We are all air-heads

By **Mathew Wedel**

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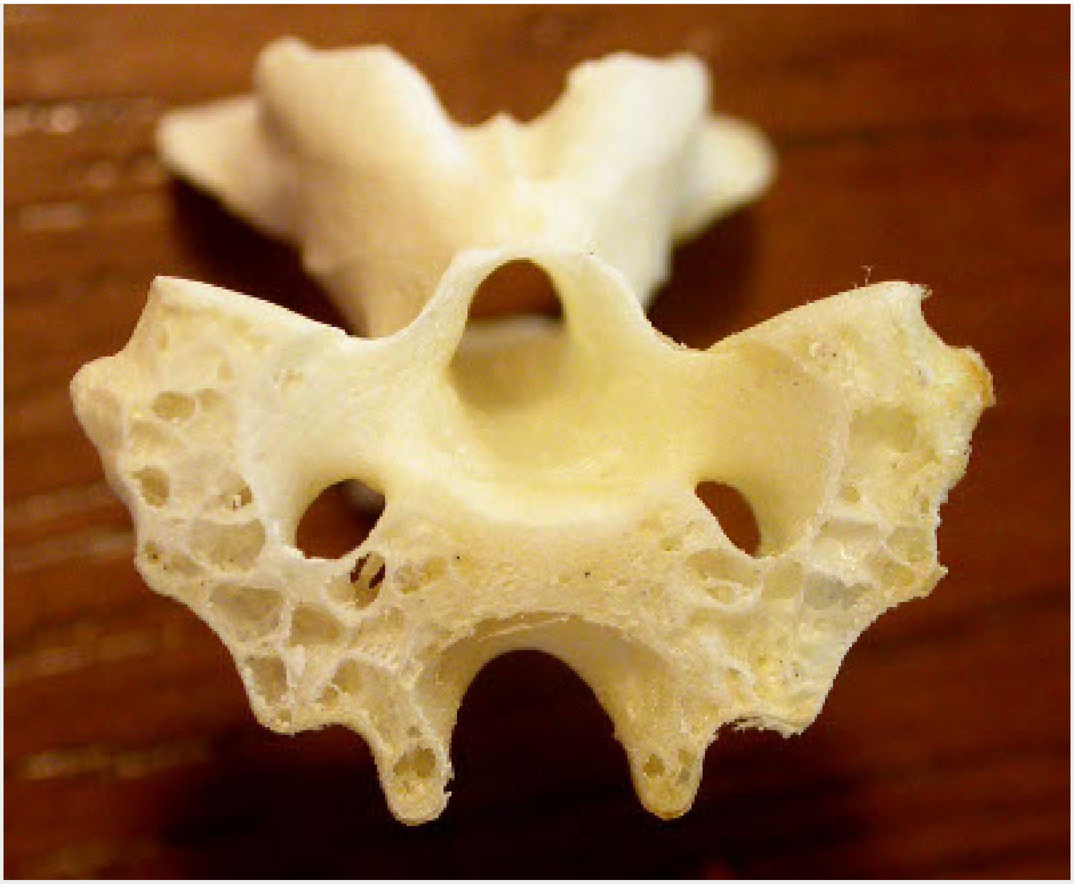
From the hollow horns of *Triceratops* to the sinuses in your skull, air-filled bones are always mysterious - and sometimes painfully so.



A vertebra from the neck of a turkey, sanded down to reveal the honeycomb of air spaces inside. Credit: Mathew Wedel

IN 1758, BRITISH anatomist John Hunter was doing bad things to birds. He cut off the wing of a live chicken at the middle of the upper wing bone, and immediately tied a string tightly around its windpipe to strangle it.

A young hawk got similar treatment, only instead of losing a wing, it had one of its legs lopped off at mid-thigh.

Hunter wasn't pointlessly torturing the birds. Although gruesome by modern standards, Hunter's experiments were designed to solve a mystery more than 2000 years old.

Since at least the time of the ancient Greeks, observant naturalists had noted that many of the bones in the skeletons of birds were filled with air rather than bone marrow. This raised a perplexing question: how did the air get into the bones?

Some people had hypothesised that the air spaces in the bones communicated with the lungs, but no one had been able to show a connection.

Hunter had found another way to test the hypothesis: both of his mutilated birds survived, at least for a bit, and were able to breathe despite having their windpipes tied off.

In a 1774 account of his experiments, he wrote that “the air passed to and from the lungs by the canal in [the] bone” – the bones being the upper wing bone of the chicken and the thighbone of the hawk.

IT WASN’T EASY on the birds. Breathing through holes in their bones was so difficult “as to render it impossible for the animal to live longer, than to prove evidently, that he did breathe through the cut bone.” (One imagines that the trauma of having a limb severed without anesthesia and then being strangled might also have added to the birds’ distress.)

Although the import of the discovery was no doubt lost on his test subjects, Hunter was the first person in history to successfully show that the air-filled bones of birds are indeed connected to the lungs.

Air-filled bones may seem exotic, but you have been carrying around a set for most of your life: the sinuses in your forehead and cheeks and behind your nose and ears. During fetal development and early childhood, the bones that house your sinuses are invaded by air-filled sacs, or *pneumatic diverticula*, that develop from your nose and middle ear.

These diverticula are lined by the same delicate mucous membranes as the inside of your nose. Even after they are done forming, the sinuses all retain tiny openings to your respiratory airways. Simply by having sinuses, you have personal experience with one of the most important aspects of air-filled bones: to form and be maintained, the air cells inside the bones have to maintain a constant connection to the outside.

IF THE NARROW connection between a sinus and the outside air is blocked – by swelling of the membranes, or a solid plug of mucus – the air inside the sinus will start to be taken up into the tiny blood vessels inside the lining membranes.

This creates a negative internal pressure that we experience as a sinus headache.

Sometimes a sinus headache can make you feel like part of your head is about to implode. Your nerve endings aren’t lying to you. There really is a partial vacuum in there, although it’s far too weak to collapse your bones or even measurably stress them.

Nevertheless, the body will offset the negative pressure by filling the sinus with something, usually mucous or clear fluid.

The warm, wet, dark conditions in a closed-off sinus are perfect breeding grounds for bacteria and other microorganisms, which can cause a sinus infection and further irritation of the membranes that line the air cells – sinus headaches can get you coming and going.

Eventually, if the sinus is isolated from the outside for weeks or months, the former air cells can be completely filled in by the growth of new bone tissue, leaving the patient with a fractionally heavier skull and one less infection-trap to worry about.

IN HUMANS AND other mammals, air-filled bones are normally limited to the skull. Birds have sinuses like ours, but they also have air-filled bones in the rest of the skeleton.

The extent of the air in the skeleton varies widely among bird species. In the largest running and flying birds, almost any bones can become filled with air – in pelicans, even the bones of the hands and feet.

On the other hand, diving birds such as loons and penguins tend to lack air-filled bones entirely; their skeletons are filled with marrow, like our own. And with good reason: air-filled bones would serve as permanently inflated balloons that would make diving more difficult.

All of these air spaces in the skeletons of birds are ultimately connected back to the respiratory system, by tube-shaped pneumatic diverticula much like the ones that connect to your sinuses.

The tiny, thin-walled diverticula tend to collapse when they're not actively inflated, and in dissection their tissue-thin linings are easily lost among the many membranes of the body, which explains why no one had been able to prove their existence until John Hunter's grisly but dramatic experiments.

For decades, scientists assumed that the air-filled bones of birds were adaptations to lighten their bodies for flight. Although that is probably one of the functions of air-filled bones in birds, we now know that their evolutionary origins go back much further, to their dinosaurian ancestors.

ALMOST ALL OF the theropods – *T. rex* and its two-legged, toothy kin – and giant, long-necked sauropods also had air spaces in their vertebrae and ribs, and a few even had air in the bones of the pelvis. Some dinosaurs also had sinuses in their skulls.

In *Triceratops* and other horned dinosaurs, the big horns over the eyes were hollowed out by sinuses, just like the horns of modern-day sheep and cattle.

For sauropods with necks up to 15 metres long, air-filled bones may have been one of the keys to getting huge without also becoming impossibly heavy.

The functions of air-filled bones in many other animals are more mysterious.

Although horned dinosaurs had skulls up to three metres long, the sinuses in the skull were comparatively tiny and would have had a negligible effect on the weight of the head.

The same is true for *T. rex*, and for ourselves. While human sinuses are often claimed to lighten our heads, they only change the mass by about 1%. So why do we have them – especially when they cause us occasional discomfort?

OHIO UNIVERSITY ANATOMIST Lawrence Witmer has argued that it is a mistake to focus on the function of the spaces in air-filled bones, which vary wildly in size, shape, and location.

Witmer suggests that instead we should look at what all air-filled bones have in common: the thin membranes that connect the spaces in the bones back to the respiratory system.

Perhaps it is just an inherent property of these membranes to invade any bones they come in contact with. The resulting spaces are raw material for evolution to work with, in ways both obvious – as in the extremely delicate, thin-walled wingbones of a pelican – and not so obvious: our perplexing, frustrating, fascinating sinuses.

Air spaces inside bones can be hard to get a good look at. Unless you are (un?)lucky enough to have a CT scan or MRI performed on your head, you'll probably never see your own sinuses, although you'll almost certainly feel them now and then.

But the air spaces in bird bones are easy to see – all you need are some leftover bones from the table and a little safe and easy work in the kitchen. Here's what to do:

1. Save the vertebrae from the neck or torso of a cooked bird. Bigger bones are easier to work with, so try to get hold of a turkey or a goose. All of the same bits are there in a chicken or a duck, they'll just be smaller.

2. Carefully boil the bones for 30 minutes to an hour to loosen any remaining meat.

3. In a dish of warm, soapy water, scrub off any remaining meat or gristle. Sponges, brushes, and thumbnails all work well.

4. In a small, covered container, completely immerse the bones in dilute hydrogen peroxide. The ordinary drugstore variety is fine. Soak the bones overnight to degrease them and turn them a pleasing white color.

5. Using sandpaper, sand off the ends of the vertebrae to reveal the internal air spaces. This just takes a few minutes, and it's safer and easier than trying to cut or saw such small and fragile bones.

Final step: amaze people at dinner parties with your anatomical knowledge. And ponder the fact that you – like a chicken and *Triceratops* – are an airhead.

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More information:
Mathew Wedel at Sauropod Vertebra Picture of the Week
Western University of Health Sciences