs (Yochem and Stewart 2009). Phocids molt annually, which, in monk seals specifically, means losing and replacing large patches of the epidermis and attached hair (Berta, et al., 2015). They also have a thick blubber layer which, alongside their hair, insulates them and helps them retain body heat underwater (Liwanag, et al. 2012).

The bones of the limbs are all relatively short ("Musculoskeletal System and Locomotion" 2006). All pinnipeds express a reduction in the fifth intermediate phalanx, a bone in the hand which is equivalent to one of the bones in a human pinky finger ("Musculoskeletal System and Locomotion" 2006). The forelimbs of the phocids are shaped differently from the otariids (sea lions); in otariids, the forelimb is better equipped to support the torso when on land than the phocid forelimb ("Musculoskeletal System and Locomotion" 2006). The same goes for the hind limbs of each species ("Musculoskeletal

System and Locomotion" 2006). Phocid hind limbs are very small compared to otariid hind limbs, and cannot support the body; instead, the hind limbs are primarily used to propel the animals through the water (Reidenberg 2007). Otariids can stand on all four limbs (Reidenberg 2007). The phocids and otariids are both marine mammals and pinnipeds that spend time on land, but the skeletal structure of phocids has evolved and made them less equipped for terrestrial life than otariids ("Musculoskeletal System and Locomotion" 2006; Reidenberg 2007).

The heart of pinnipeds closely resembles that of other mammals, including cetaceans ("Respiration and Diving Physiology" 2006). Thus, there were no notable evolutionary changes to the heart that would aid in living an aquatic lifestyle ("Respiration and Diving Physiology" 2006). They do have larger and more complex blood vessels, which allows them to hold more blood, and thus, more oxygen when diving ("Respiration and Diving Physiology" 2006). Pinnipeds have a highly compliant chest wall that allows for the deflation of the lungs necessary for long periods of time spent underwater (Fahlman, et al. 2014). Pinniped lungs are lobulate, like other terrestrial mammals (Fahlman, et al. 2014).

The nervous system of pinnipeds is not well researched, but according to current knowledge, it does not have many special adaptations to aid in aquatic life (Sawyer, et al. 2016). Pinnipeds have evolved a brain roughly similar in size to that of apes (Sawyer, et al. 2016). They also have very sensitive whiskers used for sensory input (Sawyer, et al. 2016).

Like in cetaceans, pinnipeds have reniculate kidneys (Ortiz 2001). This structure was likely evolved to accommodate diving behavior in these animals (Ortiz 2001). Also similar to cetaceans, the evolution of the reniculate kidney structure does not appear to be related to osmoregulation (Ortiz 2001).

The male reproductive system of pinnipeds lacks a scrotum, which raises the same issue as in cetaceans regarding thermoregulation and protection of the testes (Orbach, et al. 2017). The thermoregulation is controlled by an inguinal venous plexus that cups the testes; due to the location of the hind limb with regards to the testes, the blood flow through this venous plexus allows the animal to maintain the thermoregulation of the testes (Orbach, et al. 2017). There is a similar structure in females that helps regulate the temperature of the fetus in a pregnant animal (Machado, et al. 2012). In all pinniped species, the penis has a bone, but this is unrelated to their existence as aquatic mammals (Machado, et al. 2012). As with cetaceans, the genitalia are internal, which helps with thermoregulation and hydrodynamics (Pabst, et al. 1998).

Human Anatomy

In humans, the sensory system consists of the organs relating to the five major senses: somatic, vision, audition, gustation, and olfaction (Widmaier, et al., 2016). The brain is important in the proper function of all of these senses, but it will be discussed later. The somatic sense refers to the sense of touch, and it is the perception of stimuli interacting with somatic receptors located in the skin, hair, and underlying tissues (Widmaier, et al., 2016, p. 200). Vision is the perception of different wavelengths of light. The eye in humans is spherical, and consists of several components, including a pupil and an iris (Widmaier, et al., 2016, p. 204). The eyes are connected to the brain by the optic nerve, which transmits information obtained by the eye to the brain for processing (Widmaier, et al. 2016, p. 204). Audition is the perception of sounds through use of the ear, which is very complex and has most of its functionality within the head (Widmaier, et al., 2016, p. 215). The outer ear, which is the part immediately visible upon looking at a human head, acts as a funnel to amplify and direct sounds (Widmaier, et al., 2016, p. 215). The middle ear holds the bones malleus, stapes, and incus; the inner ear houses the cochlea (Widmaier, et al., 2016, p. 217). All of these are vital to the processing of auditory stimulus. Gustation and olfaction are closely related. Gustation is associated with the tongue and taste buds primarily, while olfaction is associated with the nose and somewhat with the taste buds as well (Widmaier, et al., 2016, p. 223). These two senses combine to allow processing of smells and of items placed within the mouth (Widmaier, et al., 2016, p. 224).

The skin and hair, as already mentioned, is related to the sense of touch. Human skin has mechanoreceptors that are activated by touch and pressure (Widmaier, et al., 2016, p. 201). Humans also have hair all over the body, except for the palms of the hands and the soles of the feet (Widmaier, et al., 2016). The body hair is sparse on most of the body, but is dense on the head, under the arms, and on the area around the genitalia (Widmaier, et al., 2016). There are specialized hairs protecting the eyes and nose (Widmaier, et al., 2016). Hair is important in triggering the somatic sense and in protecting the skin from harmful agents (Yesudian 2011).

The adult human skeletal system consists of 206 bones (Warren 2019). The four limbs are long and specialized for modern terrestrial life (Warren 2019). Humans have hands with opposable thumbs, like their ancestors (Warren 2019). Humans also have legs designed for bipedal locomotion (Warren 2019). The evolution of this style of locomotion in humans also resulted in the spine having an upright posture (Warren 2019). The skeletal muscle attaches to the skeleton and allows humans to move (Warren 2019).

The human digestive system consists of the mouth, esophagus, stomach, small and large intestines, colon, rectum, and anus (Widmaier, et al., 2016, p. 527). When consumed, food is ground by the teeth and mouth, and then sent through the esophagus, which is a long tube that connects the mouth to the stomach (Widmaier, et al., 2016, p. 528). The stomach and digestive organs that follow in this process are located in the abdomen (Widmaier, et al., 2016, p. 527). The food travels through the stomach, small intestine, large intestine, and colon to the rectum where it gets expelled through the anus as waste (Widmaier, et al., 2016, p. 528). This process digests the food, and it extracts nutrients from it for use by the body; the unused material becomes waste (Widmaier, et al., 2016, p. 528). The liver is also involved in digestion, by filtering the blood that comes from the digestive tract (Widmaier, et al., 2016, p. 528).

The circulatory system circulates blood and oxygen throughout the body (Widmaier, et al., 2016, p. 366). The heart, located in the chest, pumps blood into the lungs, where it is oxygenated and sent back to the heart (Widmaier, et al., 2016, p. 366). From the heart, it then travels through the aorta and to the rest of the body through a complex system of blood vessels (Widmaier, et al., 2016, p. 366). Blood then circulates back to the heart, where the cycle restarts (Widmaier, et al., 2016, p. 367). The lungs and heart are protected by the ribcage (Widmaier, et al., 2016, p. 367).

The major organs of the nervous system are the brain and the spinal cord (Widmaier, et al., 2016, p. 171). These constitute the central nervous system; the peripheral nervous system is made up of a network of nerves extending throughout the body (Widmaier, et al., 2016, p. 176). The brain is a complex organ that processes the input of stimuli and the body's subsequent response (Widmaier, et al., 2016, p. 171). The sensory system, which was discussed earlier, relies upon the brain to process the information that the senses collect (Widmaier, et al., 2016, p. 179). The spinal cord is a cylinder of soft tissue surrounded by the bones of the spine, and it connects to the brain and the peripheral nervous system (Widmaier, et al., 2016, p. 177). The spinal cord functions to relay information from the nerves to the brain, and vice versa (Widmaier, et al., 2016, p. 177).

Human kidneys are connected to the bladder by the ureter (Widmaier, et al., 2016, p. 486). The kidneys are smooth, unlike those of cetaceans and pinnipeds (Widmaier, et al., 2016, p. 486). Alongside the production of urine, kidneys are important in managing water and ion concentration in the body (Widmaier, et al., 2016, p. 486). Urine that is produced is sent through the ureter to the bladder, which is then expelled from the body through the urethra (Widmaier, et al., 2016, p. 486). The kidneys are located on either side in the abdomen, and the bladder is located in the lower abdomen (Widmaier, et al., 2016, p. 486).

The male reproductive system consists of a penis, two testes surrounded by a scrotum, epididymides, and vasa deferentia (Widmaier, et al., 2016, p. 605). The penis does not have a bone (Widmaier, et al., 2016, p. 605). The penis and testes are suspended outside of the abdomen (Widmaier, et al., 2016, p. 605). The scrotum provides protection for the testes, and the testes being external helps with thermoregulation, as the process of making sperm requires a temperature below internal body temperature (Widmaier, et al., 2016, p. 605). The female reproductive system consists of the vulva, vagina, cervix, uterus, ovaries, and fallopian tubes (Widmaier, et al., 2016, p. 614). The vulva is the external part of the system, which includes the labia minora and majora, mons pubis, vestibule, and clitoris (Widmaier, et al., 2016, p. 614). The rest of the system is internal, and is in the pelvic region (Widmaier, et al., 2016, p. 614).

MERMAID ANATOMY

With the knowledge of these relevant organisms, the discussion may now focus on the likely adaptations that would arise in an aquatic hominin species. In the previous section on evolution, it was established that the hypothetical species which this paper is addressing would have evolved over roughly 2 million years. Compared to the pinnipeds and cetaceans, this is a relatively short amount of time to adapt to aquatic life. Given that the time scale is comparatively small, the creature would likely not be as specialized for life underwater as pinnipeds and cetaceans.

In the section on relevant anatomy, basic adaptations made by cetaceans and pinnipeds were discussed. Common benefits of the body plans of these organisms are the ability to regulate body temperature in an underwater environment and the ability to navigate quickly through water. Thus, this mermaid will likely have adaptations that serve a similar purpose. The mermaid also would likely not be wholly aquatic. Cetaceans have had ample time to establish an existence that is entirely underwater, save for when they must breach the surface for air. Pinnipeds have become aquatic creatures, but they still are able to move on land, a skill that the cetaceans have lost. Mermaids would also likely retain the ability to exist on land in some capacity.

Following the same outline given in the previous anatomy discussion, the sensory system of mermaids shall be addressed. The eyes of other species seem to not have any particularly beneficial adaptations in this environment, so there would likely be little noticeable change driven by the environment. The ears of pinnipeds and cetaceans have been either reduced or lost entirely, as an adaptation benefiting underwater movement and speed. Thus, in the mermaid, there would likely be a similar adaptation involving the reduction in size, and likely a flattening against the head to reduce any hindrance on movement or speed. There may also arise some method of either preventing water from entering the ear and causing issues, or an adaptation that allows water to enter the ear without complications. This would require more in-depth research into the anatomy of the ear in humans and relevant species, but it is not relevant here, as the goal is to develop a general anatomy. The nose is a bit difficult to address, as the two types of animals discussed have wildly different morphologies in this regard. The nose of the cetacean, the blowhole, is on the top of the cranium; given the difference in time between cetacean evolution and the mermaid evolution, this likely would not follow in the imagined creature. The nose of pinnipeds, on the other hand, remains on the front of the face in the form of two nostrils on the snout of the animal. The mermaid nose would likely be similar, as a flattened organ on the front of the face. Again, like the ears, there would be problems with the inhalation of water; it is likely that an adaptation involving the closing of the nostrils would be beneficial and would result in the nostrils looking like two slits on the front of the face.

The matter of the skin and hair of the mermaid must next be addressed. Cetaceans are hairless, and pinnipeds are not. Humans today, while having reduced hair, are still not hairless, although they have evolved under different circumstances than this mermaid will be assumed to have evolved. Thus, given the time constraints on the species and the fact that humans have hair as well as one of the existing relevant marine mammals has hair, the mermaid likely would have hair. The nature of the hair, however, is difficult to predict based on the given information. Following the example set by cetaceans and modern humans, the mermaid shall have reduced hair across the body. It would also develop either thick fat reserves or a layer of blubber as cetaceans and pinnipeds have done. This would aid in thermoregulation for the species.

The skeletal system is a difficult topic to approach thoroughly, given the complexity of it. Since the purpose of this project, again, is to get a general idea of the anatomy of the mermaid, there will not be an in-depth discussion about the skeleton; rather, it is more important to focus on the general changes to limbs and other parts of the body. In cetaceans, the forelimbs are flippers, the hind limbs have reduced to only remnants visible in the skeleton, and the tail has become a large flat paddle. All of this has made locomotion in the water easier for these animals. In pinnipeds, the forelimbs and the hindlimbs have reduced and become flattened. It is likely that a similar adaptation would arise in mermaids. The bones of the arms would shorten. The hands would alter in such a way as to reduce the gaps between digits, either through the growth of webbing between fingers, or the shortening of the fingers and hand into a shape more like a paddle or flipper. The hind limbs would likely shorten and flatten in a similar manner. The tail that is expected from a standard mermaid would not evolve; even if the conditions aligned to create such an adaptation, it would arise far later in time, and would be a result of changes made to the hind limbs. For a comparison, the limbs would be similar to those seen on pinnipeds and would allow the mermaid to still spend time on land.

The mermaid digestive system would be like the human digestive system. The cetacean digestive system is different from pinniped and human digestive systems because of its artiodactyl ancestry, which granted it a multichambered stomach. There is no apparent reason for any adaptations to arise in the mermaid digestive system that were necessitated by the underwater environment, except perhaps for a change in diet. However, even a diet change would not cause a notable difference.

The circulatory system would adjust in ways similar to cetaceans and pinnipeds. The adaptations they developed allow them to increase the amount of time spent underwater; the ability to empty the lungs further than terrestrial mammals and an increased ability to intake oxygen would be seen in mermaids as well. To the observer, it might appear as slightly larger lung size and larger blood vessels. There are no obvious adaptations of the heart, however, so these would likely be the only observable changes in mermaids.

The nervous system would likely not be much different from the hominin nervous system. There are no notable adaptations that are advantageous for aquatic life in cetaceans and pinnipeds. The brain and spinal cord, as well as the peripheral nervous system, would be like those of humans.

The most notable aspect of the urinary system in cetaceans and pinnipeds that is different from that of humans is the kidneys. The former two have reniculate kidneys, whereas the kidneys of humans are smooth and not multi-lobed. Given that the reniculate kidneys in these animals are not attributed to an advantage in osmoregulation, it appears that this adaptation is unrelated to the aquatic environment. Thus, the kidneys in mermaids would be smooth and like those in humans. There were no notable evolutionary changes in the rest of the urinary system of cetaceans and pinnipeds, so there is no basis for any other predicted changes in mermaids.

The reproductive system in both pinnipeds and cetaceans has, as with the rest of their bodies, adapted in favor of faster and easier locomotion underwater. This results in largely internal genitalia for either sex. It also results in problems with thermoregulation of the testes and ovaries. In both pinnipeds and cetaceans, there is an adaptation of a countercurrent heat exchange system to handle this problem; there is a system of blood vessels near the organs in question that allows the organism to regulate the temperature and risk damaging the sperm or the eggs. In mermaids, it is possible that the genitalia would similarly evolve to be internal for the same reason, with a heat exchange system to manage temperature. The mammaries of mermaids might be trickier to address. In humans, mammaries are on the torso, while in marine mammals, they are in the region of the abdomen. Considering the distance between the two places on the body, it's unlikely that mammaries would migrate to match the anatomy seen in pinnipeds or cetaceans. However, remaining on the torso would provide a disadvantage in movement and speed, as it would detract from the overall smooth, torpedo-like shape that is seen as beneficial in pinnipeds and cetaceans. Given that it is already predicted that the mermaid would develop thick fat reserves, perhaps the mammaries would simply reduce in size and be covered by fat or blubber. The rest of the reproductive system likely would not change except to accommodate any changes from having external genitalia to having internal genitalia.

CONCLUSION

If one were to envision a mermaid while using existing biological and evolutionary knowledge, it would not appear as the traditional mermaid. Following the oldest recorded mythology of mermaids back to Assyria and the Mediterranean Sea provides an environment in which relevant animals have adapted to live and thrive. These animals, as well as humans, provide a framework upon which a version of the mermaid that might be considered more realistic can be created. Given that this is inherently an endeavor of the imagination, this process could result in any number of variable "realistic" mermaids; in this case, the resulting mermaid has adapted traits for thermoregulation and ease of movement in an aquatic environment. This type of project could also be explored with a focus on other specific details that would result in more variations of the mermaid.

Works Cited

Andrew, Warren. "Human Skeleton." *Encyclopædia Britannica*, Encyclopædia Britannica, Inc., 17 Apr. 2019, www.britannica.com/science/human-skeleton.

Augustyn, Adam, et al. "Mermaid." *Encyclopædia Britannica*, Encyclopædia Britannica, Inc., 20 June 2019, www.britannica.com/topic/mermaid.

Berta, Annalisa, et al. "Integumentary and Sensory Systems." *Marine Mammals*, 2015, pp. 169–210., doi:10.1016/b978-0-12-397002-2.00007-7.

Berta, Annalisa, et al. "Musculoskeletal System and Locomotion." *Marine Mammals*, 2006, pp. 165–212., doi:10.1016/b978-0120880009-6.

Berta, Annalisa, et al. "Pinniped Evolution and Systematics." *Marine Mammals*, 2006, pp. 27–50., doi:10.1016/b978-012088552-7/50004-7.

Berta, Annalisa, et al. "Respiration and Diving Physiology." *Marine Mammals*, 2006, pp. 237–269., doi:10.1016/b978-012088552-7/50011-4.

Black, Jeremy A., et al. *Gods, Demons, and Symbols of Ancient Mesopotamia: An Illustrated Dictionary*. Univ. of Texas Press, 2014, pp. 130-131.

Boxer, Baruch and Mostafa Salah. "Mediterranean Sea." *Encyclopædia Britannica*, 2019, www.britannica.com/place/Mediterranean-Sea.

Coll, Marta, et al. "The Biodiversity of the Mediterranean Sea: Estimates, Patterns, and Threats." *PLoS ONE*, vol. 5, no. 8, 2010, doi:10.1371/journal.pone.0011842.

Cozzi, Bruno, et al. "Diving Adaptations of the Cetacean Skeleton." *The Open Zoology Journal*, vol. 2, no. 1, Apr. 2010, pp. 24–32., doi:10.2174/1874336600902010024.

Fahlman, Andreas, et al. "Inflation and Deflation Pressure-Volume Loops in Anesthetized Pinnipeds Confirms Compliant Chest and Lungs." *Frontiers in Physiology*, vol. 5, Oct. 2014, doi:10.3389/fphys.2014.00433.

Galatius, Anders. "Sexually Dimorphic Proportions of the Harbour Porpoise (*Phocoena phocoena*) Skeleton." *Journal of Anatomy*, vol. 206, no. 2, 2005, pp. 141–154., doi:10.1111/j.1469-7580.2005.00381.x.

Hashimoto, Osamu, et al. "Brown Adipose Tissue in Cetacean Blubber." *PLoS ONE*, vol. 10, no. 2, 2015, doi:10.1371/journal.pone.0116734.

Herron, Jon C., and Scott Freeman. *Evolutionary Analysis: Fifth Edition*. Pearson, 2014, pp. 769-807.

Horstmann, Lara. "Gastrointestinal Tract." *Encyclopedia of Marine Mammals (Third Edition)*, 2018, pp. 397–400., doi:10.1016/B978-0-12-804327-1.00007-8.

Liwanag, Heather E. M., et al. "Morphological and Thermal Properties of Mammalian Insulation: The Evolutionary Transition to Blubber in Pinnipeds." *Biological Journal of the Linnean Society*, vol. 107, no. 4, 2012, pp. 774–787., doi:10.1111/j.1095-8312.2012.01992.x.

Machado, Alex Sander D., et al. "Genital Morphology of the Male South American Fur Seal (*Arctocephalus australis*) and Biological Implications." *Pesquisa Veterinária Brasileira*, vol. 32, no. 1, 2012, pp. 67–78., doi:10.1590/s0100-736x2012001300013.

Mass, Alla M., and Alexander Ya. Supin. "Adaptive Features of Aquatic Mammals Eye." *The Anatomical Record: Advances in Integrative Anatomy and Evolutionary Biology*, vol. 290, no. 6, 2007, pp. 701–715., doi:10.1002/ar.20529.

Mead, James G. “Stomach Anatomy and Use in Defining Systemic Relationships of the Cetacean Family Ziphiidae (Beaked Whales).” *The Anatomical Record: Advances in Integrative Anatomy and Evolutionary Biology*, vol. 290, no. 6, 2007, pp. 581–595., doi:10.1002/ar.20536.

Notarbartolo di Sciara, G. “Marine Mammals in the Mediterranean Sea: An Overview.” *Advances in Marine Biology*, vol. 75, 2016, pp. 1–36, doi:10.1016/bs.amb.2016.08.005.

Orbach, Dara N., et al. “Genital Interactions during Simulated Copulation among Marine Mammals.” *Proceedings of the Royal Society B: Biological Sciences*, vol. 284, no. 1864, Nov. 2017, doi:10.1098/rspb.2017.1265.

Ortiz, Rudy M. “Osmoregulation in Marine Mammals.” *Journal of Experimental Biology*, vol. 204, 2001, pp. 1831–1844.

Pabst, D. Ann, et al. “Reproductive Thermoregulation in Marine Mammals.” *American Scientist*, vol. 86, no. 5, 1998, pp. 440–448., doi:10.1511/1998.37.901.

Pihlström, Henry. “Comparative Anatomy and Physiology of Chemical Senses in Aquatic Mammals.” *Sensory Evolution on the Threshold: Adaptations in Secondarily Aquatic Vertebrates*, Feb. 2008, pp. 95–109, doi:10.1525/california/9780520252783.003.0007.

Piscitelli-Doshkov, Marina A., et al. “A Review of Cetacean Lung Morphology and Mechanics.” *Journal of Morphology*, vol. 274, no. 12, Nov. 2013, pp. 1425–1440., doi:10.1002/jmor.20192.

Reidenberg, Joy S. “Anatomical Adaptations of Aquatic Mammals.” *The Anatomical Record: Advances in Integrative Anatomy and Evolutionary Biology*, vol. 290, no. 6, 2007, pp. 507–513., doi:10.1002/ar.20541.

Ridgway, Sam H. “The Auditory Central Nervous System of Dolphins.” *Hearing by Whales and Dolphins Springer Handbook of Auditory Research*, 2000, pp. 273–293., doi:10.1007/978-1-4612-1150-1_6.

Ridgway, Sam H. “The Cetacean Central Nervous System.” *Comparative Neuroscience and Neurobiology*, 1988, pp. 20–25., doi:10.1007/978-1-4899-6776-3_9.

Rommel, Sentiel, et al. “Functional Anatomy of the Cetacean Reproductive System, with Comparisons to the Domestic Dog.” *Reproductive Biology and Phylogeny of Cetacea*, June 2007, pp. 127–145., doi:10.1201/b11001-5.

Rostovtzeff, M. “Hadad and Atargatis at Palmyra.” *American Journal of Archaeology*, vol. 37, no. 1, 1933, pp. 58–63. *JSTOR*, doi:10.2307/498042.

Sawyer, Eva K., et al. “Somatosensory Brainstem, Thalamus, and Cortex of the California Sea Lion (*Zalophus californianus*).” *Journal of Comparative Neurology*, vol. 524, no. 9, 2016, pp. 1957–1975., doi:10.1002/cne.23984.

Soegaard, L. B., et al. “Respiratory Properties of Blood in the Harbor Porpoise, *Phocoena Phocoena*.” *Journal of Experimental Biology*, vol. 215, no. 11, Sept. 2012, pp. 1938–1943., doi:10.1242/jeb.069872.

Strong, Herbert A. *The Syrian Goddess*. Constable, 1913, pp. 52-55.

Thewissen, J.G.M., et al. “From Land to Water: the Origin of Whales, Dolphins, and Porpoise.” *Evolution: Education and Outreach*, vol. 2, 2009, pp. 272–288., doi:10.1007/s12052-009-0135-2.

Widmaier, Eric P., et al. *Vander's Human Physiology: The Mechanisms of Body Function, Fourteenth Edition*. McGraw-Hill Education, 2016.

Yesudian, Patrick. “Human Hair - An Evolutionary Relic?” *International Journal of Trichology*, vol. 3, no. 2, 2011, p. 69., doi:10.4103/0974-7753.90799.

Yochem, Pamela K., and Brent S. Stewart. “Hair and Fur.” *Encyclopedia of Marine Mammals*, 2009, pp. 529–530., doi:10.1016/b978-0-12-373553-9.00124-3.

APPENDIX A: Rough Sketch of the Proposed Mermaid