First mammals

Being small, the secret to success

A bicoloured shrew — an extant nocturnal mammal with conspicuous whiskers

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Being small was one of the key advantages for the ancestors of mammals. Palaeontologist Elsa Panciroli explains how being small contributes to larger brain proportion, keen senses and the ongoing evolutionary success of small mammals

Exam links

AQA Surface area to volume ratio; Evolution may lead to speciation
Edexcel A Surface area to volume ratio; Adaptation and evolution
Edexcel B Classification; Natural selection; Surface area to volume ratio
OCR A Surface area to volume ratio; Classification and evolution
OCR B Significance of surface area to volume ratio; Evolution and classification
WJEC Eduqas Body size and metabolic rate; All organisms are related through their evolutionary history

A mass extinction happened about 252 million years ago. Up to 95% of life on Earth was wiped out. Reptiles emerged to fill the **ecological niches** that had until then been occupied by large-bodied animals. The ancestors of mammals that became most successful exploited a niche that was previously unfilled — being small, nocturnal, and increasingly endothermic.

Mammals remained relatively small for around 150 million years, the largest reaching the size of a badger. They had fur, and resembled rodents, but looks can be deceiving. Their anatomy was different from rodents (a group that did not emerge until after the extinction of the dinosaurs, around 66 million years ago — see Box 1).

Evolutionary success

There is a misunderstanding that mammals were held back in their evolution by the presence of the dinosaurs. But being physically big is not a measure of evolutionary success. The most populous vertebrates with the largest distribution on Earth today are small.

Evolutionary success can be defined in many ways. Three examples include wide distribution, persistence of species over long timescales, and resilience in changing environments. Mammals are one of the most successful animal groups. Many of today's small mammals belong to the order Rodentia (rodents including rats, squirrels and porcupines). However, for the first two-thirds of

Terms explained

Crepuscular Active at dawn and dusk.

Ecological niche The role of a species in its environment.

Ectotherm An animal that regulates body temperature using its environment.

Endotherm An animal capable of generating its own internal heat to maintain body temperature.

Nocturnal Active at night.

Surface-area-to-volume ratio The surface area per unit volume of an object.

Box 1 Rise of the rodents

People often describe the ancestors of mammals as 'mouse-like', but rodents (the group to which mice belong) only evolved around 60 million years ago, whereas mammaliaforms have their origins at least 220 million years ago. Although the first mammals looked superficially rodent-like, they were physically distinct, and not closely related. However, two groups of ancient mammals and close relatives developed adaptations that are similar to rodents: the tritylodontids and the multituberculates. Both groups had enlarged incisor teeth at the front of the mouth with a gap behind them called a diastema, and rows of grinding molar teeth at the back of the mouth.

The tritylodontids, multituberculates and rodents appear to have 'replaced' one another in succession: first the tritylodontids (see Box 2) lived from the late Triassic to the early Cretaceous, then multituberculates from the early Jurassic until the Eocene, and finally rodents appeared in the Palaeocene. Despite not being directly related to one another, the teeth of each group evolved along similar lines. This is an excellent example from the fossil record of convergent evolution, the process whereby organisms that are not closely related evolve similar traits independently, as a result of adapting to similar environments or ecological niches.

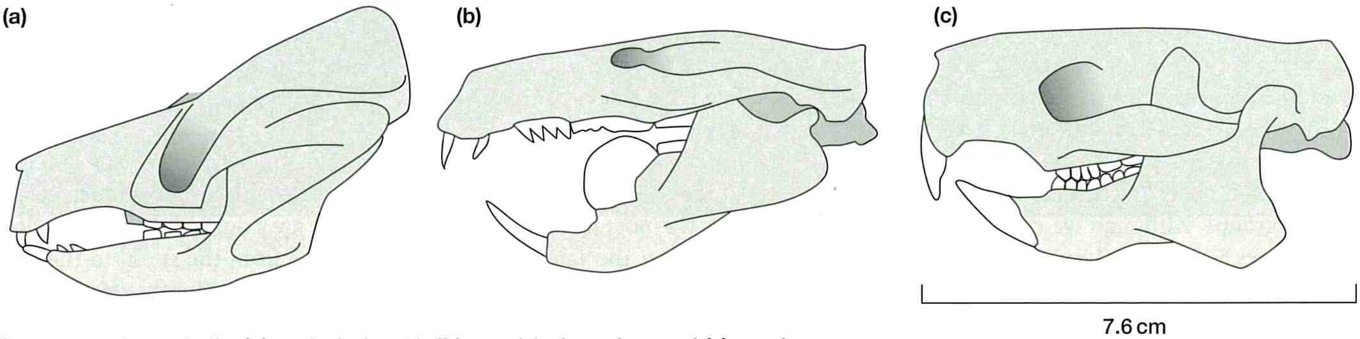

Figure 1.1 Three skulls: **(a)** a tritylodontid, **(b)** a multituberculate and **(c)** a rodent

their evolutionary story, mammals were represented by many lineages of small animals that flourished alongside the dinosaurs.

Pros and cons of being small

Being small makes it easier to hide from predators, which saves energy that would otherwise be spent fleeing. Many small mammals today are **nocturnal** or **crepuscular**. Being small makes it possible to forage for food below the leaf litter, snow, or underground, offering protection from hunters. Many are also omnivorous, feeding on seeds, fruit, insects, plant roots, flowers and fungi that meet their energy needs.

But being small does have some disadvantages. Small mammals have trouble maintaining their body temperature, due to their higher **surface-area-to-volume ratio**. They lose body heat quickly. They often 'live fast and die young', but produce frequent, large litters of offspring. This fast turnover of generations makes it possible for evolution to act quickly on small mammals, and changes in the genetic composition of their populations can happen fast.

Looking at the earliest mammal ancestors in the Triassic — mammaliaforms such as *Morganucodon* — palaeontologists now better understand their origins (see Box 2). Many of the traits that account for the success of mammals are closely linked to a reduction in body size during the Triassic. The specialisations that came with this reduction contributed to the long-term success of mammals.

Box 2 Cladistics

When talking animal evolution, palaeontologists refer to clades — groups of organisms that include all the evolutionary descendants of a common ancestor. In the evolution of mammals, we refer to Mammalia, Mammaliaformes, and Mammaliamorpha. Each one of these clades incorporates all the organisms that share an ancestor. Mammals today are all part of the clade Mammalia. Mammaliaformes includes *Morganucodon* (see Figure 2) (from the late Triassic) and all of its descendants, including Mammalia. Mammaliamorphs comprise a clade that includes the common ancestor of Mammaliaformes, and close mammal-cousins called tritylodontids. Each clade is nested in the next, like a Russian doll, and is united by a suite of shared skeletal characteristics that define it. Working out common ancestry by examining the shape of teeth and skeletons is a key goal of vertebrate palaeontology.

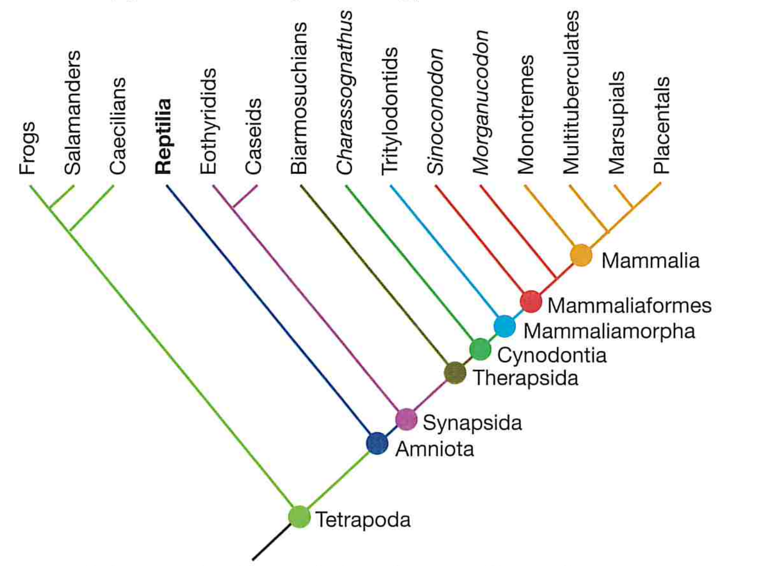

Figure 2.1 Cladogram showing evolution of mammaliamorphs, mammaliaforms and mammals over time

The nocturnal bottleneck

There is evidence that mammals went through a 'nocturnal bottleneck', when the shared ancestor of all living mammals was probably active only at night. Clues to this are found in the photoreceptors in the eyes of modern mammals. There are two main types of photoreceptor, called rods and cones. Cones are not very sensitive to light, but provide high resolution, which is good for daytime vision. Rods are more sensitive to light, but this sensitivity comes at the expense of resolution. This is better for night-time vision. Most modern mammals have a lot of rods in their eyes, and only a few cones. This gives them good low-light vision but results in colour-blindness (which means they cannot distinguish red–yellow–green parts of the light spectrum). Primates are some of the only mammals that have re-acquired good colour perception.

The greater proportion of rods over cones in modern retinas means we can say with confidence that living mammals share a nocturnal common ancestor. This gives us a minimum of around 220 million years ago for when the last common ancestor of all modern mammal lineages was alive. The shape of the eye orbit of modern mammals is linked to day/night activity, and using this we can assume that the predecessors of mammals included daytime and nocturnal animals. Nocturnal activity probably emerged several times in different groups. Although we cannot be certain how far back the nocturnal lifestyle goes in mammal ancestry, we can say for certain that by the late Triassic, mammaliaforms were exploiting the night. Even today, the majority of mammals are crepuscular or nocturnal.

Enhanced senses

Well-developed sense of smell, whiskers and good hearing are all traits advantageous to mammals. Over time, the brains of mammaliaforms grew larger compared with their body size, although they were still smaller than those of modern mammals. Some of this brain size increase was linked to their changing senses, as areas of the brain that process the senses became larger and so coped with increased information.

Smell

Most modern mammals have an accomplished sense of smell and use it for communication (such as scent marking), or to hunt for food. Mammal noses have thin, curled bones called turbinals inside them (see Figure 1). The turbinals increase the surface area inside the nose, resulting in an increase in the density of smell sensors.

Turbinals are fragile so they are not well-preserved in the fossil record. This makes it difficult to identify their origins and track their evolution. However, we know that simple ridges existed in the noses of some mammal predecessors, suggesting that their common ancestors possessed rudimentary turbinals before the Triassic. As smell became more important to nocturnal mammaliaforms, the region of the brain that processes smell — the olfactory bulb — enlarged. This enlargement can be seen in late Triassic mammaliaforms, indicating that smell was already an important sense by this time in mammal evolution.

Touch

The origin of mammalian whiskers is also hard to pinpoint in the fossil record, as they do not fossilise. However, whiskers are connected to nerve fibres, which send impulses from the snout to the brain. These nerves snake along pathways on the surface of the skull bones, and pass through small holes in these bones, called foramina. Palaeontologists have traced the appearance and evolution of these foramina in the ancestors of mammals. By the Triassic in animals such as *Morganucodon*, the pattern of these foramina is similar to that found in modern mammals with whiskers, indicating that mammaliaforms had whiskers by this time (see Figure 2).

Hearing

The evolution of the middle ear in mammals is an especially important area of study for mammal palaeontologists. Modern mammals have a wide

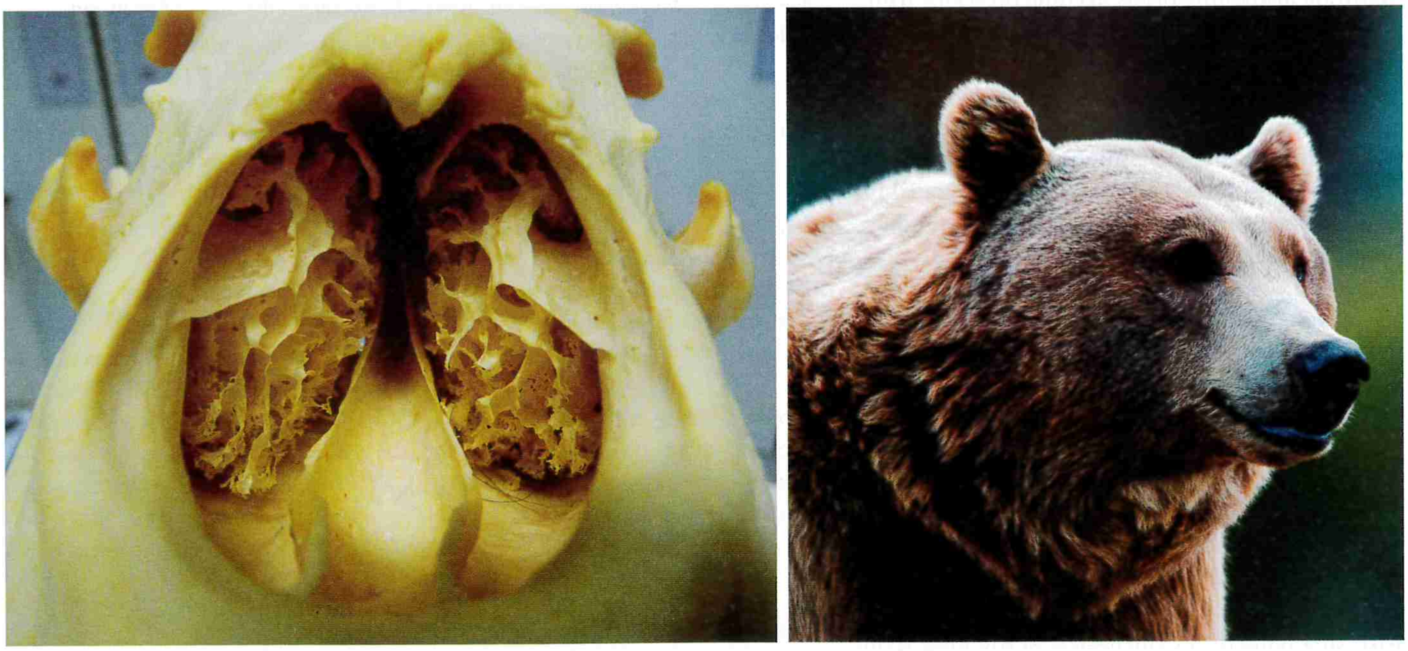

Figure 1 Left, turbinals in the skull of a brown bear (right)

Figure 2 'Morgie', the reconstruction of the extinct mammaliaform *Morganucodon*

range of hearing across high and low frequencies. Extra-sensitive hearing is vital for avoiding predators, and compensates for poor resolution low-light vision. Some small mammals, including bats, use their hearing for hunting, via echolocation.

During the Triassic, Jurassic and Cretaceous, the bones in mammaliaform jaws began to shift position. Some of them reduced in size and eventually detached from the jaw altogether, becoming incorporated into the middle ear. Recent research has suggested that the small size of the mammaliaform jaw and skull led to the rearrangement of muscles in the skull, freeing up the bones of the jaw and making the evolutionary transformation of the jaw–ear bones possible. Alongside other changes in internal ear structure, this rearrangement resulted in an increase in the frequency range and sensitivity to sound in the mammal lineage.

It's getting hot in here

Mammals are **endothermic** — they maintain high body temperatures metabolically rather than through basking and cooling as in **ectotherms** such as lizards. Birds and mammals have faster metabolic rates than other vertebrate animal groups. Endothermy allows mammals to carry out a much wider range of more sustained aerobic activity, which ectotherms typically cannot sustain.

There is disagreement about the origin of endothermy, but the upright posture of mammal ancestors during the Permian period suggests they were becoming capable of faster, more sustained movement, and their metabolism and body temperature may have increased to fuel this. The presence of turbinals also supports this, as the increased surface area they provide helps active animals recover heat and moisture during intense activity. The evolution of fur as an insulating body covering would have allowed mammal ancestors to maintain higher body temperatures. Being endothermic would have meant that mammaliaforms could regulate their body temperature when it was cold at night, an important prerequisite for being nocturnal.

Final word

For the earliest mammals — our own distant ancestors and cousins — being small provided not only a survival advantage, but a blueprint for success that has seen them through multiple extinction events over the last 200 million years. The characteristics that were present in mammaliaforms — nocturnality, whiskers, a large brain, heightened smell and hearing — emerged hand-in-hand as a suite of adaptations that made it possible to exploit new ecological niches. They have outlasted the non-bird dinosaurs, and it is possible that the smallest mammals on Earth may outlive us all.

Further reading

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Key points

- Mammal ancestors were small, nocturnal, and increasingly endothermic.
- These features gave them clear competitive advantages over reptiles.
- Whiskers, large brain, heightened smell and hearing allowed mammals to exploit new ecological niches.
- Endotherms can sustain aerobic activity better than ectotherms.