Study finds mammals diversified only after the extinction of dinosaurs

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Recently announced findings, published in the journal *Science* by Maureen O'Leary and colleagues, represent an important step in understanding the early evolution of placental mammals, and sheds light on its relation to the mass extinction of dinosaurs. The scientists report that the majority of living mammals evolved at an explosive rate following the extinction of the dinosaurs some 65 million years ago.

Using a powerful new computer program to sift through over 4,500 anatomical traits, 10 times more than any previous such research, from 86 living and 40 fossil species, the large team of researchers from a number of institutions developed a proposed reconstruction of the ancestor of all placental mammals. The group also refined the understanding of the subsequent evolution of major mammalian groups. Placental mammals include most living forms of mammals, ranging from rodents to primates, but exclude marsupials and monotremes.

Placental mammals give birth to live young after a long gestation in the mother's womb, during which the growing infant is fed by nutrients passed from maternal blood to fetal blood in a structure called the placenta, then transported to the infant via the umbilical cord. This is in contrast to other mammals—marsupials (e.g., kangaroos), which birth highly immature young and provide nourishment to the developing infant in an external pouch, and monotremes (e.g., the platypus), which lay eggs. All mammals descend from an earlier common ancestor and share the trait of producing milk to feed their young.

Ancestral mammals are thought to have already existed late in the Mesozoic, the "Age of Dinosaurs," based on projections using genetic "molecular clocks." These suggest that a degree of evolutionary diversification among all major groups of mammals had already taken place before the extinction of dinosaurs. However, the very early evolution of mammals is not well represented in the fossil record until the early Cenozoic, after the dinosaur extinction.

Following the disappearance of all dinosaurs (except birds) 65 million years ago, a great diversification of mammals becomes evident in the fossil record. This adaptive radiation established the major lineages that lead to the variety of mammals found today.

Did a diverse array of mammals live alongside dinosaurs? Or did dinosaurs so monopolize available ecological niches that ancestral mammals constituted only a small, insignificant component of the fauna?

Only recently, a small meteorite made headlines internationally when it struck the atmosphere above Chelyabinsk in Russia (see "Science, society and the Chelyabinsk meteor"). Did mammals come to flourish only because, apparently by chance, a far larger meteorite wiped out the dinosaurs? Or were mammals already beginning to make inroads before the mass extinction? Evaluating the natural history of dinosaurs and the mammals that overtook them requires knowledge of the ancestral placental mammal, from which all other placentals evolved, and of the timing of its evolution and subsequent radiation. This is, after all, a question of some interest, since without the mammalian adaptive radiation primates and ultimately humans would not have evolved.

The study reported in *Science* used a powerful new computer program, called MorphoBank, developed by the researchers themselves. This program seeks to combine both genetic and fossil data to create a more detailed and accurate picture than is possible using either by itself.

Genetic data can be used to gauge the relative evolutionary distances between living species. How different are the genetic (DNA) sequences of various species and, consequently, which contemporary species are more and which less closely related? Because DNA mutates at relatively constant rates (hence the term "genetic clock"), genetic differences between two or more living species can be used to estimate the time elapsed since those species diverged in evolutionary history.

The rate at which this genetic clock "ticks" is, however, based on certain assumptions: that researchers are able to know, through a few well-dated fossils, when certain living species first diverged. These dates are hard to come by and their relationship to speciation is usually contested. Discrepancies are often found, therefore, between the apparent date of such branching events based on the genetic clock and what is seen in the fossil record.

Fossils are important not only for dating certain divergence times and therefore "calibrating" molecular clocks, but also for evaluating the relationships between extinct species for which we can retrieve no DNA. Fossils contain, however, a limited set of characteristics of the original living organism: many attributes of living organisms beyond bones and teeth are simply not available for observation. Furthermore, the fossil record is incomplete and subject to vagaries of preservation, the effects of which cannot always be assessed.

These two data sets, genetic and fossil-based, represent different and partial aspects of reality, each with its strengths and weaknesses. Neither is a perfect representation of the past, nor could be. It is the scientist's responsibility to assess the data using technical expertise and evolutionary theory to develop a synthesis that seeks to more closely represent the reality of the evolutionary process. The newly reported research is an effort of this type.

The project had the dual aims of reconstructing the age and characteristics of the ancestral placental mammal and of determining the subsequent branching events that represent the adaptive radiation. The study found that the two forms of data, genetic and fossil, could be combined to create a largely, though not entirely consistent reconstruction of the branching tree of mammalian evolution. This reconstruction indicates that only the original or "stem" placental mammal lineage existed prior to the dinosaur extinction and that the earliest evidence of the adaptive radiation of mammals occurred in the Paleocene, the first period of the Cenozoic, shortly after the dinosaur extinction. This differs from previous estimates based on molecular data alone, which projected a much earlier date for mammalian diversification. The study also found that marsupials and monotremes as well diversified only after the extinction of dinosaurs.

The study further indicates that the early Cenozoic differentiation of mammals was explosive in character, occurring within only a few million years after the dinosaur extinction. This supports the interpretation that mammalian evolution had been held in check because dinosaurs occupied most of the available ecological space (the potential ecological niches), leaving very little opportunity for the ancestral mammals to diversify by adapting to new environments and food sources. Once the dinosaurs were removed, by whatever mechanism, mammals had virtually unlimited prospects, which they took advantage of very quickly.

The study also resulted in a fairly detailed reconstruction of the ancestral placental mammal, including characteristics of the skeleton, dentition, brain and nervous system, and reproductive system. In outward appearance the animal was a small, rather rodent-like creature, with a long, furry tail, and was probably insectivorous. It had a relatively large brain for its size.

The researchers conclude that the great diversity of mammalian lineages, rapidly evolving from a single placental ancestor following the extinction of the dinosaurs, demonstrates that evolution can occur explosively on geological time scales. Such leaps can take place when dynamic ecological relationships are disrupted by some factor, in this case a devastating meteor impact, creating the opening for the development of new, qualitatively different configurations.

The success of the MorphoBank program in elucidating the genealogy of placental mammals holds the promise that it may help unravel the evolutionary trees of other organisms as well. The development of this program and the research project it permitted were the result of the combined effort of a large team of scientists from a number of countries, which was funded primarily by the US National Science Foundation. This project demonstrates both the great value of international collaboration and the great danger to scientific research posed by continuing cuts in funding.