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The Genetic Origins of Dragons

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Abstract
Dragons are popular creatures in fantasy that are large winged lizards that can be the size of a house. This report looks at the basic genetic requirements to produce Dragons. It finds that HOXD and HOXc-6 genes are necessary requirements for the formation of the dragon's wings. It also investigates the size limits for birds and finds that due to the current bird size being limited by feather size dragons will likely lack them, and be closer to the ancient creatures that flew, such as the *Quetzalcoatlus*.

Introduction
In fantasy settings it is common to see a dragon be an important part of the plot, be it in a dungeons and dragons game or the Lord of the rings they are often depicted as being these ancient, powerful and intelligent creatures. In Western cultures they are large reptiles with four legs and two wings (figure 1). However, there are no examples of reptiles or mammals on Earth that fit this description, nor has anything been found in the fossil record. This paper looks at the genetic and evolutionary requirements behind the forming of a species like these Dragons.

Figure 1 – The usually depiction of a dragon in Western media. A large, scaled reptile with four legs and a pair of wings. Often also sized similar to a house [1].

Genetic Basis
Dragons usually have their wings depicted in the centre of their body, between their four legs (figure 1). To understand how this might arise the evolution of wings in birds are looked at. This revolved around the HOXD-10, -11, -12 and -13, as the primary genes responsible for the development of the bird wing from their reptile ancestors. By comparison of the genes to those in an alligator the expression of the HOXD genes, especially with the HOXD-11 gene has been shown to be a major part of the bird wing evolution [2]. It is also known that various HOX and SHOX family genes control the development and length of forelimbs such as the humerus [3].

However, these changes occurred in the forelimbs of their ancestors, resulting in birds now still being tetrapods. For a dragon to evolve in this manner the first step would be the mutation in a species of ground dwelling lizards into hexapods. In a developing embryo in birds the forelimbs grow from forelimb buds, that are located at the most anterior expression region of Hoxc-6 (also the position of the first thoracic vertebrae) [4]. From this the embryo grows its forelimbs according to its genetic code.

When considering dragons an ancestor of theirs must have had some form of mutation which allowed this third pair of limbs. Potentially the formation of a new forelimb bud dorsal to the previous bud, but still within the expression region of Hoxc-6. Following this the limb then mutates to undergo the required changes to its HOXD genes to produce the correct bone structure required for the wings. This extra forelimb bud is not genetically impossible, as the development of extra limbs has been induced

through the injection of the growth factor FGF10 in the developing embryo [4].

This extra limb would potentially be detrimental to the organism's fitness however. It would require and increased cardiovascular output, bone and muscle formation while potentially not providing a benefit to the organism. To evolve naturally it would most likely result from genetic drift rather than selection as before it become a fully functioning wing it is not an advantage. Along with the fact that natural selection doesn't evolve traits with an end goal in mind a naturally occurring example of this would be unlikely.

Limits to Flight

If it is assumed that the third pair of limbs has established itself in the population and developed into fully functioning wings, then what would be the flight capability for these wings? Fossils of *Quetzalcoatlus* have wingspans of 11 metres, however their flight ability is still in contention [5]. If dragons had evolved along similar path to birds and had more bird-like traits, then the understanding of their flight would draw close parallels with the largest birds known today.

Important aspects of flight for birds are their feathers and their bone structure. Feathers provide an important role in the aerodynamics of bird flight along with warmth and other survival mechanisms. However, they are also likely a limiting factor in the size that a bird can reach before considering the limits of their flying capabilities due to the limit at which a bird can replace the feathers [6].

Bones of birds have also selectively evolved to be specialised for flight, with a small number of genes being identified as being involved in the evolution of flight in both birds and bats, suggesting possible requirements for flight. These genes include, Bone morphogenetic protein 2 that is involved in cartilage proliferation and distal length, odd-skipped related 2 which is involved in forelimb, hindlimb and cranial development, homeoboxA11 which is implicated in bone fusion, and others such as fibroblast growth factor 32, bone morphogenic protein type IA gene etc. [7].

However the research into the genetics has also shown that the current size of birds and bats is approaching the theoretical limit for their size due to their bone structure [7]. Given this it potentially limits the potential size of a dragon. Considering that birds are currently limited in size by their feather a dragon would most likely imitate the flight of the prehistoric creatures, such as the *Quetzalcoatlus*. Although lack of knowledge about this creature's methods of flight also limit the possibilities for dragon flight.

Conclusion

This paper has identified a few of the essential genes that would be involved in the origin of dragons. Identifying that to produce and shape the wings on a dragon would require changes in the HOXD-10, -11, -12, -13, SHOX and HOXc-6 genes to produce the iconic dragon. However, due to limitations this paper has only briefly touched on the countless other genetic requirements necessary and so future research can be done to flesh out almost every aspect of a dragon's anatomy.

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