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# Building a Dragon

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INTRODUCTION

What makes a dragon a dragon? As my four years at the University of Montana drew to a close, it came time to create something that encompassed all of my years here, something that goes to the core of who I am and why I came here. The possibilities were endless; I've learned so much about biology while pursuing my Wildlife Biology degree at the University of Montana. A daunting sea of options stretched out before me, but when a friend approached me about assisting her with her project, everything fell into place.

As budding biologists, my friends and I have always liked to complain about biological errors in the media, and dragons, with their anatomically incorrect six limbs, were easy pickings. When my friend Ellie asked me to illustrate her final project by drawing biologically correct dragons, I soon realized that to design a dragon that could actually exist, I would need to know what evolutionary forces had shaped the dragons that I would be illustrating. This paper is the summation of four years of learning, incorporating multidisciplinary concepts from areas of biology such as evolutionary biology, behavior, anatomy and physiology, as well as the myth and lore that informs our interpretation of how a dragon should look and behave.

HISTORY

How would you know a dragon if you saw one? Dragons are found in multiple stories from across cultures. There are two main body styles of dragon, eastern and European styles. The eastern dragon is long and serpent-like, wingless and with short legs. The European dragons, which I decided to model my dragons after, are chunkier, with large, bat-like wings (Fig. 1).

*Fig. 1. A European-style red dragon. It has the correct number of limbs and is therefore delightful.*

Both styles have spikes and horns around their heads, similar to horny toads. Here we have the basic characteristics of a dragon: cat-like yet reptilian bodies, slender heads with manes of spikes, and bat-like, leathery wings.

*YI QI*

As intelligent flying reptiles, one would assume that dragons come from *Archaeopteryx,* an ancestor of birds. However, there's a distinct aesthetic problem with a bird-like dragon: bird wings. There's no way that the majestic, fire-breathing dragons of old had feathery wings! Enter the ancestor of dragons, *Yi qi*. Unlike the ancestors of modern birds, *Yi* had bat-like wings, with a membrane of skin providing a wide surface area to catch the air. This tiny proto-dragon was a sparrow sized omnivore alive during the Upper

Jurassic period. Found in the Hebei Province of China in 2015, *Yi qi* was a maniraptoran theropod with preserved evidence of membranous wings, the first of its kind (Xing et al 2015). The name *Yi qi* actually means “strange wing.” What made *Yi qi* unique from other theropod dinosaurs was a styliform element, a “curved, distally-tapered, rod-like structure extending from the ulnar side of the carpus” (Xing et al 2015) (Fig. 2).

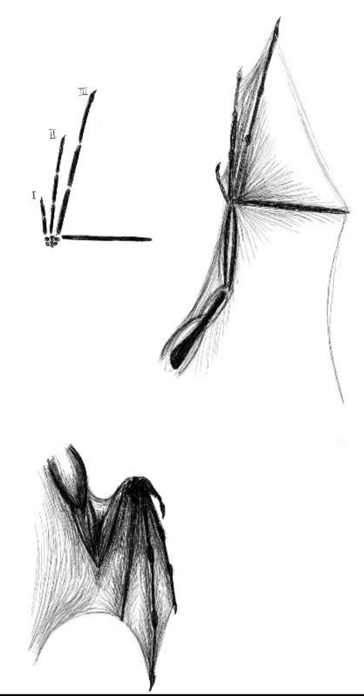

*Fig. 2. A sketch of the three elongated fingers and styliform element as well as a drawing of the folded wing.*

This styliform element (Fig. something) was essentially an extended wrist bone which helped provide structure to the patagium, and it is found in both Pterosaurs and flying squirrels (State News Service 2019). The membranous wings of *Yi qi* were such a bizarre find that scientists doubted the accuracy of their interpretation until 2019, when *Ambopteryx longibrachium* was discovered in the Liaoning Province (State News Service 2019). Possessing a styliform element homologous to that of *Yi* (Xu et al 2015), *Ambopteryx* confirmed that something as bizarre as a web-winged dinosaur had in fact existed. *Ambopteryx* is distinguishable from *Yi* by an ulna twice as wide as the radius, a short tail ending in a pygostyle (a specialized fused tailbone found in birds that allows for the attachment of tail feathers), a forelimb 1.3 times longer than the hindlimb, a straight, rod-like postacetabular process of the ilium (the rear of the pelvic bone), and a tibia shorter than the humerus (Xu et al 2015). These two dinosaurs are members of a family called Scansoriopterygidae, a group of non-avian theropods that branched off from Pennaraptora just before the appearance of Paraves, the clade that eventually developed into modern birds. *Ambopteryx* added insight into the diet of scansoriopterygids through analysis of its stomach contents. The stomach of *Ambopteryx* contained a small number of gastroliths (stones retained in the digestive tract to aid in the grinding of food) as well as fragments of bone, suggesting that scansoriopterygids were omnivorous. The membranous wings were likely used similarly to those of a flying squirrel to aid in gliding between trees, and the two digits that remained relatively un-elongated were probably used for climbing. Along with being an incredible scientific discovery, these two specimens are the foundation of a whole new clade: dragons.

FIRE

If I were to find a scansoriopterygid skeleton buried in the earth, what would tell me that I had found an early dragon and not another member of this clade? *Fire*. The famed quality of dragons. How is fire breathing possible? Bear with me as I briefly venture into a realm of dubious science that I will twist to fit my own selfish desires. To make a fire breather, one simply needs a combustible substance and catalyst to the reaction. A good candidate is methane, a combustible gas produced by bacteria in the digestive system.

To ignite, methane requires a concentration of 5 to 15% methane per air volume, with the strongest explosions occurring at 9.5-10% methane by air volume at standard temperature and pressure (cdc.gov). There is enough methane in the digestive system to ignite, but how are we going to get the methane out? Typically, methane is produced by bacteria in the intestines, but most of the methane would be lost to flatulence. There is also the manner of expulsion. No self-respecting dragon is going to go around burping fire, and the ignited methane would remain in a cloud near the dragon's head, possibly causing severe burns. The methane needs to somehow be expelled forcefully through the lungs. Methane is biologically inert and therefore not harmful on its own, but it's classified as a simple asphyxiant because it displaces oxygen in the lungs, leading to suffocation at high concentrations (National Research Council 1984). However, it takes about 500,000 ppm of methane to cause suffocation and only 50,000 ppm to ignite the methane, so there is no danger of suffocating our dragon to achieve high enough levels of methane in the lungs to ignite. Now, we just have to figure out how to move the methane from the intestines to the lungs.

Codd et al (2007) contests that maniraptorans had respiratory systems similar to those of modern birds. Birds have a rather unique respiratory system composed of multiple air sacs as well as lungs (Fig. 3).

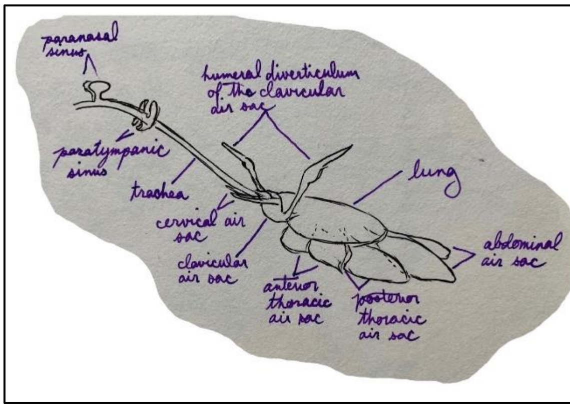


*Fig. 3. A drawing of the avian respiratory system, showing lungs and multiple air sacs.*

It takes two breaths for the inhaled air to complete a full circuit through the body. The first inhalation travels through the lungs to posterior air sacs, and the first exhalation moves the air to the secondary bronchi for gas exchange. The second inhalation moves the air to the anterior air sacs, and the second exhalation moves the air through the primary bronchi and out of the trachea (Heard 1997).

This form of respiratory system is incredibly efficient for two reasons. One is that the bronchi are arranged in such a way to provide counter-current exchange, with the air flowing at a right angle to the capillaries for maximum oxygen absorption. The second reason that avian respiration is so efficient is that the inhaled air flows in one direction, so that stale, deoxygenated air isn't mixing with fresh, oxygenated air as it does in mammalian respiration (Heard 1997). In fact, as we will discuss later, it is possible that this marvelous respiratory system is responsible for dragons' ability to grow as large as they do. With such a wonderfully complex respiratory system, it would be easy for me to sneak in a couple extra air sacs to sequester and store methane from the intestines. On the second inhalation, methane can be drawn from the posterior methane storage sacs, and on the second exhalation, the methane can be forced out through the lungs. As birds use breathing muscles rather than a diaphragm, a dragon could have exceptionally strong breathing muscles to force the gas out, which would of course be reflected in its skeleton. As a steady stream of methane is flowing out of the dragon's mouth, the only task remaining is to ignite it. The easiest way would be to produce a spark with the front teeth so that the methane doesn't catch fire until it is out of the dragon's mouth. To make the spark, the dragon has to eat a diet high in sugar. When you bite a wintergreen lifesaver you can see a spark. This is from a reaction called triboluminescence which occurs when the sugar crystals break apart, releasing free electrons that transfer energy to the atmospheric nitrogen. The excited nitrogen atoms release most of the extra energy as UV light, creating a tiny lightning strike in your mouth (Hartel and Hartel 2014) and igniting the methane. And there we have it, a fire-breathing dragon that can only make fire soon after eating. When a dragon isn't using its methane to make fire, it can simply exhale the excess.

FLYING

An important characteristic of our ancestral dragon is flight. As scansoriopterygids, dragons began as gliders, but at some point, they must have transitioned from gliding to flapping flight. The evolution of flapping flight is highly contested, but scientists have three main theories as to how it evolved. The first theory is the ground-up, or cursorial, theory. The idea behind this is that the animal starts as a ground predator that leaps up to catch insects with its forelimbs. Over time, evolution favors higher jumps and better control in the air (Hedenström 2002). The second theory is the tree-down, or arboreal, theory. In the arboreal theory, an animal starts in the trees, and eventually becomes a glider as gliding between trees takes less energy than climbing up and down the trees. Eventually, the gliding evolves into powered flight (Hedenström 2002). The third theory is the most recent, and that is the Wing Assisted Incline Running (WAIR) hypothesis. In 2003, Matthew Bundle and Kenneth Dial performed a series of experiments on chukar partridge chicks. In this experiment, the chicks ran up an incline to a safer perch up higher. They continued to raise the incline until the chicks were running on an almost vertical surface. They noted that the chicks used their wings to run up the surface and keep their center of gravity pressed into the substrate (Bundle and Dial 2003).

These experiments helped to explain the use of half of a wing. This question has been raised many times, because evolution favors the individuals who survive and reproduce, but how would a little stub of a proto-wing help you survive better than your cohorts? Under the WAIR hypothesis, the half of a wing becomes an asset towards running to safety (Bundle and Dial 2003). Davis continued his experiment from chicks to adulthood, simulating the evolution from a proto-wing to a fully developed wing. Based on evidence, it appears that *Yi qi* was a glider, so for our intents and purposes *Yi* evolved flapping flight after becoming a glider, the top-down hypothesis. So, there we have it. A small, omnivorous glider that will become the ancestor of dragons.

LOCAL ADAPTATION

Now that we have a common ancestor, let's figure out what would happen to it if it were to move into different environments. To do this, we must first discuss how animals tend to adapt to different environments. I decided to focus on four different ways that an animal can change in response to its environment: shape, size, wing structure, and behavior.

*Shape*

Body shape is a critical variable in how an animal survives in its environment at particular temperatures. Animals from cold areas tend to be chunkier, whereas animals from warmer areas tend to be more slender (Newman 1953). Chunkier animals have a smaller surface area to volume ratio. This helps them retain heat because they have more body mass, which produces heat, than skin surface, which loses heat, in comparison to a more slender animal. More slender animals have a larger surface area to volume ratio, which enables them to shed heat more easily.

*Size*

Animals in cooler environments tend to be bulkier. In fact, the higher in latitude you go, the higher body mass tends to be, as evidenced by distributions of *Puma concolor* across North America (Young and Goldman 1964) Size also depends on prey availability, if there's not enough to eat you won't be able to support a larger body mass.

Colder regions are where I would like to have really big dragons. But how big can something be and still fly? Consider giant pterosaurs. There is evidence that the avian-like respiratory system that is found in both pterosaurs and our dragons was responsible for the ability of pterosaurs to weigh up to a couple hundred kilograms and still be capable of powered flight (Ruxton 2014). This is because it's much more efficient than the mammalian tidal respiration system, providing the animal with enough oxygen to withstand the demands of powered flight (Ruxton 2014). So, theoretically, our dragons can be quite big.

*Wings*

Wing structure depends on the purpose of the wing. Gliding wings tend to be longer in proportion to the body, whereas wings used for flapping flight are shorter (Lindhe-Norberg, Brooke, and Trewhella 2000). In some situations, the dragon may not need large wings or be able to meet the energetic requirements of flying, in which case the wings would be highly reduced and perhaps only used for occasional gliding or even swimming.

*Behavior*

In terms of adaptation, behavioral adaptation is every bit as important as physical adaptation. A dragon that lives in a cold environment may burrow or build nests to keep warm, whereas a dragon in a hotter environment may seek water or become nocturnal or crepuscular (active in the morning and evening) to avoid being out in the harshest sun. different prey and vegetations cover would lend itself to different hunting styles, and food availability in part would dictate population density and therefore the ways in which dragons would seek out mates.

ENVIRONMENTS THAT FASCILITATE CHANGE

As you can see, each of the adaptations I listed above are dependent on what kind of environment the dragon lives in. Below are some different environmental factors and how they might affect the appearance and behavior of a dragon.

*Cold*

A cold-adapted dragon would tend to be larger, bulkier, and thick skinned or possibly feathered. In areas with little vegetation, it would likely be mostly carnivorous. Special care would need to be taken to reduce heat loss through the wings. This could be in the form of reduced wings, thick, leathery skin, or a feathery or downy covering. This dragon would likely not breathe fire due to a lack of carbohydrates to facilitate the necessary reaction.

*Hot and Dry*

A dragon found in a more desert area would likely be leaner in form to facilitate heat loss. It would also be larger than its ancestor to enable it to eat larger prey.The membranes of the wings could also be used to shed heat much like the ears of a desert hare. In an area with little vegetation, the dragon would probably be cryptically colored, with rougher skin to reduce water loss (Fig. 4). This cryptic coloration would allow it to be an ambush predator as well. Alternatively, it could hunt and dive from the air similarly to a hawk. It would likely not breathe fire due to its diet.

*Fig. 4. This is a desert adapted dragon. Its long and slender in shape with spike-covered skin.*

*Hot and Wet*

The rainforest environment is where we found our dragon ancestor, so we know how a dragon in that environment would look and behave. A small dragon would have plenty of sustenance in the form of insects, and it wouldn’t need to worry about keeping itself warm with a small body size. Close confines of trees would enable gliding and climbing to be its forms of mobility. In an environment with plentiful resource, this dragon could even live in social groups (Fig. 5).

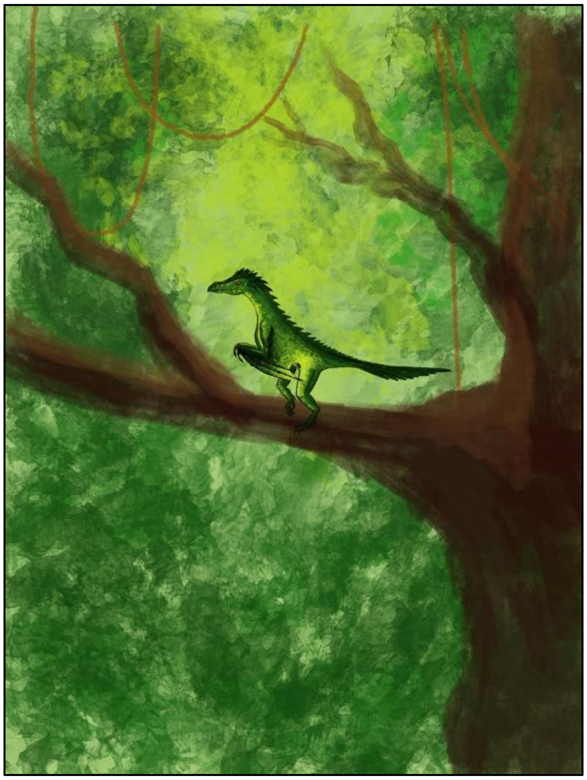

*Fig. 5. This is a rainforest dragon. It is small, bipedal, and arboreal.*

*Temperate Grassland*

In this open environment we could have aerial predators much like those of the desert. The dragons here would likely be larger for warmth, and they might build burrows or even migrate for the cold seasons. They would be mid-sized and moderately robust to deal with the changes in temperature year round.

*Temperate Mountainous*

I want these dragons to be really big and bulky, much like the dragons of European legend. Here is the perfect place for gigantism to develop. A very large dragon would have no trouble keeping itself warm, and it could eat large ungulates, using fire to subdue them. These dragons would likely be solitary, and possibly territorial. They would likely be quadrupedal, and excellent jumpers to help them take off from the ground. As an aerial predator with fire breathing abilities, these dragons wouldn't need camouflage to capture prey, and males could be brightly colored to attract mates.

## A VERY BRIEF PHYLOGENY

Now that I've touched on a few ways that a dragon can adapt to its environment I wanted to make a quick tree of traits. I picked a few behavioral and physiological adaptations and tried to place them on a tree to see how the different evolutionary steps could have happened and how they would have supported dragons in different environments (Fig.6).

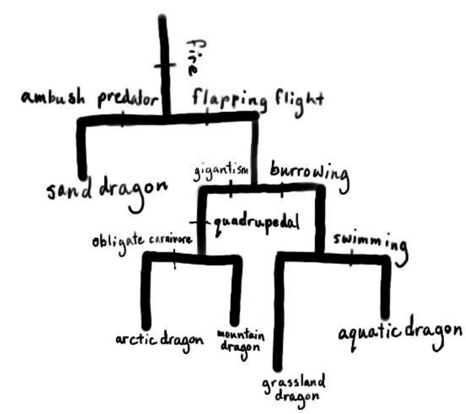


*Fig. 6. This tree starts with the evolution of fire, and continues to flapping flight, burrowing, and swimming. When gigantism is introduced, the dragons become quadrupedal.*

CONCLUSION

I hope that you have enjoyed reading about dragons, I certainly have enjoyed writing about them! Dragons may not be real, but science is. If you know the concepts of how things work in the natural world, you can reflect them onto any template you want and create fantastic worlds in your head.

AKNOWLEDGEMENTS

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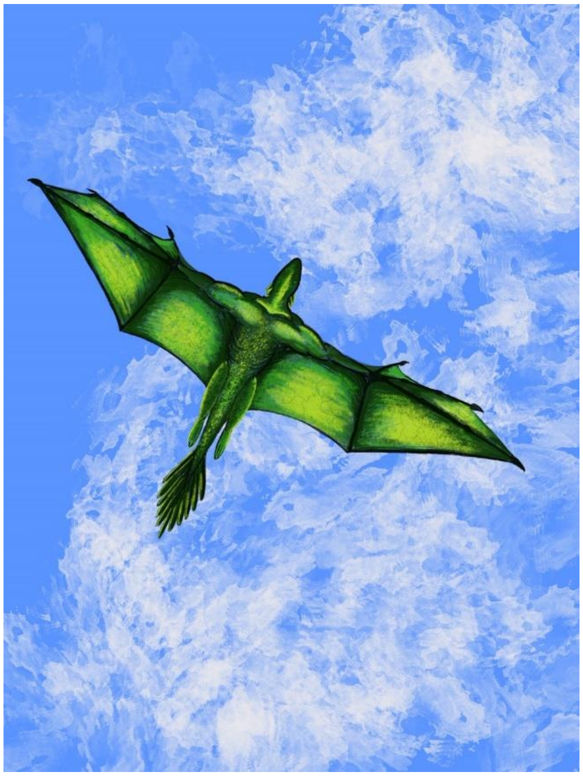

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