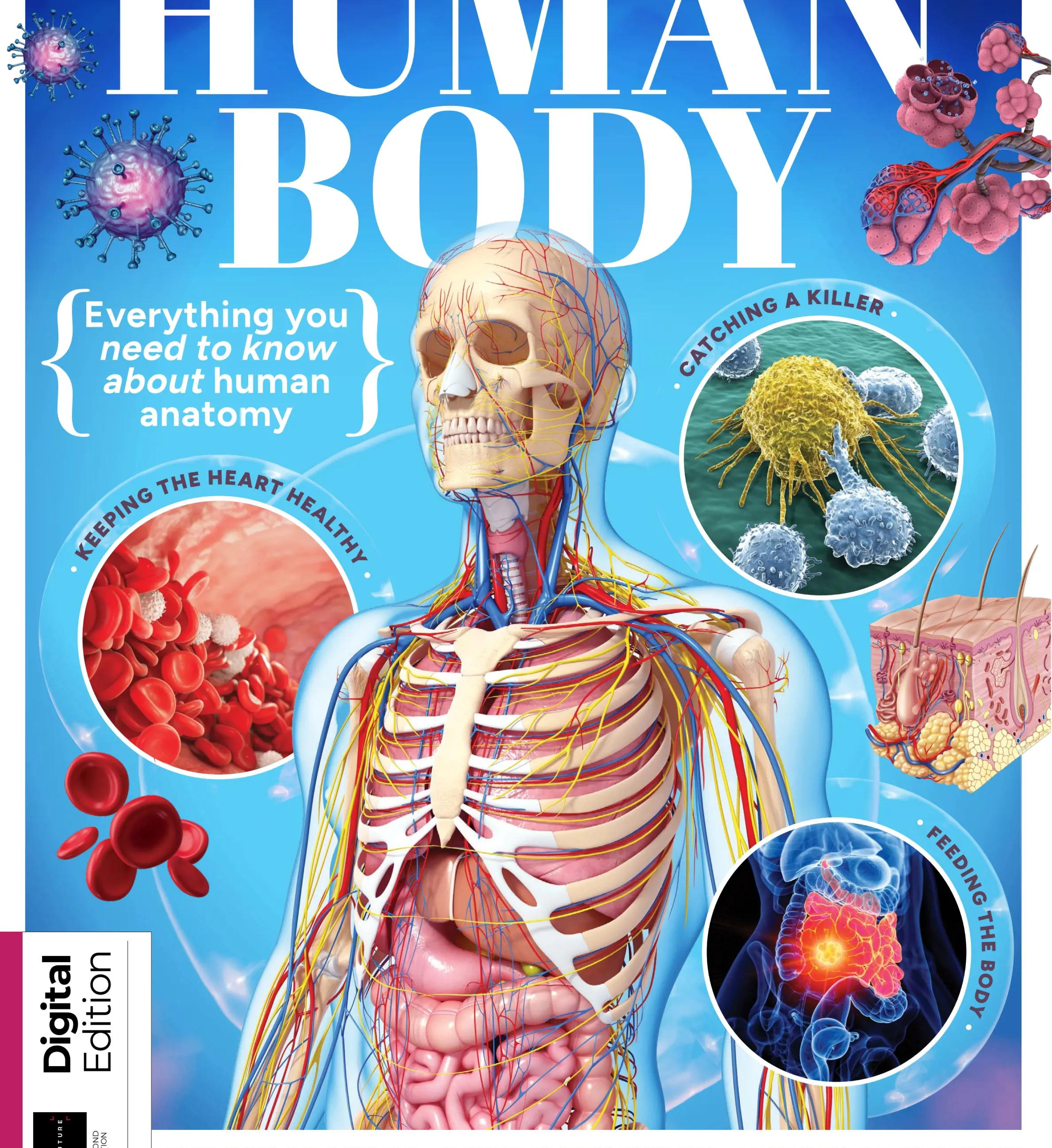
NEW

COMPLETE GUIDE TO THE HUMAN BODY



Everything you *need to know about* human anatomy

Digital Edition

FUTURE

SECOND EDITION

BIOLOGY OF AGEING • INSIDE EVERY SYSTEM • HISTORY OF ANATOMY

WELCOME

Ever wondered what's going on beneath the surface of your skin? Or what exactly the point of skin is? Or why that thought even crosses your mind? In this brand-new publication, discover the remarkable thing that is you! From the role of your organs and the body systems that they support, to how these systems work together to keep you alive, discover everything you could want to know about how you work.

Elsewhere, find out what happens to our bodies as we age, and track the fascinating history of anatomy and how we've come to learn all that we know about human beings.

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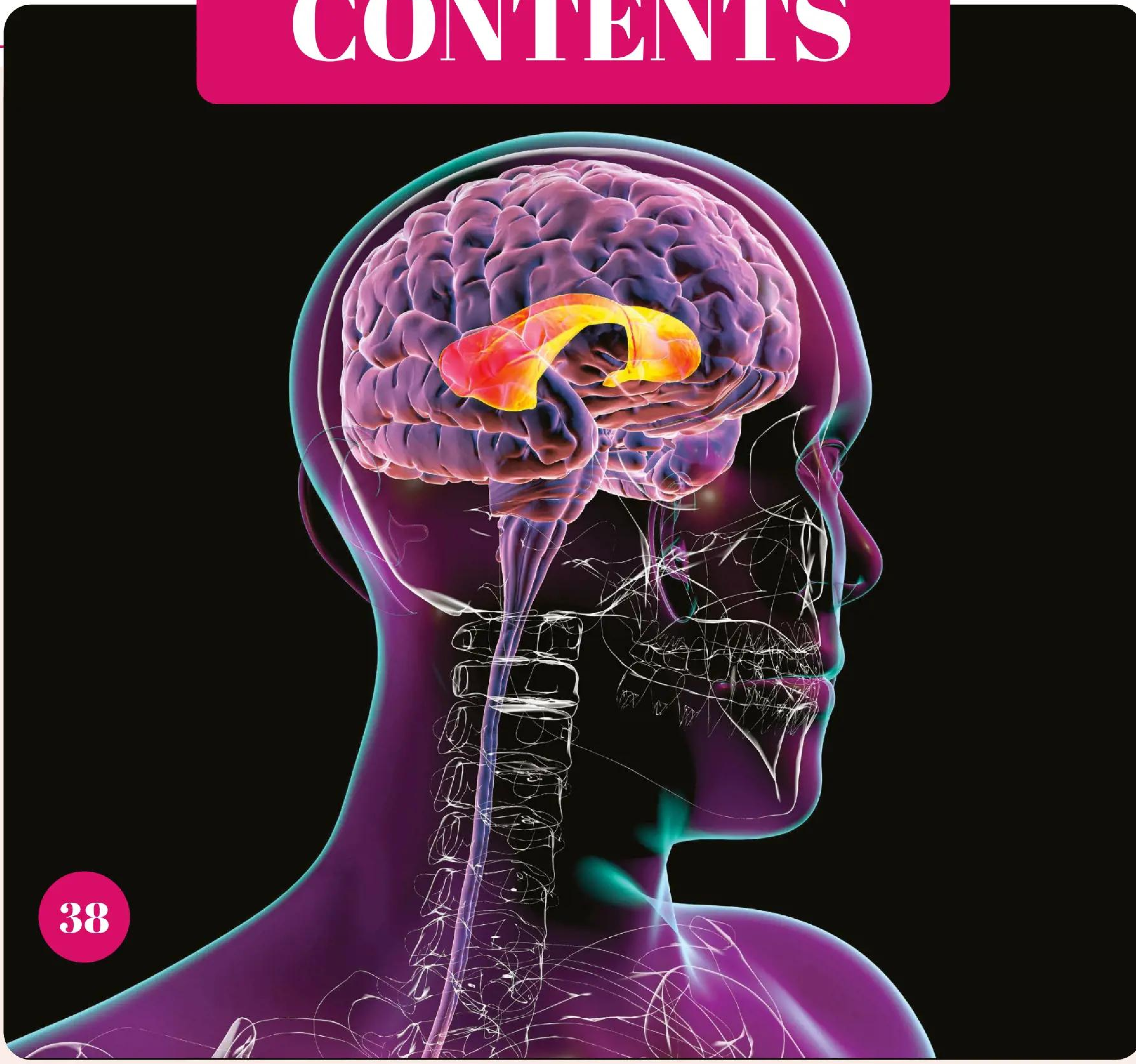

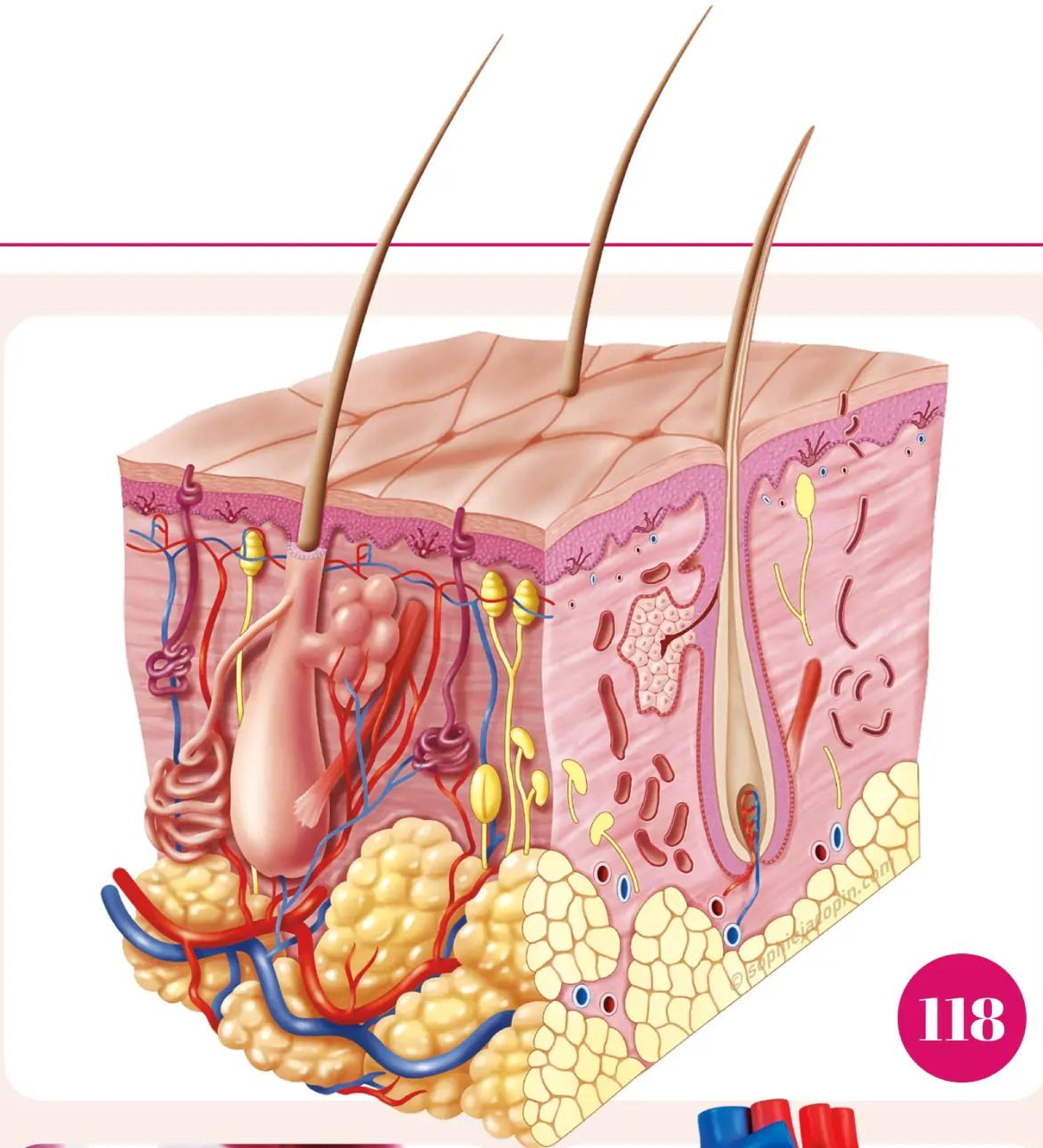
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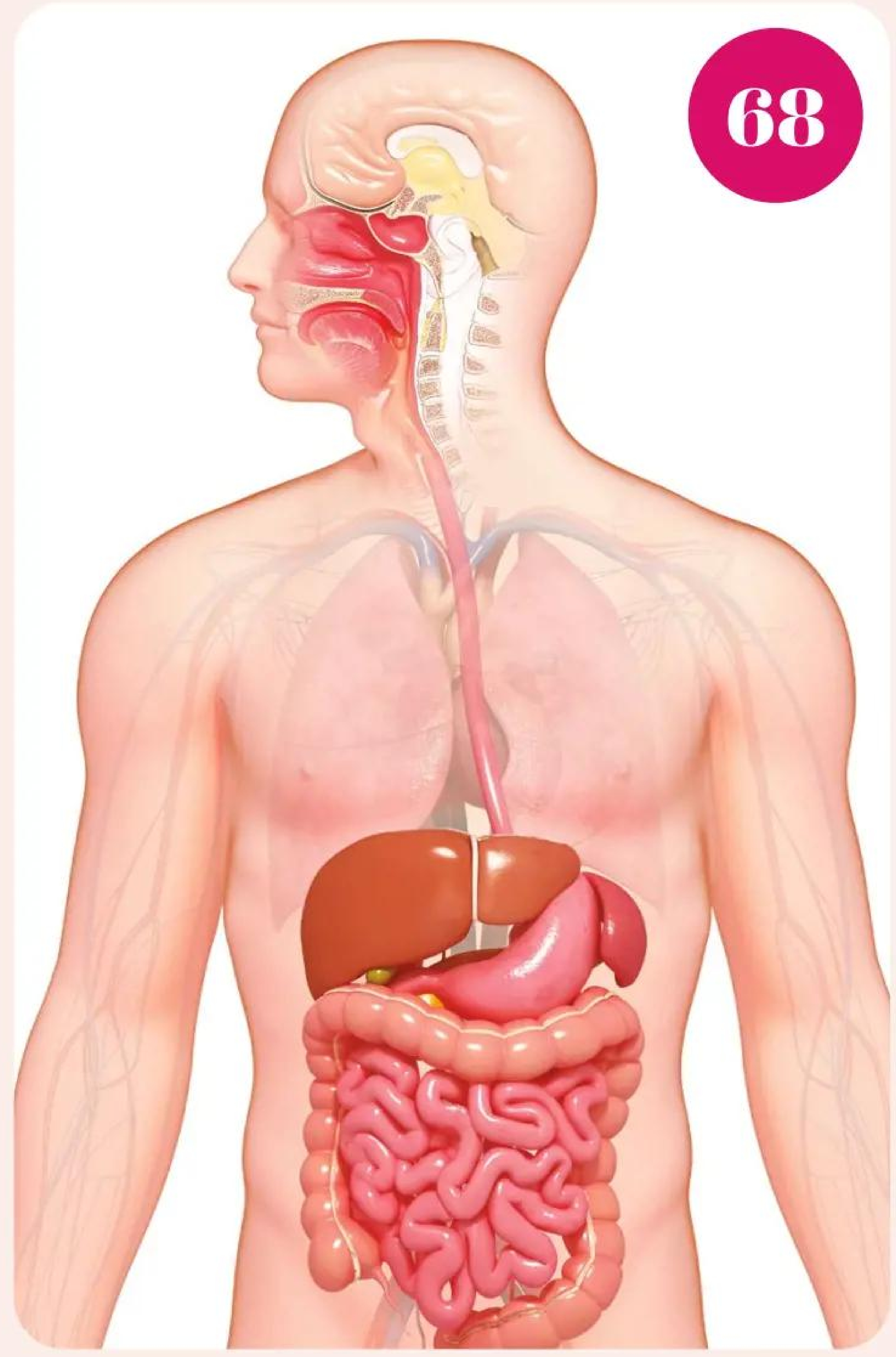
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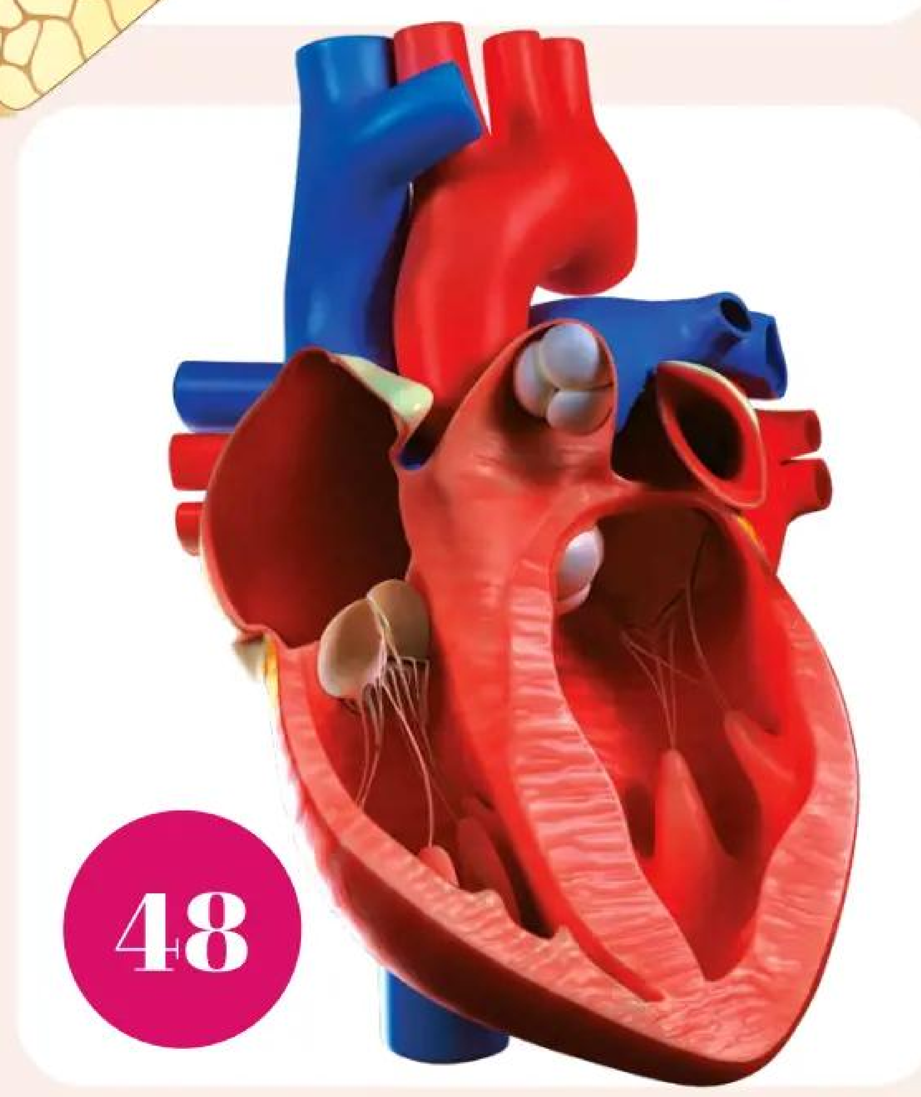
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Come with us on a journey under the skin.

HUMAN *ANATOMY*

What anatomy is and how this knowledge helps our understanding of the human body

WORDS BY EDOARDO ALBERT

This 1617 painting by Michiel Jansz van Mierevelt shows Dr Willem van der Meer dissecting a body surrounded by medical students

People are like books: different covers but on the inside, we're all red. In fact, given that two universal human experiences have been birth and war, it's apt that the earliest practical applications of anatomy came in midwifery and battlefield medicine. Later, these early applications were married to anatomy's partner, physiology.

A simple way of distinguishing the two is that anatomy is the study of the body and the way its parts are arranged, while physiology is the study of how bodies work. To put it even more simply: anatomy looks at what something is while physiology studies how that thing works.

History of anatomy

A visit to a medical dissection is sobering. The bright, sharply defined organs and vessels that you see in medical drawings or in Operation (the game) are not there. Instead, it's a bit of a mess: vague objects, strange tubes, all shoved in on top of each other with no obvious order. Opening the body is not like reading a book: its meaning has to be teased out. Couple this with the understandable reluctance of relatives to allow the bodies of their loved ones to be used as exploratory sites and it's perhaps no surprise that anatomy, as a scientific discipline, is relatively recent.

However, people did have a practical knowledge of some aspects of anatomy in the deep past. As part of the preparations for mummifying bodies, the Egyptians had to learn about the soft organs of the body in order to remove them, while the skills necessary to set broken bones stretch back before recorded history.

Apart from the Egyptians, the birth of settled civilisations did not bring any advances in anatomical knowledge as these ancient civilisations generally forbade the dissection of human bodies. One brief exception was around 300 BCE in the city of Alexandria, when the laws against dissection were lifted, and a Greek physician, Herophilus, made the first systematic dissections of corpses, distinguishing various parts of the body; he was the first to state that nerves are distinct from blood vessels and tendons.

The discoveries of Herophilus and his successors were assembled by Galen in his authoritative treatises, which became the foundation for medical knowledge during the next millennium. However, while there was little published work on anatomy during the Classical and Medieval eras, studies of excavated bodies show that doctors, particularly doctors from the Medieval period, had extensive practical knowledge of anatomy. This was demonstrated by the surgeries they carried out on men wounded in battle – a surprising proportion of whom survived despite suffering what appeared to be catastrophic injuries.

It was Leonardo, the archetypal Renaissance man, who put anatomy back on the page. His exquisite drawings of his own dissections became the precursor for the true founder of modern anatomy, Andreas Vesalius. Rather than relying on assistants, Vesalius did his own dissections while instructing surgery students. Doing so, he realised that much of Galen's work was inaccurate and he became a vocal advocate for critically appraising previous medical knowledge through personal investigation. His writings on anatomy revolutionised the subject, placing it on a scientific footing and providing the fledgling science with a systematic language with which to describe its findings.

Vesalius and his successors identified the major parts of the body, including the skeleton and its articulating muscles, the blood and nervous systems and also the digestive and reproductive systems. These detailed studies of anatomy led to major advances in physiology and, ultimately, to William Harvey's work on the circulation of the blood.

These early anatomists had opened the book of life and had started reading what it said. But at first they were limited to what is called gross anatomy; that is, what can be seen with the naked eye. However, as microscopes improved, anatomy was able to start moving in closer. With the improved equipment of the 19th century, anatomists realised that the cell is the fundamental unit of living creatures.

The 20th and 21st centuries have brought even higher magnifications, enabling anatomists to operate at the molecular level. However, these new discoveries all fit into the framework of knowledge first laid out by Vesalius in the 16th century – one of the most enduring advances in human knowledge ever made.

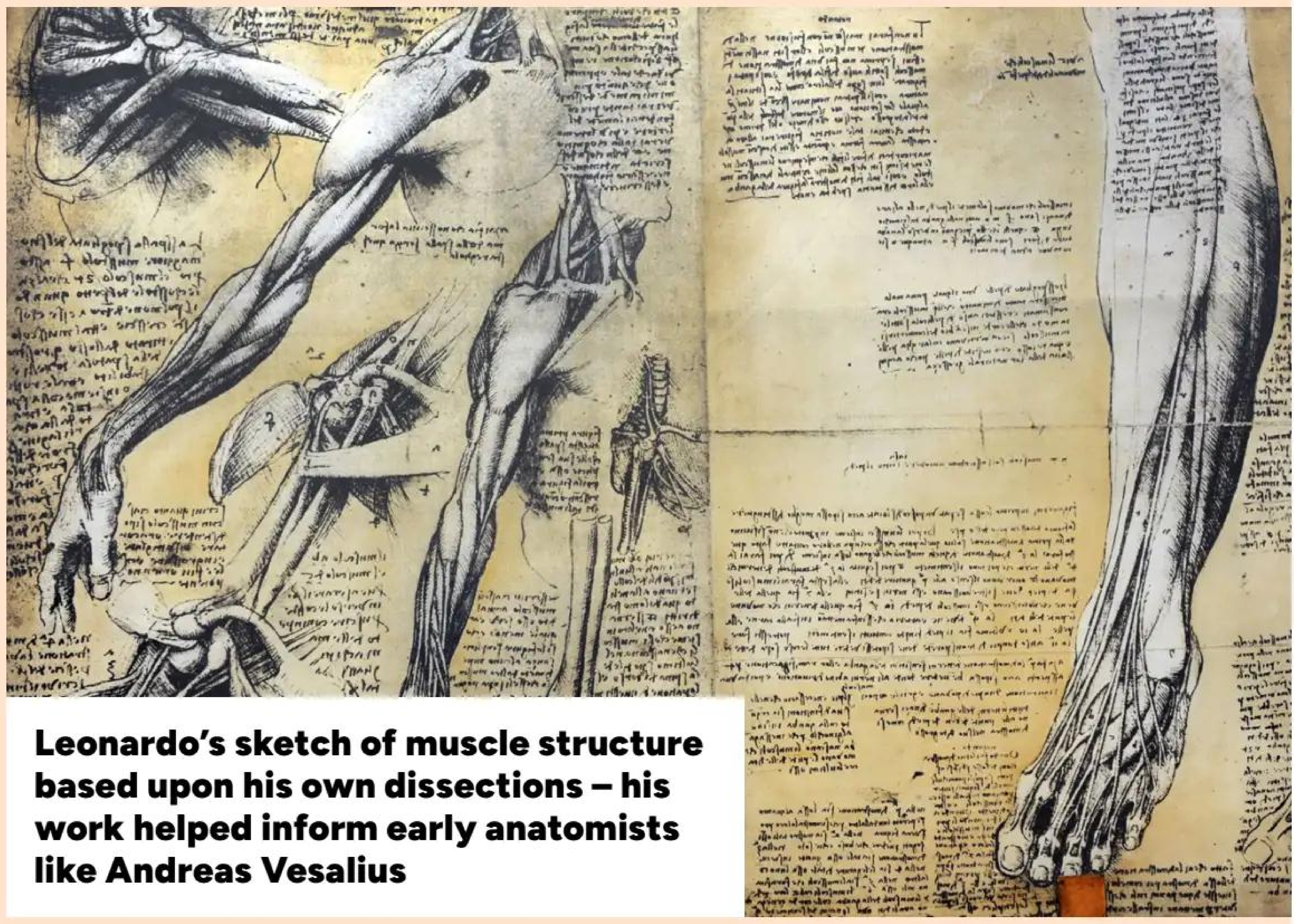
"Vesalius and the first anatomists mapped out the skeleton as carefully as a cartographer charting the ocean"

The anatomical divisions

The first anatomists had to explore the interior of the body by knife and eye. People had millennia of practical knowledge of bones but Vesalius and the first anatomists mapped out the skeleton as carefully as a cartographer charting the ocean. In doing so, the bones became the contours of the map of the body.

The normal adult body has 206 bones, although there are people who have more bones as a results of having extra digits, additional vertebrae and ribs. Bone is classified as a connective tissue – we will go into the different types of tissue later in this article – and the skeleton serves as the anchor point for muscles as well as providing protection for internal organs.

The need to specify the position of the bones in the body produced some of the foundational terminology of anatomy, terminology which can be daunting at first. However, knowing the meaning of a few terms will make understanding the different parts of the body easier.



Leonardo's sketch of muscle structure based upon his own dissections – his work helped inform early anatomists like Andreas Vesalius

Let's run through a few of the most important terms. Superior means higher in the body and inferior means lower in the body. This is fairly obvious. However, the next pair of terms – medial and lateral – can cause some confusion. Medial means nearer to the midline of the body and lateral means further from the midline of the body (the line being drawn between the legs, up through the genitals and belly button and out of the top of the head). When using anatomical terms, however, the body is imagined in a particular position, with the palms of the hands facing forward and the thumbs on the outside. The forearm has two parallel bones, the radius and the ulna. In a normal standing position, the radius and the ulna lie perpendicular to the body direction but, anatomically, with the palms facing forward, the radius is lateral, further out, and the ulna is medial, closer to the midline of the body. Finally, anterior means in front of the body and posterior indicates behind, while superficial and deep are thankfully self-explanatory.

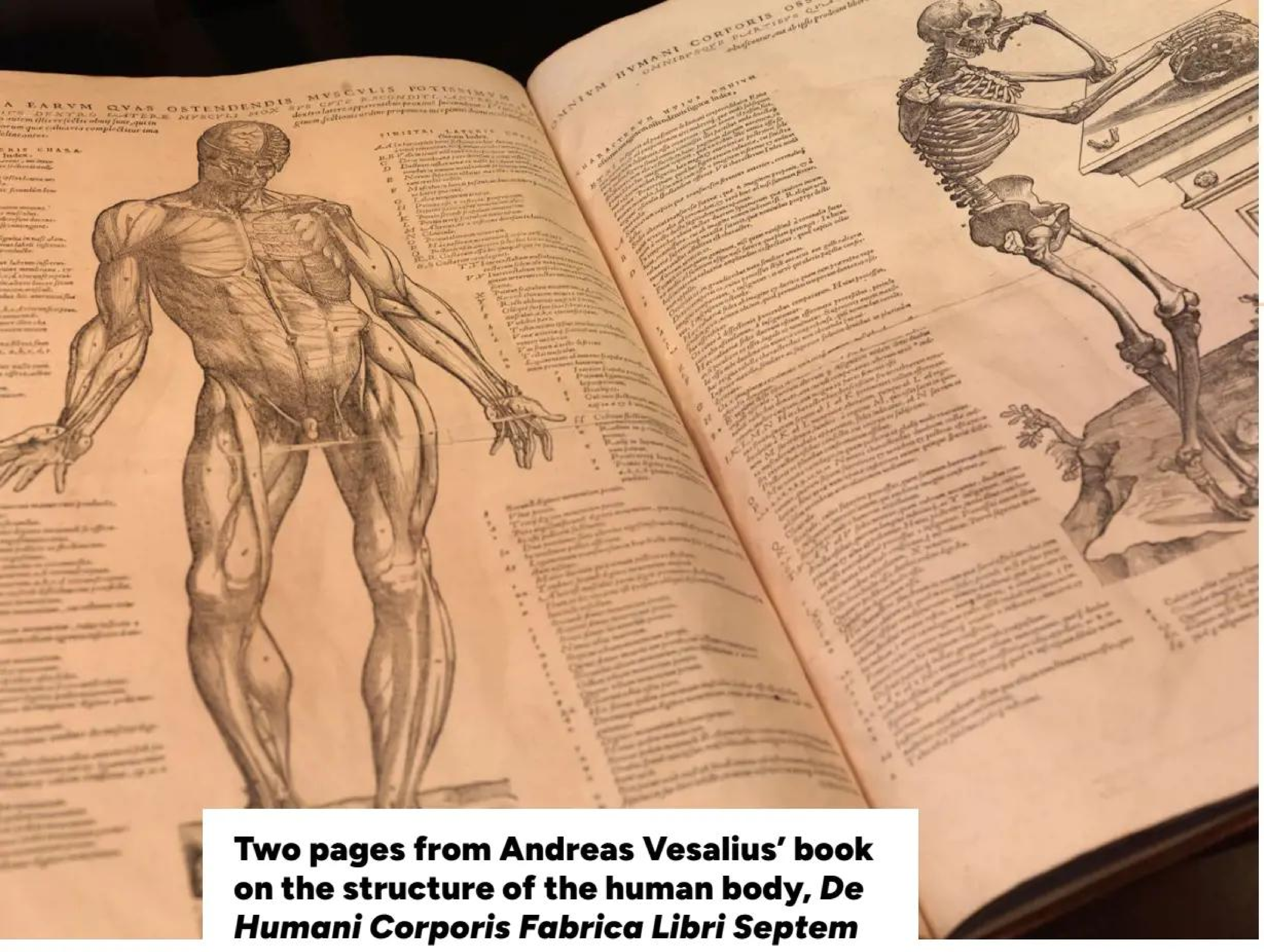
It took a while for a standardised list of terms to develop. By the mid-19th century, medical textbooks were bulging with different names for the same thing: there were 50,000 names for different body parts in use in Europe, often with a score of synonyms for the same part of the body. Doctors were getting lost in language. Faced with this medical confusion, in 1887 the German Anatomical Society began the mammoth task of simplifying and standardising medical terminology. By 1895, and with the help of other anatomical societies, the number of medical terms had been reduced to a more manageable 5,528. As anatomy has advanced, it has been necessary to add more names to the list, and the most recent edition of the *Terminologia Anatomica* has 7,500 entries, but that still represents a considerable improvement over the terminological effusion of the 19th century.

"By the mid-19th century, medical books were bulging with different names for the same thing"

The basic organisation of the body

Human beings are mammals and vertebrates. Our basic structure is provided by the spine and the attached bones. Movement is produced by muscles anchored to the bones. As well as providing the fulcrum of the body, the spinal cord serves as the conduit through which the

Cells, life's building blocks, come in all sorts of shapes: this is a blood cell



Two pages from Andreas Vesalius' book on the structure of the human body, ***De Humani Corporis Fabrica Libri Septem***

nerves in the spinal cord carry information to and from the brain.

The skeleton provides the supporting structure that supports internal cavities containing separate organ systems. The lungs are in the pleural cavity, and the liver, spleen and intestines lie in the abdominal cavity. The central nervous system is divided from the rest of the body by the blood-brain barrier.

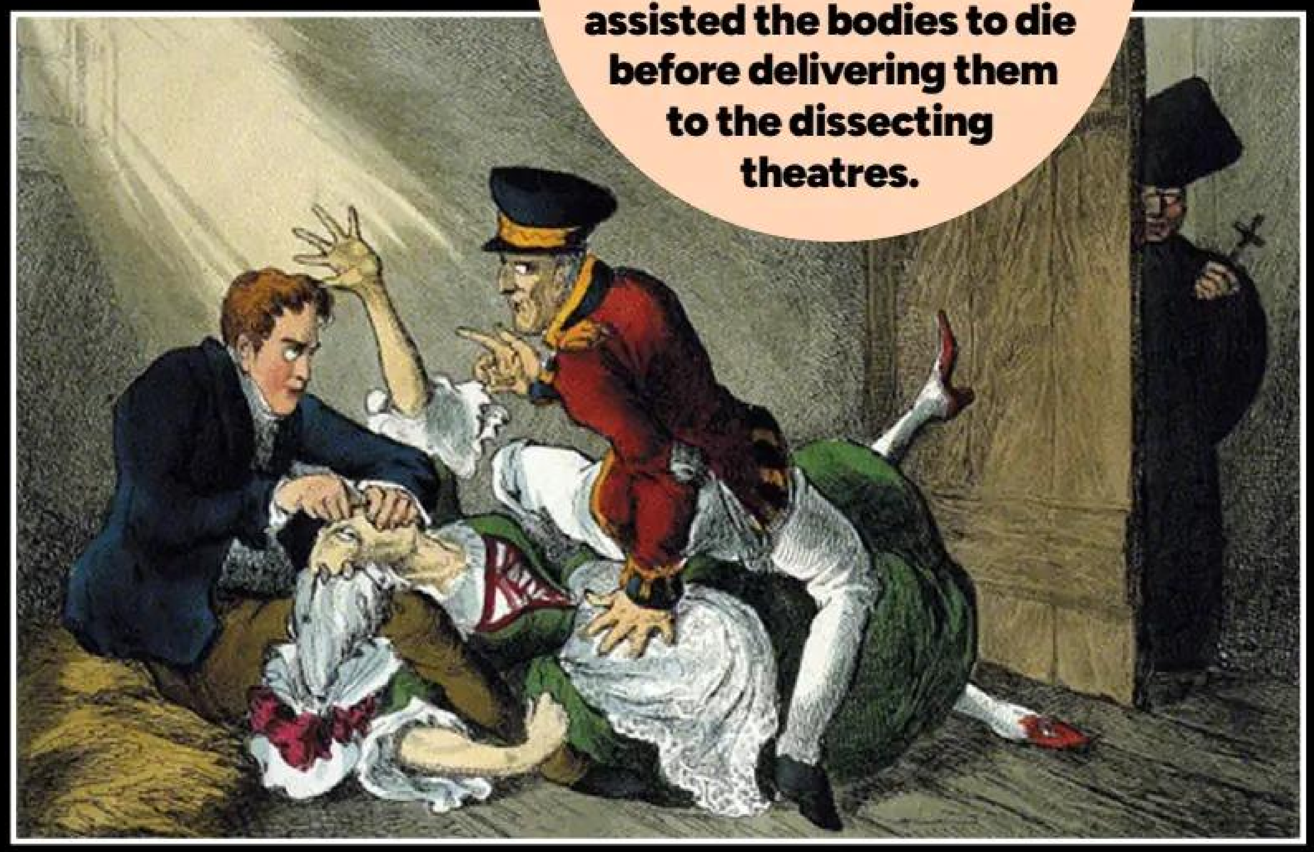
Working from small to big

It was 19th-century advances in microscopy that brought the discovery that the basic unit of the human body – indeed, of all living creatures – is the cell. Cells themselves can be classified into four basic groups: epithelial cells, which are basically the body's lining, including the skin and the covering for our organs, cavities and passageways; muscle cells, which are characterised by the ability to contract; nerve tissue, which can carry electrical signals; and connective tissue, which hold together body tissues (bones and blood are classified as connective tissue alongside the more obvious ligaments and tendons).

The first hunters, when eviscerating their prey, had already realised that animal and human bodies contain discrete internal structures that are not bones. These are the organs. Anatomically, an organ is a group of tissues that has a discrete structure and a particular function. To take the heart as an example, it is made up of all four types of tissue, it is a structural unit and its task is to pump blood around the body.

This is the human body in outline. But it's a fractal organism: look deeper and new levels of organisation are revealed. While we understand it better now, there is still plenty to learn. In the rest of this book, we go on a voyage of discovery under the skin. Enjoy the ride.

So great was the demand for cadavers in the 19th century that some suppliers, such as the notorious Burke and Hare, assisted the bodies to die before delivering them to the dissecting theatres.



Not enough bodies

The early anatomists often had to resort to extreme means to acquire the bodies they needed for dissection

One of the behaviours that distinguish humans from animals is that we dispose of our dead. Doing right by the dead is as old as our species and it serves many vital purposes, including binding the living and the dead in ongoing communion. But for anatomists, this care for our dead posed serious difficulties: how to acquire the bodies they needed to explore the great within. Andreas Vesalius started his explorations by stealing a body hanging from the gibbet outside his home town. As prohibitions against dissection eased, the bodies of executed criminals were often given to anatomists after a suitable period of display (although the processes of decay made dissection more difficult). In a macabre attempt to ensure the famous anatomist, Gabriele Falloppio, had a fresh body the authorities gave him a condemned, but still living criminal, with instructions that the body was his once he had carried out the execution. One can imagine a rather awkward interview: "Tell me, how would you like to die?". The criminal apparently asked for a pain-free end, which Falloppio gave him through an opiate injection. Other anatomists went further. William Harvey, who became famous for his discovery of the circulation of the blood, lost his father and sister to early deaths but, with a devotion to the advancement of knowledge that would be beyond most people, he dissected them both.

To overcome the shortfall of corpses necessary to train medical students, Parliament passed the Anatomy Act in 1832, which allowed medical schools to take the bodies of people who died penniless in the workhouses. Nowadays, people will their bodies to help train future generations of students. Vesalius would be amazed but gratified.

UNDERSTANDING *LIFESPAN*

The one thing that unites all of us is death and the steps along that long road

WORDS BY EDOARDO ALBERT

Birth, childhood, adolescence, adulthood, old age and death: the path we all follow.

While the Reaper can come at any age, thankfully he comes far less often for children today

There's a reason death is known as the great leveller. King or pauper, genius or fool – it makes no difference in the end. We all die. It's the great equaliser and the ineluctable fact of life. However, the last century has seen some extraordinary changes in how we die. And there are now whispers among some researchers that the Reaper might, in future, be delayed, even thwarted entirely. So let's look at the science of living and dying.

In the 6th century BCE, the Greek philosopher Heraclitus observed that you could never step into the same river twice. The body, our constant companion, might seem solid and enduring but it too is in a constant state of flux. Cells, the body's building blocks, are always being replaced, although the rate of change varies hugely. The rule of thumb is that those cells in contact with the outside world, the cells in the lungs, the stomach, the intestines, and the skin, are replaced rapidly. Those with less external contact endure longer: about ten percent of our skeleton is replaced annually, while the cells of the central nervous system are replaced only very slowly. The exception are the cells in the eye lens, which seem to age with us without being replaced.

This constant churn of replacement is carried out by our stem cells. We've only recently found out that, far from being only present in bone marrow, stem cells occur throughout the body. The number of stem cells reduces as we age and adult stem cells lose the ability to turn into any type of cell, becoming limited to a particular set of cells. Stem cells are attracting interest precisely because of their ability to become new types of cell. This is one of the most active fields of research in gerontology, the science of ageing.

Gerontology has developed greatly over the last few decades in response to huge changes in lifespan and mortality. In 1900, the average life expectancy in the UK was 47 years. In 2000, that had increased to 77 years. By 2020, that had improved further, to 81 years. This improvement has been worldwide and, while most pronounced in developing countries, it has occurred everywhere. In 1950, the people of Chad, one of the poorest countries in the world, had a life expectancy of 35 years. In 2022, that had increased to 55 years. The largest reason for the change is the reduction in infant mortality. In 1900, for every thousand babies born, 228 would die before reaching the age of five (in 1800, the figure was 329 in a thousand). So in that century, the rate of survival had improved from one in three to one in four. But by the year 2000, in the UK only seven children in a thousand died before their fifth birthday. For the first time in human history, parents can be confident of seeing all their children grow to adulthood.

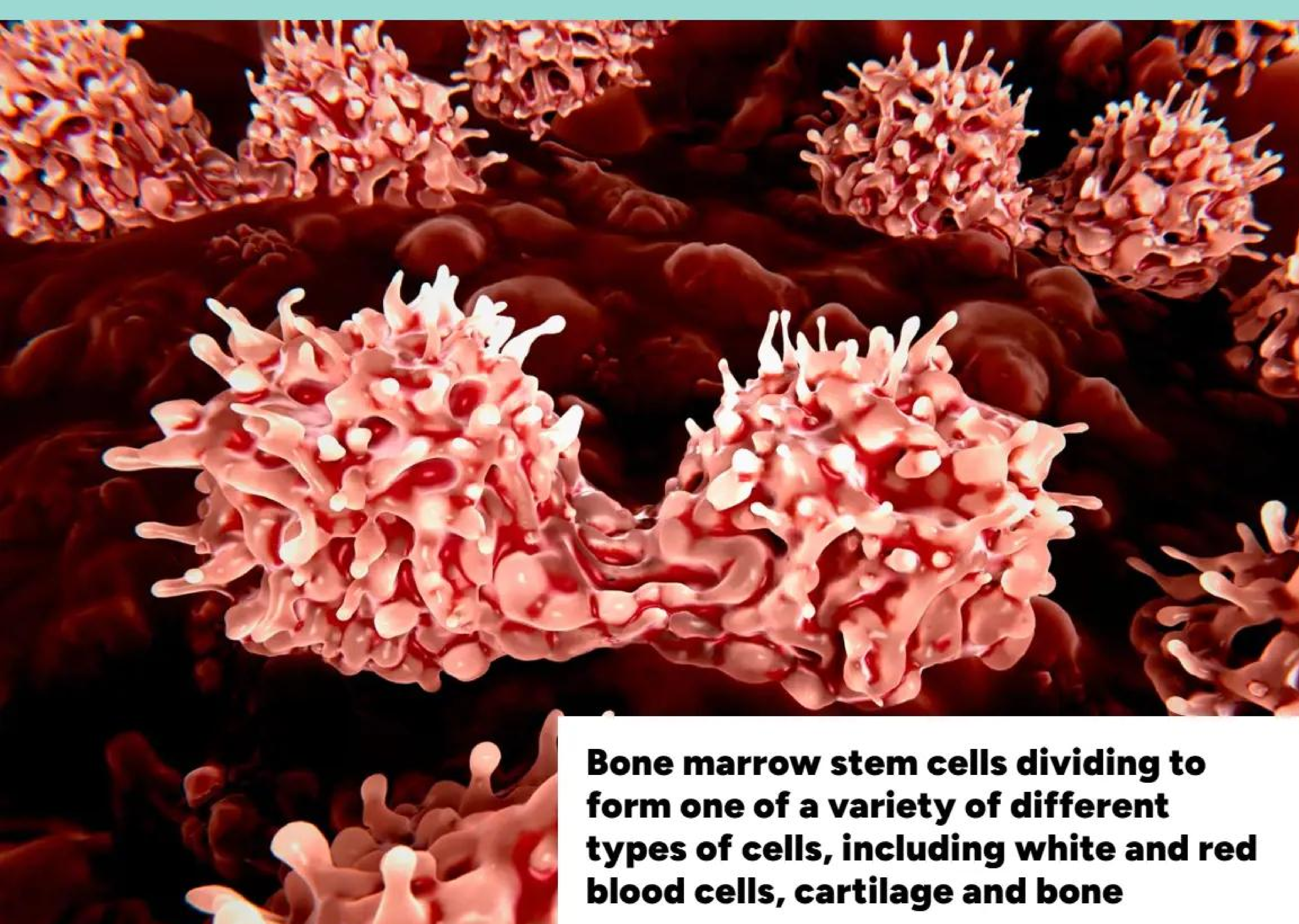
The other major change is how we die. In 1900, half of deaths were caused by infectious diseases such as tuberculosis and diphtheria. Now, infectious diseases are responsible for only a few percent of deaths. Today, we die from non-communicable diseases such as heart disease, cancer, strokes and dementia.

The modern ways of death are aspects of lifestyles. It's why the popular press is full of features about how changing your diet can reduce the risk of heart disease or cancer. We all know now that if you stop smoking, you greatly reduce the chance of getting lung cancer. Also, along with the features on healthy lifestyles you'll probably also see articles about middle-aged tech billionaires who have employed an army of health consultants and doctors to lengthen their lifespans.

The good news – for us, if not for the tech billionaires – is that all that expensive advice is almost useless. The lifestyle rules for living longer are simple and anyone can follow them. Keep active, both physically and mentally. Eat sensibly and don't get fat. Drink in moderation and don't smoke or take drugs. Stay engaged socially, cultivating relationships with family and friends (lonely people demonstrably die younger).

And really, that's it. All the rest is over-hyped nonsense that might, statistically, add a few days to average lifespans but nothing more. Indeed, even if we were to win the much-desired fight against cancer, it would probably add just over three years to the average life. Eliminating heart disease would give us a further five-and-a-half years. However, if we should suddenly find a cure for Alzheimer's and other forms of dementia, it would only add 19 days to the average lifespan. Obviously, though, any extra time with loved ones is desired.

"The lifestyle rules for living longer are simple. Keep active, eat sensibly, drink in moderation, don't smoke or take drugs"



Bone marrow stem cells dividing to form one of a variety of different types of cells, including white and red blood cells, cartilage and bone

Because while we're living longer, an increasing proportion of that increase is spent in ill health. In Victorian times, death normally followed quickly upon final illness: a short, sharp dying. Now, we decline slowly, with the majority of people spending a month or two in intensive care following years of increasing frailty.

As such, the best response to ageing is not to try to live longer but to live better. For that, the strategies already mentioned are the best because there's not much we can do about the other fundamental factor: our parents. Reaching the age of 80 is largely a question of lifestyle but after that it's mostly down to genetics. The oldest woman in history, Jeanne Louise Calment, lived to 122 despite continuing to smoke until she was 117 and eating a kilo of chocolate a week, single-handedly defying all the typical advice for living longer.

The advice is general because we don't understand ageing. Its physical manifestations are obvious and occur across species: skin loses elasticity, blood vessels break more easily, the immune system becomes less effective. All the physical systems deteriorate. At the most basic level, the heart becomes less efficient as we age, driving steadily lower volumes of blood around the body. This is one of the reasons that remaining physically active is vital, as this is the best way to slow down this deterioration.

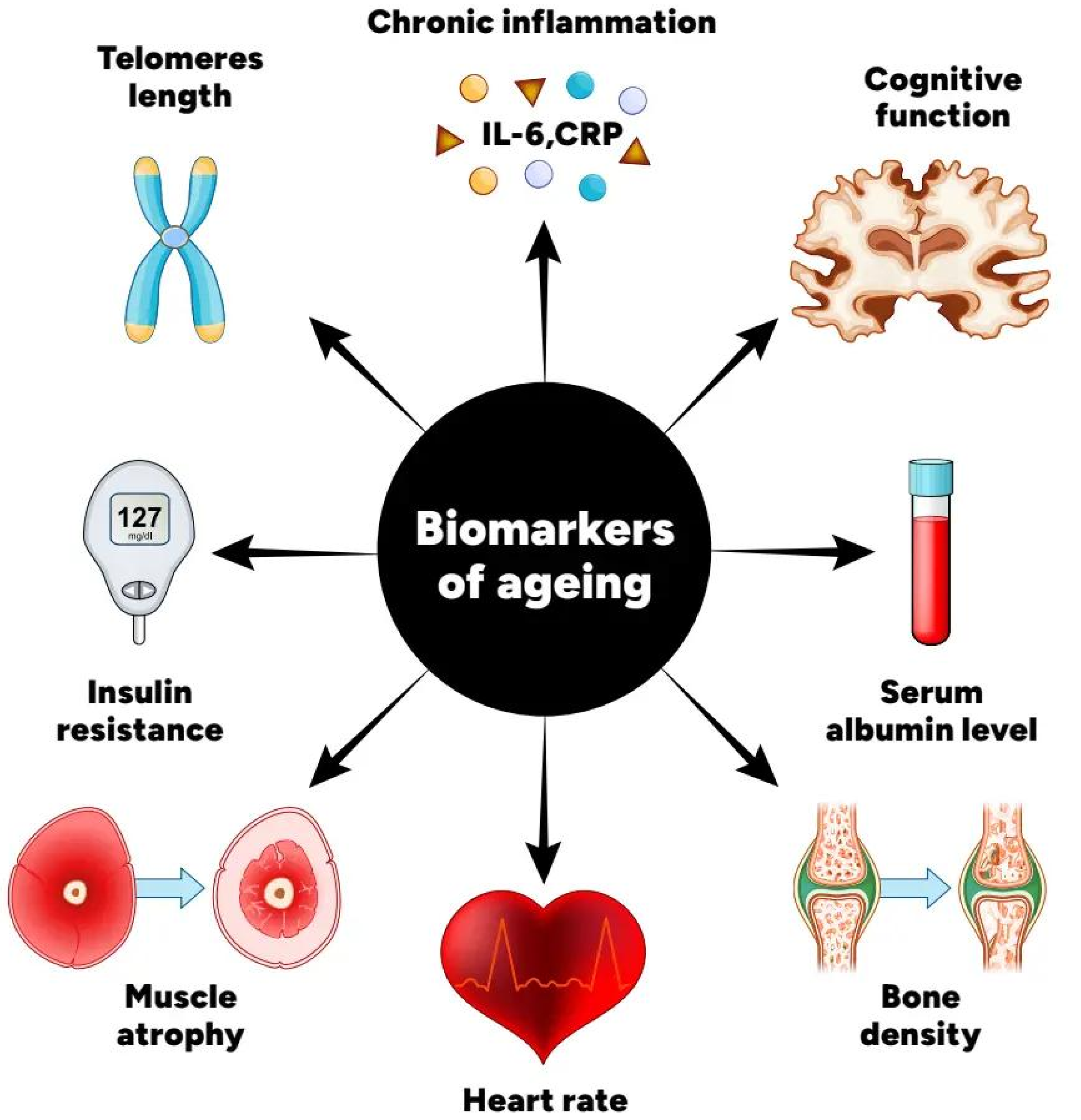
One aspect of ageing is, however, almost unique to us as a species: the menopause. In all other land-based mammals, death follows closely upon the cessation of reproductive ability. It is only women who can live for decades with no further possibility of having children. The only other animals that share this characteristic with us are not our nearest relatives among the apes but some species of whale: orcas, short-finned pilot whales and, recently added to the list, belugas and narwhals. Scientists theorise that menopause developed in humans because the physical dangers of pregnancy become too great with increasing age but continuing to live allows the mother to help her own children survive. This is supplemented by the grandmother hypothesis, which states that stopping reproduction in middle age allows a woman to help her grandchildren survive too: ensuring the survival of four grandchildren is equivalent, genetically speaking, to having an additional child. When the risk of childbearing becomes too great, grandchildren become the better genetic investment.

While women lose the ability to reproduce, men can continue to father children into old age. But the curious fact is that, as measured across all known cultures and times, men statistically live shorter lives than women. This is even stranger when coupled with the fact that men, naturally, don't face the risk of childbirth, which has killed a significant proportion of women. From the mid-19th century, when cause of death was first required on death certificates, we find a rate of about 50 mothers dying for every thousand births – that is, women had a one in 20 chance of dying when giving birth (that has reduced to a one in 10,000 chance in Britain today).

So if you want to live to a great age, be a woman, live moderately, exercise carefully, keep active and social, and take great care in choosing your parents. It also helps to be well off. Socio-economic status is a clear predictor of age at death: while the meek might inherit the earth, the rich live here longer.

Orcas are among the very few animals to also experience the menopause

The biology of ageing



But as to why we age: we don't know. There are literally hundreds of theories, which can be grouped into three major categories: the build up of cellular waste, wear and tear, and genetic mutation. Any one of these might be true, or any combination of them, or it might be something else entirely.

The crux of the matter is that, however much care you take with your lifestyle and even with the best set of genes, your body is programmed to die. The first realisation of that came in 1961 when Leonard Hayflick found that human stem cells grown in the lab could divide 50 times but after that, they ceased to work. Cells have senescence built in. Later work found that part of the cell's DNA, called telomeres, counted down the division clock: the telomere chain shortens with each cell division until, after roughly 50 divisions, the telomere chain ends and cell division ceases.

Not surprisingly, this finding produced much excitement. Find some way to stop the telomeres shortening and we could stop, even reverse, ageing. Unfortunately, decades of work have shown this is not the case. Many more processes are involved in ageing alongside telomeres and messing about with telomeres can have unforeseen consequences: telomerase, the enzyme that tells the cell it has reached its telomere limit, also sets off cancerous growth, by telling a cell to keep on dividing.

Among gerontologists there's a huge spread of thought as to the limits of their science. Some believe the body is hardwired to an age limit of about a hundred years and it is impossible to change this. Others think advances in various fields, particularly our understanding of gene therapy, will enable significant extension of the human life span. In essence, they believe that it will be possible to slow down the ageing clock or even to stop it entirely.

Scientists searching for the Elixir of Life have little difficulty finding funding for their research, as this is a search that has been going on since the dawn of history. Whether it will succeed remains to be seen but perhaps more thought ought to be given to the consequences should it succeed: a division between those who can pay for life-prolonging treatment and those who can't would be the most fundamental division in human history.

Jeanne Calment, who died in 1997 at the age of 122, was 39 when the World War I broke out

Growing up and growing old

How we change, from birth to death

STAGE 1: Newborns (0-3 months)

Ejected unceremoniously into the world, the newborn first has to breathe. Babies have heads that are proportionally much bigger than adults, taking a quarter of the body in comparison to an eighth. Parts of the skull are still soft: the fontanelles.

STAGE 2: Babies (4-24 months)

This is a time of extraordinary growth. By two, a baby's height will have grown by 75 percent while his or her weight will have increased by a factor of four. The brain undergoes tremendous development as the child learns to move and starts to speak. Teeth break through.

STAGE 3: Toddlers (2-3 years)

As suggested by the name, toddlers' development is particularly concerned with learning to stand and then walk. The brain makes connections with its muscles, refining control with cells specialising in their functions. Speech continues to develop.

STAGE 4: Children (4-12)

After the explosive growth of the first years, growth slows but continues steadily. Muscle control becomes more refined while overall strength increases. Brain development prioritises learning, particularly through widening social interactions and in play.

STAGE 5: Teenagers (13-17)

Having had relatively steady growth through childhood, puberty floods the body with new hormones. The reproductive organs develop, girls start menstruating and boys' voices break. Peer relations become increasingly important and risk-taking increases. It's a rough ride.

STAGE 6: Adults (18-64)

The body reaches its peak in different areas at different times. For explosive sports it's in the mid-20s, while for endurance sports the mid-30s are the best. Most Nobel prizes are given to work done by men and women in early adulthood but artistic ability matures later. Emotional and social intelligence continues to improve as we age: people get demonstrably pleasanter as they age.

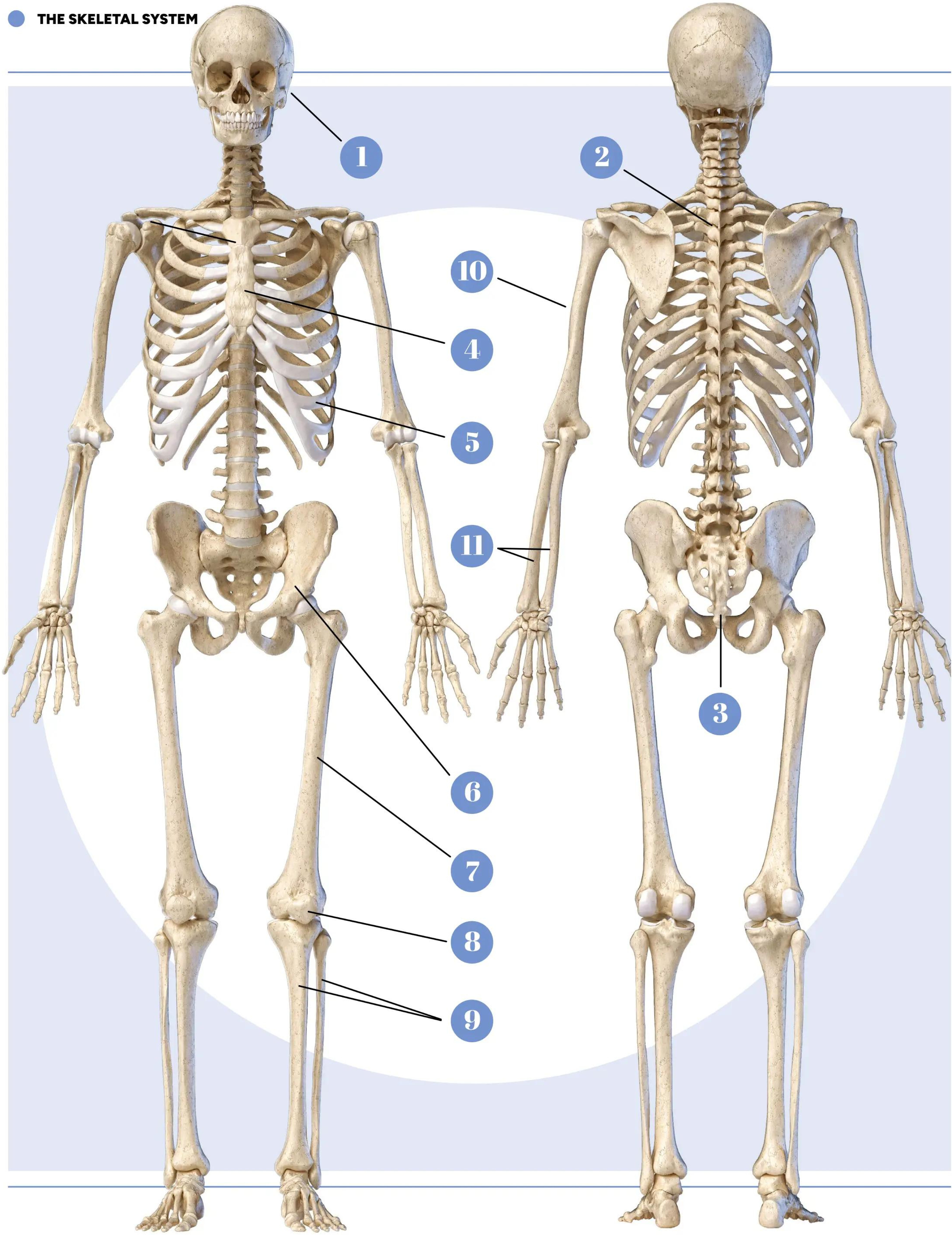
STAGE 7: Older adults (65+)

Ageing brings a gradual lessening of physical abilities. The heart pumps less blood, we lose bone tissue so bones become more brittle and brain neurones start to die. In all cases, a 'use it or lose it' clause applies. Even an active pensioner will notice a decline – but the decline will be slower than for people who sit on the sofa and stare at the TV.

THE *SKELETAL SYSTEM*

Our scaffolding is on the inside – but bones do more than just hold us up

WORDS BY EDOARDO ALBERT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BREAKDOWN OF A SYSTEM

1

Skull

The skull is actually composed of 22 bones, which fuse together during childhood.

2

Spine

Working from bottom to top, the spine is composed of five fused sacral vertebrae, five lumbar vertebrae, 12 thoracic vertebrae and seven cervical vertebrae.

3

Coccyx

This is the end of the spine. It comes from the Greek word for the beak of a cuckoo, because it's supposed to look like this (ornithologists demur).

4

Sternum

The sternum, or breastbone as it's also known, helps protect the heart, oesophagus and lungs, and connects to the ribs through coastal cartilages.

5

Ribs

The rib cage protects the lungs and heart. There are 24 ribs, 12 on each side. Flexible coastal cartilage connecting the ribs to the sternum enable the rib cage to expand and contract as we breathe.

6

Pelvis

The pelvis connects the upper body to the legs, protects the intestines, bladder and sex organs, and supports the trunk. Unlike other parts of the body, there are marked differences between female and male pelvises to allow women to give birth.

7

Femur

The femur is the longest bone in the body. It fits into the pelvis via a ball-and-socket joint while the knee joint is supported by two collateral and two cruciate ligaments.

8

Patella

The patella sits at the front of the knee, protecting the joint.

9

Tibia and fibula

We have two bones in our calves. The tibia is the thicker bone on the inside and the fibula is the thinner bone on the outside.

10

Humerus

The humerus is the largest bone in the upper body, connecting shoulder to elbow.

11

Ulna and radius

Two bones support the forearm. With your palms facing forward, the radius is the outer bone and the ulna is the inner bone.

Fact file

Everything you need to know about the skeletal system

What does the system do?

It holds the body up and provides the pivot points that the muscles move.

Why is it important?

Without it, we'd be a pile of goo.

When does this system develop in a foetus?

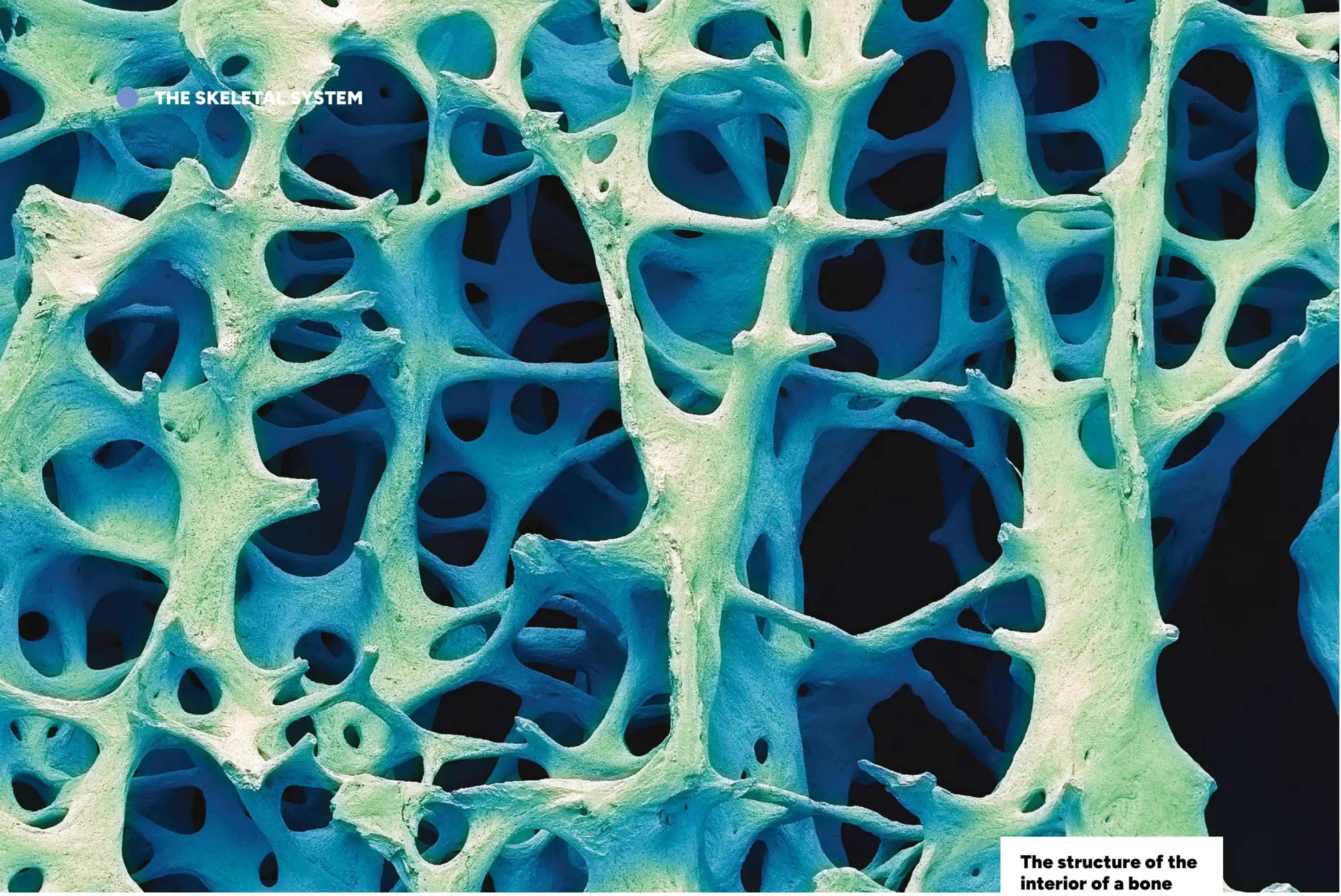
The spinal column starts developing between six and seven weeks into pregnancy but bone growth continues into adulthood, not stopping until the mid-20s.

What organs are part of this system?

Bones.

What are common conditions associated with this system?

Arthritis and scoliosis.



The structure of the interior of a bone

© Getty

Standing up isn't easy. We forget as we get older, but any parent watching their wobbly baby making their first steps, sees how difficult it is to coordinate legs, body and arms, and then get them moving. The difficulty is gravity. Get your balance wrong and gravity grabs you, dragging you back down to the ground.

It was much easier in the sea. Water is thick. It's supportive. Stop moving and you'll just lie there, supported by the sea. It's possible for underwater creatures to grow huge and rely on the support of the water all around them. In 1886, a lion's mane jellyfish was measured with a 2.1-metre (7-foot) bell (the floaty bit on top) and tentacles extending 36.6 metres (120 feet). But, you might say, a jellyfish lives up to its name: all it does is float around in the sea, like an underwater balloon. It doesn't need anything to give it a structure.

Then let us present to you Mr Octopus. The largest giant Pacific octopus found was ten metres (33 feet) across and weighed 272 kilograms (600 pounds). Unlike jellyfish, octopuses do not just hang in the water but crawl, in sinuous waves, over the sea bottom, as well as swimming by tentacle paddling and also by jet propulsion. They do all this without a skeleton. This is possible because the surrounding water holds and confines the bodies of undersea creatures.

But when life first emerged from the water, it was faced with a vast range of difficulties to overcome. The first land plants adapted by staying low and close to the water, trailing green fingers into seas and rivers. But with the light coming from above, growing up towards the light benefited these first plants and they solved the problem of support by pumping so much water into the cells of their stems, they became strong enough to hold the plant upright against the constant drag of gravity.

However, this sort of support will only go so high. To make trees, a different form of support was required: wood.

That's all very well for plants, but animals have to move. The easiest way of supporting a body against the effects of gravity, as well as protecting it from dehydration, is through having a hard, impermeable skin, an exoskeleton. This is the solution to the problem of support taken by insects. But exoskeletons present their own problems. In particular, growth is difficult when encased in rigid armour.

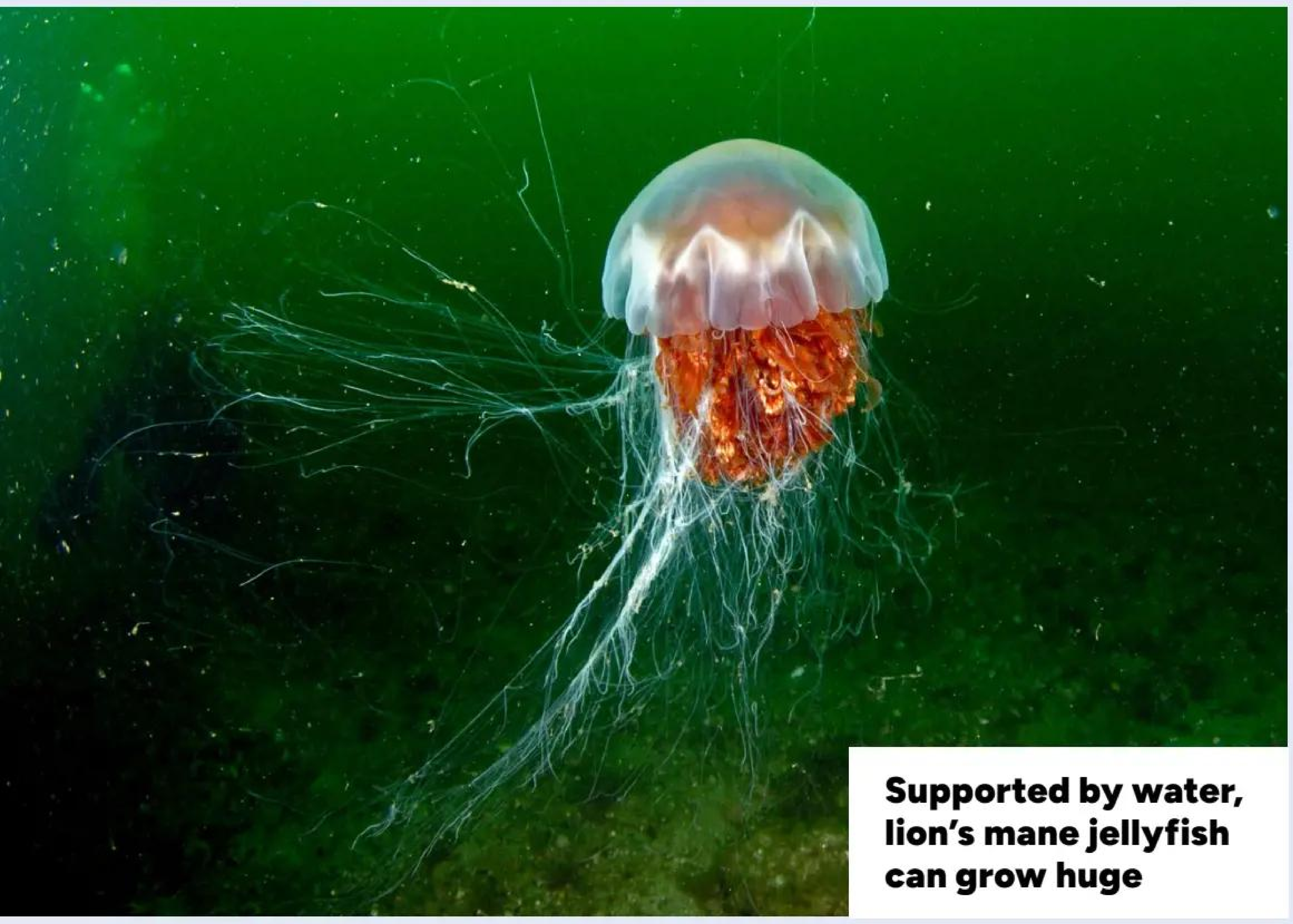
For larger animals, including humans, the problem of support on land was solved by having skeletons on the inside and wrapping flesh and muscle around them.

Most people have 206 bones. This number is not rigid, as about 13 percent of the population have an extra pair of ribs and children born with Down's syndrome often lack a pair of ribs. These are the most common reasons for extra or fewer bones, although somewhere between one in 500 and one in 1,000 children are born with an additional finger or toe.

Our bones are not evenly spread through our bodies. There are 52 bones in the feet and 54 in the hands, so over half our bones are present in our extremities.

Remove the bones from a body and we would sink into a quivering mound of flesh and rapidly expire. But while the skeleton's most obvious role is as support, it also acts as a set of mobile pivots, providing the binding points for muscles, tendons and ligaments while running through a huge range of motions, from the almost 360-degree freedom of the shoulder to the relatively restricted hinge movements of the elbow and knee, to the fused bones that make the skull.

However, the skeleton has other jobs apart from scaffolding. Being hard and strong, it protects the vital organs of the interior. The ribs wrap protective bands



Supported by water, lion's mane jellyfish can grow huge

"While the skeleton's most obvious role is as support, it also acts as a set of mobile pivots for muscles, tendons and ligaments"

around our lungs and heart, while the brain, something of a primadonna among organs, demands and gets its very own crash helmet in the skull.

Bones are hollow but not empty: they're filled with marrow that churns out the billions of blood cells we need during our lifetimes. Bone marrow makes up about five percent of total body weight and produces 500 billion of blood cells every day. Which means that during an average life time of 80 years, our bone marrow produces 3 quadrillion blood cells (that is a 3 followed by 15 zeros). And it's not just red blood cells the marrow produces, but also white blood cells and platelets. Which means that bone marrow is an intrinsic part of our immune system, too.

In fact, there are three types of bones if we classify them by their function, although many bones serve two or all three of these functions. The function we all know is making joints, the articulation points for our body (although some joints, particularly those between the different plates in the skull, fuse and become rigid). Then there are the bones that contain marrow and churn out all those different sorts of blood cells. Among these bones are the femur, pelvis, humerus and sternum (although they are also parts of joints). And finally, bones also store fat. Yes, rather surprisingly, some bones store fat in the form of adipose tissue. These bones have yellow bone marrow rather than red bone marrow. The stored adipose tissue can be converted to triglyceride and released back into the body if it is needed. In newborns, pretty much all bone marrow is of the red, blood-cell producing type but as we get older, the bones in our arms and legs convert to yellow marrow so that they can store fat.

Three tiny bones in our ears, the hammer, anvil and stirrup, or malleus, incus and stapes, take the sound vibrations that set our ear drums vibrating and transmit them, via their own motion, to the inner ear, where motion is turned into nerve signals to send to the brain. So, a small part of the skeleton is vital for hearing.

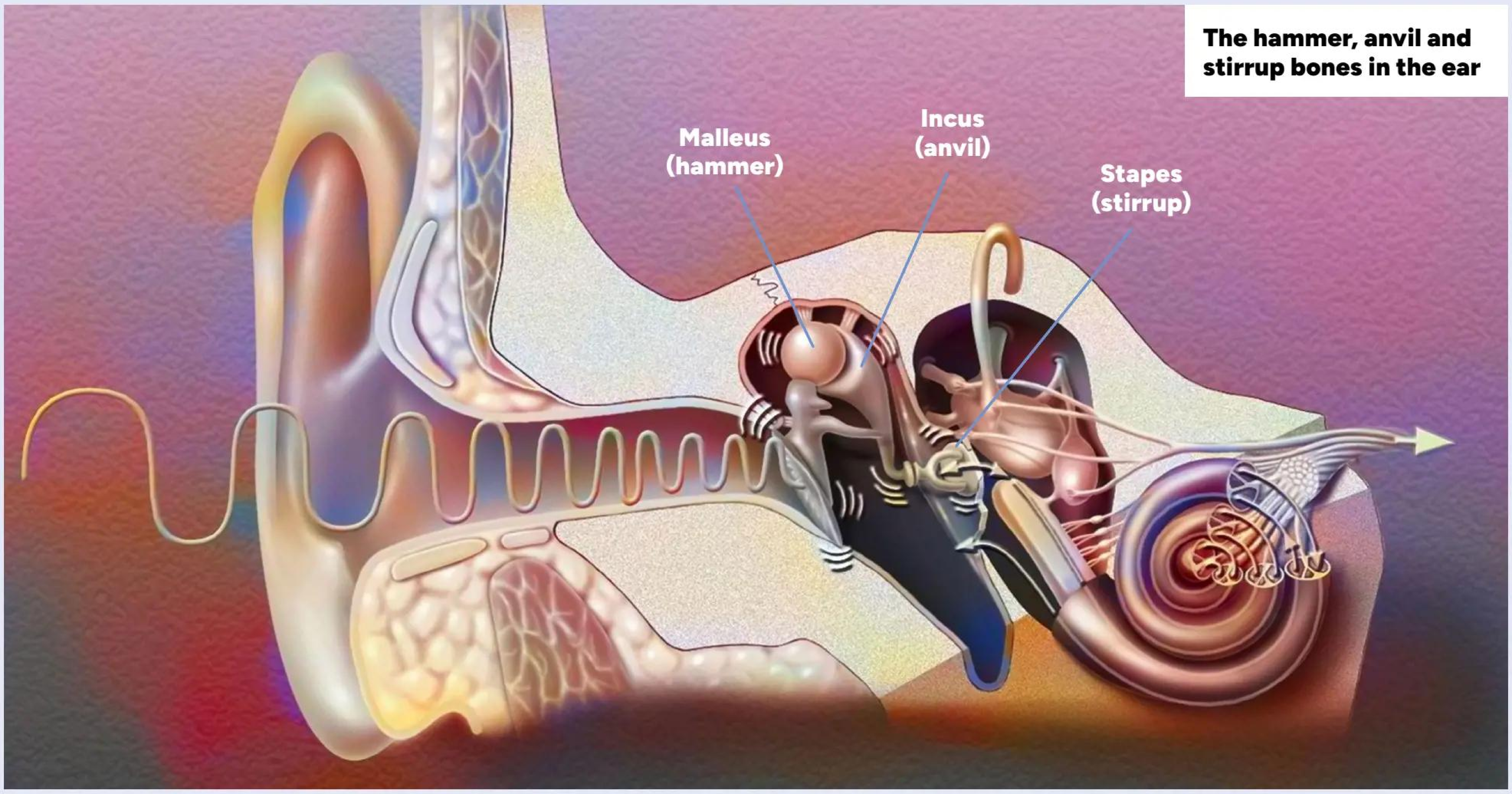
The skeleton, the hard, inert residue of our earthly lives that archaeologists dig up centuries later, might also play a role in memory and emotions. This role really does come as a surprise. It turns out that the skeleton is part of our endocrine system (the hormones that regulate the body's functions). Bones produce osteocalcin and at the start of the century, geneticist Gerard Karsenty discovered that osteocalcin is also a hormone (it was previously known for binding calcium into bones). With its hormonal hat on, osteocalcin helps to regulate glucose levels, affects moods, increases male fertility and facilitates spatial learning and memory formation. This last role could be particularly important in explaining a medical mystery. Doctors have long observed that regular exercise slows down the progress of Alzheimer's and dementia without knowing why. But regular exercise strengthens bones and stronger bones produce more osteocalcin, so this might be the reason why exercise benefits dementia sufferers.

In fact, bones are another example of the general biological maxim of 'use it or lose it'. Astronauts undergoing zero gravity in space are always placed on a vigorous exercise regime, but no matter how much

In space, no one needs bones, so the body starts breaking them down.

exercise they do, they still lose bone mass while in orbit. This confirms that gravity is the great bone maker. Not having to support itself against gravity's overwhelming pull, the body simply starts converting bone to other uses. If we should ever get to create space colonies, their native inhabitants might find that they could never venture down the gravity well.

Bones work the other way, as well. If you use your bones, then they will grow. The excavated skeletons of medieval archers reveal that the shoulder and arm used to draw back the bowstring – strings that had a pull of 120 pounds – became hugely developed in comparison to the other arm and shoulder. The same is true for sportspeople who pursue sports that use the dominant



The hammer, anvil and stirrup bones in the ear

A bone alone

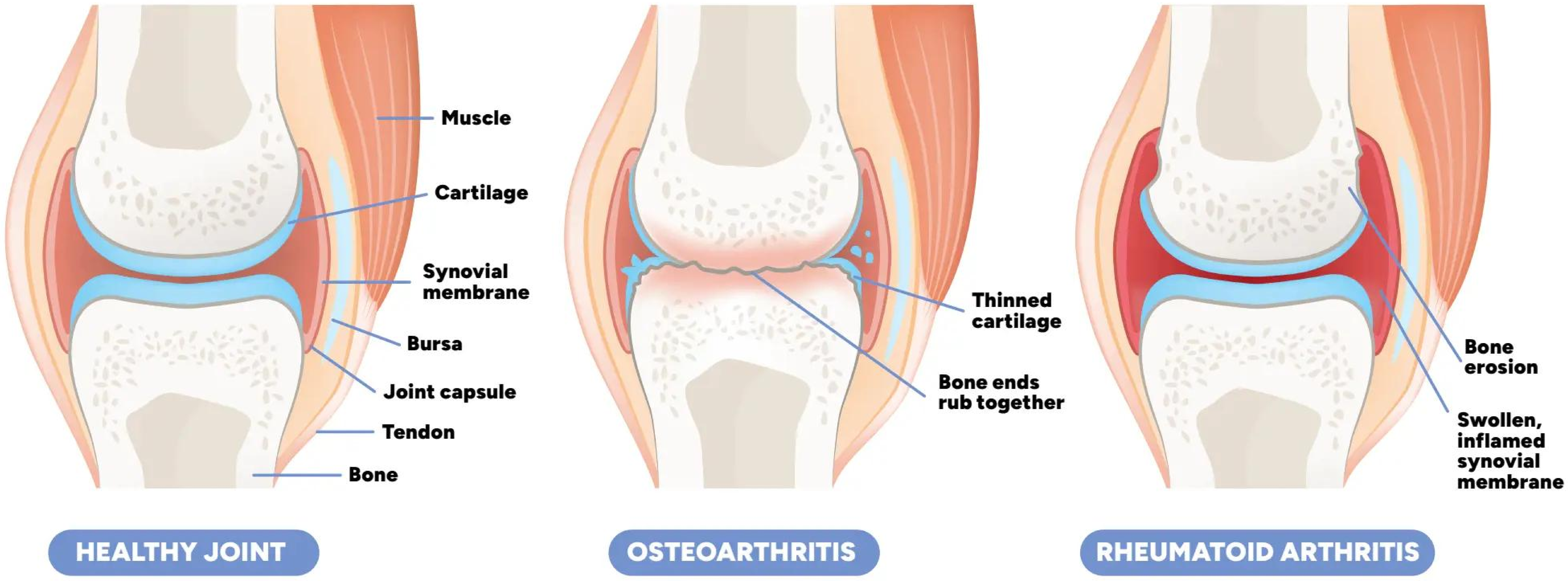
The hyoid bone is unique and it does some unique things

The hyoid bone is located in the neck above the thyroid cartilage (your Adam's apple). Of the 206 bones in the body, the hyoid bone is unique because it is the only 'floating' bone in the body. This means it is not attached to any other bone. Bones normally attach to each other through ligaments but the hyoid bone 'floats' above the larynx in the neck. The reason it floats is so you can swallow. The hyoid bone's freedom of movement means the larynx can move up and down. The larynx hangs down from the hyoid bone and the extrinsic (outside) muscles of the tongue are attached to the top of the hyoid bone.

The hyoid bone allows us to swallow safely. When we swallow, the muscles above the hyoid contract and lift the larynx up and out of the way. At the same time, the epiglottis closes over the windpipe (trachea), sealing it off so that food can travel down the oesophagus unimpeded and the lungs don't end up trying to breathe your dinner. It is, however, a complex series of movements that can go wrong. Humans are the only creatures that regularly choke.

To find the hyoid bone, place your hand on your larynx (the front of the neck) and swallow. You'll feel the larynx move up. Now yawn. This time the larynx moves down. This is all possible because of the free-floating hyoid bone.

Cartilage working and not working



arm: tennis players have roughly 30 percent more bone in their racket arms.

Bones are hollow not just so that they have somewhere to store bone marrow. Having hollow bones makes our skeleton lighter (an adult's bones will weigh about nine kilograms (20 pounds)), but it also makes them stronger. Structural engineers have long realised that hollow tubes are stronger than solid rods, particularly when resisting bending. For most animals, a broken leg is fatal. So hollow bones not only make sense for weight reduction but also in reducing the risk of a break.

Another feature unique to bone among body tissues is that it heals without scarring. A knife cut will leave a scar, however sharp the blade. But if you break a bone and then set it, when the bone has healed there will be no visible sign of where the break was. Bone can even grow more bone to fill a space: surgeons sometimes remove sections of bone and, with appropriate support in place, the bone will grow back: up to 30 centimetres (12 inches) of new growth in the leg bones.

As to what this bone is made of, the answer is that it's a mixture of inorganic (60-70 percent) and organic (40-30 percent) materials. Bone's fundamental ingredient is collagen. Collagen is a protein and it's very, very useful: about 30 percent of the body's proteins is collagen. We have so much of it because it is so adaptable. It forms fibres to make muscles. It can be transparent in the cornea and opaque in the white of the eye.

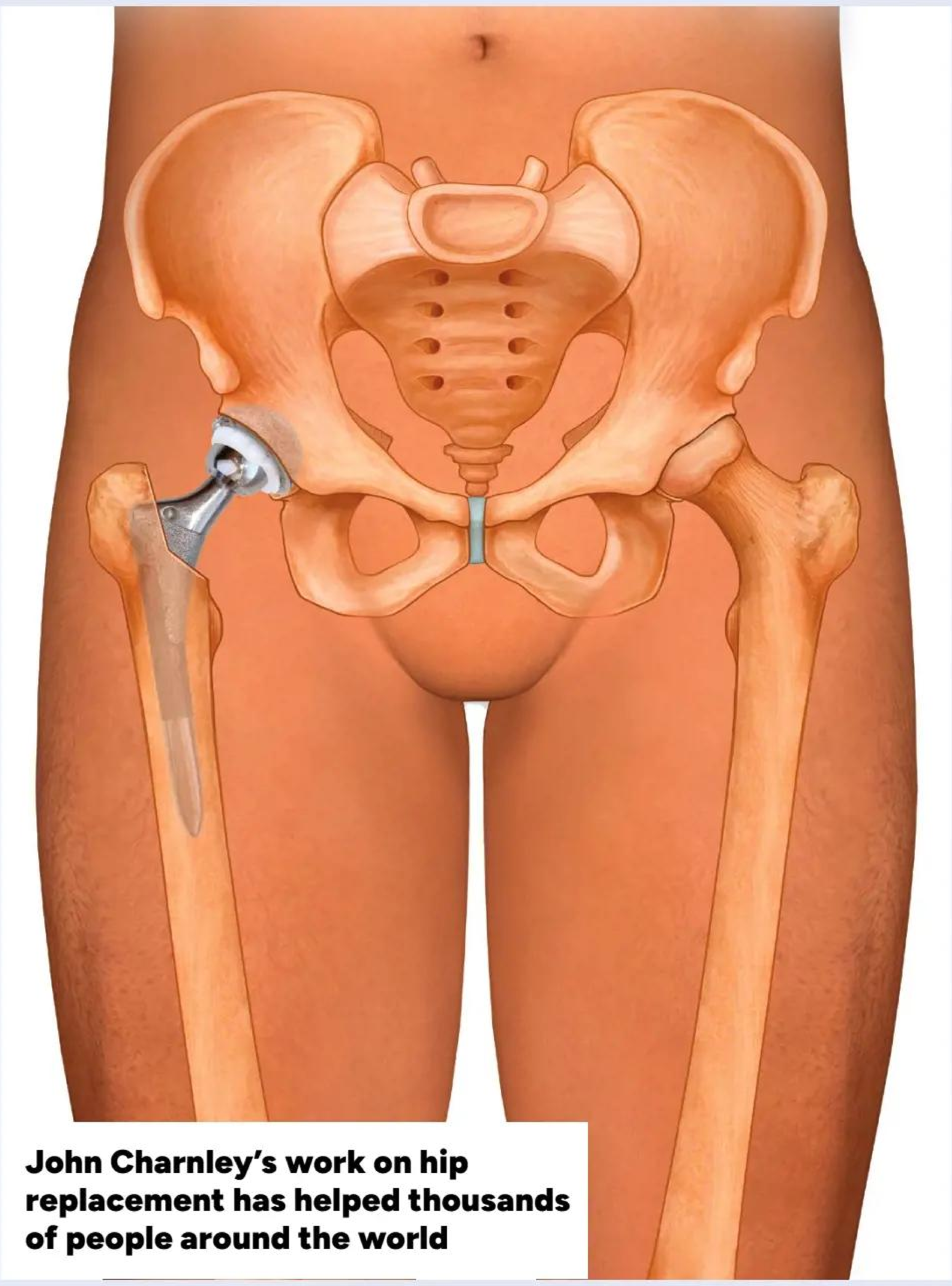
As well as bone, collagen makes up the greater part of bone's vital partner, cartilage. Cartilage is the smooth covering that allows different bones to slide easily over each other in our joints. Anyone who has ever eaten a chicken leg will have seen cartilage and, sometimes, popped it off the bone.

Cartilage is just as special as its bony partner. It's extraordinarily smooth: smoother than glass – in fact, it's five times smoother than ice. But as well as being smoother than glass and ice, it's also tougher: it doesn't crack. Its main drawback is what happens when cartilage gets damaged or worn out. Because it doesn't have a blood supply, cartilage can't repair itself, which makes osteoarthritis, where the cartilage wears out and bones come into direct contact, so difficult to treat. About all that doctors can do is prescribe painkillers, suggest lifestyle changes to lose weight, and give information on exercises to improve muscle strength around the joint so that it is better supported.

As cartilage is so vital to our wellbeing, it pays to look after it. The best way to do so is movement. Moving ensures that the cartilage in our joints is lubricated by lots of synovial fluid (the biological equivalent to the oil we put into the engine of a car to lubricate the moving parts). Cartilage can be worn down by overuse but, outside of professional sportspeople, this is not usually a problem today. Our sedentary lifestyles not only pump less synovial fluid through our joints but they also lead to weight increase. Not surprisingly, putting on weight puts more strain on cartilage.

This is seen most often in the hips. In fact our hips and spine cause us a lot of problems. We are unique among mammals in standing on two legs. But that has meant the bones and joints that evolved for creatures using four legs have had to adapt to our bipedal gait. The hips need to anchor and support our legs, which contain the strongest muscles in the body, while at the same time the hips have to bear our whole body weight. Not surprisingly, this produces huge amounts of pressure on the sockets where the femur fits into the pelvis. This can wear away the protective lining of cartilage. Bone grinding on bone is extremely painful and, because cartilage does not regrow, in the past there was very little that doctors could do about this. The only option was to fuse the femur to the hip, reducing pain but at the price of stopping any movement in the upper leg.

John Charnley is a name few people apart from orthopaedic surgeons have heard of, but he has probably been responsible for one of the greatest reductions in human suffering over recent decades. Doctors had tried for decades to find a way of replacing the worn-out hip joint to no avail. All the combinations of materials they had tried failed, leaving the sufferer no better off than



John Charnley's work on hip replacement has helped thousands of people around the world

"Our bones, the framework [of] our bodies, are the longest-lasting part of us"

before. It was Charnley who, through dogged research, discovered that replacing the head of the femur with a stainless-steel knob and coating the socket – the acetabulum – with plastic produced a long-lasting joint resistant to wear. Charnley trained many surgeons in his methods and materials and, as a result, hip replacement surgery has become a medical standby, returning mobility and health to many thousands of people a year worldwide.

Apart from cartilage, tendons and ligaments also connect to our bones and, not surprisingly, they are both classified as connective tissues. As to the difference between tendons and ligaments, it comes down to what they connect to. Tendons attach muscles to bones. Ligaments tie bones together. Tendons, being extensions of the muscle they are joined to, are somewhat elastic although, as anyone who has torn an Achilles tendon knows, there are limits to their elasticity. Unfortunately for those who do suffer tendon injuries, tendons take a long time to heal as they have a limited blood supply.

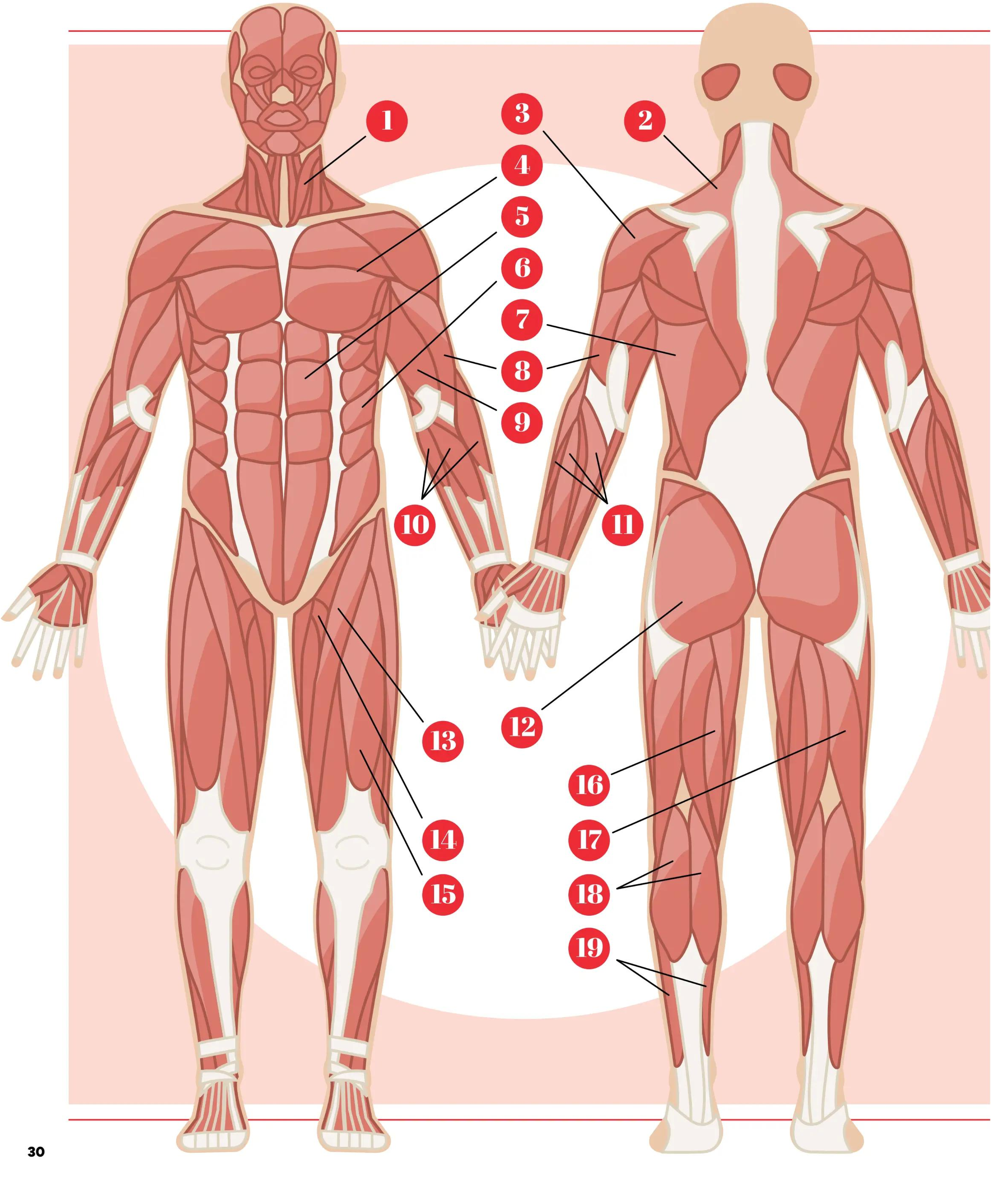
It's easy to find the Achilles tendon: it's the ridge down the back of the ankle. It's more difficult to find ligaments. Binding bone to bone, they are generally deeper inside the body. They can stretch to a degree so that, even if a joint becomes dislocated, the ligaments connecting the bones don't normally break. However, if the ligaments remain extended for too long, they can't return to their previous state. This is why, with dislocations, it's vital to reset the joint as quickly as possible, otherwise the ligaments may become permanently stretched, leading to ongoing weakness in the joint.

Our bones, the framework upon which our bodies grow, are the longest-lasting part of us. When the flesh has long since melted away, it is the bones that endure. This is testament to their strength and toughness, a strength and toughness born of millions of years of carrying us through all the vicissitudes of life against the constant pull of gravity. So give a thought to your bones: they serve us incredibly well, generally with very little thought from the person relying on them.

THE MUSCULAR SYSTEM

Uncover the magic of muscles and how they get your body moving

WORDS BY EDOARDO ALBERT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BREAKDOWN OF A SYSTEM

1
Sternocleidomastoid
Binds head to trunk and turns the neck.

2
Trapezius
Moves the head, neck, arms and shoulder, and helps to stabilise the spine.

3
Deltoid
Moves the arm and stabilises the shoulder.

4
Pectoralis major
Adducts and rotates the arm.

5
Rectus abdominis
Stabilises the internal organs and the body when it is moving.

6
External oblique
Helps the body to twist.

7
Latissimus dorsi
The widest muscle in the body. It moves the shoulders and helps with respiration.

8
Triceps brachii
Extends the elbow, straightening the arm.

9
Biceps brachii
Flexes the elbow, bending the arm.

10
Finger flexors
Bends the fingers.

11
Finger extensors
Used to extend or straighten the fingers.

12
Gluteus maximus
The biggest muscle in the human body. It extends and rotates the thigh.

13
Sartorius
A multipurpose muscle, flexing, adducting and rotating the hip, and flexing the leg at the knee.

14
Adductor longus
As the name indicates, this muscle adducts the thigh at the hip.

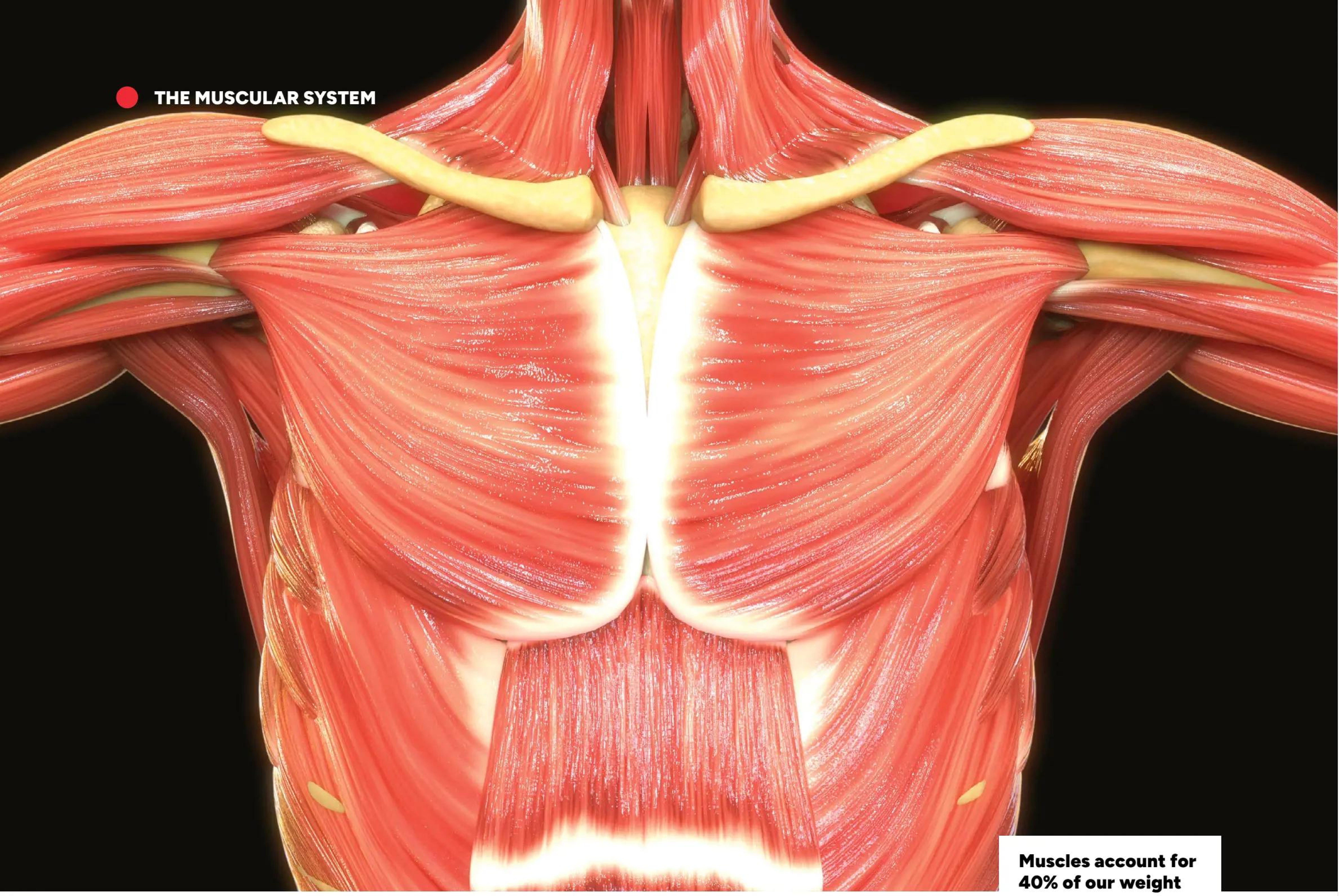
15
Rectus femoris
This is the only muscle that extends from over the hip to the knee, flexing the thigh at the hip and extending the leg at the knee.

16
Semimembranosus
Rotates and flexes the knee and extends the hip.

17
Biceps femoris
Flexes the knee and extends the hip.

18
Gastrocnemius
Flexion at the knee and plantar flexion (pointing the toes) at the foot.

19
Soleus
Plantar flexion. Plays an important role in allowing us to stand.



Muscles account for 40% of our weight

While our skeletons hold us up, it's our muscles that move us. Human beings have roughly 600 muscles – the exact number varies slightly – that are engaged in constant subtle movement, even when we're sitting down. Most of the time, our muscles serve us unobtrusively, doing what we want without us having to think about the doing – if your nose itches, you don't need to consciously think about how to scratch it.

However, under the skin, a symphony of synchronised actions is taking place. To get up from a chair requires the coordination of over a hundred muscles. Even tapping a finger takes ten muscles.

With so many muscles required to enable us to make the full range of movements of which we're capable – watching an Olympic gymnast is a good way of appreciating just how wide that range of movement is – it should come as no surprise that muscles make up about 40 percent of our weight. However, because muscle is a metabolic hog, it is particularly affected by the usual bodily dictum of 'use it or lose it'. Astronauts in zero gravity demonstrate this perfectly. Even a short time in orbit, between five and 11 days, will see them losing a fifth of their muscle mass.

Perhaps the best example of how our muscles coordinate to produce movement lies in those most characteristically human appendages, our hands. Each hand has 17 muscles that operate it, together with 18 muscles in the forearm that also help move the hand. These muscles are attached, via tendons, to the 27 bones in the hand. There are also three major nerves as well as 45 other nerves, and 123 ligaments. This vastly complex assemblage of muscles, bones, tendons, ligaments and nerves allows the hand the extraordinary range of movements of which it's capable, ranging from grabbing and scratching, through to a professional pianist moving all of their fingers independently and simultaneously.

> **“One thing we often don’t realise is our muscles are busy working even when we are fast asleep”**

So muscles are marvellous. But one thing that we often don’t realise is that our muscles are busy working even when we are fast asleep. There are, in fact, three types of muscle. The type that enables us to walk, run, get up and sit down is called striated muscle. (It’s sometimes also called skeletal muscle as this type of muscle is anchored to our bones.) Striated muscle is under our conscious control. However, the other two types of muscle are not under our conscious control. These are smooth muscle and cardiac muscle. Smooth muscle also moves us, but what it moves is the stuff inside us: it lines the walls of blood vessels as well as the intestines, the stomach and the urinary system. The contractions of smooth muscle moves food down our gut and dilates and constricts our blood vessels. Cardiac muscle makes most of the heart and its constant, untiring rhythmic contractions are the most obvious marker of life.

Smooth muscle looks different from striated muscle through a microscope and that difference is referenced in their respective names. Under magnification, striated muscle appears to have stripes, while smooth muscle doesn’t. This is because striated muscle is made up of functional units called sarcomeres, and it is these that give the muscle its banded appearance. Smooth muscle mainly consists of single-unit muscles, which means that the whole muscle contracts together.

In single-unit smooth muscle, all the muscle cells operate together. This is the type of smooth muscle that makes the walls of the long tube that runs from the mouth to the anus, winding around in our guts. Working together, single-unit smooth muscles create waves of contraction that slowly work their way along our intestines, gently pushing balls of chewed up food, which are called boli (bolus in the singular) from the stomach, through the small and large intestine, into the bowel and then out through the anus. Unusually, the outer sphincter muscle in the anus is, generally, under conscious control, so that we can stop ourselves defecating even when our internal receptors are frantically signalling that the bowel is full and needs to be emptied.

Single-unit smooth muscles also line blood vessels, expanding and contracting to regulate blood pressure. They also bunch around the eyes and under the skin, where by contracting they can make hair stand on end.

By contrast, multi-unit smooth muscle cells operate independently of each other. These are mainly found in the lungs and large arteries.

Apart from its appearance, the key difference between smooth and striated muscle is how it is controlled. We don’t need to think about moving food from the stomach into the intestine. Nor do we consciously regulate blood pressure or increase the diameter of bronchioles in the lung when we are running. Smooth muscles also come into play during labour and ejaculation. Two areas where we might not think of smooth muscles operating are when our hair stands on end, through cold or fright, and the constant adjustments of the pupil and lens in the eye.

As is clear, none of these functions are under conscious control. However, the nervous system does tell the body’s smooth muscles what to do but it does so via its alternative signalling system, the endocrine system,

Fact file

Everything you need to know about the muscular system

What does the system do?

It moves us, holds us upright, protects us, allows us to breathe, wee and poo, pumps blood around the body, generates heat and pushes babies out.

Why is it important?

Without it, we’d be plants.

When does this system develop in a foetus?

Muscles start to develop in the third month of pregnancy, between weeks nine and 12.

What organs are part of this system?

Muscles are themselves organs.

What are common conditions associated with this system?

Muscle injuries are most common: strains, tears, sprains. Muscular dystrophy is a genetic disorder causing weakening of the muscles.

which we can think of as a chemical signalling system using hormones and neurotransmitters to control smooth muscle function.

While smooth muscles do get time off, the cardiac muscle never has a chance to relax. There it goes, beating on, without pause or rest. Which begs the question, why doesn't it get tired? After 30 or 40 press-ups, most of us have reached a limit and simply can't push our bodies up again. But the heart keeps going, even when the other muscles have reached their limit, and it does so without apparent complaint. Our chests might be heaving, our legs might be so heavy we can't move them, but the heart keeps going strong. How does it do this?

To understand, we first need to know why our skeletal muscles get tired in the first place. Put simply, they run out of fuel and oxygen. They deplete their reserves of glucose and the body can't get fresh glucose to them quickly enough, leading to a build-up of waste products such as lactic acid. Also, the blood vessels serving the muscles can't get enough oxygen to them.

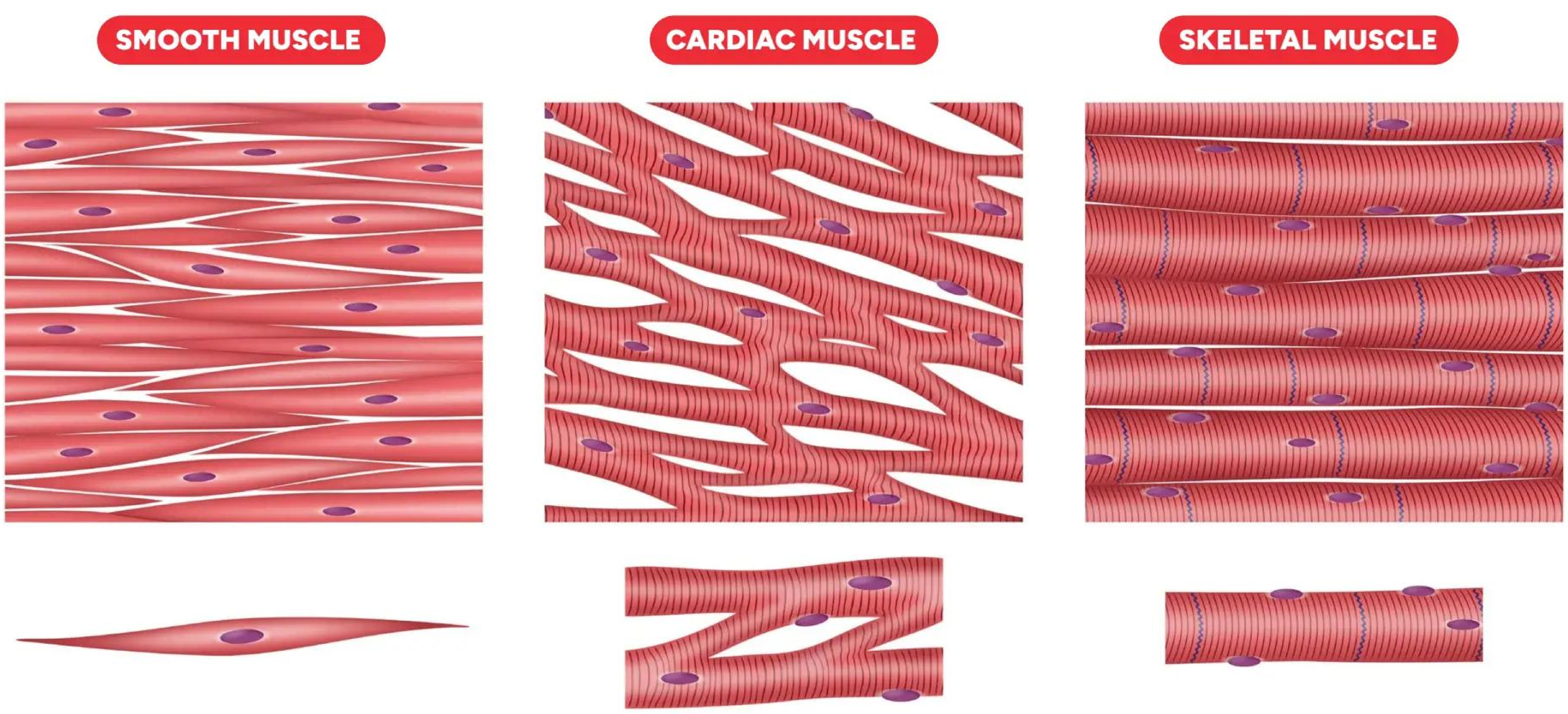
Looking at the heart and its constituent cardiac muscles, anatomists discovered that it has a much richer blood supply, which ensures it receives enough oxygen even when it is working hard. Cardiac muscles are also much better than skeletal muscles at producing energy because they have a much higher proportion of mitochondria than skeletal muscles. Mitochondria are the little energy factories in the cell. Cardiac muscle is 35 percent mitochondria, skeletal muscle is only between three and eight percent mitochondria. Having so many mitochondria, cardiac muscle is able to prevent the build-up of lactic acid and other waste products.

> **"The heart keeps going, even when the other muscles have reached their limit, without complaint"**

But the heart doesn't just depend on super cells to keep going. When the demands upon it increase, the heart pumps faster and this engages the body's automatic response, releasing hormones such as adrenaline and noradrenaline that increase the heart rate and strength of contractions, so it can pump more blood around the body.

In the longer term, if you regularly place an increased load on your heart through exercise, the cardiac muscles will respond by growing, allowing the heart to pump more

Three types of muscle tissue and cell



Not all of us are Olympic gymnasts but we all start off as flexible as Max Whitlock

blood through your bloodstream with each heartbeat. Endurance athletes such as cyclists and marathon runners have low resting heartbeats because their hearts are, literally, bigger and stronger and can therefore pump more blood with each beat. As an example, the average resting heart rate of cyclists who take part in the Tour de France is 42 beats per minute, where the average resting heart rate of ordinary adults is between 60 and 100 beats per minute. Assuming a heart rate of 70 beats a minute, during an 80-year life the heart will beat over three billion times. But the professional cyclist's heart will beat a mere 1.8 billion times during their lifetime.

Having looked at the different types of muscle, let's now take a closer look at how muscle cells actually work. The core movement of muscles is contraction. By contracting, muscles pull on the bones to which they are anchored, making them move around their pivot point. Each muscle is made of long fibres and the fibres are groups of thinner fibrils. The fibrils are where muscle contraction happens. Fibrils have long chains of two proteins, called myosin and actin. Myosin chains are relatively thick while actin chains are thinner. Myosin and actin filaments run alongside each other within the muscle. When the muscle contracts, the chains of myosin and actin remain the same length but they slide past each other, contracting the muscle. As muscles contract and relax, the thicker myosin chains put out cross bridges that lock onto the actin chains. A muscle contracting and relaxing makes innumerable cross bridges as the protein chains lock and then separate. This is one of the reasons why it's a good idea to warm up and stretch before exercising, as it gives the muscle fibrils, which might have got a bit stuck, a chance to loosen up and move more easily past each other.

The tongue's eight muscles allow us to bend it into all sorts of shapes.

Stick it out

The tongue is just all muscle.

Your tongue works hard. When chewing, it pushes the food against the hard palate as well as moving the food around the mouth, all while making sure it gets out of the way of those chewing teeth. Luckily, we don't have to think about this last task because we all know how painful it is when the body gets it wrong and we bite our tongues. The tongue performs this role among animals as well as humans, but for us it has a unique role: helping to form the sounds we make when we speak. The different vowel sounds are formed by different placements of the tongue, while the tongue also works with other parts of the mouth to produce the consonants. Tongue twisters are difficult precisely because the tongue placement of consecutive sounds is so different that it's difficult to say them quickly. But as teachers know all too well, we can keep talking for hours without our tongues getting tired. This is because the tongue is composed of eight muscles that have a considerable degree of redundancy, so the tongue can be moved into the required position by different sets of muscle fibres. Practice can also improve articulation. Actors work on this during voice training but it's simply a continuation of the work we do as babies and toddlers when we play with sound – babbling and making noises, learning to speak and laying down the muscle memory in the tongue.

Our muscles also contract at different rates. Smooth muscle contracts relatively slowly; there's no particular need to hurry when moving dinner down into the intestines. Striated (skeletal) muscle obviously needs to contract faster, as it has to deal with emergency situations. But the fastest reacting muscles in the body are the orbicularis oculi, the muscles that snap the eyelids shut when something threatens to fly into the eye. Triggered by the corneal reflex, the orbicularis oculi contract in a fraction of a second, closing the eyes in less than 0.1 seconds. As our eyes are so important to us, it's not surprising that the muscles protecting them are so quick at doing so.

Muscles generate heat when contracting. They also generate heat when extending while tense, say when you try to put a heavy plant pot down on the ground without dropping it. The heat is a by-product of the chemical reactions that power the muscles but it also serves a vital metabolic function: it provides the majority of the warmth that makes us warm-blooded, allowing us to live in the temperate and cold latitudes of the world.

Having seen how muscles work, now let's look at how they move our bodies, starting from the top and working our way down. To do so, we need to know the main terms for the different joint movements that the muscles produce. Flexion is when the joint angle decreases. Bicep curls are an example of flexion. Extension is when the joint angle increases, as in reaching for something at the limit of reach. Abduction is when the joint moves away from the midline of the body. The body has a built-in stretch reflex to prevent muscles being over-extended and nowhere is this reflex stronger than with abduction movements, as anyone who has tried to do the splits will know! This is because abduction movements leave the body's core dangerously exposed. Adduction is the opposite to abduction, when muscles move the joint towards the midline of the body. In the lower half of the body it's one of our rarer movements, but an example is a skier's knees when swerving round corners. Rotation is what it implies. Hold your leg straight and rotate it and you are rotating your hip joint.

Knowing the terms, let's see how our muscles enable us to flex, extend, abduct, adduct and rotate our joints, starting from the top.

The neck carries the head and as our distance sense receptors are all in the head, it has to turn the heavy head to wherever we sense danger. The neck turns the head

Under the skin, we're muscle

primarily with the sternocleidomastoid muscle, which extends in a V from the top of the sternum up either side of the neck to the skull, locking the head to the body as well as providing the muscle strength to turn the neck.

Moving downwards, the back is the source of more difficulties than any other part of the body. This is for two reasons. Firstly, we alone among mammals walk exclusively upright but spines evolved on land among animals that walked on four legs. The adaptations necessary to enable us to walk put considerable strain on the back, particularly in its lower sections. However, the back does generally work very well so long as it is allowed to do what it is supposed to do: move. We evolved as hunter-gatherers, walking 20-40 miles a day. Sitting down for eight hours a day is not good for any part of the body, but particularly not for the back. Many muscles for the neck, shoulder and hips have their origin in the back, so any problems in the back can spread to other areas.

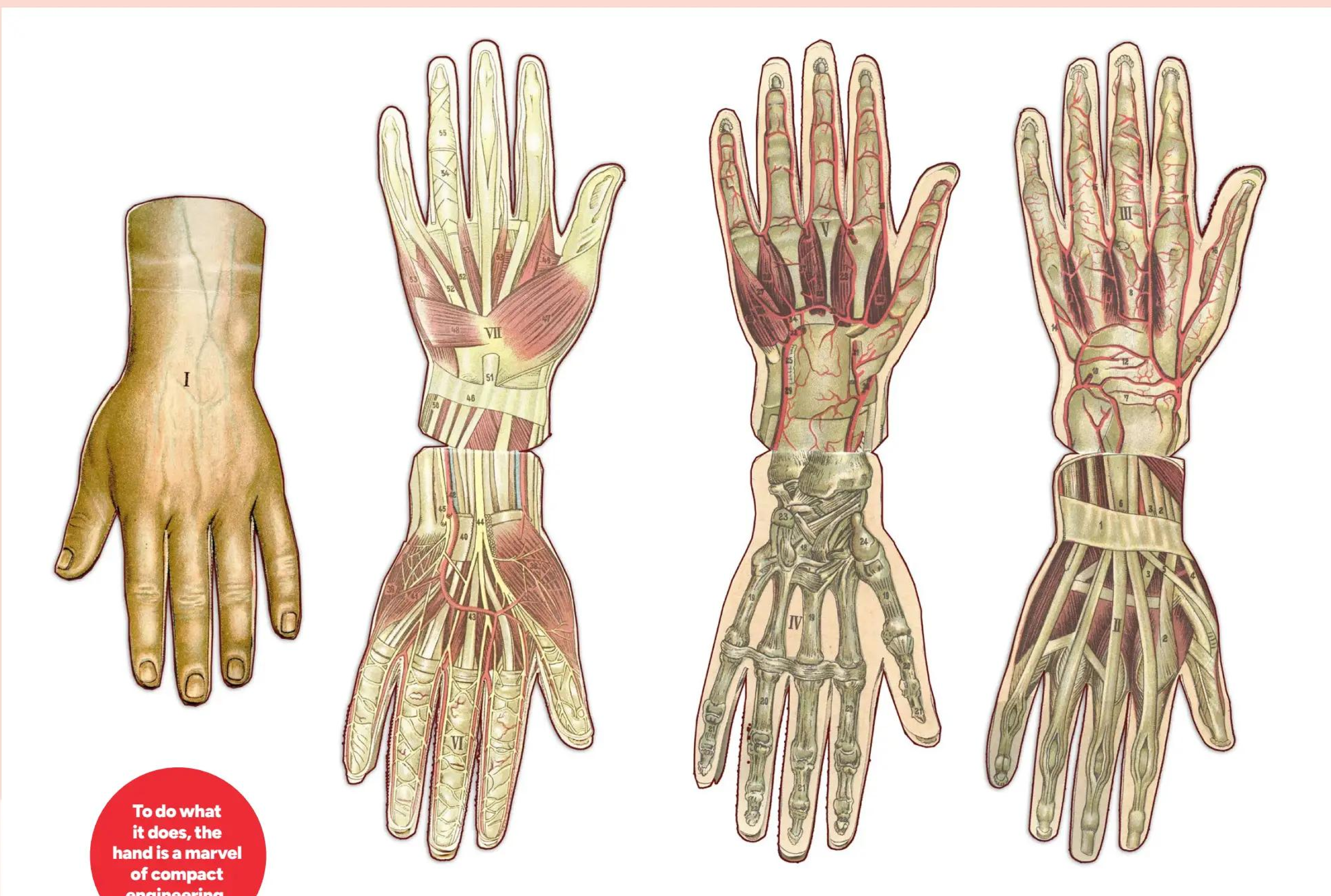
Of all the joints in the body, the shoulder is capable of the greatest range of motion. It's a relatively loosely fitted ball-and-socket joint that has its muscles spread over the chest, back, shoulder and down into the arm. Because of the wide range of movement offered by the shoulder, 16 muscles work to move and stabilise it, including the four rotator cuff muscles, which work primarily to stabilise the joint; the shoulder blade muscles that mainly move the joint; and then a further eight muscles, including the deltoid, biceps and triceps, that all work to provide the extraordinary range of motion of which the shoulder is capable.

The hip is also a ball-and-socket joint, but we all know that our legs do not have the same range of movement that our arms have. This is because the socket of the hip joint is deeper. This embeds the head of the femur more deeply into the joint, which makes the joint more secure but at the price of a loss of mobility. However, security and stability are the premium virtues of the hip joint: it's possible to get away from a predator if you have a dislocated shoulder, but a dislocated hip leaves us helpless on the ground. The hip joint is also held in place by extremely strong ligaments that serve to lock the bones in position in the joint.

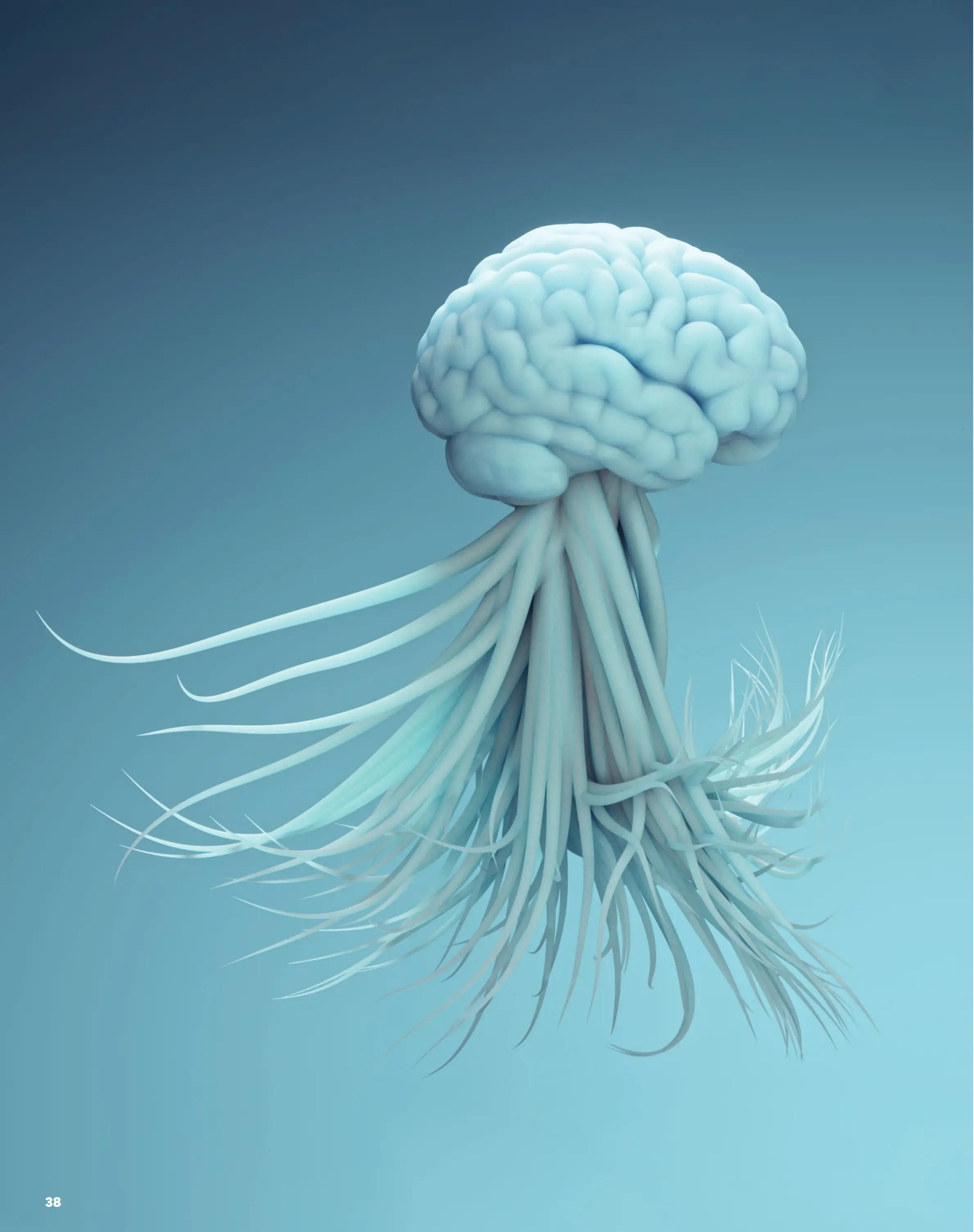
> **"Our muscles enable us to flex, extend, abduct, adduct and rotate our joints"**

Moving out from the trunk, the legs and arms – articulating only in one plane at the elbow and knee – have a relatively simpler set of muscles moving them, extending and contracting as we bend and straighten our limbs. As mentioned, the hands and also the feet have a highly complex suite of muscles regulating their movements.

Because we eat meat, and most of the meat we eat is muscle, muscle may be the most familiar part of the body to us. But take it off the dinner plate and look at what it does and muscle becomes what it has always been: a marvel.



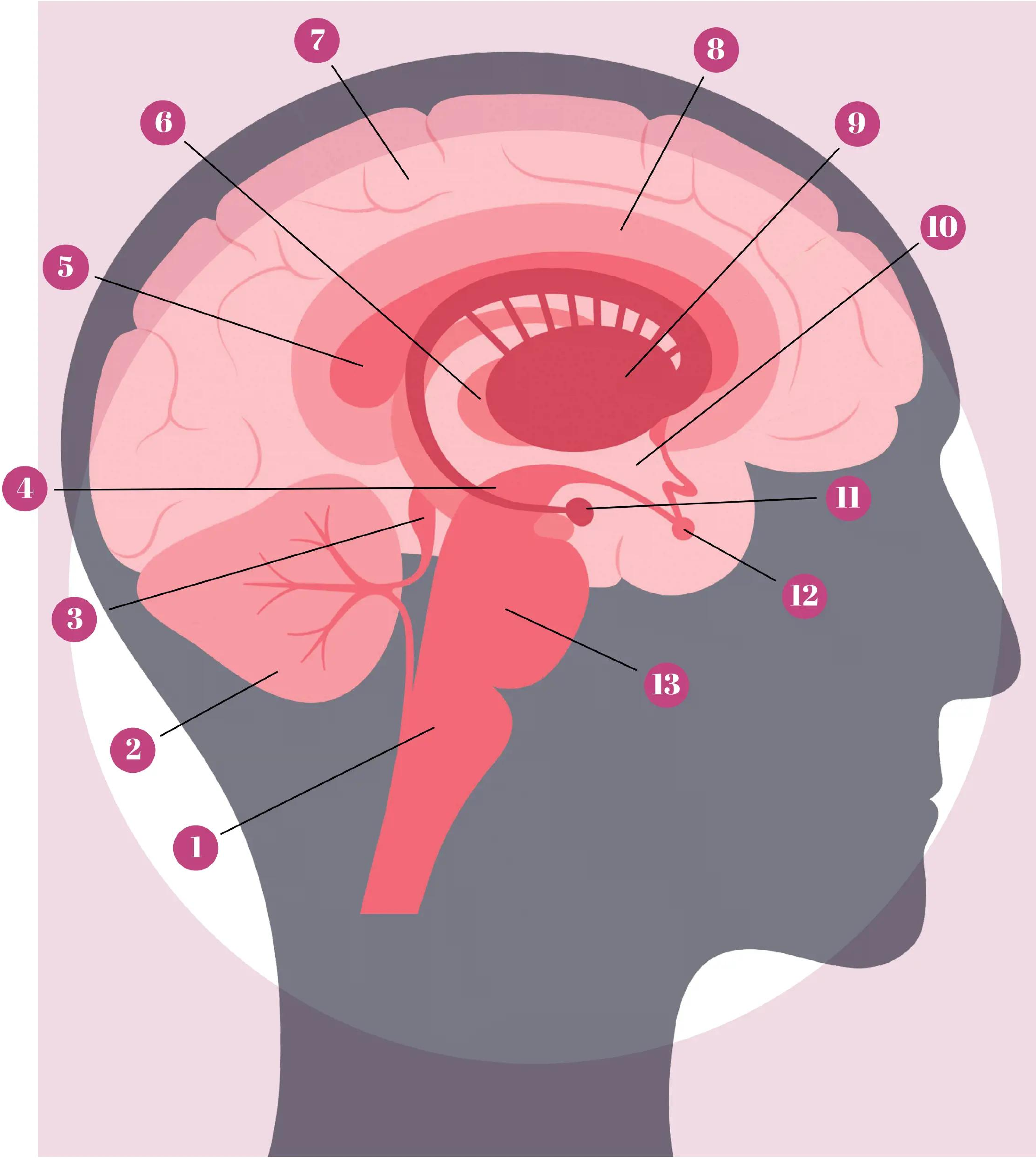
To do what it does, the hand is a marvel of compact engineering.



THE NERVOUS SYSTEM

This is where it all happens...

WORDS BY EDOARDO ALBERT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BREAKDOWN OF A SYSTEM

1
Brain stem
Connects the brain to the spinal cord and regulates breathing, heart rate and other life functions.

2
Cerebellum
Controls balance as well as complicated movements.

3
Hippocampus
Stores long-term memories.

4
Midbrain
Connects different regions of the brain and controls eye movements and pupil dilation.

5
Corpus callosum
Connects the two hemispheres of the brain.

6
Thalamus
Relays all sensory information, with the exception of smell, to the cerebrum.

7
Cerebral cortex (cerebrum)
Where all the higher mental functions, including language, thinking, making decisions and personality, happen.

8
Cingulate gyrus
Processes emotion and helps to control behaviour.

9
Basal ganglia
Motor control to the body.

10
Hypothalamus
Hunger, thirst and the sex drive.

11
Amygdala
Interprets and contextualises emotions, linking feelings to memories and learning.

12
Pituitary gland
Produces the hormones that regulate the body.

13
Pons
The sleep/wake cycle and breathing.

Fact file

Everything you need to know about the nervous system

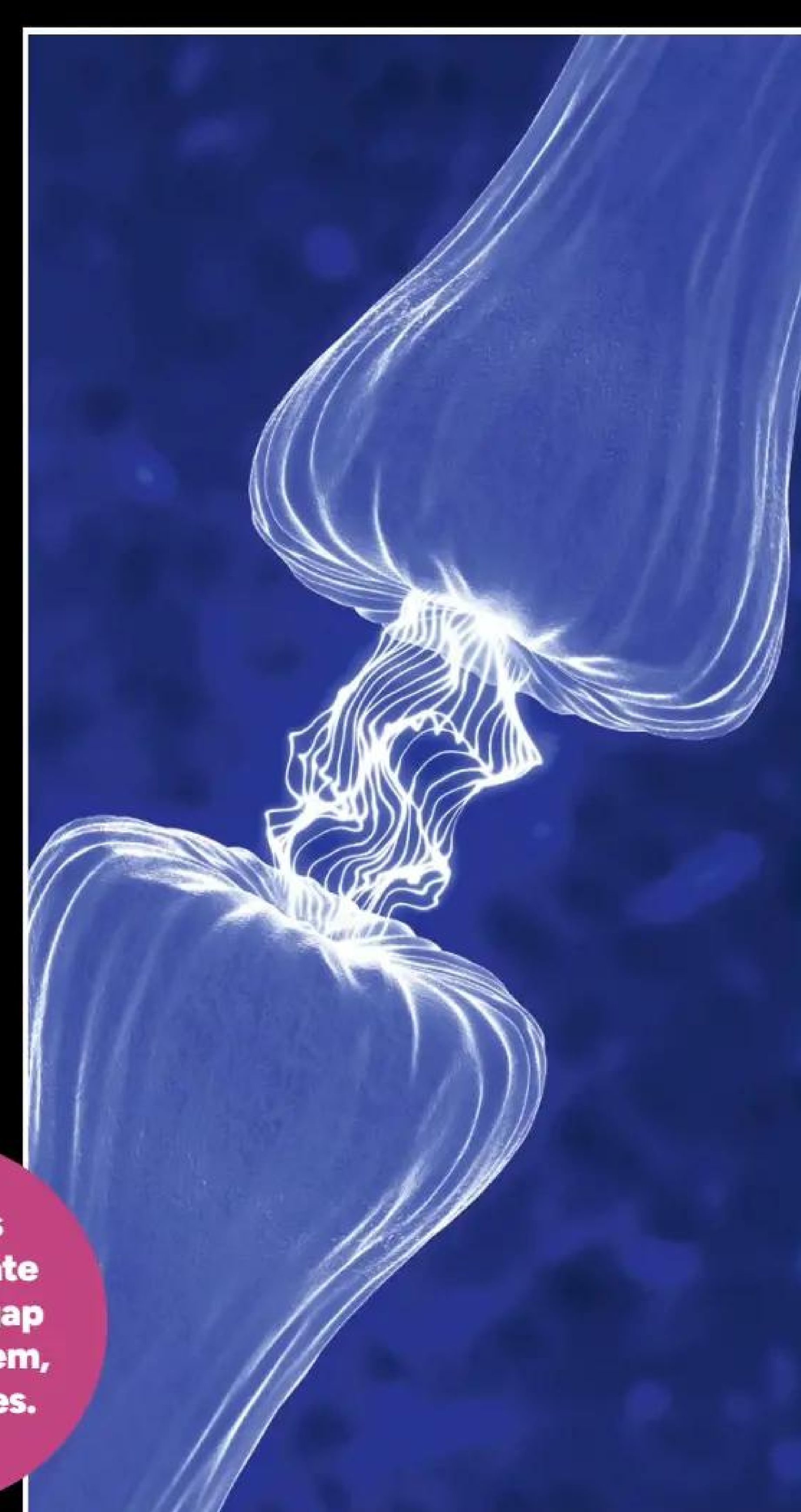
What does the system do?
Pretty well everything.

Why is it important?
Not only does it enable life, it is also the system that makes us human.

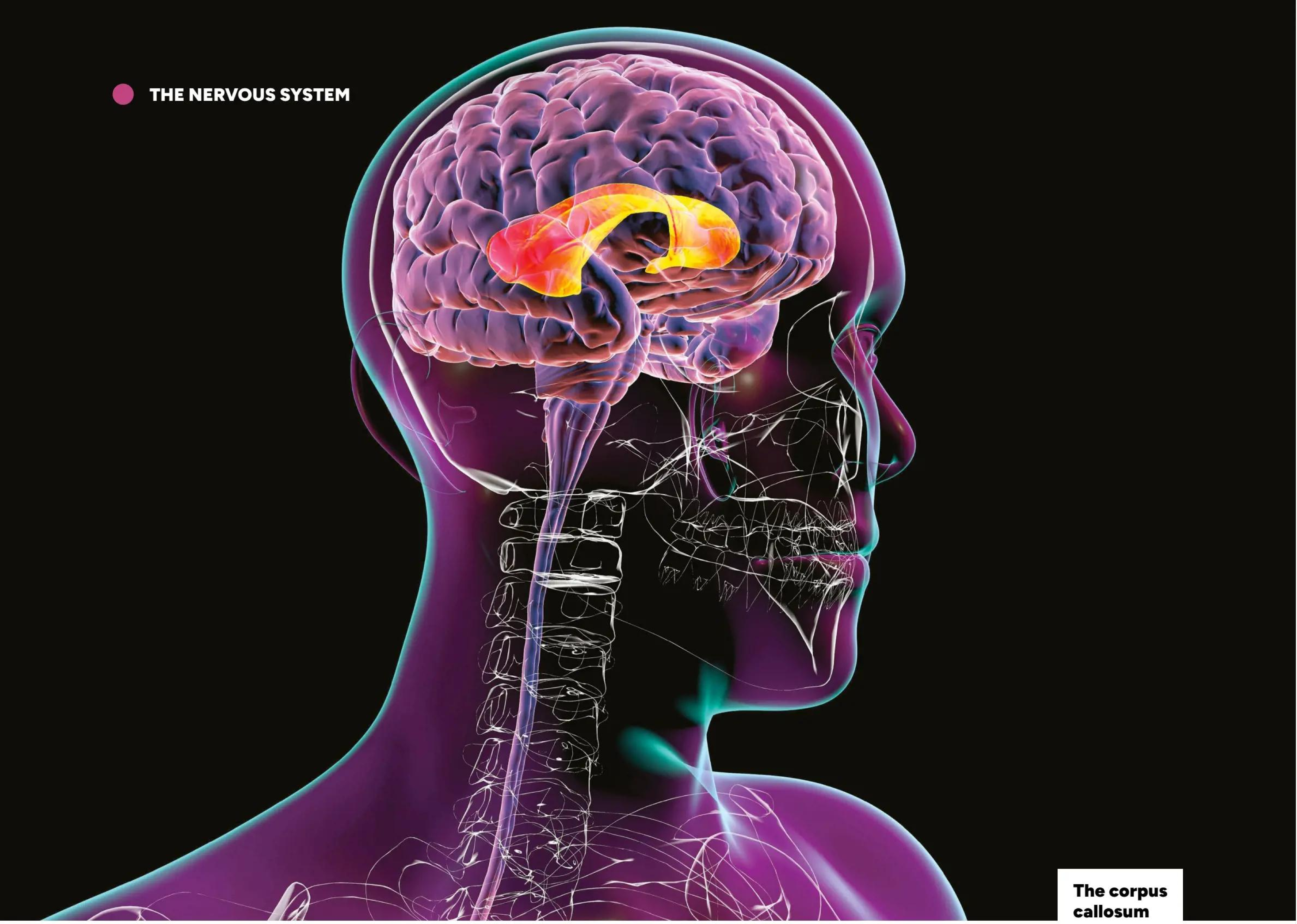
When does this system develop in a foetus?
The brain begins to develop during the third week of pregnancy.

What organs are part of this system?
The brain and the spinal cord.

What are common conditions associated with this system?
Strokes, dementia, Parkinson's disease, epilepsy.



Neurones communicate across the gap between them, the synapses.



The corpus callosum

It's not actually grey. Drill through a living skull and the brain underneath it isn't grey but rather a pale pink. The 'grey matter' of which our brains are supposedly composed is a consequence of death cutting off the brain's blood supply, along with the chemicals used to preserve the body for dissection. But unlike the body's other organs that, when living, give conspicuous evidence of their vivacity by pulsing, throbbing and thrumming, the brain, sitting in its skull helmet, remains strangely inert. The life of the brain goes on under the surface but that life animates the rest of our bodies.

While the brain might seem passive, it exerts its influence on the rest of the body through the nervous system. If you could view the brain and nervous system distinctly from the body, it would appear as an exceptionally large walnut sitting atop a broad river flowing down the spinal cord, with four large tributaries running down the arms and legs. Like streams flowing into rivers, the nerves themselves branch as they run towards the extremities, creating a fine network of receptors and transmitters covering the whole body. The whole thing looks strangely like the map of the Amazon and its tributaries.

But while the brain does not look like much to the naked eye, it's the place where marvels happen. The greatest marvel is you. Yes, you looking at this page. You are seeing black shapes on the page and you are turning these squiggles into meaning inside your head. Every stage of this process is extraordinary and much of it we don't understand at all. While we have made some progress with knowing how the eye transmits its vision of the outside world to the brain, and how the brain interprets that information, we are still a long, long way from understanding how activity in the brain underwrites the conscious understanding of you the

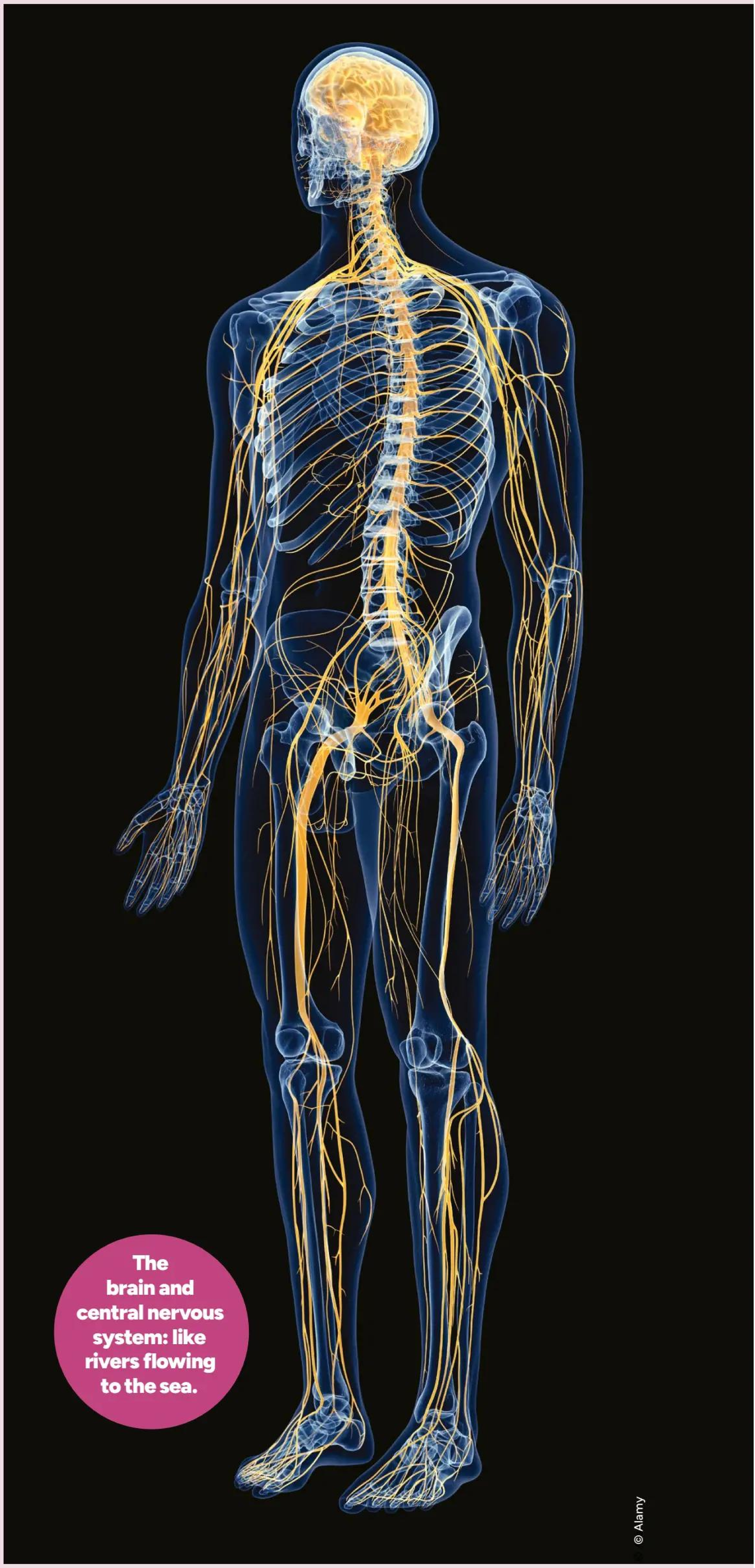
> **“Mimicking a walnut, the cerebrum is divided into two hemispheres, connected via the corpus callosum”**

reader, from the semantics of language to the intractable problem of consciousness itself.

The part of the brain you see in pictures, the grey matter of popular understanding, is the cerebrum. This deeply wrinkled – the wrinkles are as particular to an individual as fingerprints – section of the brain is the newest, in evolutionary terms, and it's where most of the capacities that we think of as distinctly human are located. Further mimicking a walnut, the cerebrum is divided into two hemispheres that are connected via the fibrous corpus callosum. Generally speaking, each hemisphere controls one half of the body, although for a reason that we don't understand, the brain hemispheres control the opposite side of the body. Right-handers have a dominant left hemisphere and vice versa.

The hemispheres themselves have four lobes, the frontal, parietal, temporal and occipital. Mental functions are generally located in specific lobes.

In cases of severe, life-threatening epilepsy, surgeons have sometimes cut the corpus callosum, which stops communication between the two halves of the brain. Doing so seems to stop the feedback loop that would lead to a fit but, when the operation was first carried out, the strange thing was that it seemed to have no other effect. The patient carried on as before. It was as if cutting the channels between the two halves of the brain did not matter. But more subtle experimentation revealed that cutting the link seemed almost to make for two centres of consciousness. The dominant hemisphere continued as before but sometimes the other hemisphere might reveal its own preferences. In the case of one patient, he found that one hand pulled up his trousers but the other pulled them down. Half his brain wanted to get dressed, half did not. One hemisphere usually exerts dominance, however, so the patients carry on largely as before.

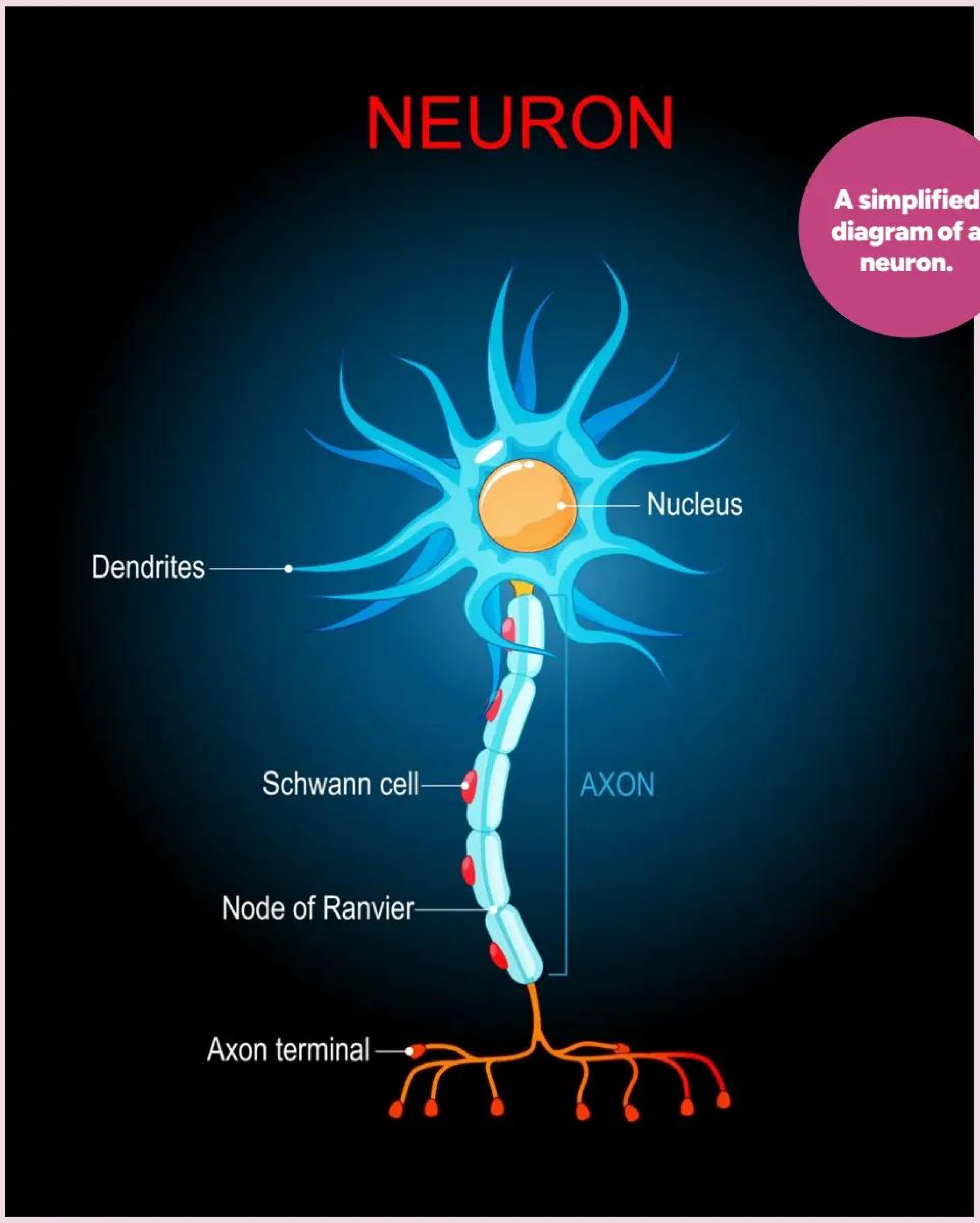


The brain and central nervous system: like rivers flowing to the sea.

While the cerebrum sits on top of the brain, producing our higher mental functions, the deeper areas of the brain are vital for our physical and emotional functioning. We share these parts of the brain with our evolutionary ancestors and many unrelated animals. The cerebellum is one of these ancient brain structures. It rides piggyback on the top of the spinal cord and behind and under the cerebrum. While the cerebellum makes up ten percent of the volume of the brain, it actually contains more than half of the neurons in the brain. It needs all these neurons because the cerebellum is in charge of balance. This is a vital function in all animals but the task is made more difficult for our cerebellums, as humans teeter around on two legs.

The brainstem connects the brain to the spinal cord. This is the oldest part of our nervous system in evolutionary terms and it's in charge of basic life functions such as the heart beat, breath and sleep.

There are further small structures within the brain that play fundamental roles in our lives, among them the amygdala, hypothalamus and hippocampus. The amygdala interprets and contextualises emotions, linking feelings to memories and learning. Brain scans have shown that the amygdala is active at night, suggesting it might be partly responsible for dreams and nightmares.



A simplified diagram of a neuron.

> **"One calculation said the brain can hold 2.5 million gigabytes of information"**

The hypothalamus is pretty tiny, the size of a sultana, but it's responsible for hunger, thirst and the sex drive, it tells you to go to sleep and watches the levels of sugar and salt in the blood. The hippocampus is vital to memory and learning.

While these different structures in the brain are responsible for very different areas of our lives, they all carry out these responsibilities with the same set of tools: neurons. Our brains have about 86 billion of these specialised nerve cells. Neurons look very different from most cells. The main cell body, the soma, projects branching fingers, called dendrites, that connect to other neurons. Extending from the base of the soma is a long tail, the axon, which splays out its own dendritic fingers at its termination, connecting to a different set of neurons via tiny gaps between the dendrites called synapses. Diagrams suggest that axons have only a handful of dendrites but that's actually a result of simplification. In fact, axons extend thousands of dendrites from their terminus.

Axons vary hugely in length. In the brain, they might be a millimetre but the nerve cells that originate in the brain and go down the spine can have axons that are a metre (3.2-feet) in length. It's these connections that enable the brain to do what it does, all 100 trillion of them. To give some idea of the scale of this, there are a thousand times more synaptic connections in your brain than there are stars in our galaxy, and there's at least a hundred billion stars in the Milky Way. One calculation suggested that the brain can hold 2.5 million gigabytes of information but that's probably an underestimate, as the brain can adapt to changing physical circumstances, particularly when young and growing.

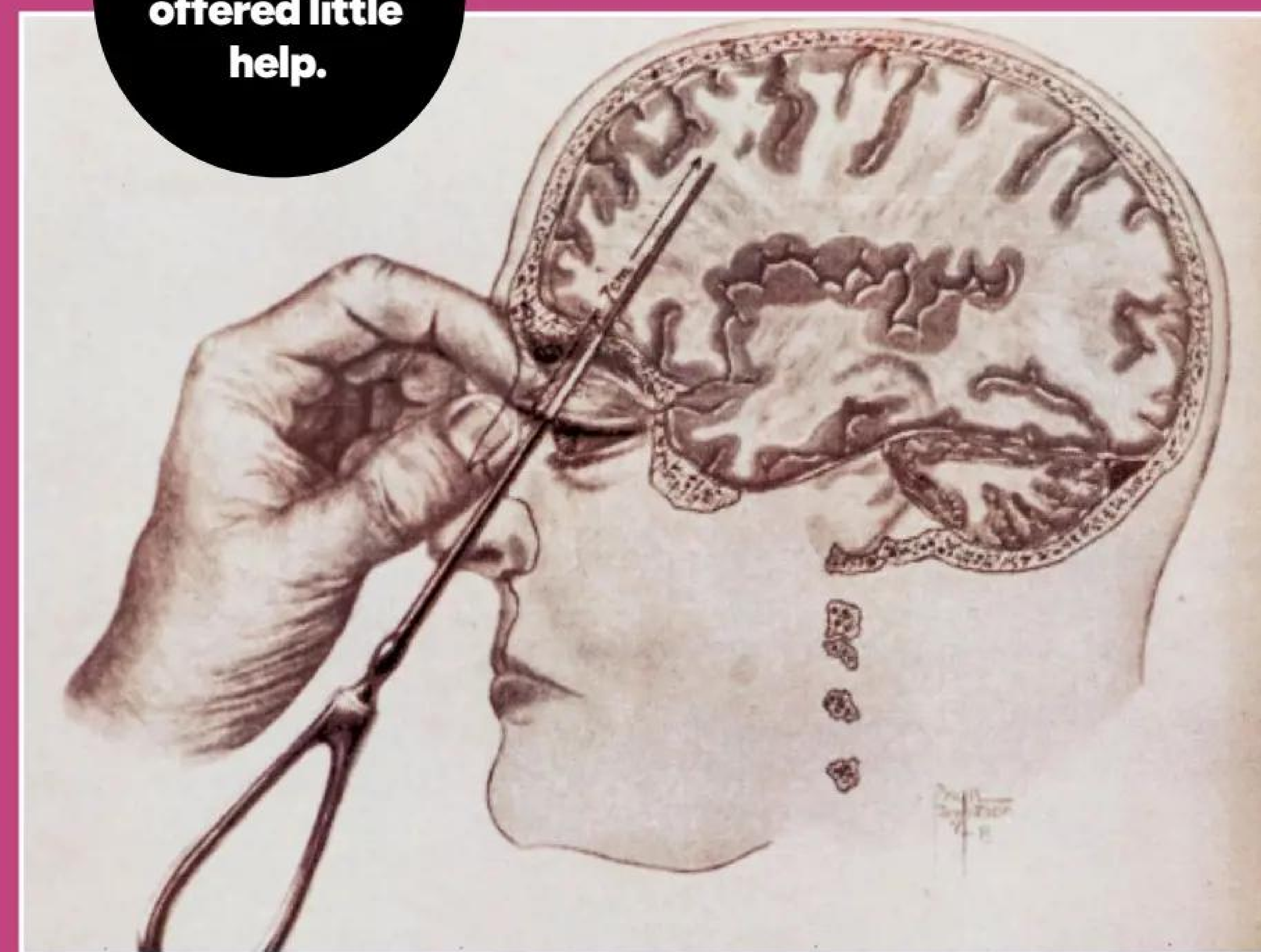
A good example of the brain's adaptability is provided by a case reported by Dr James Le Fanu. A middle-aged man underwent a brain scan only for his astonished doctors to see that two thirds of his skull was occupied

John F Kennedy's sister, Rosemary, who was lobotomised at the age of 23

by a cyst. The cyst was benign and it must have been in place since he was a baby. The extraordinary thing was that the patient was perfectly normal intellectually. His growing brain had wired itself to cope with having only one third of the normal space.

There is continuing debate over whether the brain can produce new neurons after childhood. Brain growth is explosive in the first five years of life and it has largely finished by the age of ten. However, new synaptic connections continue to be made throughout the teenage years and into early adulthood. So it's true: teenagers really do think differently from grown-ups. These differences are exaggerated because the production of dopamine, the brain's pleasure hormone, reaches a peak during the teenage years, making teenage emotions more piercing and enduring than at any other time of life. As far as new neuronal growth is concerned, while scientists remain undecided as to whether this happens, it has become increasingly clear that older brains are able to reconnect themselves following traumatic events such as strokes. Although it is easier for younger brains to set about rewiring themselves, there is now evidence that older people

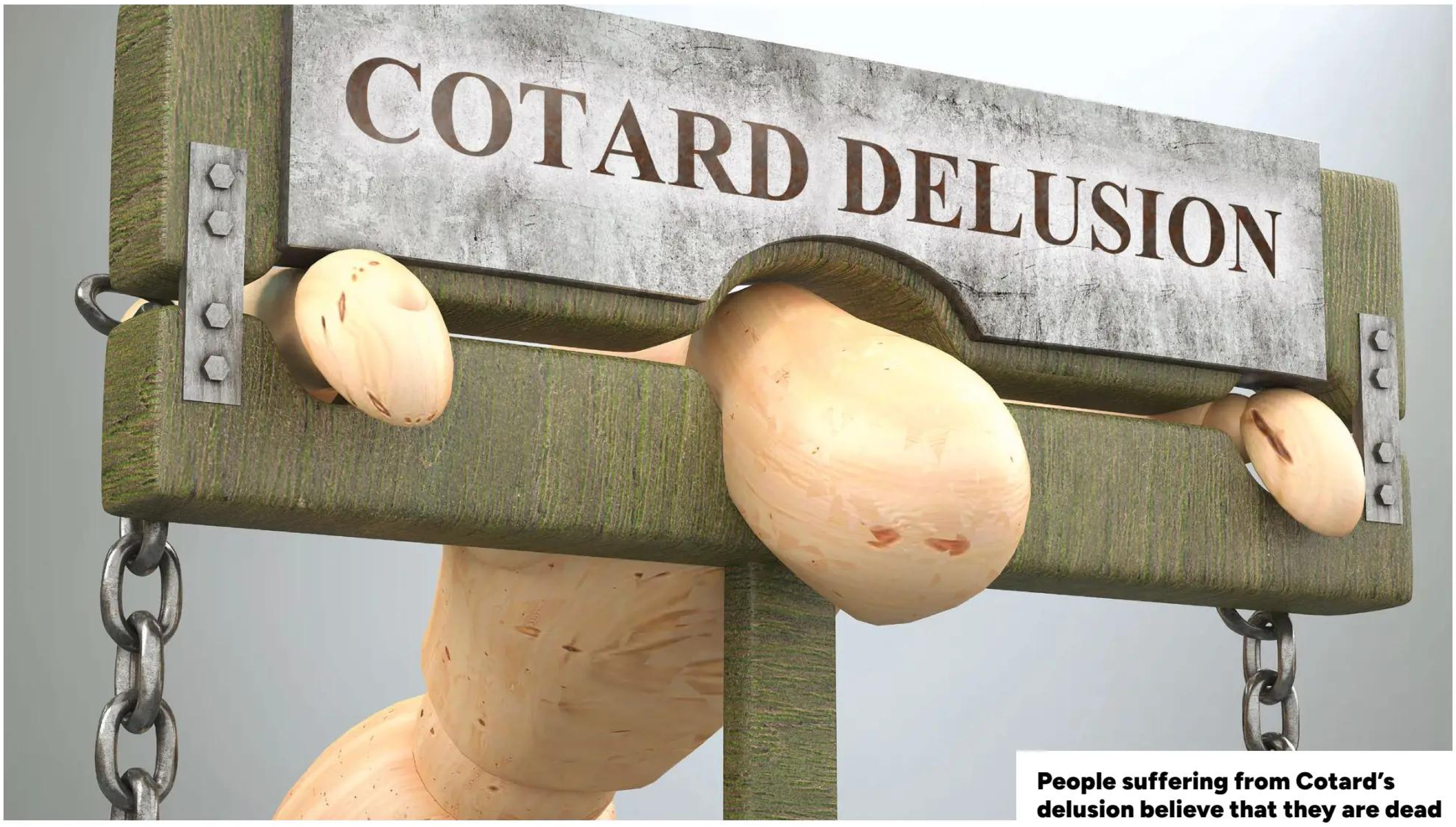
A crude operation that offered little help.



When science goes wrong

How the best and brightest supported a vile neurological surgery

In November 1941, 23-year-old Rosemary Kennedy, the elder sister of future president John F Kennedy, was sedated and, while still conscious, neurosurgeon James Watts began to remove parts of the frontal lobes of her brain. Rosemary was subject to mood swings and erratic behaviour and her overbearing father, Joseph Kennedy, had decided that a new surgical procedure would cure his headstrong daughter who was threatening to damage his political ambitions. The operation left Rosemary Kennedy permanently unable to speak and she was incontinent. She spent the rest of her life in institutions. The operation was known as a lobotomy and it had been pioneered by Egas Moniz, a Portuguese professor of neurology. In 1949, Moniz was awarded the Nobel Prize for his work. Lobotomies were enthusiastically taken up by the medical profession as cures for all manner of psychological disorders. The procedure's most enthusiastic proponent, Walter Jackson Freeman, performed more than 3,000 lobotomies over 25 years, in many cases literally sticking an ice pick up through the eye socket and wiggling it to sever the connection of the frontal lobe to the brain. Freeman's youngest patient was four. Freeman and his associate, James Watts, reported that 63 percent of their patients improved, 23 percent were unchanged and 14 percent worsened. In reality, at least 100 of his patients died as a result of the operation and many others were left permanently damaged. Before we condemn, it's worth remembering that the best and most progressive people of the time were all in favour of the utility of the operation. One wonders if there might be any medical procedure today that we will look back on with similar horror, wondering how people could have let it happen.



People suffering from Cotard's delusion believe that they are dead

will also benefit from extended physiotherapy following strokes to help regain function.

Strokes are a human peculiarity. They are extremely rare in other mammals but in humans they are the second-most common cause of death, after heart disease. No one really understands why this should be the case. The brain takes more than its share of blood from the heart, and yet we still get strokes. It's as much of an enigma as the mysterious case of our shrinking brains. Yes, our brains are getting smaller, and significantly smaller at that. By taking casts of excavated skulls, scientists have been able to measure that the average brain volume of people who lived 10,000 years ago was 1,500 cubic centimetres (91 cubic inches). Today, the average brain volume is 1,350 cubic centimetres (82 cubic inches). Although the difference might not seem much, it's about the size of a tennis ball. That's a pretty significant amount of brain to lose. So does this mean we are getting stupider? No one really knows. The example of the man with the cyst shows that brains can function with less space, so it's possible that our brains have simply become more efficient. Alternatively, the penalties for stupidity may have declined with the rise of civilisation, allowing for a general lessening in mental abilities. Such a phenomenon should perhaps make us less eager to accept wholeheartedly the aid of artificial intelligence in our lives.

While the brain sits snugly at the top of the nervous system, it sends out its scouts and messengers to the farthest reaches of the body through the long column of the spinal cord and the nerves radiating out from it: the central nervous system. The peripheral nervous system contains the nerves that go out to the peripheries of the body. The nervous system is classified further into the somatic (voluntary) nervous system, which we use when doing any intentional action, and there is also the autonomic nervous system, which controls the things that happen without our thinking about it, such as sweating and breathing. The autonomic nervous system is itself split into the sympathetic and parasympathetic nervous systems. The sympathetic nervous system takes charge when we're in flight-or-fight mode, the parasympathetic nervous system holds sway during the rest-digest parts of our day.

Unlike the nerves in the central nervous system, the nerves in the peripheral nervous system regrow relatively easily. The general incapacity for regrowth by nerves in the central nervous system is why a broken back can result in complete paralysis from the break downwards.

Our nerves send information about the outside world to the brain and relay its instructions back again. Perhaps the most obvious message is pain. Pain is such a universal experience of life, and its message so apparently clear, that you would assume understanding how it works would be straightforward. However, this has proved to be far from the case. The textbook example of pain and reaction is how your hand will jerk back from something hot before you even have a chance to register that it's hot. In certain cases, such as this, the central nervous system acts before the pain signal has reached the brain, sending the withdrawal response to the arm while the pain signal is still travelling to the brain. So the pain response is active, responding to different types and intensity of pain in different ways.

Pain starts at nerve receptors called nociceptors. These are nerves that are specialised for pain. We have different nerve endings for touch and temperature. Nociceptors are keyed for three different sorts of pain: chemical, thermal and mechanical. So it's your nociceptors that convey the information that you've accidentally stuck your finger in the fire. Some nociceptors work across chemical and thermal stimuli, which is why eating chemically spicy food is perceived as a burning sensation. Showing how much there is still to learn about pain, scientists have not yet identified the nociceptors that respond when you hit your thumb with a hammer. Yes, the nociceptors that respond to mechanical pain – crushing, piercing, cutting – are still a mystery to us.

Our minds are bigger than our brains, for they contain wonders

> “Despite advances by neuroscience, the central nervous system remains mysterious”

However, whichever nociceptor is triggered, the message gets sent to the central nervous system via a fast-response channel and a slow-response channel. Two different types of nerve transmit pain messages at different speeds and produce different sensory feedbacks. The fast channel is the 'ouch' channel, the immediate sharp sensation of pain. The slow one is the 'ow' channel, the long throb you get for a few minutes after hitting your thumb with a hammer. But what happens when the signal gets to the brain exacerbates the mystery of pain. Where most brain functions are localised in particular areas of the brain, the pain response is general. It can occur anywhere. Stub your toe today and one part of your brain will respond. Stub it again tomorrow and an entirely different part of the brain will react. We have no idea why this should be the case.

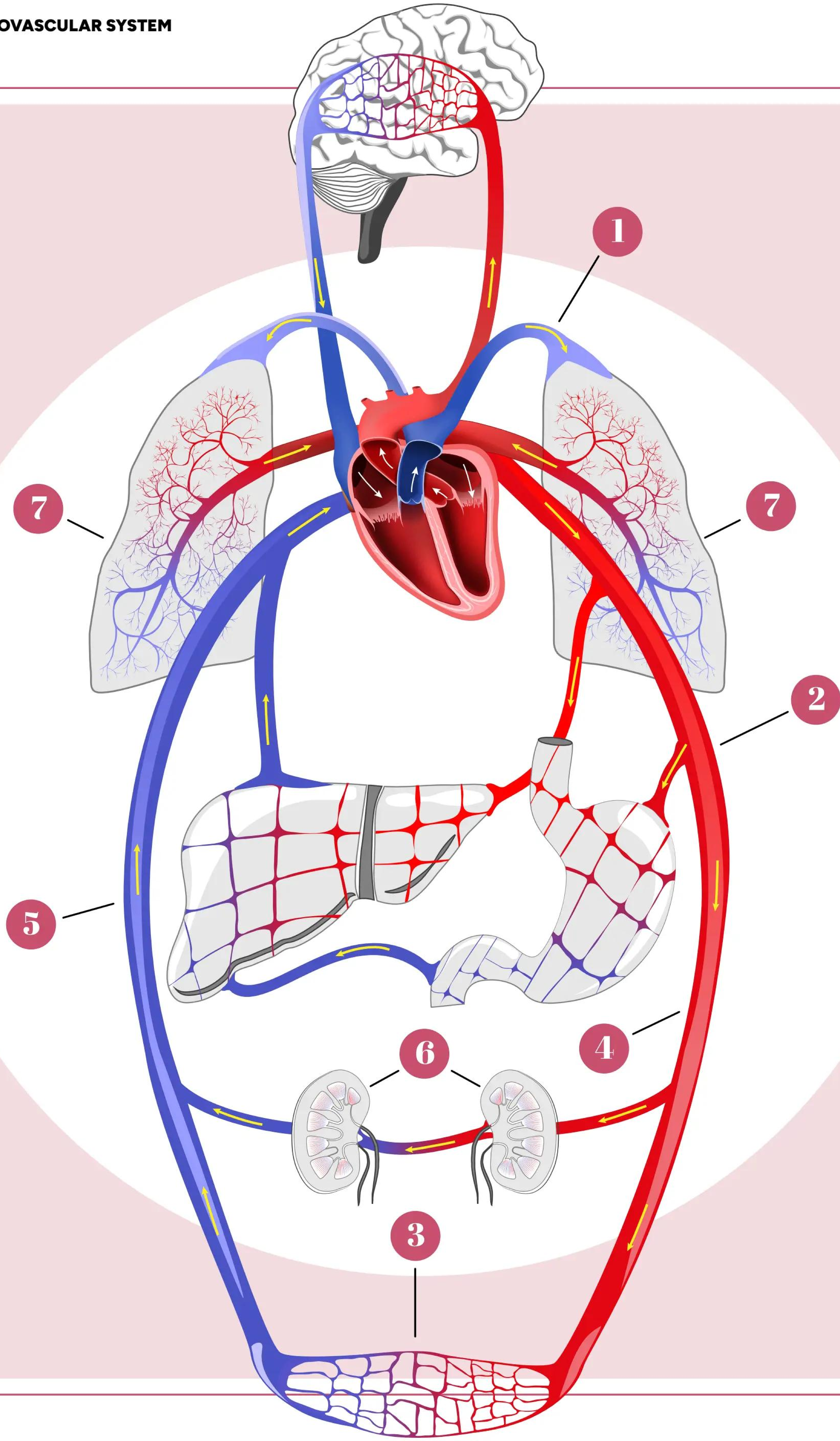
Despite recent advances by neuroscience, the brain and central nervous system remain mysterious. Sometimes, and for reasons we don't understand, the link between the brain and body can break, leaving someone trapped inside their body, fully conscious but unable to respond. Strange syndromes can produce bizarre behaviours; people suffering from the Cotard delusion are sure that they are dead, the Riddoch syndrome leaves people unable to see objects if the object is still.

The palace of our minds is vast, seething with thoughts and emotions. Looking up at the night sky and its innumerable stars, the mind that perceives it is more capacious yet, for it sees the stars and knows that it seems them too. And that is the greatest mystery of them all.

THE *CARDIOVASCULAR* *SYSTEM*

How blood finds its way around the body and the heart-shaped pump that propels it

WORDS BY SCOTT DUTFIELD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BREAKDOWN OF THE SYSTEM

1

Pulmonary circulation

The portion of the circulatory system whereby deoxygenated blood moves from the heart to the lungs and returns deoxygenated.

2

Systemic circulation

Oxygenated blood travels from the heart to the rest of the body delivering oxygen and collecting carbon dioxide as a waste product.

3

Capillaries

Numerous small blood vessels, composed of both arteries and veins, exchange materials with adjacent tissue cells.

4

Arteries

Blood vessels that carry oxygenated blood around the body.

5

Veins

Blood vessels that carry deoxygenated blood around the body to the heart.

6

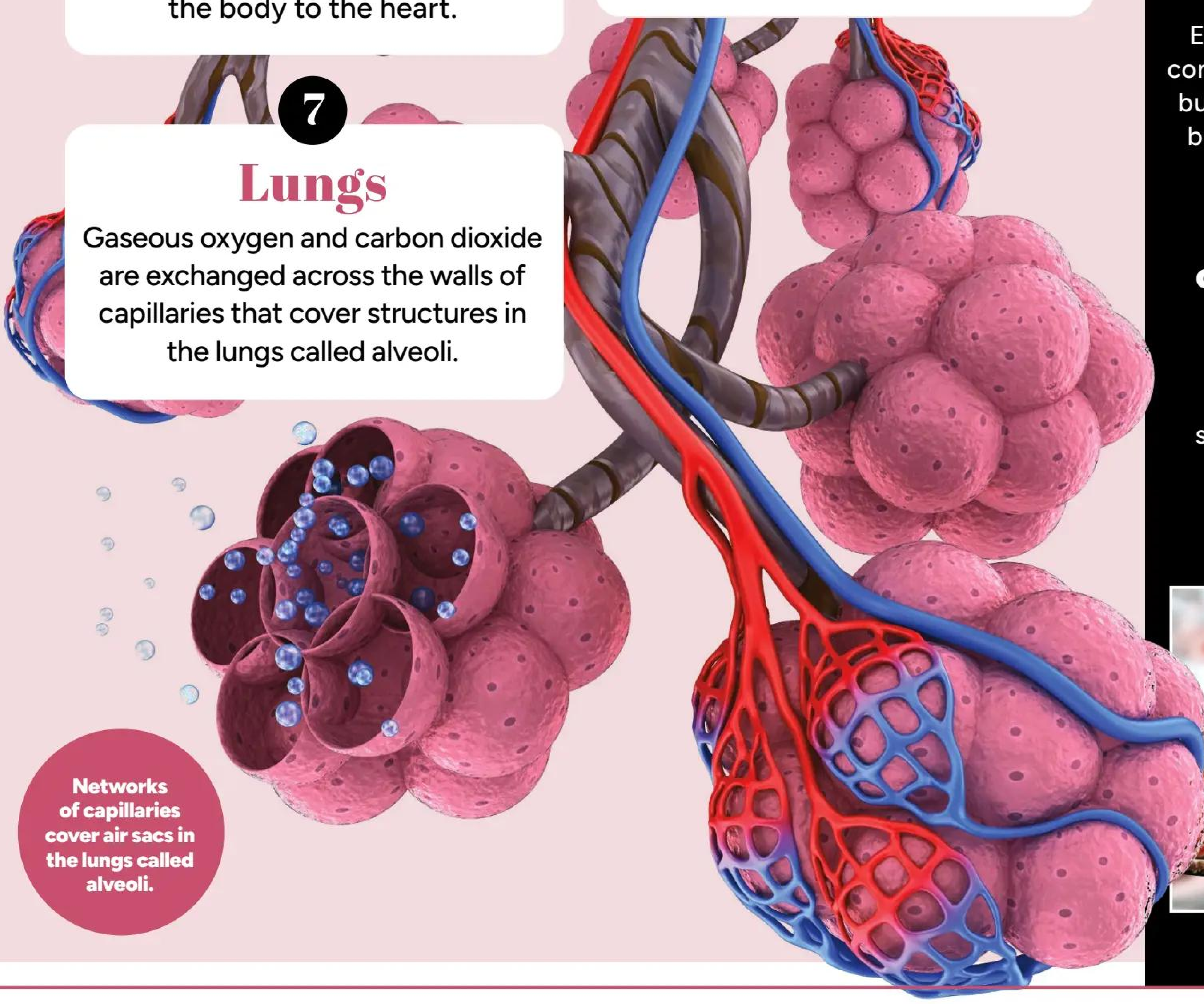
Kidneys

Waste products, such as urea, and any extra water are removed from the bloodstream through the kidneys.

7

Lungs

Gaseous oxygen and carbon dioxide are exchanged across the walls of capillaries that cover structures in the lungs called alveoli.



Networks of capillaries cover air sacs in the lungs called alveoli.

Fact file

Everything you need to know about the cardiovascular system

What does the system do?

The circulatory system is responsible for transporting around five litres (ten pints) of blood around the human body and delivering it to every organ, tissue and muscle within it.

Why is it important?

Blood carries and offloads vital oxygen to the majority of cells in the body, which require it for respiration and survival.

When does this system develop in a foetus?

Within the first four weeks, an embryo starts to develop an early circulation system to supply the body's other emergent systems with vital blood.

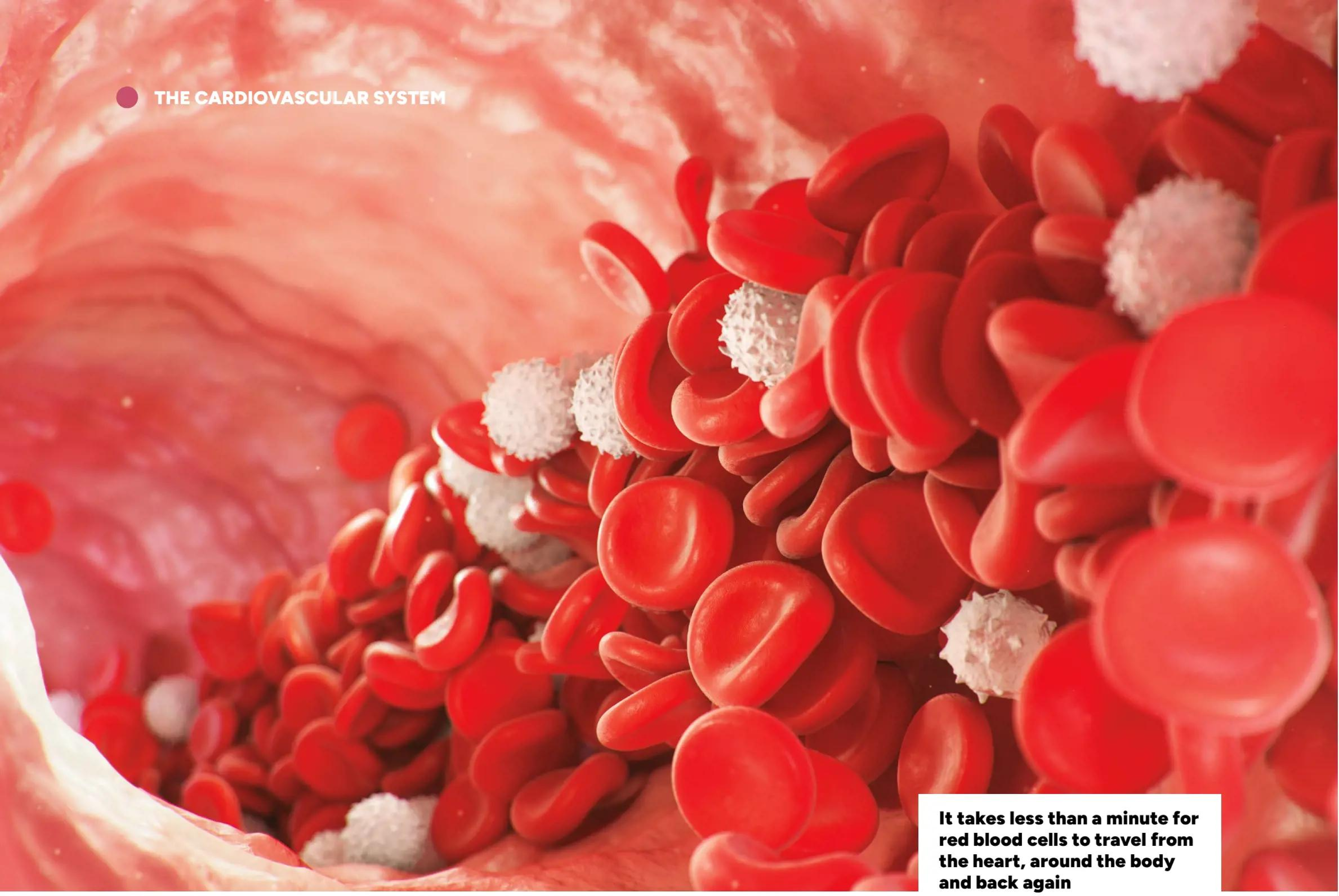
What organs are part of this system?

Every organ in the human body is connected to the circulatory system, but the heart is integral in pumping blood around the system, and the lungs supply vital oxygen.

What are common conditions associated with this system?

Atherosclerosis, known as the hardening of the arteries, and several heart-related conditions, such as arrhythmias and hypertension, are common circulatory conditions.

Slowly, over time, high cholesterol levels form mounds of plaque within the arteries.



It takes less than a minute for red blood cells to travel from the heart, around the body and back again

The cardiovascular system, also known as the circulatory system, is the body's essential blood delivery highway, consisting of a network of interconnected vessels that transports vital cells, nutrients and hormones.

Riding along this biological superhighway is the life-maintaining fluid called blood. Every second, two to three million red blood cells are produced deep within the body's bone, known as the marrow. Within the bone marrow, transformative stem cells – known as hemocytoblasts – rapidly evolve in just two days to become new red blood cells.

Red blood cells are curious little cells which, unlike the majority of other cells in the body, have no nucleus. For the rest of the cellular population, the nucleus is the information centre of the cell, giving it instructions on how to behave. Without a nucleus taking up available space, there's more room for red blood cells to carry around a vital pigment called haemoglobin. Other than producing its crimson colour, haemoglobin acts as the molecular carrier for oxygen.

Following their manufacture within the bone marrow, red blood cells find their way into the cardiovascular system via a dense network of blood vessels called capillaries. For around 120 days, red blood cells are then pumped around the body on a continuous cycle of oxygen pick up and drop off. However, when the cells become damaged or die, some of the body's immune system cells, called macrophages, break them down and remove them.

Red blood cells aren't alone with the body's vast network of blood vessels. Alongside the 35 trillion red blood cells drifting through the body's bloodstream are sticky cells, called platelets, and members of the immune system, called white blood cells.

Hitching a ride through the body's blood circulation gives white blood cells the best opportunity to encounter any unwanted pathogenic invaders, such as viruses and bacteria, and destroy them. These additional cells make up just four per cent of blood's total composition.

Platelets, on the other hand, act as a biological glue and form blood clots at the site of injury, such as at the site of a cut in the skin. This cellular barrier prevents vital blood cells from escaping the cardiovascular system while the body heals. When the levels of platelets are low, such as in those who suffer from a genetic condition called haemophilia, the clotting process is stifled and a simple cut can lead to extended bleeding and cause serious health issues.

The majority of blood, around 55 per cent, is composed of a yellowish fluid called plasma. Acting as the freight train on the circulatory railway, plasma provides the vehicles for not only red blood cells, platelets and white blood cells, but also countless other hormones, proteins and nutrients that keep the body ticking over.

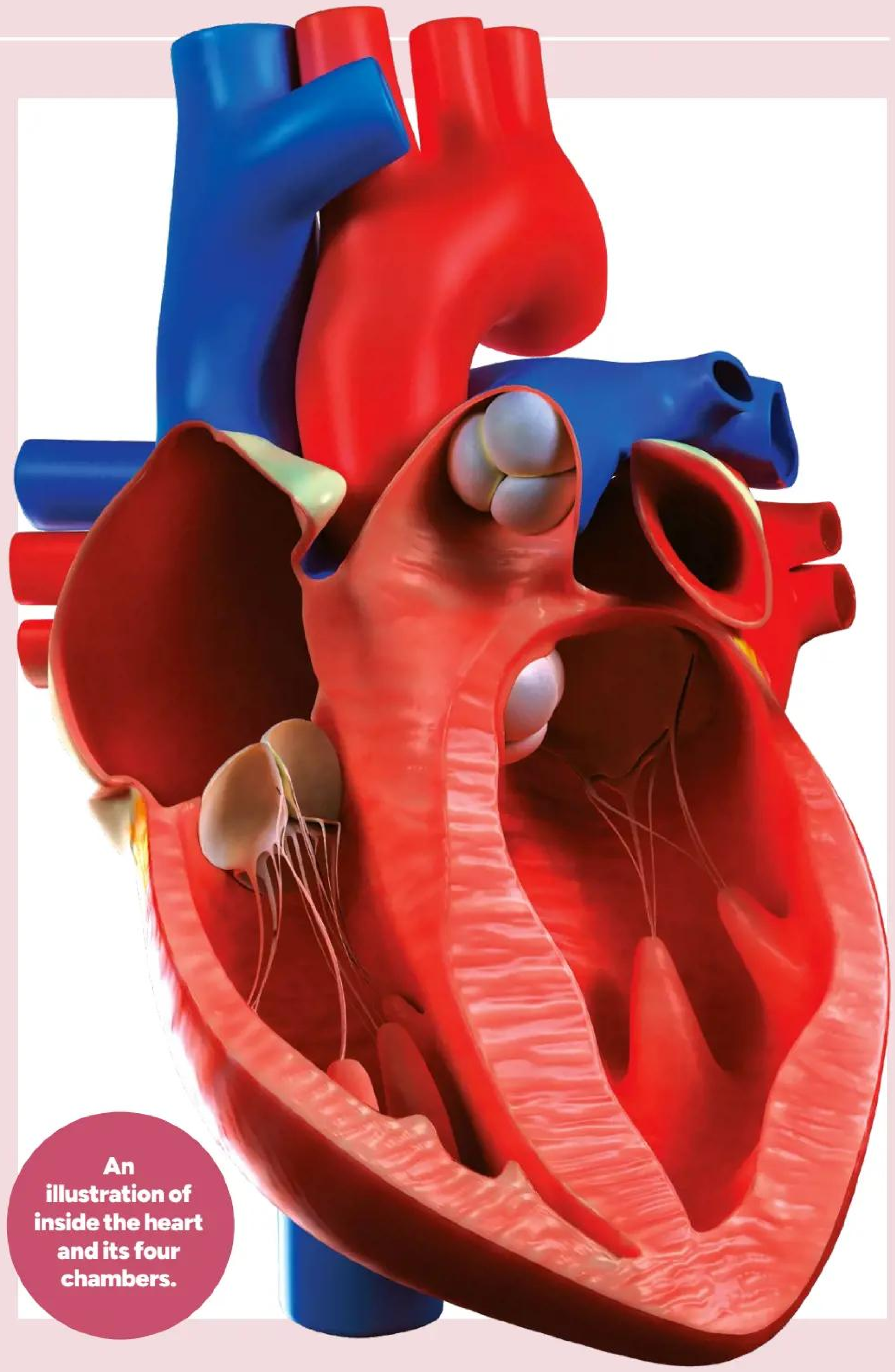
Inside the heart

So how does this fluid find its way around the body?

It all starts at the fist-sized muscular organ called the heart. Found in the centre of the chest, sandwiched between a pair of lungs, the heart's sole purpose is to pump blood in and out of its chambers, generating enough force to propel it around the body.

The heart is divided into two halves, which are separated by a muscular wall called the septum. Within each half are two chambers, known as the atrium and the ventricle. To propel blood through the cardiovascular system, the chambers will relax and contract under the electrical guidance of a natural pacemaker, called the sinus node. Between 60 to 100 times a minute, the sinus node releases an electrical stimulus that travels through the tissue of the heart's muscle through both atriums, causing them to contract. The impulse then moves to the ventricles, which also causes them to contract. This period of contractions is known as systole, whereby blood is pumped out of the heart.

"The heart's sole purpose is to pump blood in and out of its chambers, generating enough force to propel it around the body"

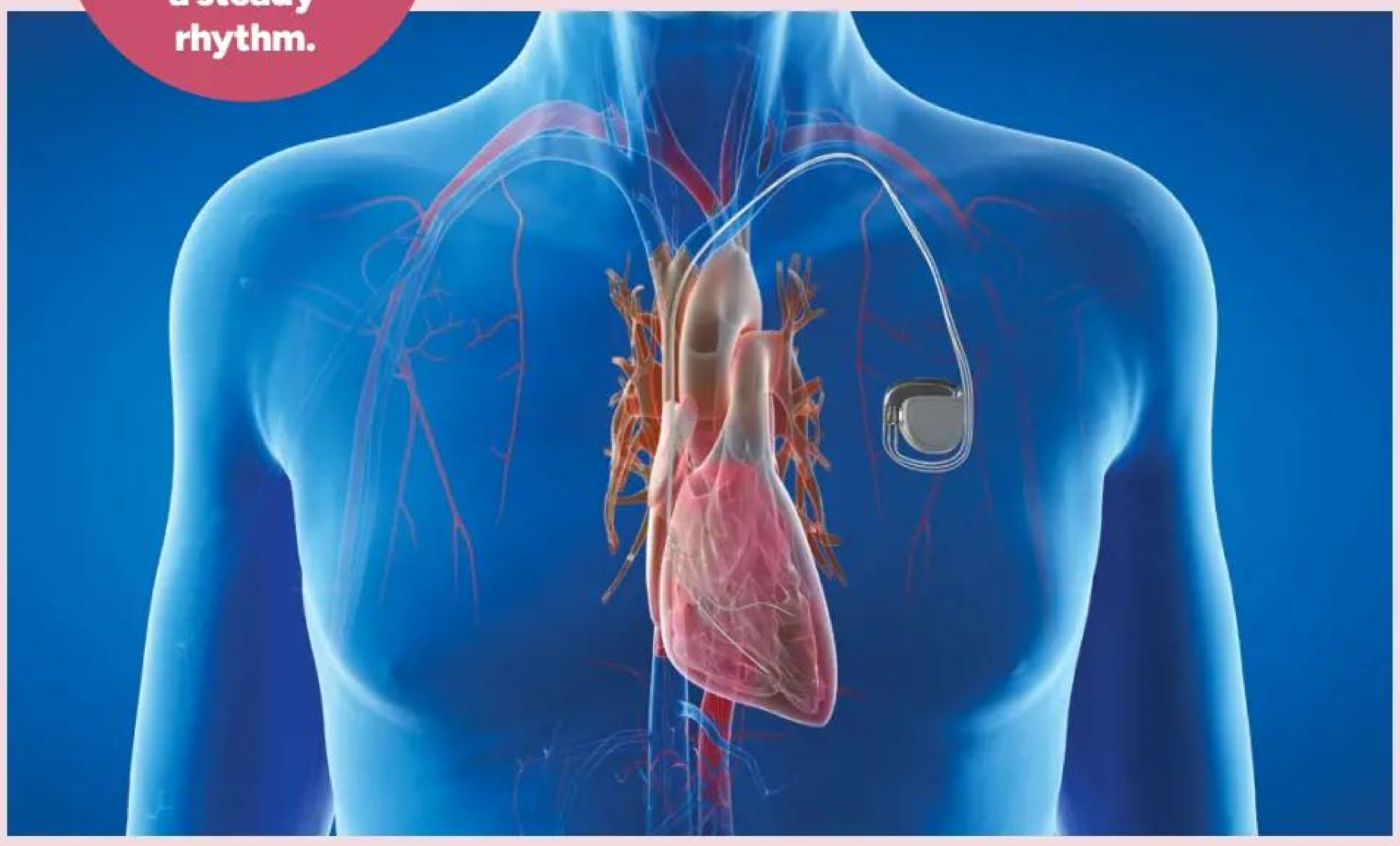


An illustration of inside the heart and its four chambers.

When the electrical signals of the sinus node become uncoordinated, it can result in the development of a rhythmic issue called an arrhythmia. Faulty or misfiring signals can make the heart beat irregularly, either too fast (tachycardia), or too slowly (bradycardia). To step in for the sinus node and remedy rhythm irregularities, an artificial pacemaker can be surgically installed. Once implanted beneath the skin, the pacemaker systematically delivers a low-energy electrical impulse through electrode wires that have been fed through veins connecting to the heart.

During the short period when the electric impulse has subsided and the muscle relaxes, known as the diastole, blood is free to fill each atrium. Then another wave of contractions moves it through valves separating the chambers and into the ventricles. After another contraction, the blood is forced from the ventricles through another valve and exits the heart through one of two vessels called the pulmonary artery or the aorta.

This repeating cycle of muscle relaxation and contraction creates a heartbeat. Unlike many other electrical signals generated in the body, heartbeats are powered by the brain. The human heart operates myogenically, meaning that specialised muscle cells in the heart cause it to contract, without nerve impulses. Even in the event when a person is declared brain dead, the heart will continue to beat until the lungs, or an artificial ventilator, stops supplying it with oxygen.


An illustration of a pacemaker hooked up to a heart to maintain a steady rhythm.

Following bloodstreams

The blood heading out through the aorta starts its journey to the rest of the body through one of two parts of the cardiovascular system. This is called systemic circulation.

This portion of the cardiovascular system is responsible for delivering its oxygen-rich haemoglobin to the tissue and organs that need it, through blood vessels called arteries. These tube-like structures run throughout the body and branch off into smaller structures called arterioles. The anatomy of the artery walls consists of three distinct layers. The first, innermost layer is the tunica intima, consisting of simple epithelial cells and elastic fibres. The following tunica media layer is the thickest of the three layers, and is formed of tough, smooth muscle cells. At the outermost layer, called the tunica adventitia, are heaps of collagen and elastic fibres. Together, these three layers work together to build strong and flexible blood vessels. The width of the body's arteries varies from as thin as a human hair to around two centimetres wide at the aorta.

Blood that travels through the systemic circulation eventually passes through delicate bundles of blood vessels, called capillaries. These are the sites where haemoglobin off-loads its oxygen passengers and passes them off to neighbouring tissue. In return, carbon dioxide, a waste product of cellular respiration, binds to

the haemoglobin and some proteins found in the blood's plasma. Some organs – such as the kidneys or liver – have an excessive network of capillaries, due to their high oxygen and nutrient demands; whereas other areas of the body – such as the skin – don't require as many.

The capillaries are also where arteries and veins meet. Once depleted of its oxygen supply, blood continues moving through the body via blood vessels called veins. This deoxygenated portion of circulation is called the venous system. The anatomy of the veins isn't unlike the arteries – there is just one important addition: valves. On its journey through the arteries, blood flows downwards away from the heart. However, blood moving through the veins has to defy the pull of gravity to climb its way back towards the heart, especially in the legs and the arms. Ensuring that blood keeps flowing in the right direction, a series of venous valves prevent the back flowing of blood on this last leg back to the heart. This portion of the cardiovascular system is also the most vast, containing almost 70 per cent of the total value of blood in the body.

Blood arrives back at the heart through a large vessel called the superior vena cava, and begins the second half of the circulatory system known as pulmonary circulation.

After a couple of contractions, the deoxygenated blood is forced through the heart's right atrium and ventricle before heading out through the pulmonary artery. To regain its supply of oxygen, red blood cells head towards the lungs for a top-up.

While passing through the extensive network of capillaries within the lungs, carbon dioxide is exchanged into air sacs within the lungs called alveoli, and oxygen is obtained. Having passed through the lung's capillaries, reoxygenated blood is transported back to the heart through the pulmonary vein, ready to start the cycle all over again.

Like any other organ, the heart requires oxygenated blood to function. Despite being constantly filled with blood, the muscles of the heart receive their supply from one of the first vessels to branch off the aorta called the coronary artery. Similarly, a coronary vein then sends blood back into the heart's right atrium to be pumped to the lungs for reoxygenation.

All in all, the body contains around 60,000 miles of blood vessels, which is around two and a half times as long as the circumference of the Earth.

Issues with the circulatory system

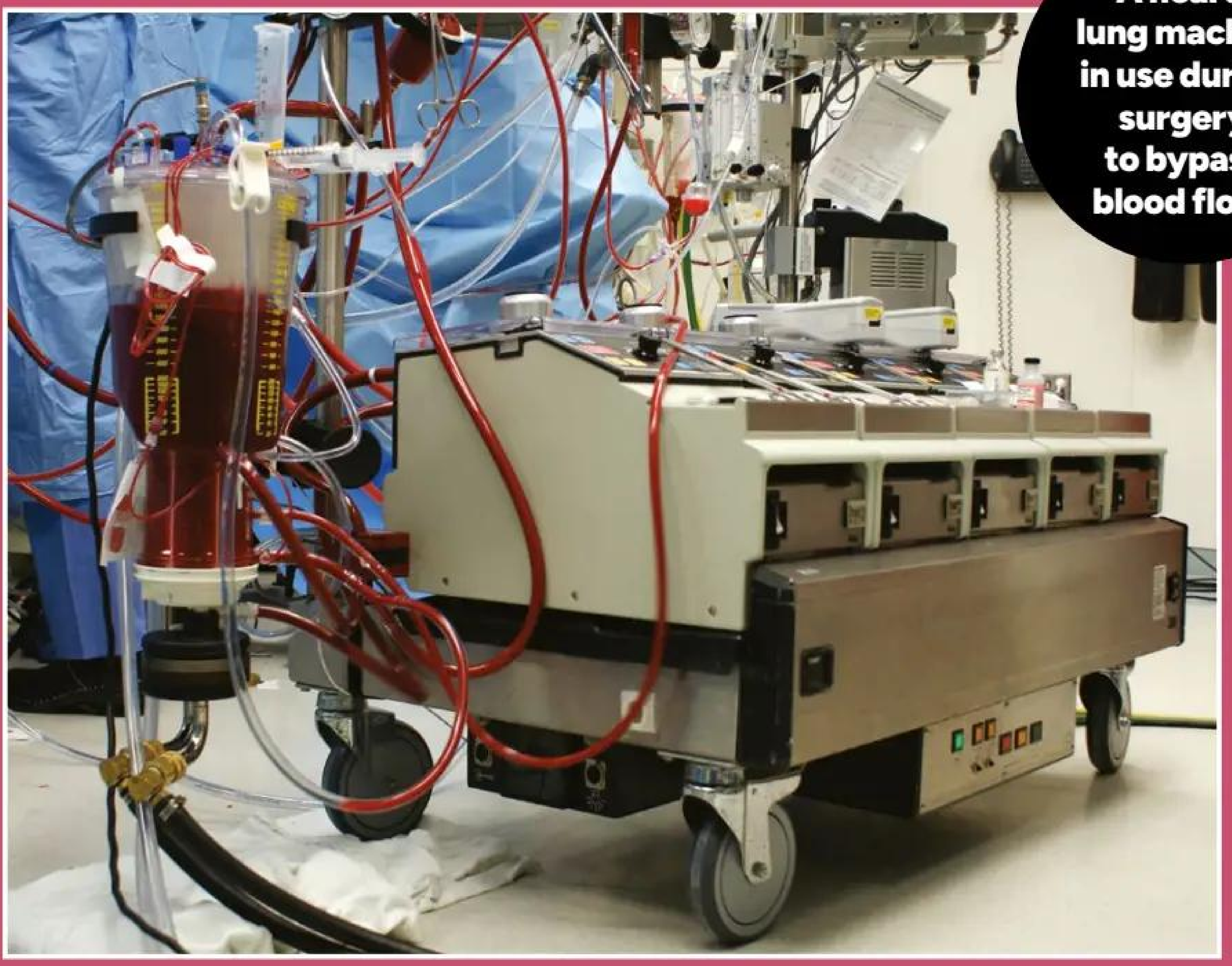
Several diseases and conditions can affect the function of the heart and the wider cardiovascular system, some of which develop long before a person is even born.

Around 1.2 per cent of births worldwide are affected by cardiac developmental defects, referred to as congenital heart disease (CHD). In the first six weeks of pregnancy, a foetal heart begins to form, along with a network of blood vessels. During this time, potential anatomical defects can emerge. CHD defects aren't

Artificial pumping

What happens to the body's blood supply when the heart needs a repair?

How can you operate on a heart, when the body needs it to pump blood to stay alive? It's a question that had left scientists scratching their heads until the 1950s, when an artificial cardiovascular system was invented, known as a cardiopulmonary bypass. Instead of flowing through the heart and lungs, blood is drained from the body and pumped through a machine that acts as a temporary replacement for them both before the blood is fed back into the body. Tubes called cannulas, are attached to the heart's superior and inferior vena cava, and blood flows into a reservoir. It is then passed through an oxygenator to supply the blood with much-needed oxygen, while also removing carbon dioxide waste. The blood is then pumped back into the body via another tube that has been connected to the aorta. The process completely bypasses the natural organs, giving surgeons the opportunity to carry out lengthy surgeries and transplants while keeping the patient safe and alive.



A heart-lung machine in use during surgery to bypass blood flow.

Red blood cells passing through the capillaries found in a human scalp

common, but are varied and can include a small hole between the upper chambers of the heart – known as an atrial septal defect – and malformation of vital values that prevent blood from travelling the wrong way, such as pulmonary atresia.

The exact cause of CHD remains unknown, but several risk factors, such as smoking, diabetes and certain medications during pregnancy, have been linked to its development. Some genetic factors contribute to the development of CHD, sometimes meaning that the disease can be inherited. Similarly, CHD is often seen alongside other genetic conditions, such as Down syndrome. Many mild CHD problems don't require treatment, while others require some medication to manage blood pressure and heart rhythms. For the more severe, life-threatening defects, surgical repairs or even a heart transplant are required.

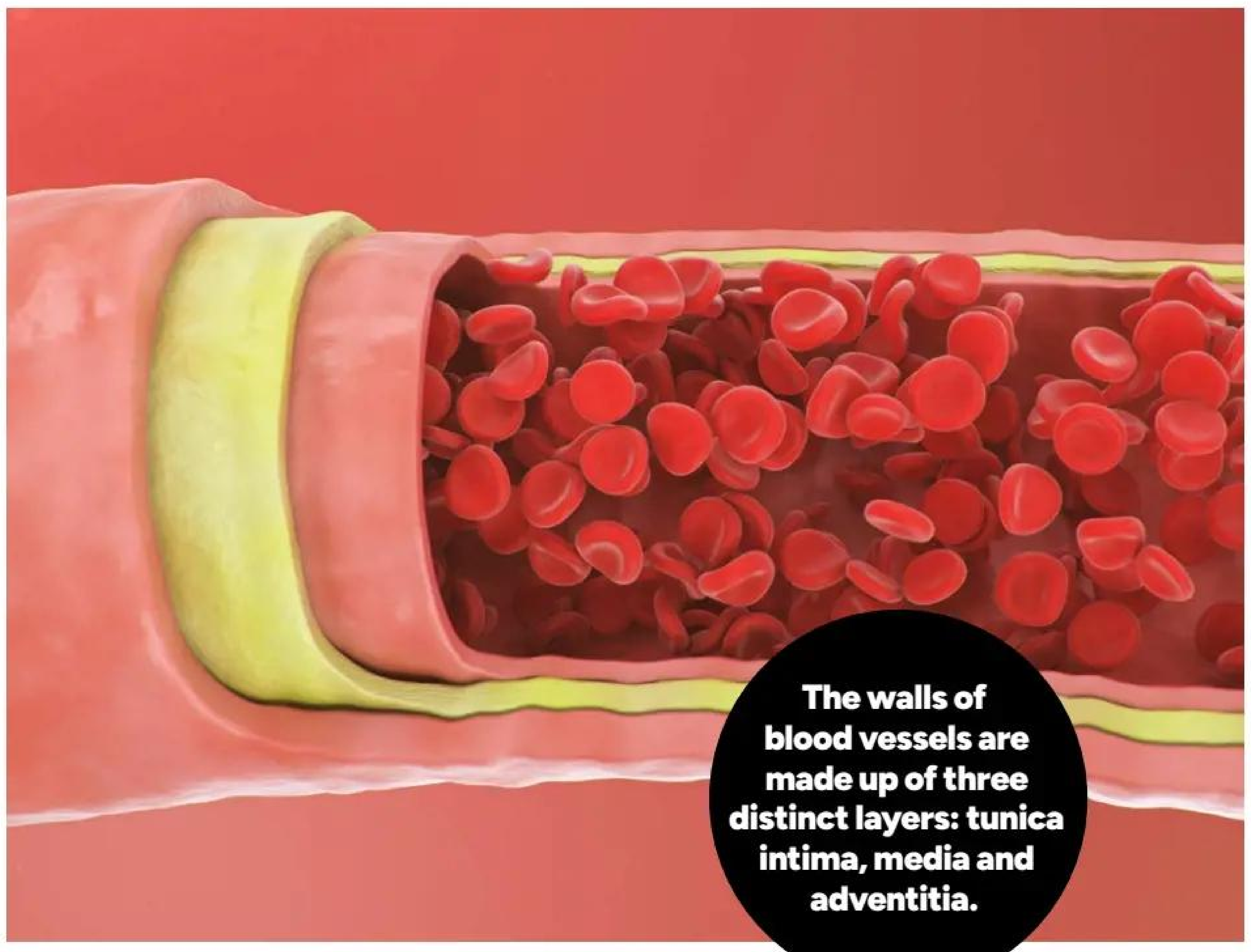
As well as genetic malformations, the arteries and veins are also at risk of being damaged by external forces. One of the biggest nemesis to the body's blood vessels is a fatty substance known as cholesterol. Typically, cholesterol is a useful substance that the liver uses to build cells and hormones. However, when there's more cholesterol in the body than the liver knows what to do with, then it begins to hang out in the bloodstream, creating cholesterol mounds, called plaque, and causing red blood cell pileups. The buildup of plaque within the blood vessels can come from consuming an unhealthy diet containing cholesterol-rich foods, such as fatty meats and dairy.

Unhealthy habits, such as smoking, also contribute to the formation of plaque. The various chemicals in a cigarette increase the stickiness of the blood platelet cells, causing them to clump together more easily and form harmful clots.

When plaque buildup reaches the point where it causes the blood vessels to narrow, conditions such as atherosclerosis develop. Much like the building pressure of a knotted hose pipe, when the body's arteries and veins become clogged by the plaque, blood pressure can increase to the point that it causes vessels, such as the aorta, to bulge and even rupture. When blockages prevent the heart from receiving enough blood, cardiac muscles become damaged, which can ultimately lead to myocardial infarction, more commonly known as a heart attack.

There are several medications that can be used to tackle blocked blood vessels, such as drugs called statins. These cholesterol-fighting drugs work by slowing down the production of cholesterol in the liver, which subsequently causes the liver to draw it out of the blood and turn it into a digestive fluid called bile. Similarly, a medication commonly known as 'blood thinners' is used to fight the risks of further blockages in the arteries. Despite its misleading name, blood thinners don't thin the blood. Instead, it is an anti-clotting medication that stops platelets from clumping together and prevents clots from forming.

If the artery walls have become too thick with plaque for medicine alone to treat, surgical intervention is required. A common surgical procedure for tackling atherosclerosis is known as an angioplasty, whereby a



The walls of blood vessels are made up of three distinct layers: tunica intima, media and adventitia.

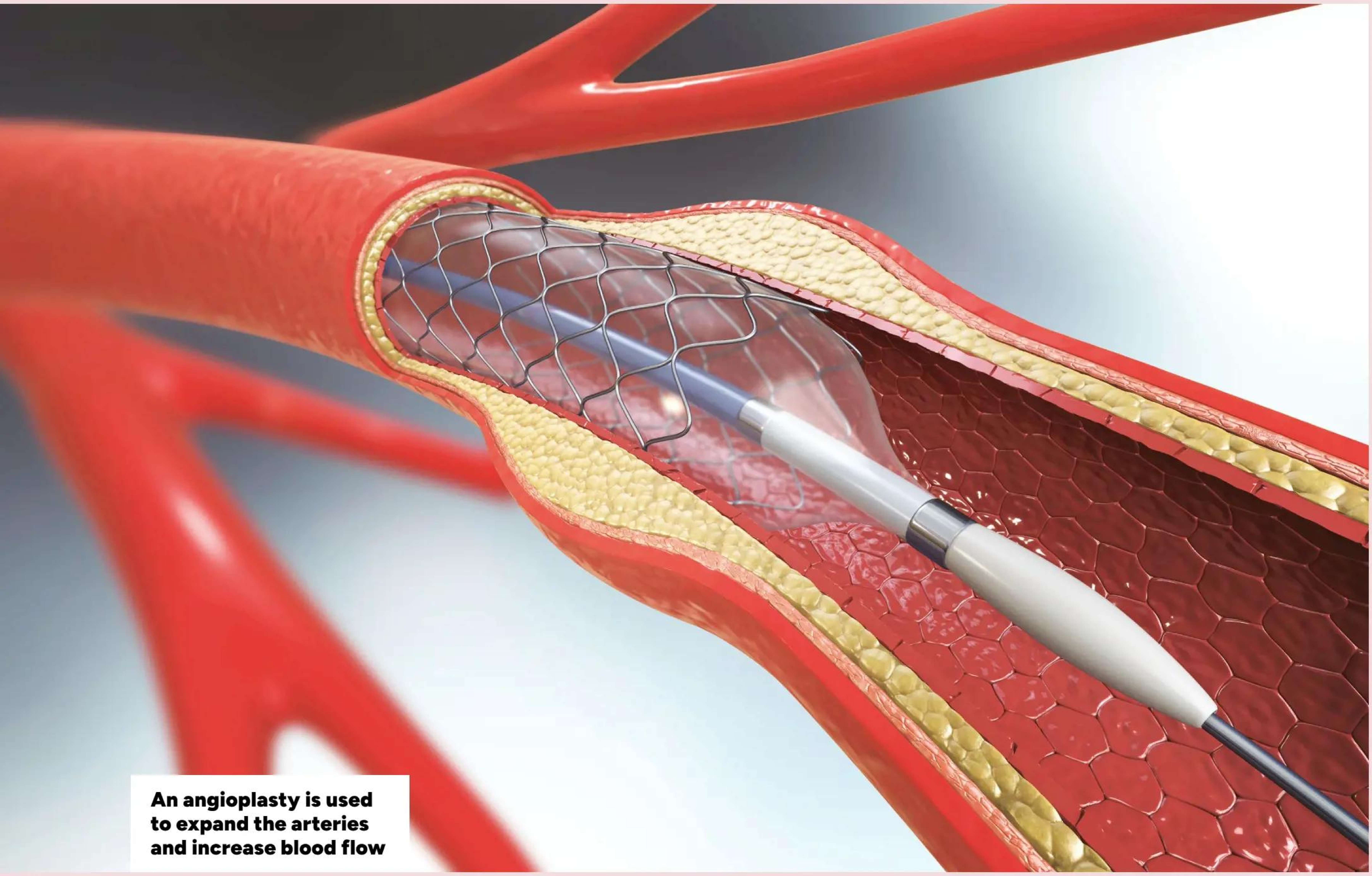
catheter is inserted into the vessel and a balloon is inflated at the tip. The balloon opens up the artery and enables the blood to flow more freely. To maintain blood flow, a metal mesh tube, called a stent, then replaces the balloon for a permanent solution.

With all of the body's integral systems, the cardiovascular system isn't immune from experiencing the negative effects of increasing age. High blood pressure, known as hypertension, along with artery stiffness, are just some of the ways the cardiovascular system changes over time. As the blood vessels age, malleable elastin fibres in one of the many layers that form the vessel start to decay, reducing its elasticity. Also, calcium deposits from within the blood contribute to the stiffening of the artery walls.

Arterial stiffness has been associated with atherosclerosis and increases the risk of stroke. However, maintaining optimal levels of vitamin D and K has been shown to help slow down the rate of artery calcification.

"The cardiovascular system isn't immune from experiencing the negative effects of increasing age"

Other than ditching cigarettes, making healthy lifestyle choices can have a massive impact on the overall wellbeing of the cardiovascular system. Exercise, for example, is one of the best ways to keep the cardiovascular system fit and healthy. Moderate to vigorous physical activity is enough to not only strengthen your heart muscles but also increase blood flow by widening the arteries. Some research suggests that being active can reduce the risk of developing circulatory heart disease by as much as 35 per cent.

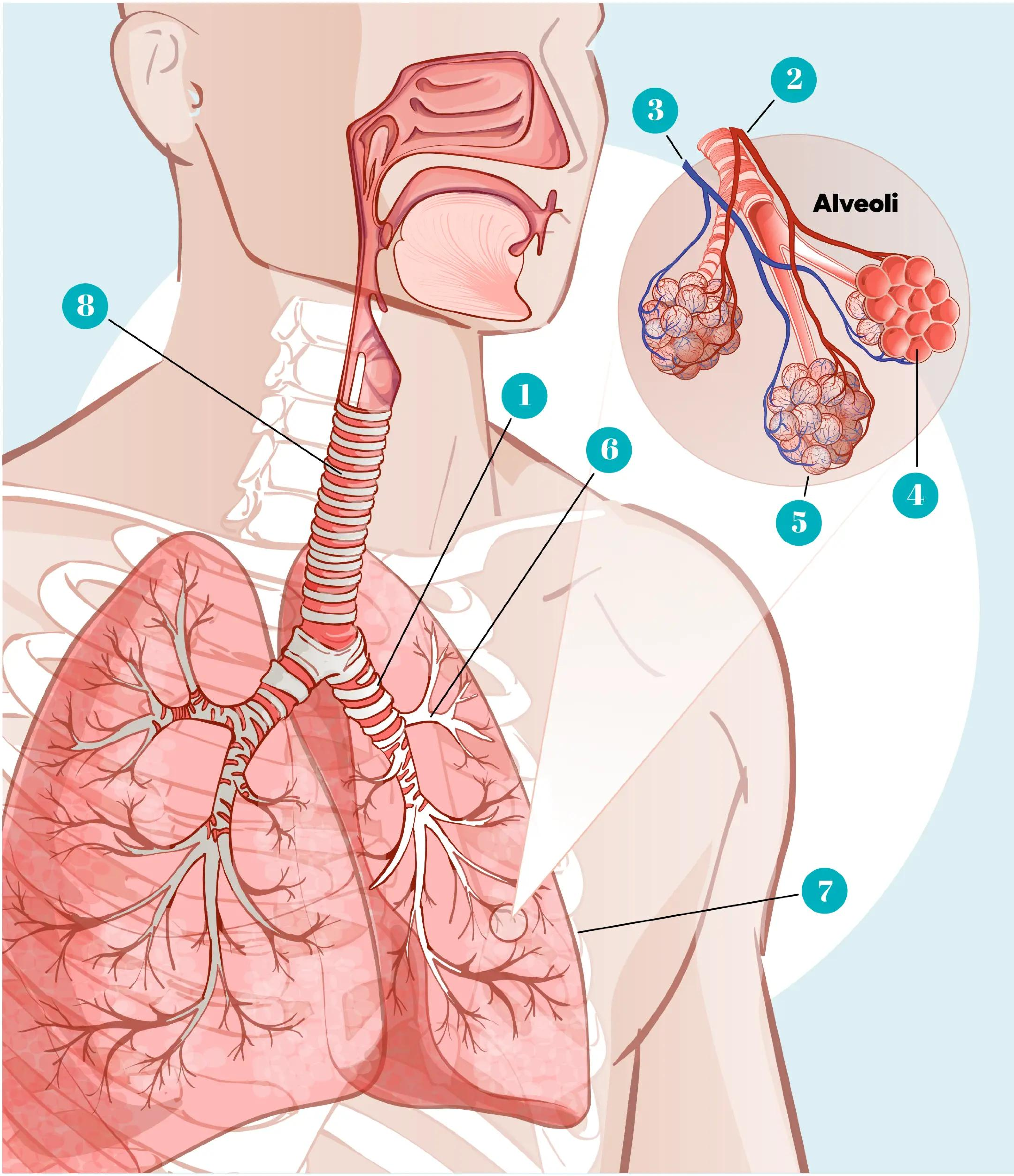


An angioplasty is used to expand the arteries and increase blood flow

THE RESPIRATORY SYSTEM

How does this core passageway keep your body's crucial gas levels well-balanced?

WORDS BY AILSA HARVEY



Alveoli
1
2
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5
6
7
8

BREAKDOWN OF A SYSTEM

1

Bronchi

Two large cartilage tubes connect your trachea to the lungs, splitting inhaled air into the left and right lungs.

2

Arteries

Deoxygenated blood enters the lungs in arteries, where they divide into small capillaries.

3

Veins

After gas exchange has taken place through the capillaries, oxygenated blood leaves the lungs through veins, to travel around the body.

4

Alveolus

Gas exchange occurs in these small air sacs within the lungs. Alveoli are one cell thick, making the process quick.

5

Alveolar sac

Alveoli bunch together in tightly packed bundles called alveolar sacs.

6

Bronchioles

These are smaller air passages that branch off from the bronchi to carry air throughout the lungs.

7

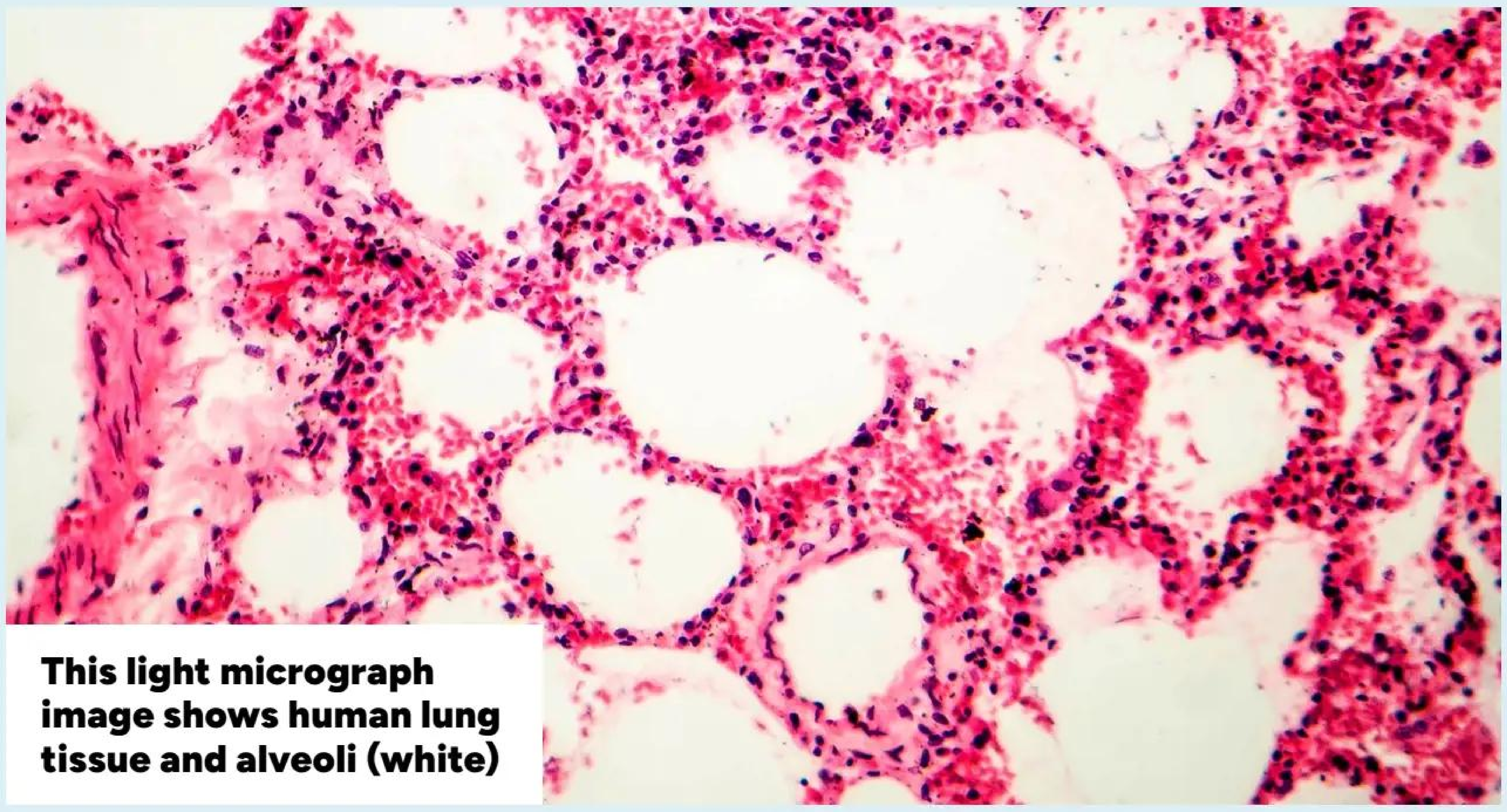
Lungs

The lungs are pinkish-grey organs that make up the majority of the respiratory system.

8

Trachea

This is the windpipe, which connects the voice box to the lungs. Air from the nose and mouth is directed into the trachea.



This light micrograph image shows human lung tissue and alveoli (white)

Fact file

Everything you need to know about the respiratory system

What does the system do?

The respiratory system delivers fresh air to the body and removes waste gases.

Why is it important?

It keeps the body's blood and tissues oxygenated. Body cells produce carbon dioxide that needs to be removed.

When does this system develop in a foetus?

The lungs develop at four to six weeks. They are filled with fluid until the baby is born and can take its first breath.

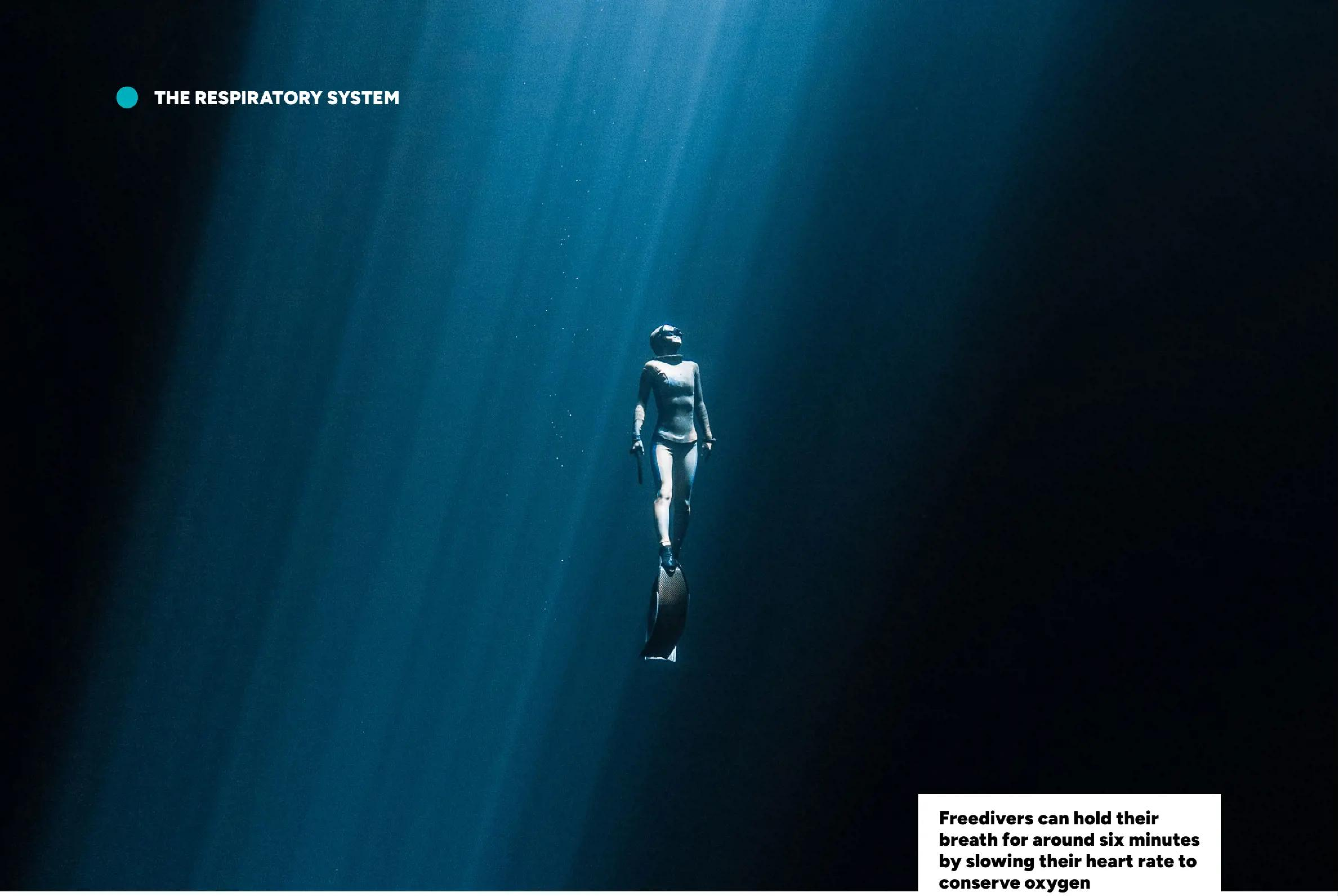
What organs are part of this system?

The six main organs are the lungs, nasal cavity, pharynx, larynx, trachea and bronchi.

What are common conditions associated with this system?

The most common conditions that impact the respiratory system are asthma, cystic fibrosis, tuberculosis, pulmonary hypertension, emphysema and lung cancer.

Damaged lung tissue shows up as shadows on hospital chest x-rays.



Freedivers can hold their breath for around six minutes by slowing their heart rate to conserve oxygen

Oxygen is the most essential element for human life. If our bodies were unable to utilise this gas– which makes up more than a fifth of Earth's atmosphere – the brain would suffer permanent damage after just four minutes with low-to-no oxygen in the bloodstream. If this continued for another four minutes, the body would completely shut down.

The respiratory system is a vital and complex arrangement of delicate tissue, miniscule sacs, methodical muscles and biological tubing that work together to obtain oxygen from the body's surrounding air supply. The average person inhales 25,000 times in one day, resulting in around 11,000 litres of air entering the lungs, which can be considered the centrepieces of the respiratory process. These organs collect air, filter out the valuable oxygen, and empty out the body's waste gases. Every organ relies on this system, in order to produce energy for all functions– from digesting food to moving and thinking.

Without the components of the respiratory system you wouldn't have a voice. Your voice box (or larynx), which is a hollow organ in the neck above the windpipe, is responsible for creating the sound of speech. This organ also relies on the exhaled waste gases from the body. As the lungs force out this air up towards the nose and mouth, it passes through the voice box. The air pushes past thin, slightly obstructing tissue in the voice box called vocal cords, which vibrate to produce sound waves. Sound is released during an inbreath or outbreath. However, people generally speak during exhalation because the sound waves need to travel outwards to be best projected. Speaking on an inbreath feels and sounds far less natural.

No conscious thought is required to initiate the breathing of this system. However, the vital aspect of its delicate organs and structure has long been admired by humans. Ancient Egyptians held the knowledge that the lungs and windpipe work together to make each breath possible and keep each individual strong and healthy. Showing how much they valued this biology, the ancient Egyptians created a hieroglyph that displayed the two organs to symbolise the unity between the two lands of upper and lower Egypt. After all, the respiratory system works to keep the human body surviving harmoniously.

Take a breath

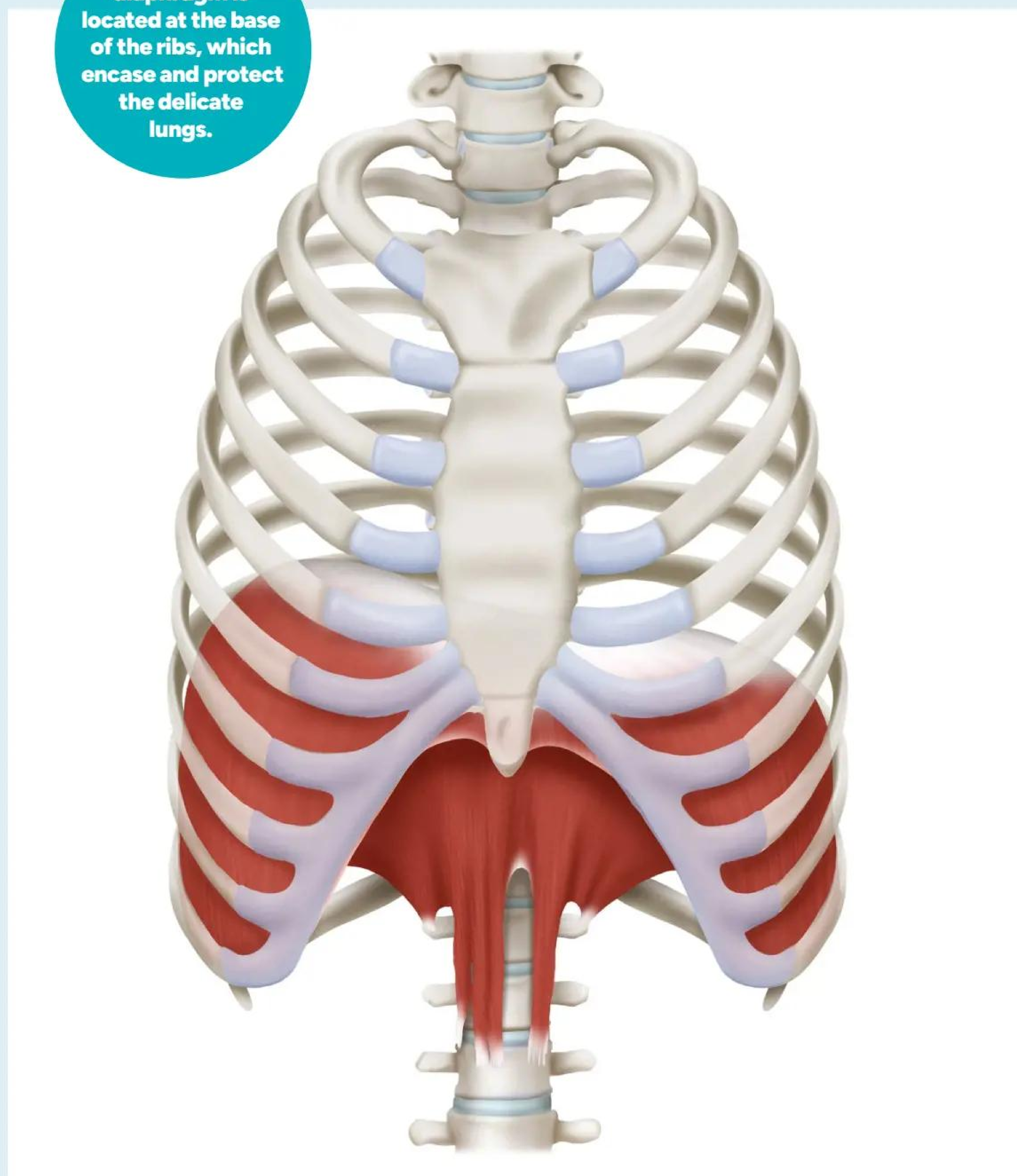
Just below the lungs is a sheet of muscle called the diaphragm. When you inhale, the diaphragm contracts. In this action it pulls downwards, while the protective rib cage that surrounds the lungs opens upwards and outwards slightly. Together, both of these movements make the space in the chest – or thoracic cavity – larger and the pressure inside it decreases. When this pressure is lower than the atmospheric pressure outside the body, air rushes into the space to fill the lungs. This is because air always moves from an area of higher pressure to a lower one.

During exhalation, the diaphragm returns to its relaxed position, with its arched shape reaching upwards nearer the top of the thoracic cavity. The space decreases in volume, which increases the pressure and forces the lungs' held air through the windpipe and back out of the body.

How often are you aware that you need to contract your diaphragm? The physical actions of moving this muscle and opening up the ribs are controlled by the autonomic nervous system. This is also referred to as the involuntary nervous system, as the actions it controls require no conscious thought to execute.

Like a pre-programmed computer, the autonomic nervous system controls the speed of the breathing mechanisms based on external environments and biological stimuli. For example, sensor nerves in the joints and muscles pick up on the rate of movement being carried out. When you are taking part in physical activity, the rate of inhalation and exhalation is sped up unconsciously.

> "Ridding the body of its cells' build-up of waste gas is one of the primary functions of the respiratory system"



The diaphragm is located at the base of the ribs, which encase and protect the delicate lungs.

The importance of gas exchange

The greatest indicator for more frequent and deeper breathing is the increased presence of carbon dioxide in the body. Ridding the body of its cells' build-up of waste gas is one of the primary functions of this system. After the body has absorbed oxygen from Earth's atmosphere, there is space in the lungs for carbon dioxide that is being carried in the bloodstream. As it passes through the lungs, the blood releases the gas to be exhaled through the nose or mouth.

Each cell in the lungs' alveoli are densely packed so that the optimal number of cells are working to exchange gases across the organ's membrane. And, to make this a speedy swap, the distance the gas has to pass through is only one micron thick. One micron is the equivalent to a microscopic one 10,000th of a centimetre. The lungs of the respiratory system are a unique and delicate site, where the body's life-supporting blood becomes separated from the 'external' air by just one cell.

The journey of oxygen from the outside air to the body's blood is achieved in three major stages: ventilation, diffusion and perfusion. Ventilation refers to the intake of air into the 480 million alveoli that make up the lungs. For the constant exchange of gases carbon dioxide and oxygen, the process is diffusion. Diffusion is the movement of any particles from an area where it is in higher concentration to an area of lower concentration until they are evenly spaced across a membrane. Because the blood is repeatedly being pumped back to the heart from the lungs, the blood that passes through the lungs is always being resupplied with that of higher carbon-dioxide and lower oxygen than the newly inhaled air.

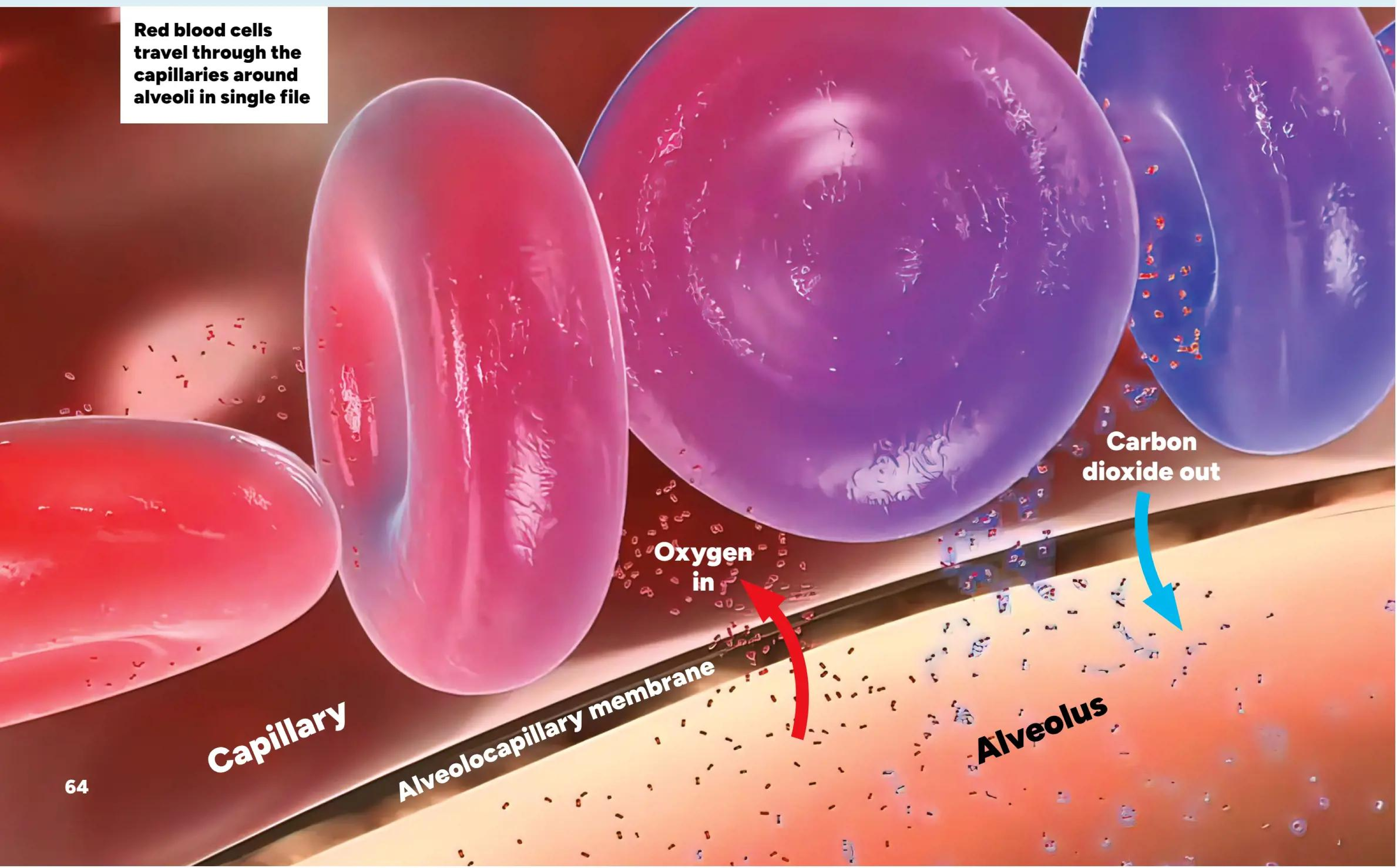
Therefore, the blood is always being replenished with oxygen, while the carbon dioxide is diffusing into the lung cavities. This is called moving down the concentration gradient and it is an efficient process for sustaining life at all times, because it requires no energy. Instead, the random movement of all particles is what causes the net flow of gases to be successful.

Perfusion is the process in which the blood pumping through the lungs is forced into a network of capillaries. These blood vessels travel through the walls of the alveoli and have a diameter smaller than 0.025 millimetres, increasing the surface area of the blood vessels that are touching the lung tissue.

Using an inhaler during an asthma attack can prevent lung damage.

Respiratory to circulatory

The respiratory system and circulatory system work closely together to assist the main functions of each one. The former system is what makes the blood a valuable substance. Think of the oxygen as the fuel for the blood. While the circulatory system is the transportation method for blood to every organ in the body, the respiratory



Red blood cells travel through the capillaries around alveoli in single file system delivers the life-supporting fuel. Although blood carries other important nutrients and hormones, these can't be used by body tissue in the absence of oxygen.

The two systems are dependent on each other, but both carry out the same task of removing carbon dioxide and supplying oxygen to the entire body. The difference between them in this role is that while the respiratory system has the core role of supplying the gas and creating an access point into the body, the blood has access to all areas of the body and is the delivery method.

Disorders and damage

Despite respiration usually working as a constant gas circulation system, not everyone breathes through this life-sustaining process effortlessly. 545 million people, or 7.4 per cent of the world's population, have a chronic respiratory condition, which can make them more conscious of each draw of breath. This can be through symptoms of breathlessness or severe pain during the gas inhalation and exchange.

Asthma is one of the most common chronic respiratory system conditions. Around 300 million people suffer from asthma, which is the inflammation of the small airway tubes (bronchioles) in the lungs. The first challenging outcome of inflamed bronchioles is that the passages for air become narrower, limiting how much air can fill the lungs. Secondly, the irritation from the inflammation can cause a buildup of mucus, as the asthmatic lungs are more sensitive to dust, pollen, smoke, mites and other inhaled particles. Mucus is essential in the lungs for filtering out these polluting particles from the bloodstream, but when it is over-produced it can block gas exchange and leave asthma sufferers fighting for breath. To prevent an asthma attack, airborne steroid medication can be delivered directly to the lungs in an oral inhaler. As the sprayed medication reaches the bronchioles, it relaxes the contracted muscles around the airways to widen them and give oxygen better access to the bloodstream again.

Can you regulate your respiratory health?

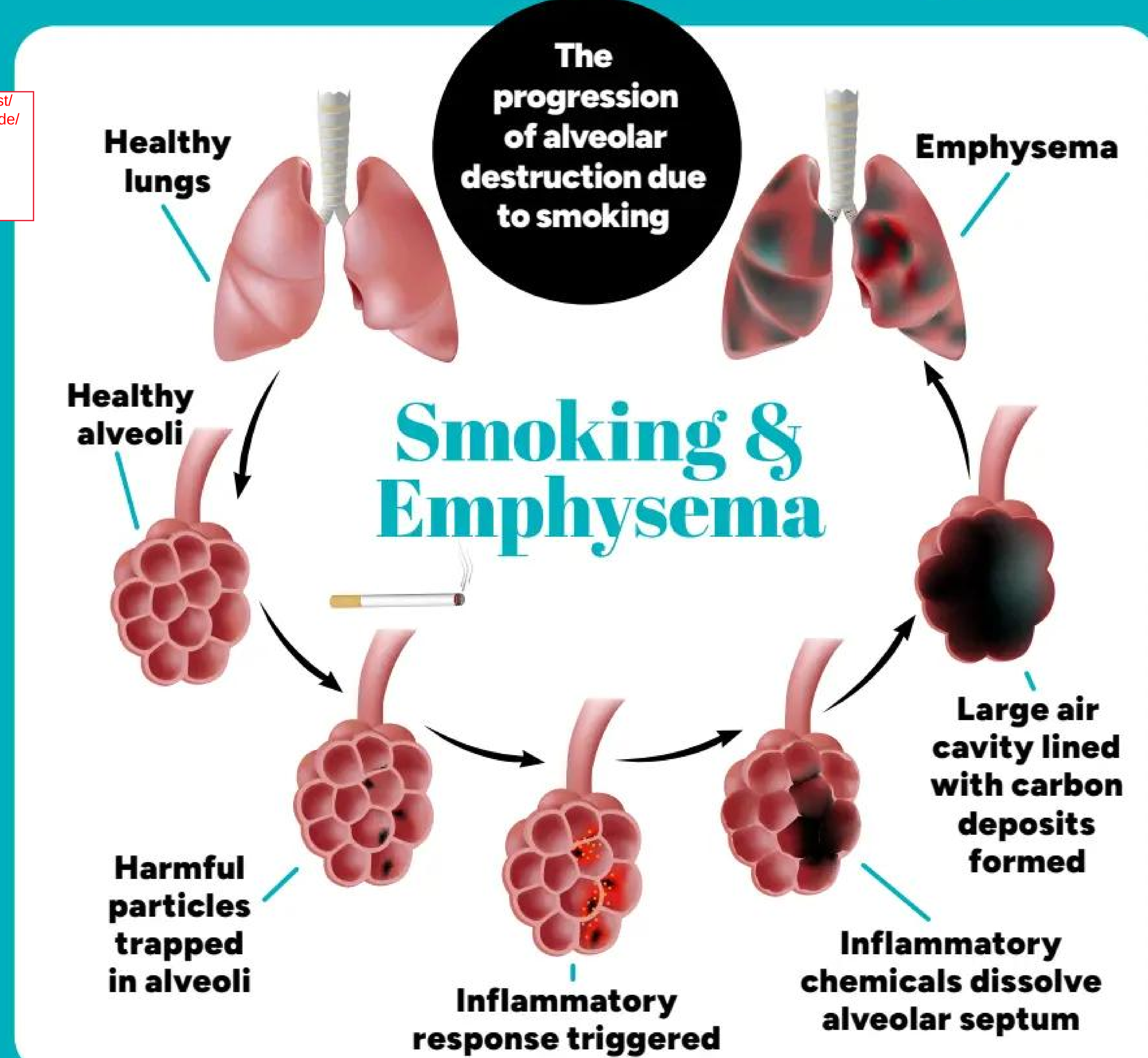
These lifestyle choices and location types can help you protect your lungs

For as long as we are living, we count on our lungs to automatically and consistently expand and deflate, delivering our bodies with oxygen. But, are there any ways we can enhance their health and efficiency?

First, it's essential to consider what causes a decline in respiratory health. The types of gases you expose the lungs to impact how well the system is going to achieve its main function, and one habit that greatly damages these organs is smoking. In Earth's atmosphere, the air we natura breathe contains mostly nitrogen and oxygen. But, a single inhalation of cigarette smoke includes 7,000 chemicals that gain direct entry to the lungs. Tobacco smoke contains carbon monoxide, which enters the bloodstream in place of oxygen, damaging the tissues. The chemicals also irreversibly impair the air sacs along the lining of the lungs, limiting the surface area on which gas exchange can take place. As a result, long-term smokers find it harder to breathe on a daily basis.

Polluted air isn't always due to habits. In dirty or over-populated areas, the small particles of dust or vehicle fumes can cause inflammation in the lungs. Oxygen doesn't pass so readily through the lungs when they are heavily inflamed.

For stronger and healthier lungs, exercise is a proven aid. When you engage in physical activity regularly, your body becomes used to efficiently uptaking oxygen. Even though a tough workout can leave you breathless and perhaps provide temporarily fragile lungs, the muscles around them become stronger with training. Constrastingly, calm breathing exercises can make your body more familiar with the action of long, deep breathing. This fills the lungs and ensures all the space is being used to absorb oxygen into the bloodstream. If you take quick, shallow breaths, fewer alveoli are used and there is less time for oxygen to be exchanged.



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A sign of hypoxemia (low blood oxygen) is blue skin or lips

Cystic fibrosis is another disease that causes mucus to build up in the airways. However, this is an inherited condition that is often far more severe than asthma. It is the buildup of mucus in the body that isn't restricted to the lungs but can also include the digestive tract and other organs. Medicine can be taken to thin the mucus and make it easier to breathe and cough up some of the mucus barrier.

Other medical conditions that hinder the lungs' job are lung cancer and tuberculosis. Lung cancer is the uncontrolled growth and division of cells that accumulates into a tumour within the lung. This hard mass can grow in a way that blocks airways and reduces the organs' access to oxygen. Conversely, tuberculosis is an infection caused by external organisms' cells – the bacteria Mycobacterium tuberculosis. This bacterial infection is airborne, so its first point of contact is the lungs. If the immune system can't fight off the infection, the number of the microorganisms multiplies and they attack the lung tissue.

The lungs can be damaged by environmental factors, such as smoking and the long-term exposure to industrial pollutants. Healthy lungs have high elasticity, meaning that after small damage and inflammation, the airways and air sacs inside them can bounce back to their original size and efficiency, reversing any temporary damage. However, with each new period of inflammation, the lungs lose some of their elasticity, until eventually the alveoli become unusable for gas exchange. As the number of clogged air sacs and narrowed passages increase, fewer capillaries can be used to retrieve oxygen. The gradual destruction of these alveoli is called emphysema, and sufferers need to breathe much harder to get the same volume of air to circulate their body. Breathlessness and phlegmy coughs are symptoms of emphysema, as the non-functioning sacs create airway obstacles for inhaled and exhaled air.

Not all damage to the respiratory system is due to long-term exposure to irritants or a gradually worsening disease. Those who suffer a severe lung puncture from the stab wound of a sharp object, or trauma from a broken rib due to blunt force, can experience respiratory failure. A punctured lung releases air from inside the organ and into spaces around it in the body. This is called pneumothorax, and the change in air pressure may cause the lung to collapse. Surgery can prevent this from happening if medical professionals can assist quickly. The surgery involves inserting a thin needle into the space between the chest and lung to release escaped air, followed by the repair of the damaged lung tissue.

The increase in damaged lung tissue from injury prevents oxygen from being delivered to the blood, while drastic changes in pressure stop inhalation and exhalation from being triggered by the autonomic nervous system. When organs begin to receive poorly oxygenated blood, a patient starts to suffer from hypoxemia. Hypoxemia symptoms include confusion, headaches, a rapid heart rate and shortness of breath.

The brain's balancing act

At the base of the brain, an area called the medulla oblongata is driving the repetitive movements that the respiratory system relies on to gain breath. It can be found where the brain and spinal cord connect, making it an accessible location to deliver speedy signals for vital bodily processes like breathing. These nerve signals are consistently shooting from the medulla oblongata to the diagram muscles to keep the respiratory system functioning, whether you're alert and active or sleeping in your bed.

Chemoreceptors, which are specialised nerve cells that monitor changes in the blood's chemical composition, alert the medulla oblongata when the carbon dioxide levels are dropping. In response, this area of the brain directs the muscles of the respiratory system to alter the rate and depth of breathing to be faster and deeper. This restores the blood to the optimal gas levels.

Too much carbon dioxide will combine with water in the body and form carbonic acid. As a result, the body's pH level drops. The human body demands a tight pH range of 7.35-7.45. Any fluctuation in this impacts all cellular activity in the body, from growth to the movement of nutrients across membranes and brain activity. The medulla oblongata keeps the pH levels in check by quickly reacting to carbon dioxide changes. This element of the respiratory system is extremely important, because if this wasn't functioning, the body could quickly drop outside of the healthy pH range and cause a coma or death.

Stress on the system

Although the respiratory system may have mastered the regulation of breathing at low altitudes and on Earth, how does it fare in extreme environments or situations? At high altitudes, of 2,500 metres or more, the oxygen levels are considered to be very low. In addition, the atmospheric pressure drops as altitude increases.

At very high altitudes, the respiratory system goes into survival mode. This mostly involves hyperventilation, when the body breathes in short, fast breaths. By doing so, the system can usually accommodate gradual changes in altitude for short periods of time, such as when climbing a mountain. It is important to slow the pace when scaling very high mountains. If the altitude changes too quickly, the respiratory system can't adjust quickly enough and you risk getting altitude sickness. This is when not enough oxygen is delivered to tissues leading to an accumulation of fluid in the lungs and brain. The capillaries squeeze together under this oxygen deprivation, which produces leaks of blood fluid into the alveoli. Altitude sickness is unlikely to happen between altitudes of 1,500 and 2,500 metres, as long as the time spent in these conditions is limited. The condition can occur after at least four hours at 2,000 metres, however.

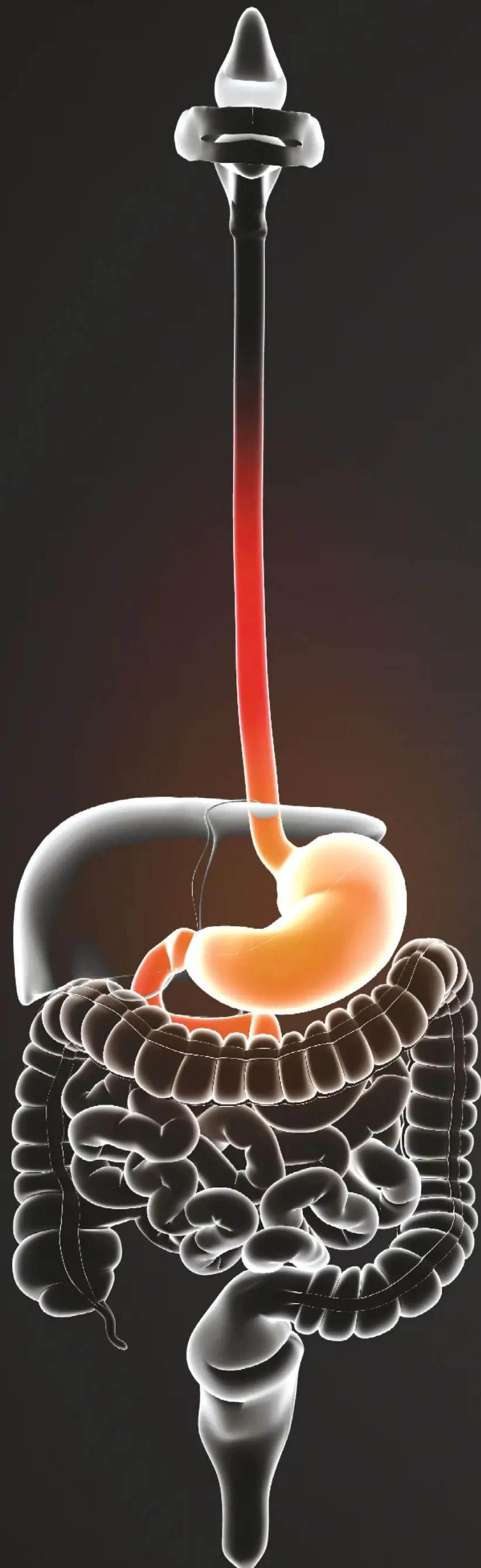
"The lungs can be damaged by environmental factors, such as smoking and pollutants"

At very high altitudes, the respiratory system goes into survival mode

Ranges in temperature across the globe can also inhibit the ease of respiration. In freezing environments, for example, breathing can become far more difficult as the mucus lining in the lungs becomes thicker and harder to clear away. Cold air is drier than hot air, and this can irritate the airways and narrow the lungs' airways. This is why air is usually directed through the nasal passage, which heats up the air from outside to enter the lungs smoothly. In arctic conditions, however, this is not enough to prevent breathing difficulties.

During any period of exercise, various tissues use up far more oxygen and release higher volumes of carbon dioxide. Because of this, the respiratory system puts in a harder graft to increase your breathing rate. This is why you may pant when running or feel obliged to stop occasionally to catch your breath. Generally, this increase escalates from 15 breaths a minute while you rest (inhaling 12 litres of air) to 40-60 breaths a minute (inhaling around 100 litres of air).

The respiratory system is flexible, essential and might appear flawed when respiratory diseases take hold. Nonetheless, the impressive communication that is forever firing between your head and chest means this system never stops fighting for your fair share of breath.



THE DIGESTIVE SYSTEM

Helping your body from top... to bottom

WORDS BY JAMIE FRIER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BREAKDOWN OF A SYSTEM

1 Mouth

Food enters the mouth and is chewed by the teeth. This process breaks it down into manageable-sized pieces for swallowing.

2 Saliva

This liquid helps to soften food so it is more malleable for chewing and swallowing. It also contains enzymes that break down starch.

3 Epiglottis

The flap of skin at the entrance to the throat stays closed to prevent oversized food slipping down the throat, and opens when swallowing takes place.

4 Esophagus

This is a tube that runs from mouth to stomach. Rings of muscle push food down and along the esophagus to the stomach.

5 Lower esophageal sphincter

This valve at the entrance to the stomach is generally closed to prevent acidic stomach juices moving into the esophagus.

6 Stomach

This organ receives food from the esophagus. Here acidic juices and enzymes continue to break food down.

7 Duodenum

The first section of the small intestine attacks food with enzymes and bile to break it down as it's pushed through.

8 Jejunum & Ileum

The second and third sections of the small intestine where nutrients and vitamins are absorbed through cell walls into the bloodstream.

9 Large intestine

Undigested food, water, dead cells and mucus get turned into a paste and pushed along the large intestine.

10 Rectum

The firm waste product gets emptied into the rectum, the second part of the large intestine.

11 Anus

Around twice a day, when the rectum is full, it empties into the anus, where stool is ejected from the body.

Fact file

Everything you need to know about the digestive system

What does the system do?

This system is responsible for taking the food that you eat, reducing it in size by chewing or breaking it down using enzymes, bile and acid, extracting the beneficial elements, converting it into waste and then expelling it from your body.

Why is it important?

The only way to get crucial nutrients into your body is to ingest food and drink and have them move through your digestive system. Along the way, vitamins, minerals, fatty acids and amino acids get extracted and absorbed into the bloodstream where they get sent around the body to where they are useful.

When does this system develop in a foetus?

The digestive system starts to develop early in a foetus, from around five weeks. However, it isn't necessary or used until it is born, as all its nutrients come from milk and are pumped directly into the bloodstream via the placenta.

What organs are part of this system?

The digestive system is made up of the mouth, the esophagus, the stomach, the small and large intestines, the rectum and anus. The liver, pancreas and gallbladder are all also part of the digestive system.

What are common conditions associated with this system?

Most issues with the digestive system happen in the stomach, rectum and anus, like bloating, diarrhoea and constipation.

Chewing food well is important to break it down and begin the digestive process

The digestive system is essential to the smooth running of the human body, as it is the one that enables you to eat food, process it, strip out the nutrients and, well, get rid of it at the end. It starts at the mouth and finishes at the anus, running the length of your torso and covering nearly nine metres (30 feet) inside your body. The system is one of the simplest in the body, as it is just made up of a long tube called the gastrointestinal tract (GI) and three organs – the liver, the pancreas and the gallbladder. However, it is certainly important that it runs smoothly, as an inefficient, diseased or incomplete digestive system can have serious repercussions for your health and comfort.

The digestive system is one of the few in the body to have a clearly defined start and end. It starts with the mouth. Chewing helps break food down, while saliva not only moistens it but also contains an enzyme that starts the process of breaking down starch. Once your food is in a manageable state, a flap in your throat called the epiglottis opens and enables the contents of your mouth to pass into the esophagus.

From here, a series of muscles contract and expand to push the food down towards your stomach. This is known as peristalsis. As it nears the stomach, a valve called the lower esophageal sphincter, which is usually closed to prevent stomach acid from escaping into the esophagus, opens up to allow the food to drop in.

Here, the breakdown continues. The food is attacked from all sides by acid and enzymes that work together to turn it into a kind of paste, known as chyme. Once it is in an acceptable consistency, the food will move onto the next stage of its journey – the inaccurately named small intestine.

Why inaccurately named? It's because the small intestine measures a ridiculous seven metres (22 feet), curled up inside your body like a successful game of Snake. Admittedly, it is narrower than the large intestine, made up of rings of muscle similar to those found

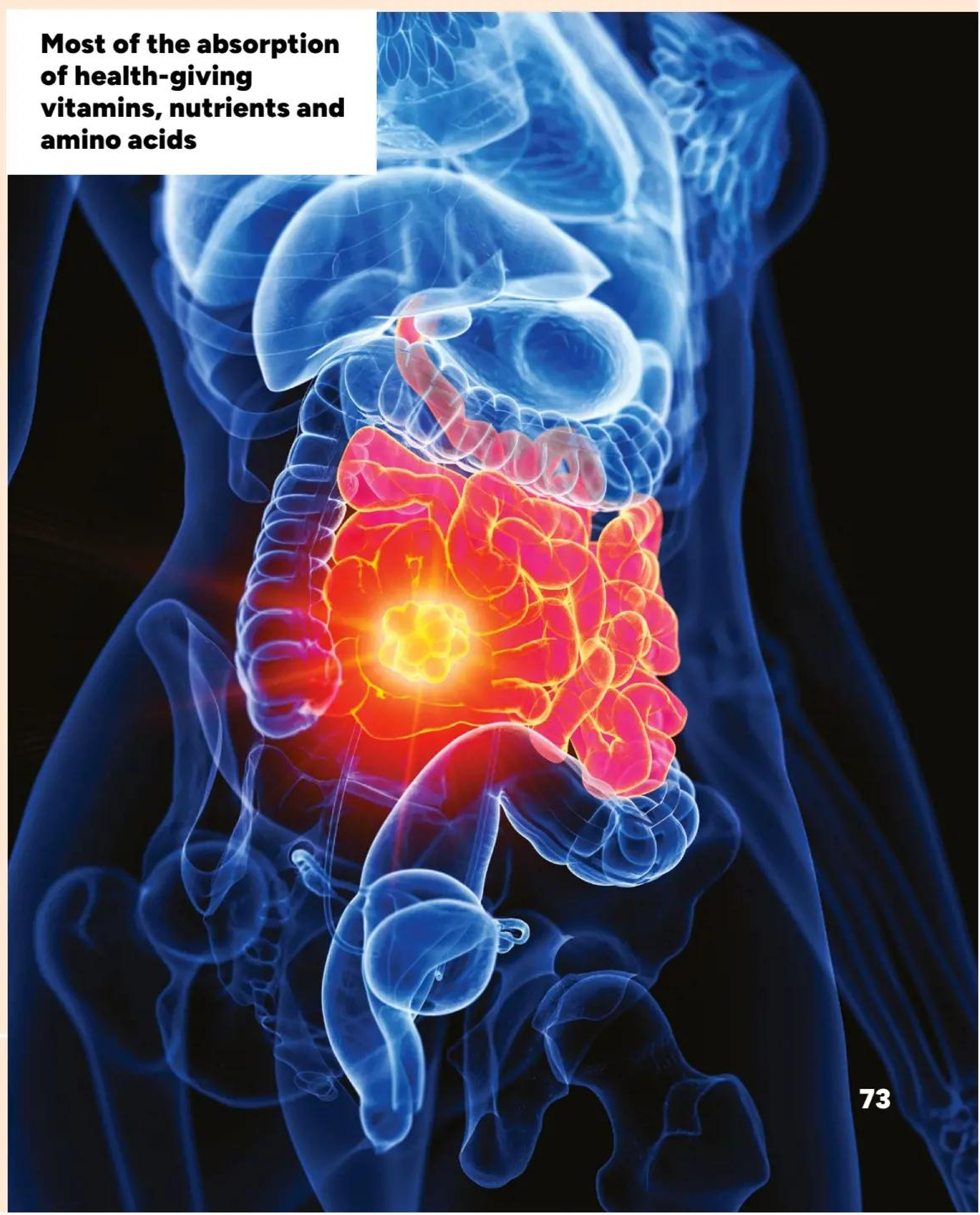
> **“The small intestine measures a ridiculous seven metres (22 feet), curled up inside your body like a successful game of Snake”**

in the esophagus. These push the food along, all the while bombarding it with enzymes and bile secreted by the pancreas and liver respectively. If the liver needs help with the production of bile, then the gallbladder helps out by providing more. The pancreatic enzymes predominantly help with the breakdown of proteins, fat and carbohydrates, while bile does the same job, focusing mainly on fats. The first section of the small intestine is called the duodenum, and this is where the majority of the breakdown takes place. The next two sections are called the jejunum and ilium, and this is where most of the absorption occurs. With the food broken down into miniscule particles, amino acids and fatty acids, it is absorbed through the walls of the small intestine and into the bloodstream, where it is carried to the organs, muscles and other body parts that need them. A good, healthy diet and an efficient, working small intestine will extract maximum benefit from the food you eat with the minimum amount of waste, providing your body with all the elements it needs to function at the highest level and prevent disease.

Talking of waste, that is the primary focus of the next stage of the digestive system. The paste-like substance that entered the small intestine has now turned into a more liquidy one as it moves into the large intestine, which measures a paltry 1.5 metres (five feet). Any food that didn't get digested by the small intestine, as well as waste water, cells and mucus, enter the colon, which is the first part of the large intestine. Here it is again moved along the system by peristalsis. Excess water gets absorbed by the walls and lining of the colon, as well as any vitamins to maintain a healthy colon. Although it's not the longest part of the system physically, this stage is the longest in terms of time. It can take between 30-40 hours for food to pass through the colon in its entirety, representing around half the total amount of time food stays in your body. The liquid waste is now more solid with the water removed as it exits the colon into the rectum – the second part of the large intestine that measures just 20 centimetres (eight inches) – via the sigmoid colon once or twice per day.

Once the rectum has filled with waste, the brain sends a signal to the system telling it to evacuate. The muscles of the rectum relax, allowing the waste to drop into the anus, the final part of the digestive system. Obviously if it isn't an appropriate time to do so, this signal can be overridden and the muscles will retighten until you're in a position to relax again.

If released, the waste enters the anus, which is one of the smallest parts of the digestive system at around five centimetres (two inches). It contains a pelvic floor muscle and two sphincters, internal and external, that perform two very important jobs. The pelvic floor muscle is at an angle that allows waste into the anus, but stops it from coming out until you have a bowel movement. This is controlled by the internal and external sphincters. The internal one is usually tightly shut to avoid any waste exiting the anus during sleep or a rectal evacuation. The external one is the last line of defence, staying shut until we're able to go to a toilet. Then it relaxes, opens and the



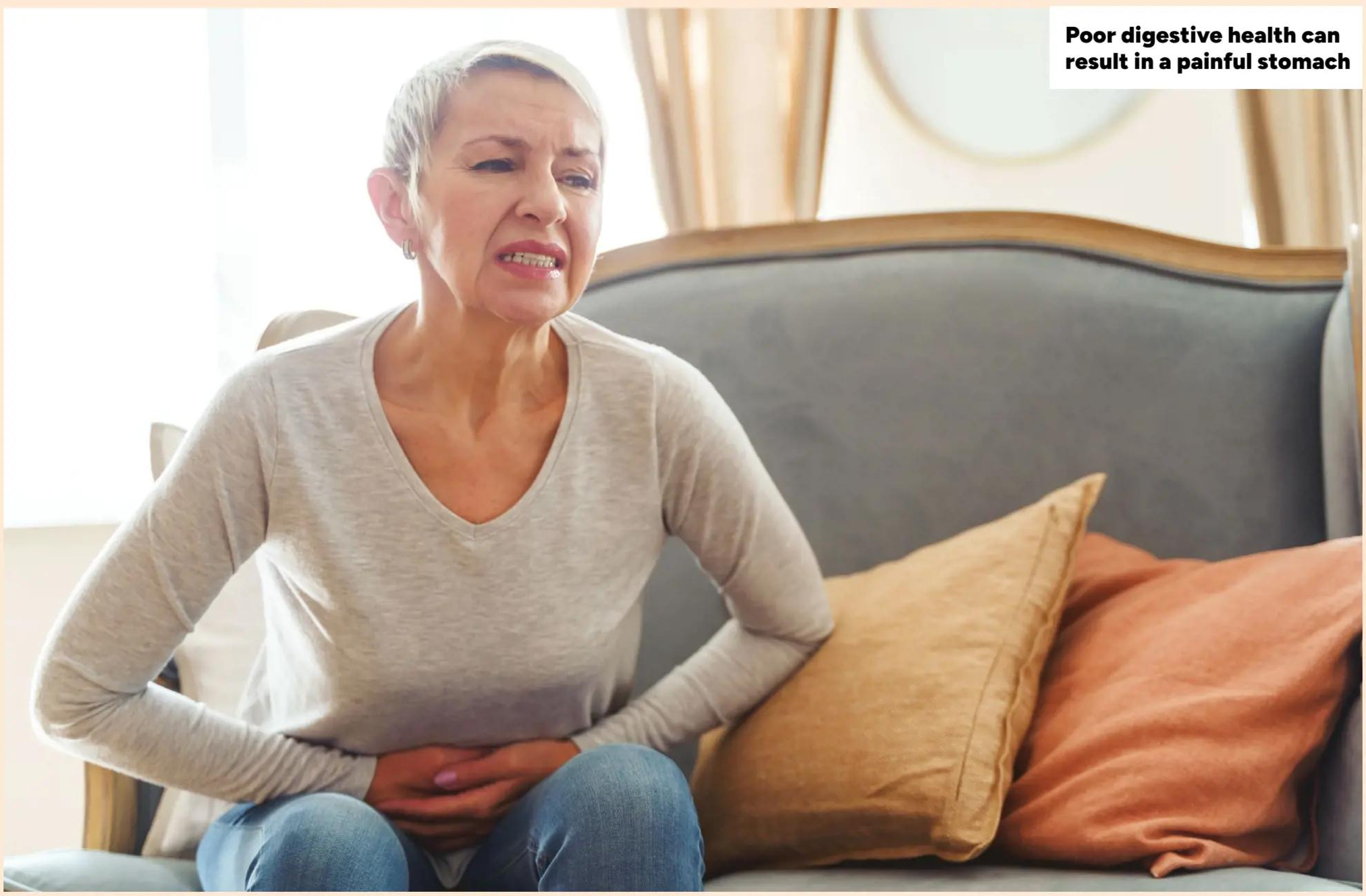
Most of the absorption of health-giving vitamins, nutrients and amino acids

final stage of the digestive system's process can safely take place. A strong pelvic floor muscle and sphincters are essential to prevent anything escaping from your anus before you want it to, so it is vital that these are kept in strong working order.

Other parts of the body rely heavily on the digestive system being as healthy as possible. Its links with the circulatory system have already been explained, as nutrients and amino acids get absorbed into the blood. The muscular system also needs good digestion, as it relies on the proteins from food to repair itself and grow. Finally, the digestive system shares two other elements with other systems in the body. The mouth is part of the respiratory system as well, while the pancreas is also involved in the endocrine system, providing blood-sugar-level-regulating hormones. So it's clear that the digestive system is one upon which several others rely, and therefore needs good care.

As with any system in the body, things can go wrong, and the digestive system is particularly at risk given the amount of external factors that are involved. The majority of your body's systems are fairly safe from most external factors. However, the digestive system experiences daily risks, as one piece of dodgy food or one closed bathroom can have unwanted repercussions. If your digestive system isn't working as it should, then any number of issues can arise, from as little as a touch of gas or bloating, right up to serious diseases such as Irritable Bowel Syndrome (IBS), constipation, diarrhoea or even cancer. One of the most common digestive system complaints is food poisoning. This is when you eat food that has been contaminated in some way, such as being partially reheated or coming into contact with germs. Once the unfriendly bacteria make their way into your stomach, your body notices that something isn't quite right and

“The digestive system is one upon which several others rely, and so needs good care”



Poor digestive health can result in a painful stomach

A good diet will help your gut feel good.

Gut feeling

How to ensure you have a happy, healthy digestive system

So we know what the digestive system is made up of, what it does, how it works, what a healthy one looks like, and what happens when things go wrong. But what can a person do to make sure it's in the best possible condition to keep them as healthy as possible? Diet is key. Whole foods, such as fruits, vegetables, legumes and so on, are very beneficial to your digestive system as they are easily broken down and absorbed into the bloodstream. Highly processed foods, on the other hand, are trickier to break down and also contain fewer health-giving nutrients and vitamins. A diet high in fibre is a handy aid to digestion. This is because fibre helps to regulate the amount of moisture in your body, and also keeps food moving along. Hydration is also key. A generous amount of water is essential in making sure your stool is soft enough to pass comfortably out of your anus. Your body is good at removing excess water, but can't add any, so the more water the better. Exercise can also help you gain a healthy digestive system. If you regularly participate in moderate exercise, this keeps things moving along your system, both due to stronger muscles, and also because activity itself helps push things along.

tries to get rid of the bacteria. This can be via vomiting or diarrhoea. The body just wants to get rid of whatever is putting it in danger, and these are the quickest ways for it to evacuate your body. Irritable bowel syndrome (IBS) is another common ailment that affects the digestive system. IBS causes bloating, stomach cramps and inconsistent stools. This happens when food doesn't move through your digestive system as it should, and can cause sufferers a lot of pain. There is no cure, but it can be managed through medication and diet. Crohn's Disease is a genetic disorder that affects your digestive system and is a form of IBS. It's a nasty condition that results in diarrhoea, stomach cramps and intense fatigue. Most of the problems arise from inflammation. As with IBS, it can be managed by medication but cannot be cured. Also painful are gallstones. These are small bits of waste in the gallbladder that can build up over time and really cause an awful lot of pain. These can be passed, but occasionally require surgery to remove. Less painful but no less horrible to endure is acid reflux. This is where the lower esophageal sphincter fails to close properly, allowing stomach acid up into the esophagus, causing that nasty, acidic feeling in the throat. You might think that the presence of any gas in your body is a bad thing, but a small amount is normal due to the chemical reactions that take place. An average person with a healthy gut will break wind between 10 and 20 times per day. However, an excess of gas could be the result of several issues. One could be an intolerance to certain foods, such as dairy or gluten. If your body fails to break these down, they unexpectedly move into the large intestine, where they react with bacteria, ferment and create unwanted gas. Gas from either end could also be air swallowed into the stomach as a result of eating with your mouth open or gulping your food and drink down. The type of gas is also important. Odourless gas indicates presence of hydrogen, which is normal for your digestive process. However, if your gas smells, that suggests methane bacteria is present in your body and you are at risk of uncomfortable bloating.

However, there are many ways to establish if your digestive system is healthy. If you find that you are having regular, pain-free and efficient bowel movements, then that's a positive sign that your gut is in good working order. There is no real set number of bowel movements you should be having in a day, but as long as they are at consistent intervals then that is what you're looking for. It's not only the regularity that's important, but the size and consistency as well. A good diet and a healthy digestive system will produce stools that are solid, firm and smooth but not overly hard or too large to pass. A functional digestive system helps get essential energy sources to your body quickly, so if you have consistent energy levels then it's a signal that everything is working as it should and your diet is right for your body's requirements. The right nutrients at the right time are crucial at all times of the day and night. Your sleep depends on having the right internal conditions in place, so if you find that you can drop off easily, it means that your gut is likely working as it should, as is your pancreas, which regulates your blood sugar levels and makes sure you're not experiencing highs and crashes. Similarly, if you notice that you struggle to concentrate during the day, you could be failing to absorb the right nutrients into your bloodstream at the right time. You might not associate the digestive system with stress, thinking it's more closely linked with the nervous system, but a healthy gut can actually help you react more positively to stressful situations. That's because stress can alter the fauna of your gut's ecosystem. If you are able to react to stressful situations without getting that horrible, gnawing, gut-wrenching pain in your stomach, it's most likely that you have a very healthy digestive system that

Saliva is crucial to the early stages of food breakdown

> **If just one element of the system failed to work, it would have major repercussions for your health**

is able to cope with a challenging situation. If you do suffer with digestive problems after experiencing stress, you'll need to look at the way you deal with unwanted situations or amend your diet to be more gut-friendly to stop that from happening.

As you have seen, the digestive system takes everything you ingest from start to finish in your body. It can be thought of as an assembly line, each section essential to allowing the next part of the process to occur. If your body wasn't able to strip the fats, nutrients, vitamins, minerals, amino acids and water from your digestive system, it would simply fail to function. Your body needs fuel to move, to think, to grow, to pump blood… and all of that fuel is provided by the digestive system. If just one element of the system failed to work, it would have major repercussions for your health. Without chewing or saliva, food wouldn't make it down the esophagus. Without effective peristalsis, food wouldn't make it to the stomach. If the stomach's juices weren't the right balance or not there at all, the food wouldn't be in a state to enter the small intestine. If the pancreas, liver and gallbladder didn't provide the required enzymes and bile, the beneficial parts of the food wouldn't be stripped out and used around the body. If the excess water in the waste product wasn't removed by the large intestine, then the stool would be very liquidy. If the rectum didn't communicate with the brain, the waste wouldn't empty into the anus or would empty without warning. Every part of the digestive system has to work perfectly for the effective consumption, processing and expulsion of food and drink. The digestive system is the engine that drives your journey through the day, and it's therefore vital to giving you a happy, healthy body.

Regular, solid, soft bowel movements are signs that your gut is healthy

THE *IMMUNE SYSTEM*

Our first and last line of defence

WORDS BY EDOARDO ALBERT

11
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5

BREAKDOWN OF A SYSTEM

1

Thymus

The training school for T cells.

2

Bronchus-associated lymphoid tissue (BALT)

Exposed to the exterior world with every breath, BALT identifies antigens, triggers the local immune response and primes memory T cells in the respiratory tract.

3

Axillary lymph nodes

Lymph is the other body fluid, a straw coloured liquid, that contains large numbers of white blood cells. Lymph nodes store and manufacture immune cells.

4

Spleen

Filters the blood and manufactures white blood cells and antibodies.

5

Inguinal lymph nodes

Immune cells in the nodes disposes of antigens in the lymphatic fluid that passes through the nodes.

6

Appendix

Functions as a reserve of lymphatic tissue and a backup for beneficial gut bacteria.

7

Peyer's patches

The bacterial fauna in the gut needs monitoring and Peyer's patches do this, working as first responders to undesirable gut bacteria.

8

Intestine

In direct contact with the outside world whenever we eat and drink, the intestine is the largest immune organ in the body. It is also host to a huge system of beneficial microbes.

9

Bone marrow

The white cell factory.

10

Tonsils

The tonsils physically stop many antigens entering the body and also host a standing force of white blood cells to deal with them.

11

Adenoids

The adenoids work with the tonsils to protect us against germs and toxins by hosting white blood cells and producing antibodies.

Fact file

Everything you need to know about the immune system

What does the system do?

The immune system protects us against invaders, be they germs, toxins or poisons.

Why is it important?

Without it we would become a short-term playground for microbes and shortly afterwards die.

When does this system develop in a foetus?

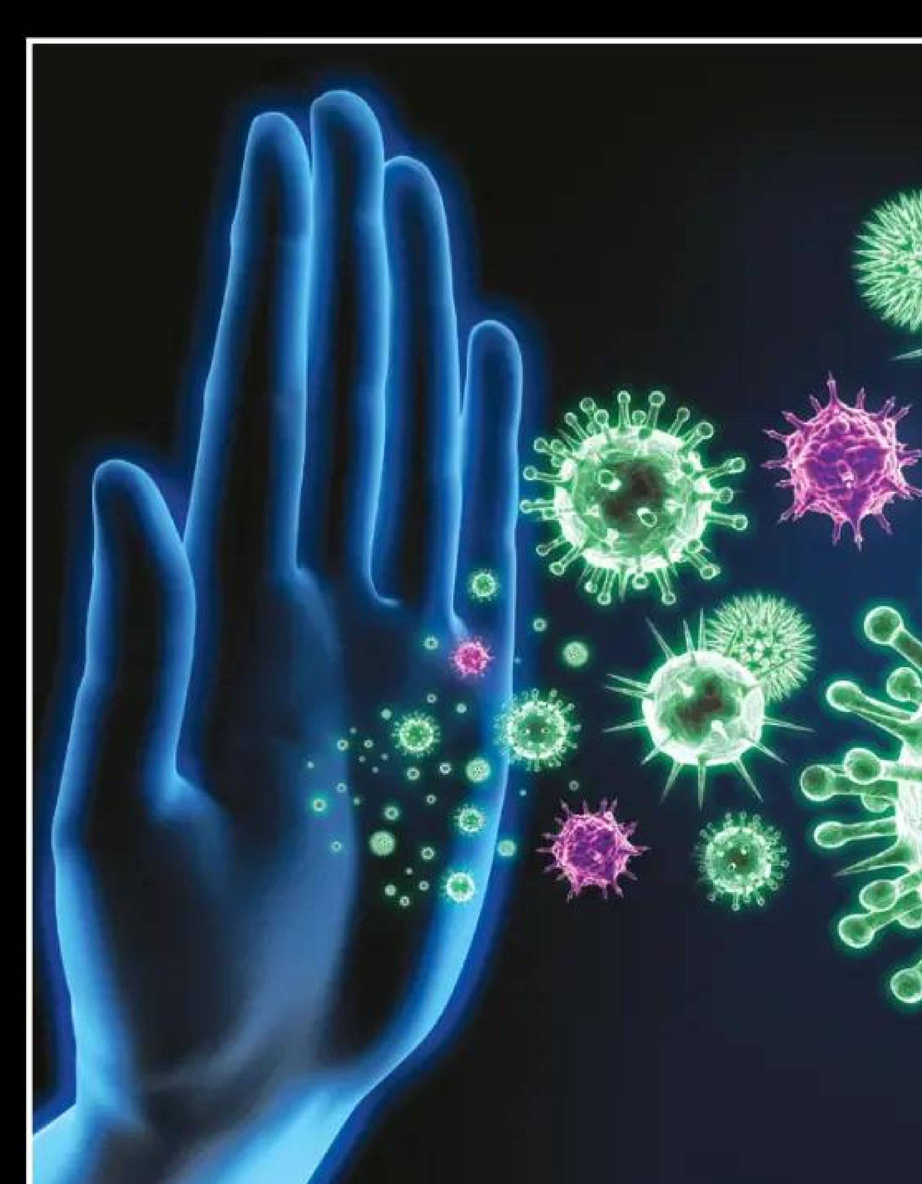
The first white blood cells are produced at nine weeks and move into the blood by 12 weeks. However, the immune system does not mature until a child is three or four.

What organs are part of this system?

The skin, mucous membranes, tonsils, lymph nodes, thymus, spleen and bone marrow.

What are common conditions associated with this system?

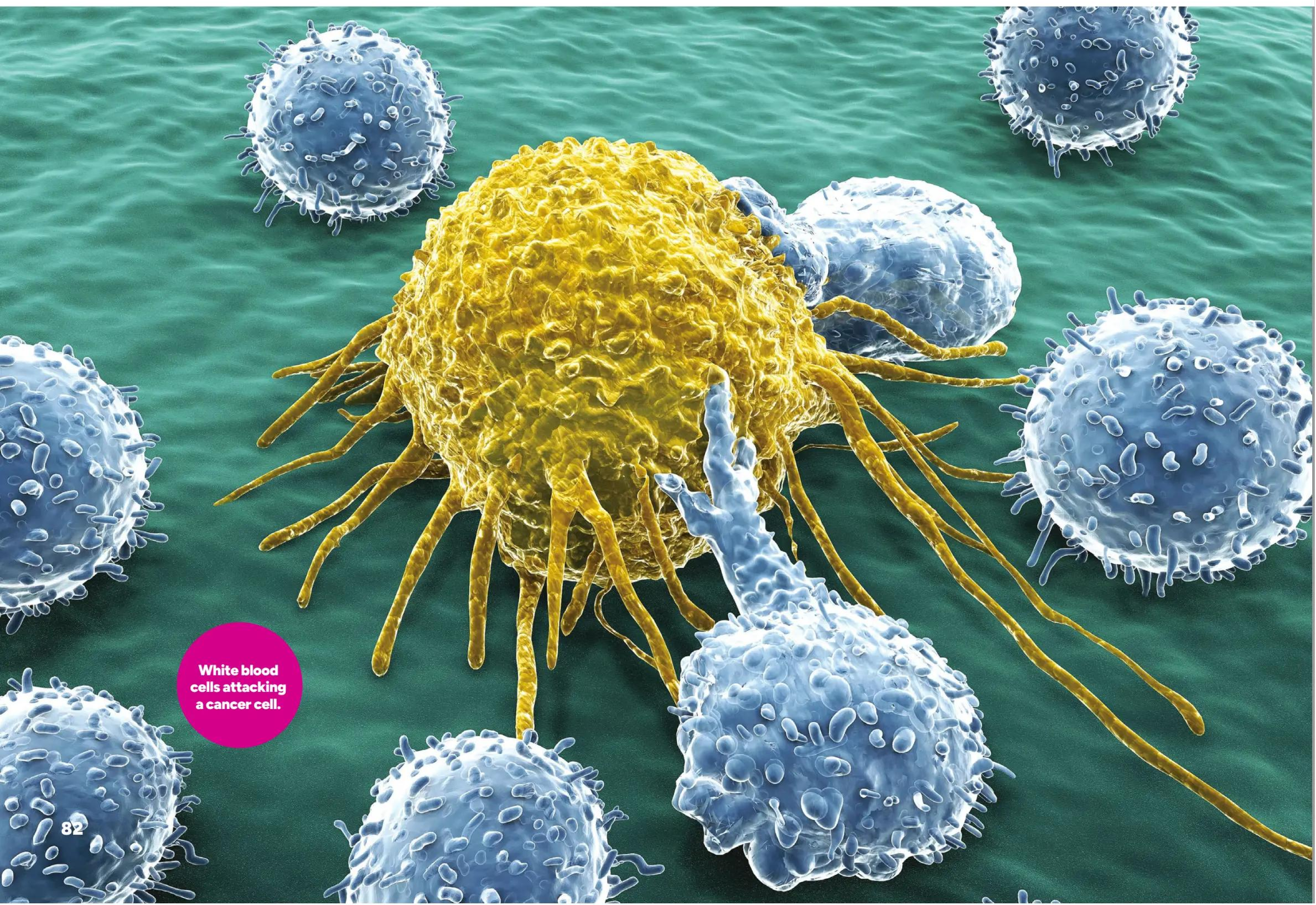
Asthma, type I diabetes, rheumatoid arthritis, lupus, AIDS, eczema, multiple sclerosis, Crohn's disease.



There are a lot of things out there that want to get inside us. Some are beneficial and some are neutral: the body's defences need to let the former in and not get too bothered about the latter. But then there are the things that mean us harm. It's the job of the immune system to stop these getting into us in the first place but then, if they do get past the first lines, to round up our internal forces and do battle with them, killing and expelling the invaders. It's a full-time job and it's the job of the immune system to do it.

Perhaps the most important part of the immune system is a part of the body we normally don't even think of as having anything to do with defence against disease: the skin. But the skin is our first line of defence against invading pathogens, as well as toxins, poisons, noxious chemicals and anything else that might do us harm. The skin is incredibly efficient at keeping these out. Just how effective the skin is as our first line of defence is illustrated by what happens when this line happens to be breached, by a cut or a wound. When the skin is pierced, we suddenly become vulnerable to a whole range of diseases that would never bother us otherwise, such as tetanus.

While the skin plays the major role when it comes to our outer defences, it is joined by other unlikely secretions such as ear wax and tears. Yes, ear wax has another function apart from providing small boys with something horrible and sticky to wave in front of their friends: it stops things getting in via the ear canal. To an insect, ears are quite an inviting space – warm, sheltered, and dark. An ideal place to hang out. Ear wax stops them. But it also stops much smaller invaders, catching bacteria and viruses in its sticky embrace and holding them there until they die.



White blood cells attacking a cancer cell.

> “Our guts contain bacteria that are beneficial to our health and the immune system has to identify them as being so”

However, should the fortress walls of the body be breached, then the interior defences come into play, and these defences are formidable – and formidably difficult to understand. But while the immune system in its entirety is extraordinarily complex, its function is straightforward: to find, identify and destroy anything that should not be in the body.

To do so, the immune system deploys a range of agents of mind-bending chemical complexity. A partial list includes antibodies, cytokines, B cells, T cells, lymphocytes, histamine, macrophages, basophils and interferons – and this is a very partial list. What's more, many of these agents of the immune system have multiple functions.

To make matters more complex, each person's immune system is as unique as their fingerprints. In part, this is because our immune systems do not come to us complete, but learn and adapt according to the challenges they face as we grow up. And as everybody will have encountered unique sets of germs and toxins during their lives, it follows that their immune systems will be unique, too.

Find, identify, destroy. All three roles are difficult but in some ways the most troublesome for our immune systems is identifying what it should attack. By no means all the foreign bodies in our bodies are harmful. Our guts contain a veritable ecosystem of bacteria that are beneficial to our health and the immune system has to identify them as being so. There are also organisms and chemicals that are harmless; it would be a waste of energy for the immune system to eliminate these.

As the pathogens that infect human beings have spent tens of thousands of generations attempting to trick, bypass or overwhelm our defences, the immune system has a major job in identifying what it should attack – and sometimes it makes mistakes. Some of the mistakes are minor and rapidly corrected. Others lead to one of the autoimmune diseases that are unfortunately becoming more common. Diseases of the immune system occur when the system identifies the wrong enemy and starts attacking the body that it's supposed to be defending, or it overreacts to harmless substances in an allergic reaction. There are a lot of these diseases: multiple sclerosis, asthma, eczema, rheumatoid arthritis, lupus and Crohn's disease.

Looking at this list, one common factor you will perhaps notice is how resistant all these diseases are to treatment. This is generally true for diseases of the immune system both because of the system's complexity and because suppressing the immune system's reaction means leaving the body more vulnerable to its usual range of enemies.

What is also clear is that these diseases are becoming much more common. Crohn's disease, an inflammation of the digestive system, was only identified in 1932. At that time, it was diagnosed in one person in 50,000 in the population. Now, less than a hundred years later, it affects one in 123 people in the UK. There has been an even steeper rise in the rate of allergies, particularly in the developed world. In the UK, at least 25 percent of people suffer from allergies, with some researchers putting the percentage at nearly half the population. Quite why the populations of richer countries suffer more from allergies than the people in poorer countries is unclear. Another curious asymmetry of autoimmune diseases is that they disproportionately affect women.


Our first line of defence: the skin


Antibodies attacking a virus by binding to it.

The best-known theory for the rise in rates of allergy is the hygiene hypothesis. The idea, advanced by epidemiologist David Strachan, is that today in the richer countries we bring up children in a much more sterile environment than our forebears, leading to less resistance to infections and pathogens (hence the theory also being dubbed the 'roll-them-in-the-dirt hypothesis', in the belief that letting children play in the soil will help to counteract their too-hygienic environments).

Whatever the reason for the rise in these sorts of problems, it's important to remember that for the majority of people and for the vast majority of the time, the immune system does its job right. Let's have a closer look at how it defends us against germs.

While the immune system employs a huge range of agents, its key troops are white blood cells, in particular lymphocytes, monocytes, eosinophils, neutrophils and basophils. Of these, lymphocytes are key. Lymphocytes are themselves divided into T cells and B cells, with T cells having two main sub-types: cytotoxic T cells (helpfully also known as killer T cells) and helper T cells.

Killer T cells do what their name says: they kill cells that have been attacked or subverted by pathogens: they're the hunter killer submarines of our immune systems. Helper T cells help other parts of the immune system react to infection. One of the things they do is prime B cells to start producing antibodies against an infection, which then attack the pathogen. But helper T cells can also become memory T cells. Memory T cells are there for the long-term defence of the body. They code the details of an infection into their structure so that, should that pathogen reinfect the body, even many years later, they recognise it immediately and kick off the body's countermeasures. Memory T cells don't forget. Most of us caught chickenpox as children. We don't catch it again because our memory T cells remember the signature of the virus that causes it and, when they spot the virus trying to sneak in again, they pass on the information to B cells, along with instructions as to the exact type of


The inflammation around a wound is a key part of the immune system's defence against infection

Saliva is an important part of our defences against disease

antibodies the B cells need to make in order to fight off the disease.

T cells are why we often become immune to diseases having caught them once. They are also the cells that allow vaccinations to work. Vaccination is essentially the process of introducing a harmless version of the disease into the body so that the body, in the guise of our T cells, can prepare its defences to deal with a full-on attack by the disease.

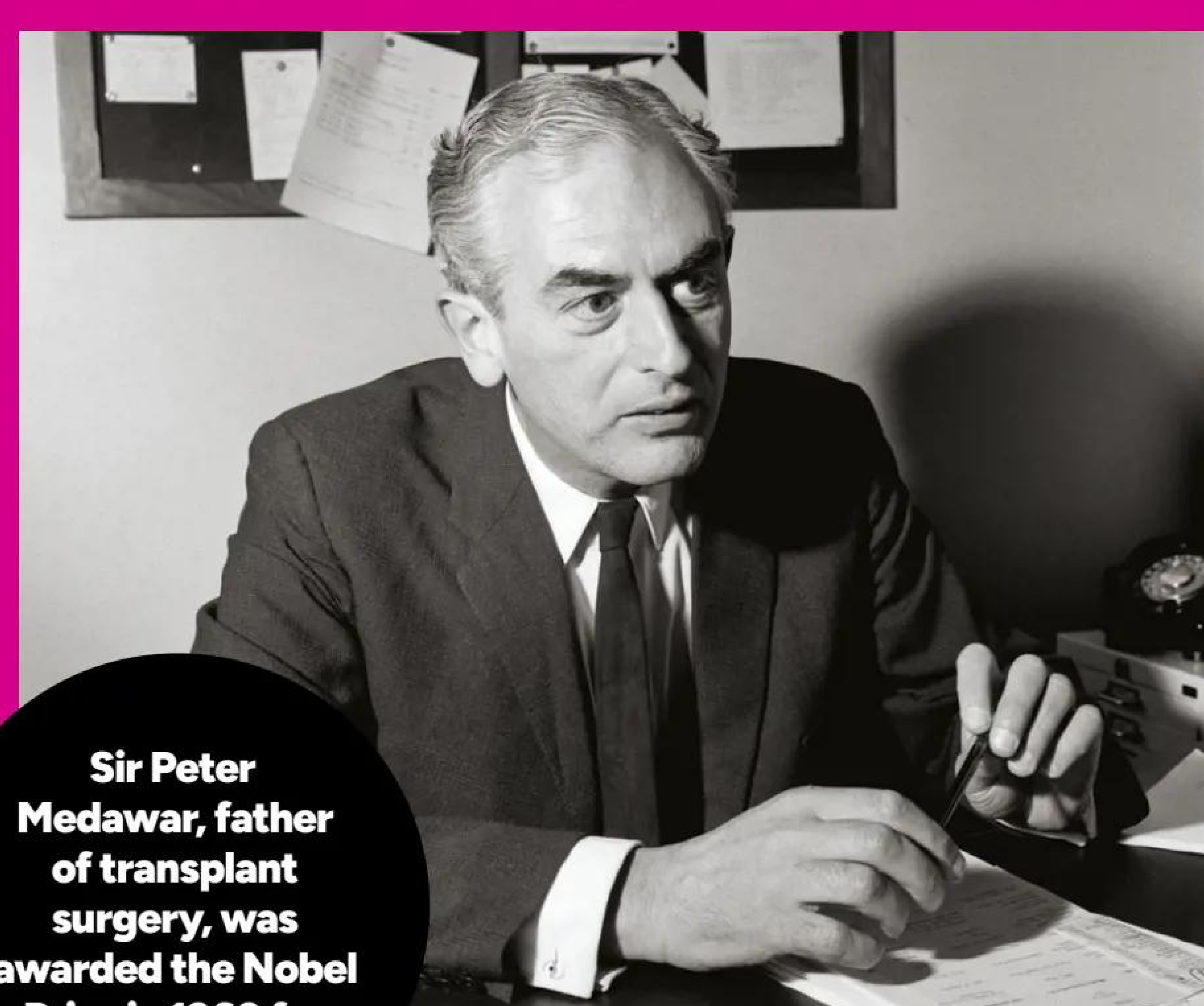
Antibodies (also known as immunoglobulin) are the foot soldiers of our immune response. Once triggered, a B cell will produce millions of antibodies, sending them into the bloodstream and lymphatic system. Antibodies are proteins and, when sent out to do battle, they circulate through the blood and lymphatic systems until they encounter the antigen (defined as any substance that makes the body produce antibodies), and then they bind to it. If the antigen is a poison, antibodies can neutralise it simply by binding to it – this changes the chemical structure of the poison, rendering it harmless. If the invader is a microbe, binding antibodies can smother it and stop it moving or prevent it from invading other cells. Some antibodies work by binding to the antigen and triggering a complement reaction. This reaction leads to the lysis (bursting) of the antigen cell or infected human cells, a signal calling phagocyte cells to the location which then ingest the antigen, and create inflammation around the area to bring more antibodies to the location to deal with the infection.

There are five types of antibody, classified according to where in the body they are found, and indicated by the abbreviation Ig (for immunoglobulin) followed by a single letter designating their location. IgG is the most

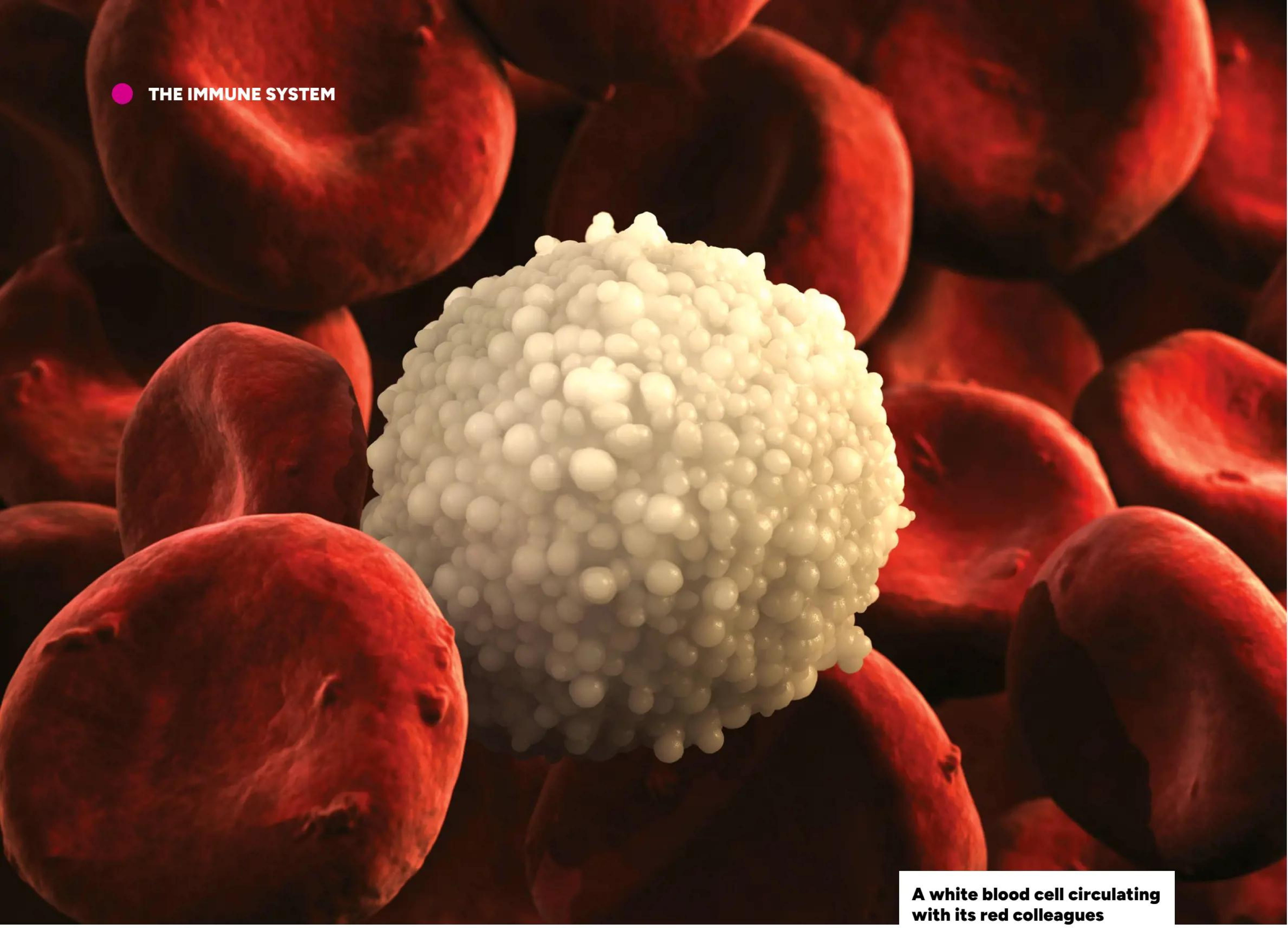
Making transplants take

The problem of organ transplants is all to do with the immune system

In 1941, a young scientist named Peter Medawar was enlisted by the RAF to investigate why it was not possible to graft skin onto burn victims. The RAF was particularly interested in this because so many of its pilots had suffered devastating burn injuries when trying to escape burning planes. Doctors had tried placing new skin on the area but, after initial success, the transplanted skin invariably withered and died. Doctors thought it was a problem with their surgical procedures and if the operation could be done better, then the graft would take. This is quite a reasonable belief: in horticulture it is perfectly possible to graft a tree onto a different root stock. But Medawar, investigating the problem, realised that when doctors tried again with skin grafts, the second transplant died faster than the first. The problem was not one of surgical technique but of rejection: the second time round, the body recognised that the new skin tissue as not its own quicker, and so rejected it faster. Investigating further, Medawar found that skin transplants would take in young mice: the body had not yet fully realised what constituted itself and what was alien, so would accept the skin graft. This insight opened up new approaches to transplant surgery. The first success came in 1954 when Richard Herrick received a new kidney donated by his identical twin brother, Ronald. The transplant took because, being twins, Richard's body recognised Ronald's kidney as its own. However, without an identical twin to donate an organ, transplants rarely lasted. It required the development of the immunosuppressant drug, cyclosporine, for transplant surgery to become feasible on a larger scale. With the success of cyclosporine and similar drugs, transplant surgery is mostly limited by lack of donors rather than the inability to perform transplants.



Sir Peter Medawar, father of transplant surgery, was awarded the Nobel Prize in 1960 for his work.



A white blood cell circulating with its red colleagues

common, accounting for 75 percent of antibodies, and is found in the blood and cell tissues. IgM antibodies occur in the lymphatic system and act as antibody first responders. IgA antibodies occur in saliva, tears, mucus and breast milk. They are why licking a wound can help prevent infection. They protect against airborne and swallowed antigens. Breast milk is rich in these antibodies, which is one of the reasons why breast-fed babies suffer fewer infections than bottle-fed babies. IgE antibodies occur in the skin, mucus membranes and lungs. They trigger the release of histamines, making them useful in dealing with allergies. Finally, there are the mysterious IgD antibodies. These live on the surface of B cells and no one knows quite what it is that they do, although researchers theorise that they help B cells mature and activate.

B cells have to mature and activate because, rather extraordinarily, B cells and T cells are trained to their roles before being released into the body. B cells are produced in the bone marrow, where their training takes place. T cells are also produced in the bone marrow but their training happens in the thymus. The thymus is an organ that is found in the chest, in front of the heart and behind the sternum. In adolescents it weighs about 40-50 grams (1.4-1.7 ounces), although it shrinks after that and may become difficult to detect in old people.

Until 1961, no one knew what the thymus did because on examination it appeared to be full of dead cells – dead T cells to be exact. Why would a gland kill cells? It was Jacques Miller, a French Australian scientist, who discovered that the thymus is a boot camp for T cells. After production in the bone marrow, the young T cells migrate to the thymus where they are tested. Those that are either ineffective at spotting and attacking antigens, or are over eager, making them liable to attack the body's own tissues, are weeded out during training and their corpses are what researchers found, to their mystification, in the thymus. The T cells that pass their final exam are released out into the body to begin their lives of ceaseless patrolling.

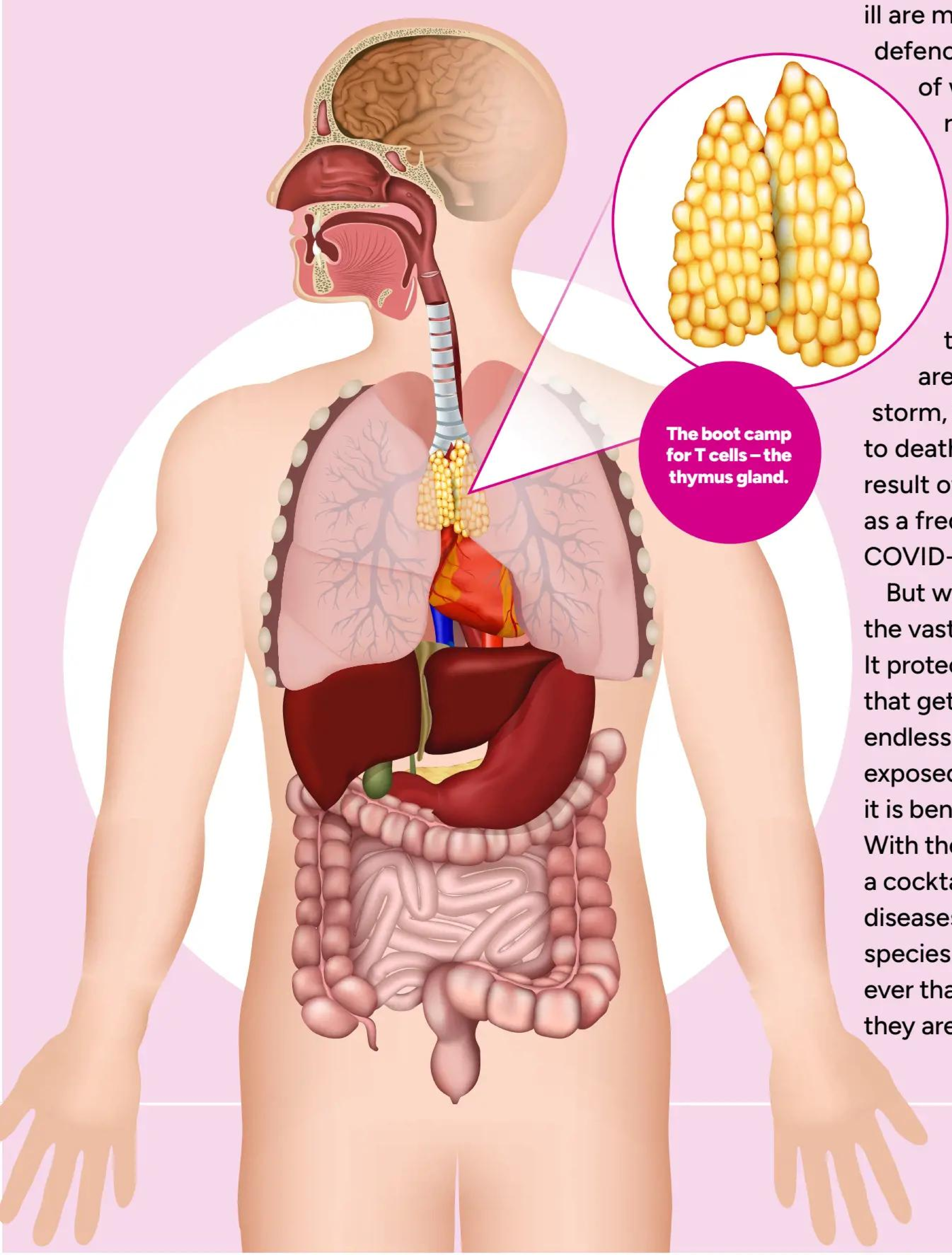
As already mentioned, inflammation is a result of the complement reaction of the immune system. Inflammation gets a lot of bad press today as being a potential cause of many disorders of the modern world, but it remains an essential part of the immune response. Its operation is seen most clearly around wounds. A breach in the skin allows pathogens direct access into the body, and requires repairs to stop the bleeding and close the wound. To deal with the emergency, the blood vessels around the injury dilate, allowing the body to rush the repair squad and the body's defenders – white blood cells – to the area. The surrounding tissue swells, putting pressure on the nerves, which results in the soreness associated with inflammation.

Unlike red blood cells, white blood cells are not confined to the blood stream. At injury or infection sites they search through the tissue for the enemy. When they find enemy pathogens, the white blood cells release chemicals called cytokines that tell the rest of the body how to deal with the threat. Cytokine signals activate other cells and direct their actions, pointing some towards the threat, or they signal for an increase or decrease in inflammation. They can also tell cells to make more of themselves, triggering white cells to proliferate to fight an infection, as well as signalling to immature cells that they need to develop into white cells to help with the infection. The symptoms we feel when ill are more often the result of the body summoning its defences than the disease itself: pus is the dead bodies of white blood cells who have died to protect us rather than corpses of the invaders.

“Inflammation remains an essential part of the immune response”

However, sometimes the body overdoes its response and the body becomes too inflamed. This inflammation can become chronic and it appears to be a significant contributory factor to conditions ranging from heart disease to obesity and arthritis. If too many cytokines are released at once, in what is called a cytokine storm, it may bring about organ failure and even lead to death. Cytokine storms happen most often as a result of respiratory infection and doctors cited them as a frequent cause of death of people suffering from COVID-19.

But while the immune system can sometimes fail, for the vast majority of us almost all the time it does its job. It protects us from invaders. It destroys the antigens that get past our outer defences. It monitors an almost endless array of new organisms and chemicals that we are exposed to throughout our lives, deciding in each case if it is beneficial, neutral or dangerous, and acts accordingly. With the modern world creating, and exposing us, to a cocktail of new compounds, with the danger of new diseases being created in the laboratory or jumping across species to find new hosts in us, it's more important than ever that our immune systems do their job. Thankfully, they are almost always up to the task.

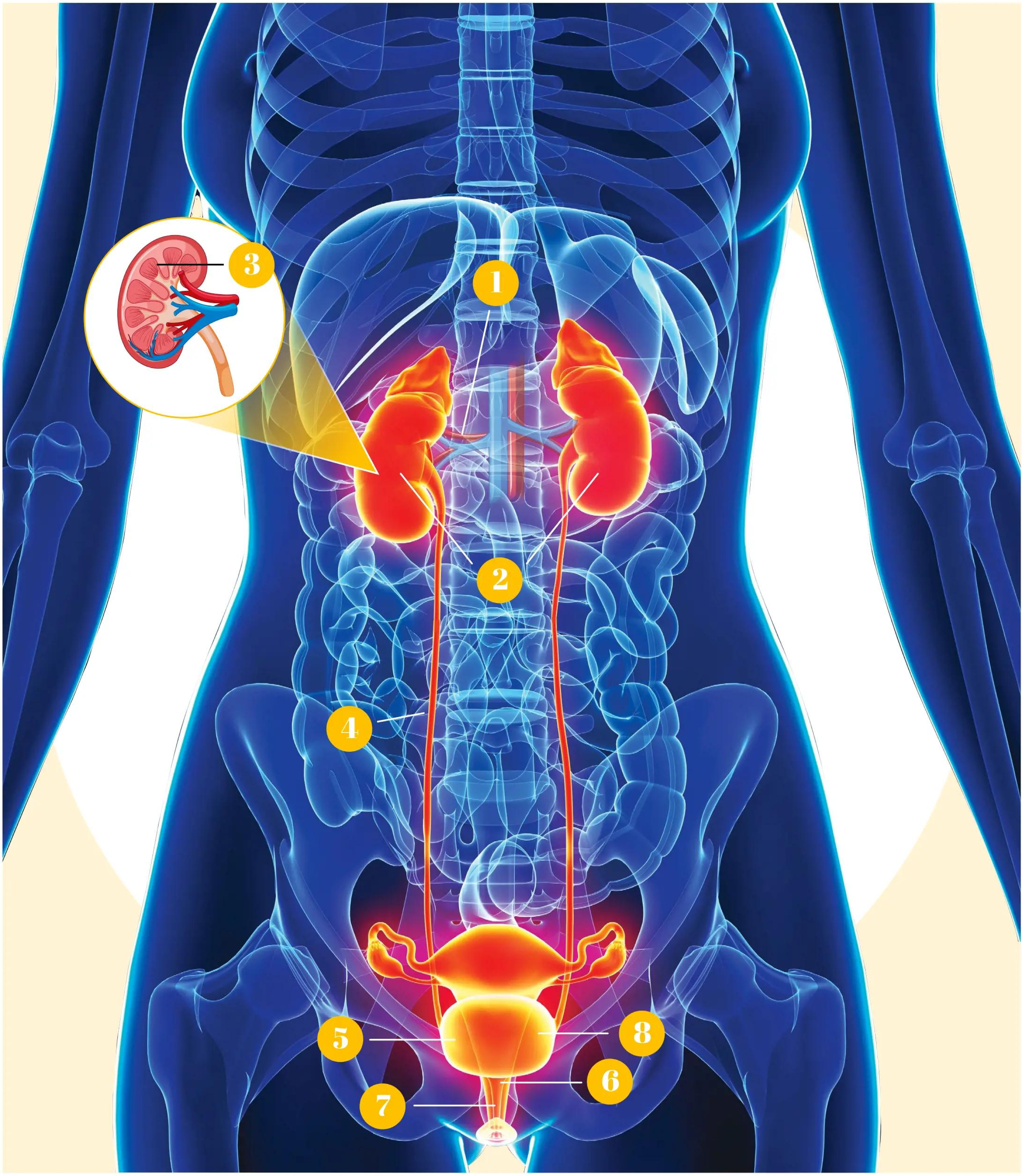


The boot camp for T cells – the thymus gland.

THE URINARY SYSTEM

Our natural filter removes water and toxic waste from the blood and body

WORDS BY JAMIE FRIER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BREAKDOWN OF A SYSTEM

1

Renal artery & vein

These blood vessels are responsible for the transportation of blood. The artery takes blood to the kidney; the vein takes blood away.

2

Kidneys

The kidneys are two fist-sized organs through which blood that contains waste products, including urea, passes. Blood is cleaned and exits one way; urine exits the other.

3

Nephrons

These are a collection of capillaries that receive blood and remove the urea from it. Each kidney contains around one million nephrons.

4

Ureters

These two tubes take urine from the kidneys to the bladder. They measure around 23cm (9in) each.

5

Bladder

This triangular, hollow, muscular organ receives and holds urine. The average bladder can hold 500ml (16fl oz) of urine for two to five hours.

6

Internal sphincter

This ring of muscle wraps around the exit of the bladder, squeezing to stop urine escaping; relaxing to release it.

7

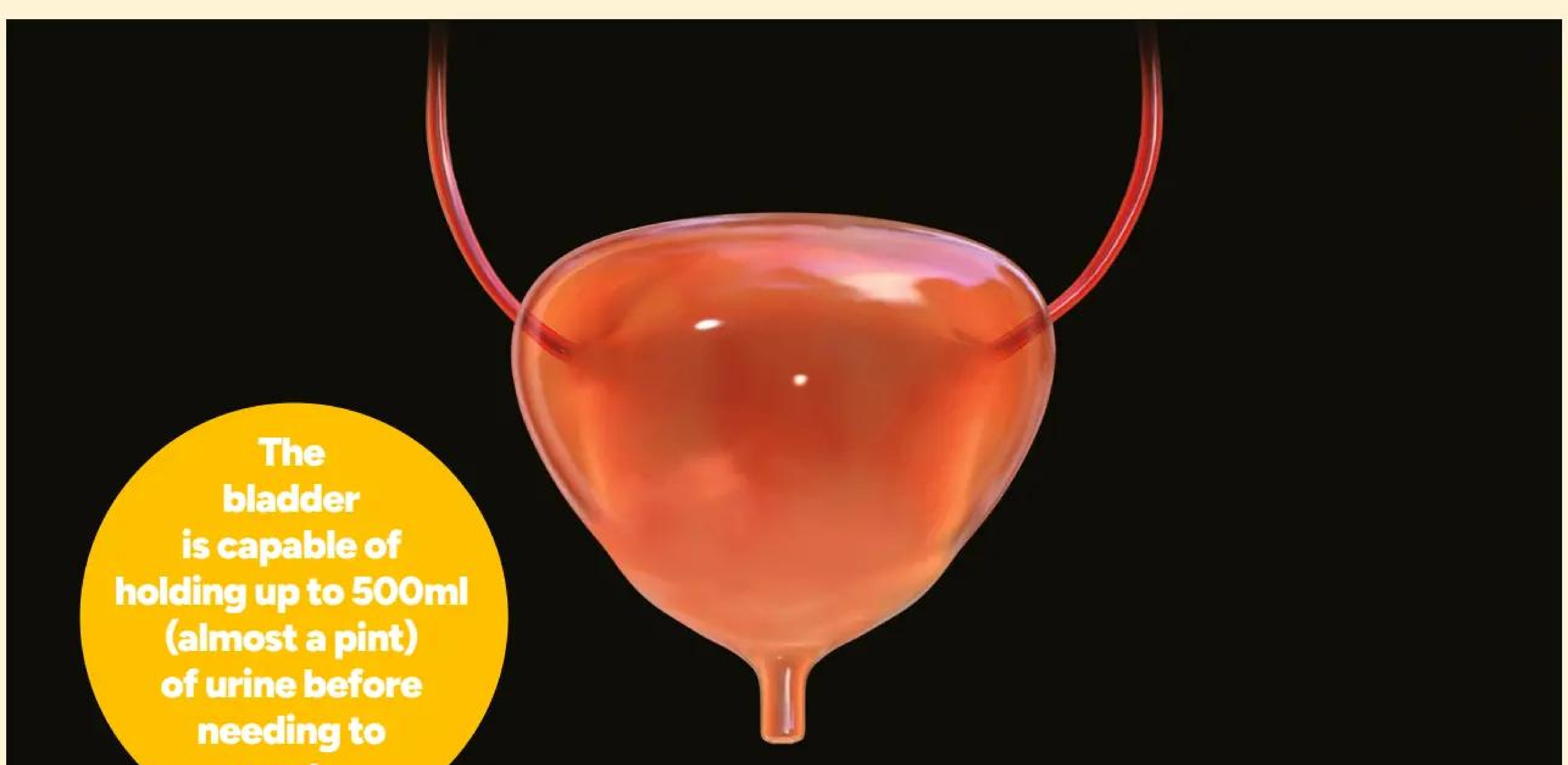
Urethra

This short tube takes urine from the bladder to the genitalia, where it is expelled from the body.

8

Urine

Urine is the product created during the urinary system process, and is made up of urea, water and other elements in fractional numbers.



The bladder is capable of holding up to 500ml (almost a pint) of urine before needing to empty.

Fact file

Everything you need to know about the urinary system

What does the system do?

The urinary system removes waste products, such as urea, from the blood in the kidneys. It converts that urea into urine, with the addition of water, and sends it down through the ureters into the bladder, then finally out through the urethra.

Why is it important?

It is an essential part of the body, because without the urinary system, dangerous waste products would remain in the body, poisoning and eventually killing us. Ammonia, which is toxic to humans, is created in the digestive process. This is converted to urea, which still needs to be removed from the body.

When does this system develop in a foetus?

The first elements of the urinary system start to appear in a foetus in week four, with the pronephros, mesonephros and metanephros, which are formative parts of the kidney. Urine production begins in week 11, which is around the same time that the bladder begins to form.

What organs are part of this system?

The two kidneys filter blood, the ureters carry urine to the bladder, the bladder stores urine, and the urethra expels it from the body.

What are common conditions associated with this system?

The majority of issues with the urinary system arise from urinary tract infections (UTIs) or sexually transmitted infections (STIs), which are caused by bacteria entering the urethra. Kidney failure is one of the most serious related conditions, and requires hospital treatment.

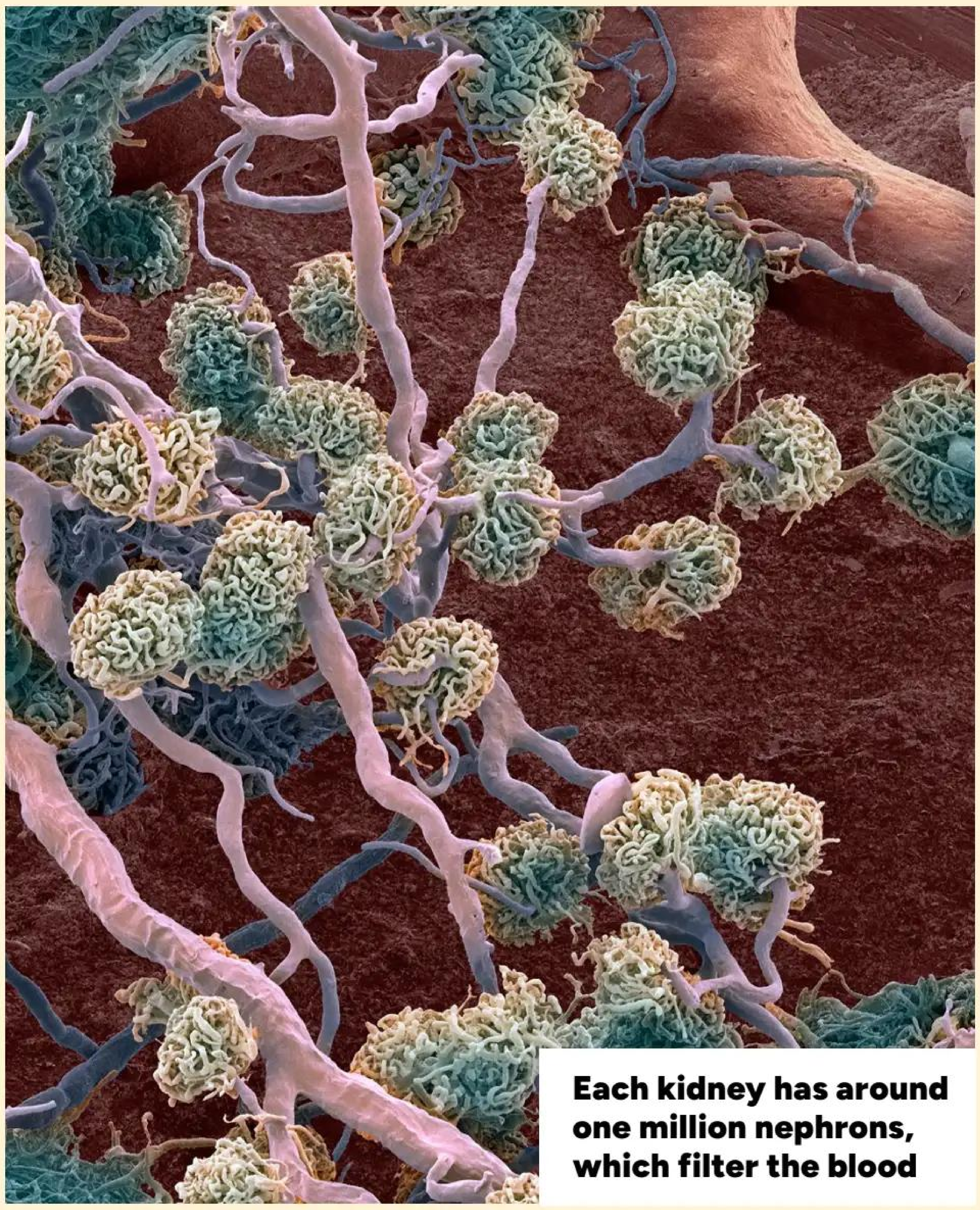
Holding onto a pee is not a good idea, so always try to go when you can

The urinary system may be far from the most glamorous of the body's systems, but it's certainly one of the most crucial. The purpose of the urinary system is to take unwanted products from the blood, convert them into urine, and flush them out of the body. It does this by filtering blood through the kidneys, sending the waste down the ureters and into the bladder, where it exits via the urethra. It's a short process but vital to the smooth running of the body.

The whole process starts before anything gets as far as the system itself. When food and drink are consumed, they are broken down, and the beneficial elements – like vitamins, minerals, proteins, amino acids and so on – get absorbed into the bloodstream. The rest of the food and drink that aren't as useful to the body stay in the digestive system and are expelled from the body as faeces.

So at this point, the blood is packed with goodness, but that is far from the end of the story. Just like many industrial processes, the production of something useful also creates byproducts that are far less desirable. The most notable and undesirable byproduct is ammonia, which forms following the digestion of protein and some vegetables. This is a dangerous substance to be in your body, so your liver converts it to a product called urea. Urea is then transported in the blood via the renal artery to the kidneys, which are two purple-brown organs located just below the ribs. These act as a kind of filtration system for removing urea from the blood. Around 150 litres (264 pints) of blood pass through your kidneys each day, with around 1-2 litres (1.8-3.5 pints) removed in the form of waste by the nephrons. These are small filters that extract urea from the blood using a bundle of capillaries known as the glomerulus. Each kidney contains approximately one million nephrons. These nephrons are remarkable pieces of body engineering as they are able to remove all the waste products from blood, while allowing the nutrients, vitamins and minerals to remain and get circulated to the parts of the body that need them.

Once the filtration has taken place, the cleaned, toxin-free blood enters the renal vein and continues its journey around the body. Meanwhile, urea, water and other waste products combine inside the kidneys to create urine that is sent along the ureters, which are small, thin tubes that connect the kidney to the bladder. Like many tubes in the body, the ureters are ringed with muscle, which contracts and expands to push its contents down its length to its intended destination in a process called peristalsis. Four to five times per minute, urine is emptied from the ureters to the bladder, a hollow, triangular, muscular organ. It is important that these



Each kidney has around one million nephrons, which filter the blood

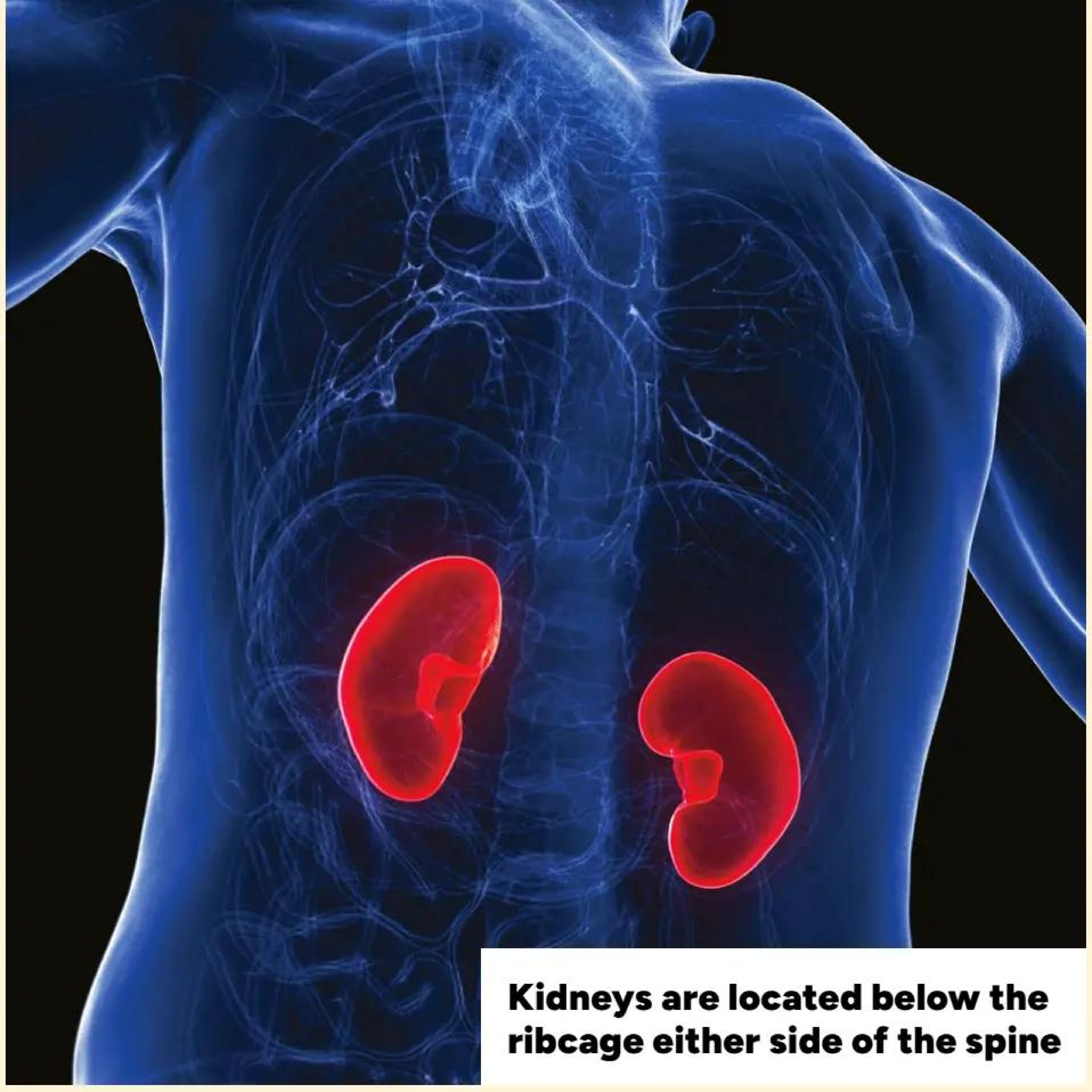
"In order to ensure your bladder doesn't empty until you want it to, between the bladder and urethra are two sphincters"

ureters are in good working order, because if they push the urine in the wrong direction, it can result in a kidney infection. Membranes flop over the opening between the bladder and ureters in order to avoid the urine flowing back up the system. The bladder slowly fills up with urine, expanding until it can't accept any more. Around 500 millilitres (16 fl oz) can be stored in the bladder from two to five hours before it tells the brain that it needs to be emptied via the urethra.

In order to ensure your bladder doesn't empty until you want it to, between the bladder and urethra are two sphincters – an internal sphincter and an external one. The internal sphincter is a ring of muscle that wraps tightly around the exit tube of the bladder to keep it shut, much like a hand holding the neck of a balloon closed. The external sphincter wraps around the internal one, providing extra pressure and support towards keeping the bladder tightly closed. These muscles weaken as a person ages, which is how and why bladder leaks occur – imagine holding a balloon by the neck and you release your grip slightly, allowing air to escape. However, by regularly carrying out pelvic floor exercises, you can keep your external sphincter stronger for longer.

When your brain and bladder decide that you've held onto the urine for long enough and it's safe to pee, it tells the external sphincter to release its grip. The brain has no power over the internal sphincter, which contracts and expands as required. However, the external sphincter can be controlled to some degree, so if you've ever found yourself clenching to avoid releasing urine at an untimely moment, it's the external sphincter that you're working. The relaxation of both sphincters allows urine to flow into the urethra, which is a short tube that takes urine out of the body, thus completing the urinary system.

It is important to check your urine after going to the toilet, as the colour can give you a steer on your



Kidneys are located below the ribcage either side of the spine

hydration levels. If it is almost clear with just a hint of yellow then you are well hydrated. The darker your pee gets, the less hydrated you are, so it is an indication that you should drink more water. You should aim to drink roughly 1-2 litres (1.75-3.5 pints) per day, ideally mostly from water, but other, non-sugary drinks also count towards that ideal amount. While dark yellow urine signifies dehydration, it is possible to notice more serious health issues by looking into the toilet. A dark-brown pee could tell you that you have issues with your liver, as that suggests the presence of bile; while any blood in your urine means that you should visit the doctor straight away as that could be a sign of a serious health problem like cancer.

While the removal of urea from the body may not sound as important a system as, say, the nervous, skeletal or circulatory system, it is in fact vital to the smooth running of the body, and any problems within it can lead to serious health issues. Starting with the kidneys, should anything go wrong with these two fist-sized organs, then you are in trouble. The effective filtration of urea from the blood is essential to keeping your body healthy. If the nephrons allow too much urea to pass by them and not remove it from the blood, then this toxic waste product could have major repercussions. Too much urea in the bloodstream could result in kidney failure, seizures and heart attacks, so it's important to get symptoms checked as early as possible. Chronic kidney disease affects around 10 per cent of the world and has side-effects including weight-loss, lethargy, nausea and sleeping issues. If kidney disease affects just the one kidney in a person's body, this can be managed because two working kidneys aren't essential to living, but if both kidneys stop working, then dialysis is required. During kidney dialysis, a blood vessel called an arteriovenous fistula (AV fistula) is created in your arm. Needles are then inserted into the AV and blood extracted. The blood flows into the dialysis machine, which performs the same task as a kidney, cleaning the blood of urea and other toxins. It is a time-consuming

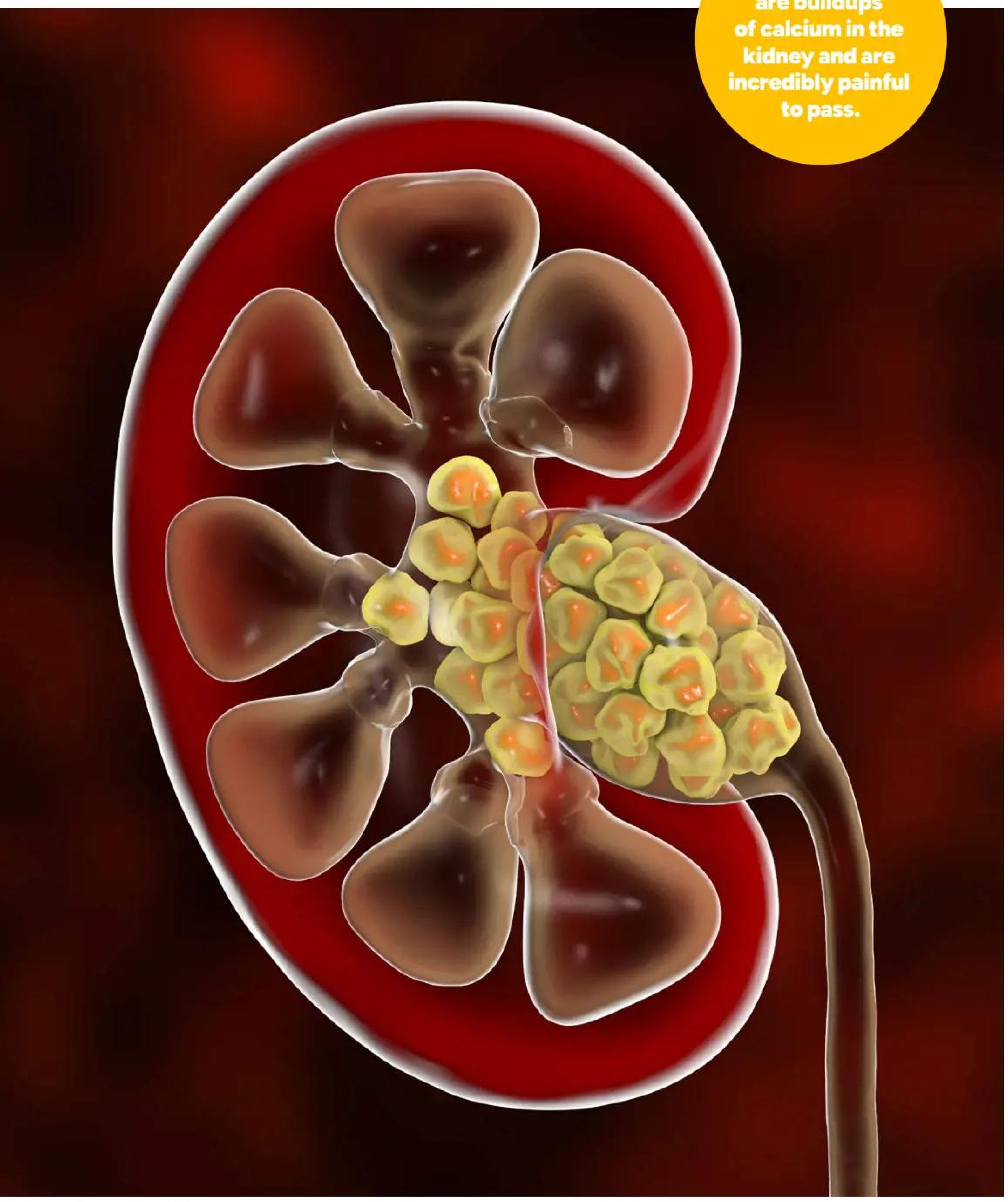
You may associate stomach pain with the digestive system, but a poorly functioning bladder can also contribute

Unappealing as it sounds, checking your pee can help spot underlying health issues.

See your pee

Your urine could hold the key to identifying illnesses

It is often difficult to know when something is wrong inside your body without expert knowledge. If you have a cut or broken bone, you can easily tell what the problem is, but internal systems are a bit more of a mystery. However, there are a number of clues that the urinary system can give to hint at an underlying issue. One of the easiest to spot is changes in how you urinate. If you normally have a solid stream of light, straw-coloured urine, but suddenly you're finding it difficult to go, it's coming in spurts or is a different colour to normal despite hydration levels staying the same, this is a sign that you have an infection, blockage or organ failure. Blood in the urine is another clear sign that something is very wrong inside your body, so you would need to get checked out as soon as possible. It could be a minor issue, but it could be an indication of kidney or bladder cancer. Finding you have to go more or less often than usual could indicate that something is wrong, whether it be a weakening of your bladder and sphincter or your kidneys failing to process enough urea to create the required urine.



Kidney stones are buildups of calcium in the kidney and are incredibly painful to pass.

process, requiring three four-hour sessions per week, but it's essential for keeping the body safe from harmful waste products. Another option is a kidney transplant, which has been a possibility with the use of a donor since the 1950s. The kidney will need to be from a match, but can come from living people as you can get by with just one working kidney. Remarkably, if you have just the one working kidney, it can increase in size by around 50 per cent in order to compensate for the loss of its partner. This will often come from a family member who is most likely to be a successful match. The development of drugs means that the survival rate for someone who has had a kidney transplant now sits at an incredible 80 per cent – a far cry from the early days of the procedure. A study published in August 2023 has also shown that kidney cells implanted in an artificial device can perform the function of a kidney without running the risk of the body rejecting it as a foreign object. This represents a massive step forward in kidney failure management and would massively help people in the future who wouldn't then need to go through the process of dialysis.

Kidney stones are particularly nasty afflictions. These occur when waste material, usually calcium oxalate and calcium phosphate, don't get washed through the urinary system and instead build up inside your kidneys. When these form and then try to make their way through the ureters, bladder and finally urethra, it can be incredibly painful as the tubes weren't built for solids, and especially solids of any size. Some kidney stones can be passed out, while others have to be surgically removed. The best way to avoid kidney stones is to increase fluid consumption, as this dilutes urine and makes it less likely that stones will form. If you're unlucky enough for them to appear, apple cider vinegar is one cure, as it makes the urine acidic and could help dissolve the stones before they get too big.

Moving through the system, the bladder is prone to infection. This most often happens when bacteria enters it from the urethra. This is known as a urinary tract infection (UTI) or, if the bacteria entered the body due to sexual intercourse, a sexually transmitted infection (STI). Around 90 per cent of UTIs occur due to E.coli in the large intestine, which is part of the digestive system. Poor hygiene or wiping technique can transmit the bacteria to the genitals, from where it enters the urethra, bladder and, ultimately, the kidney unless it's sorted quickly. If you feel pain in your lower abdomen, have difficulty peeing or experience pain while peeing, there is a good chance you have a UTI, which needs to be treated with antibiotics. As people get older, their sphincters become less strong and less watertight, meaning that incontinence becomes a problem and urine can leak out when not intended. The condition where you wake up in the night needing to pee is called Nocturia and generally affects older people, but can also be present in younger people. This can be down to drinking fluid before bed or taking certain medications that contain diuretics, but could also be caused by diabetes, heart disease or high blood pressure.

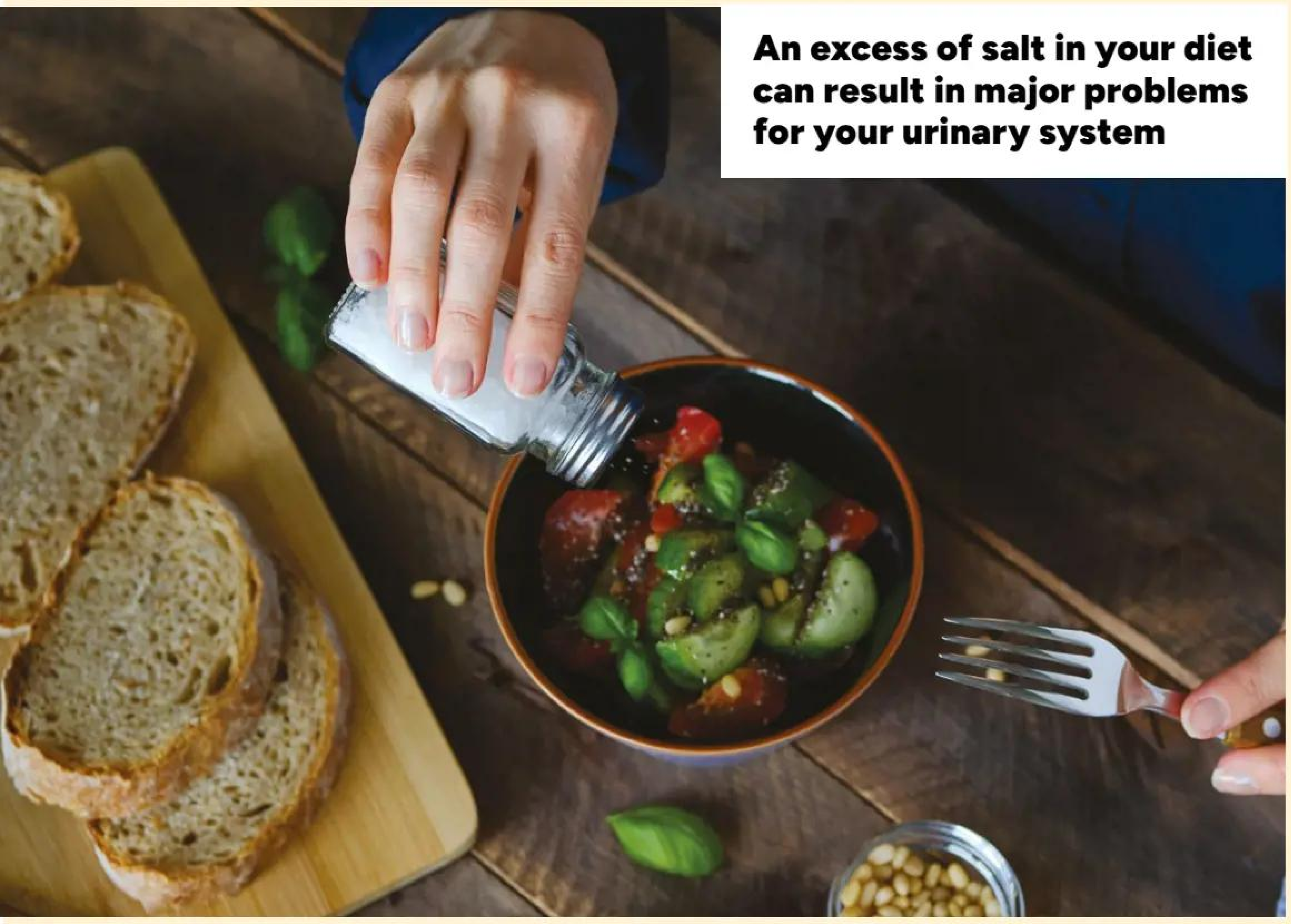
Other, less common afflictions that can affect your urinary system are glomerulonephritis, which is when the nephrons in your kidneys become inflamed, stop working and allow urea to pass through the kidneys; polycystic kidneys, in which cysts grow on the kidneys; and loss of bladder control, usually due to failed or weakened sphincters.

> **"You may think that pain in the stomach is to do with the digestive system, but it can actually be related to the urinary system"**

Conditions from other systems in the body can also affect the urinary system. Crohn's disease is an illness that affects the intestines in the digestive system, but this can also have an impact on the urinary system as inflammation in the intestines can block the ureters and make peeing tricky. You may think that pain in the stomach is to do with the digestive system, but it can actually be related to the urinary system. This is because your kidneys, ureters and bladder are all located around your midsection and could be the cause of the issue.

For a system that has so few parts, the urinary system has a lot of things that can go wrong with it, so it is crucial to keep it in good working health. Fortunately, there are a lot of things you can do to help it function. Ideally you shouldn't hold onto pee for too long. If possible, once you feel like you need to go, you should. While some people think that holding off would strengthen the bladder, it actually has the opposite effect and could result in bladder infections. When urinating, you should be relaxed, take your time and fully empty your bladder. This will also minimise the chances of a bladder infection. Similarly, try to urinate as soon as possible after having sex. This is because bacteria can be transmitted to the urethra during sexual intercourse and needs to be released. Women have shorter urethras, which are more exposed than men's, but it is possible for both sexes to get UTIs from sex. This is because the urethra is responsible for both the transportation of semen and urine in the male body, so flushing it out is to be recommended. For women, wiping from front to back is recommended, as this also reduces the risk of bacteria moving from the anus to the urethra opening. Beyond urination, there are other ways to keep your urinary system happy. Being fit, exercising regularly and watching what you eat all contribute to good physical health, but can also help to prevent bladder leakage. A diet low in fibre can lead to constipation, putting pressure on the bladder and making it difficult to go to the toilet, while diets high in meat and fat will not only lead to increased sodium, but also higher levels of urea to be stripped from the blood. Drinking plenty of water also helps the system work as efficiently as possible, especially if the weather is hot or you are exercising. This is because when the body is lacking in water due to sweat or not drinking, the pituitary gland releases a chemical that tells the body to reabsorb water back into the bloodstream and out of the urinary system. Keeping yourself suitably hydrated will avoid this situation. Drinking at least two litres (3.5 pints) of water a day ensures a good, consistent supply of fluid for your body, flushing the urea through the organs and filling up the bladder more quickly, so it can be released out of the body in double-quick time. Think of it as a water slide – the more water, the faster you shoot through and the better it is. To aid this further, limit salt intake. Salt can dehydrate the body, increase water retention, and unbalance your urine's pH levels, and the sodium can build up into kidney stones. Similarly, excessive levels of caffeine can have the negative effect of dehydration as well as disrupting your bladder.

The urinary system, while simple and unglamorous, has crucial functions without which we would be very unwell. It's an efficient, effective system that usually works well by itself, demanding nothing but water to keep it ticking over. From the kidneys down to the urethra, the urinary system is one of the body's most vital components.

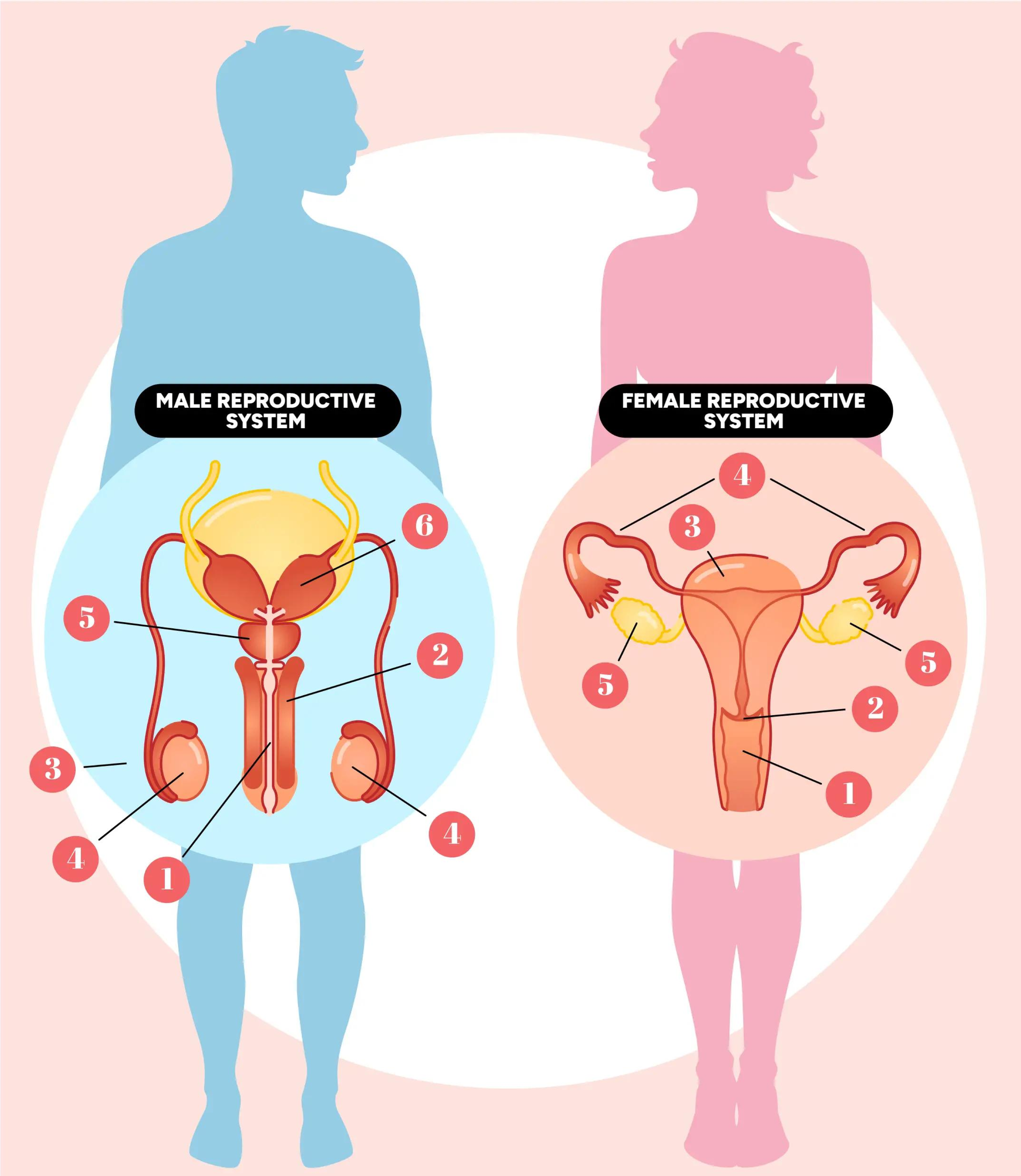


An excess of salt in your diet can result in major problems for your urinary system

THE *REPRODUCTIVE SYSTEM*

Where it all begins

WORDS BY EDOARDO ALBERT


MALE REPRODUCTIVE SYSTEM
6
5
2
3
4
1
4
FEMALE REPRODUCTIVE SYSTEM
4
3
5
5
2
1

BREAKDOWN OF A SYSTEM

MALE REPRODUCTIVE SYSTEM

1
Urethra
The tube down which semen and urine travel on their journey out of the body.

2
Penis
Becomes erect in order to enable sexual intercourse.

3
Scrotum
Protects the testes.

4
Testes
Produce sperm and testosterone.

5
Prostate gland
Produces seminal fluid.

6
Seminal vesicle
Provides ingredients for the manufacture of semen.

FEMALE REPRODUCTIVE SYSTEM

1
Vagina
Holds penis during sex and is the channel through which a baby is born.

2
Cervix
The gatekeeper to the uterus.

3
Uterus (womb)
Where a baby develops during pregnancy.

4
Fallopian tube
Channels for sperm in one direction and fertilised egg in the other direction.

5
Ovaries
Produces and stores eggs, and produces the hormones oestrogen, progesterone and androgens.

> “A meta-analysis found that sperm counts had dropped by half since 1973 in Western countries”

Fact file

Everything you need to know about the reproductive system

What does the system do?
It produces new people.

Why is it important?
Without it, we would become extinct in a generation.

When does this system develop in a foetus?
External genitals start to develop between eight and nine weeks, becoming fully formed between the 17th and 18th weeks of pregnancy.

What organs are part of this system?
For the male – the penis, testes and scrotum, and the prostate gland, urethra and vas deferens. For the female – the ovaries, fallopian tubes, uterus (womb), vagina, cervix and vulva.

What are common conditions associated with this system?
Sexually transmitted diseases, infertility, impotence, menstrual problems including excessive bleeding and cramping.

Giving birth is only the start – babies are born helpless so need absolute care

Really, it's a miracle. In fact, you and everyone else reading this, you are all consequences of miracles. It's true that we have read the human genome but that's not much more than reading the words on a page. We have only the sketchiest of ideas about how the 'words' of the genome manage to instruct a single cell to divide and multiply until it is born as a baby some nine months later.

But we do know how it begins: with a sperm cell swimming blindly towards its goal. We don't actually know if sperm cells move randomly, hoping they'll find an egg if they just keep going, or if they search for some chemical signal and move towards it. Despite their long tails, sperm are poor swimmers. It can take some sperm ten minutes to swim half a centimetre. This may be one reason why men produce so many of them in each ejaculation: it's an attempt to swamp the target in the hope that one will manage to find the mark.

Speaking of sperm numbers, it's now quite clear that male sperm counts are falling throughout the developed world. A meta-analysis found that sperm counts had dropped by half since 1973 in Western countries. No one knows why this has happened. All manner of causes has been proposed but nothing definitive has been proven. Given the vast overproduction of male sperm for the job of fertilising a single egg, it's not entirely clear whether this fall in sperm count is important. A single ejaculation shoots out between 80 to 300 million sperm (sperm are, incidentally, the only human cell expressly designed to survive outside the body: they are like little astronauts). A halving of sperm count still leaves a lot of sperm. However, there may be an issue when this is coupled with women around the world, but particularly in Western countries, opting to have children much later. Sperm from older men are subject to a higher failure rate. The same is true of the eggs of older women. This may explain in part why more and more couples are finding it difficult to conceive, around one in seven in the UK.

But it's not just men who come oversupplied to the reproductive race, women do too. Baby girls are born with a vast oversupply of eggs already stored in their ovaries. In fact, by birth, girls have already lost many of their original eggs. Female egg count reaches a maximum at about the 20th week of gestation. At that point, the growing foetus will weigh about 100 grams (3.5 ounces). She will have arms and legs and the mother might begin to feel her baby moving inside her. What the mother won't feel are the eggs developing inside her own baby's ovaries: some six million of them at this point during pregnancy. From this time on the eggs start being winnowed so that at birth, the new baby girl will have between one and two million eggs stored in her ovaries. Her bank of stored eggs continues to reduce as she gets older so that by the time she gets to her childbearing years, she will be down to about 180,000 eggs. Still, considering that the woman recorded as giving birth to the most children in history, Valentina Vassilyev, gave birth to 69 children, that still leaves plenty of eggs left over. (There is some doubt as to the accuracy of this claim as record keeping was poor in 18th century Russia. However, Mariam Nabatanzi, a Ugandan woman, definitely gave birth to 44 children between 1993 and 2019, with many of the pregnancies being multiple births. Nabatanzi's fecundity was a result of a condition called hyperovulation.)

So it is a tiny minority of a woman's eggs that is fertilised and an even tinier percentage of male sperm that does the fertilising. Let's follow the lucky sperm cell that, having been ejected and swimming frantically, finds an egg waiting for it. The egg is a hundred times bigger than its suitor cell but the egg recognises the sperm and welcomes it in: this is, after all, the point of all the palaver that preceded it. Sex is reproduction. The pleasure that accompanies it is nature's way of sugaring the pill for all the work that comes afterwards.

How a baby grows in the womb

> "A large percentage of zygotes, possibly as many as half, do not develop further because something goes wrong"

Having passed through the egg's cell wall, the sperm fuses with the egg. To prevent any other sperm getting in, the egg immediately changes its external structure, ensuring no other sperm can penetrate it.

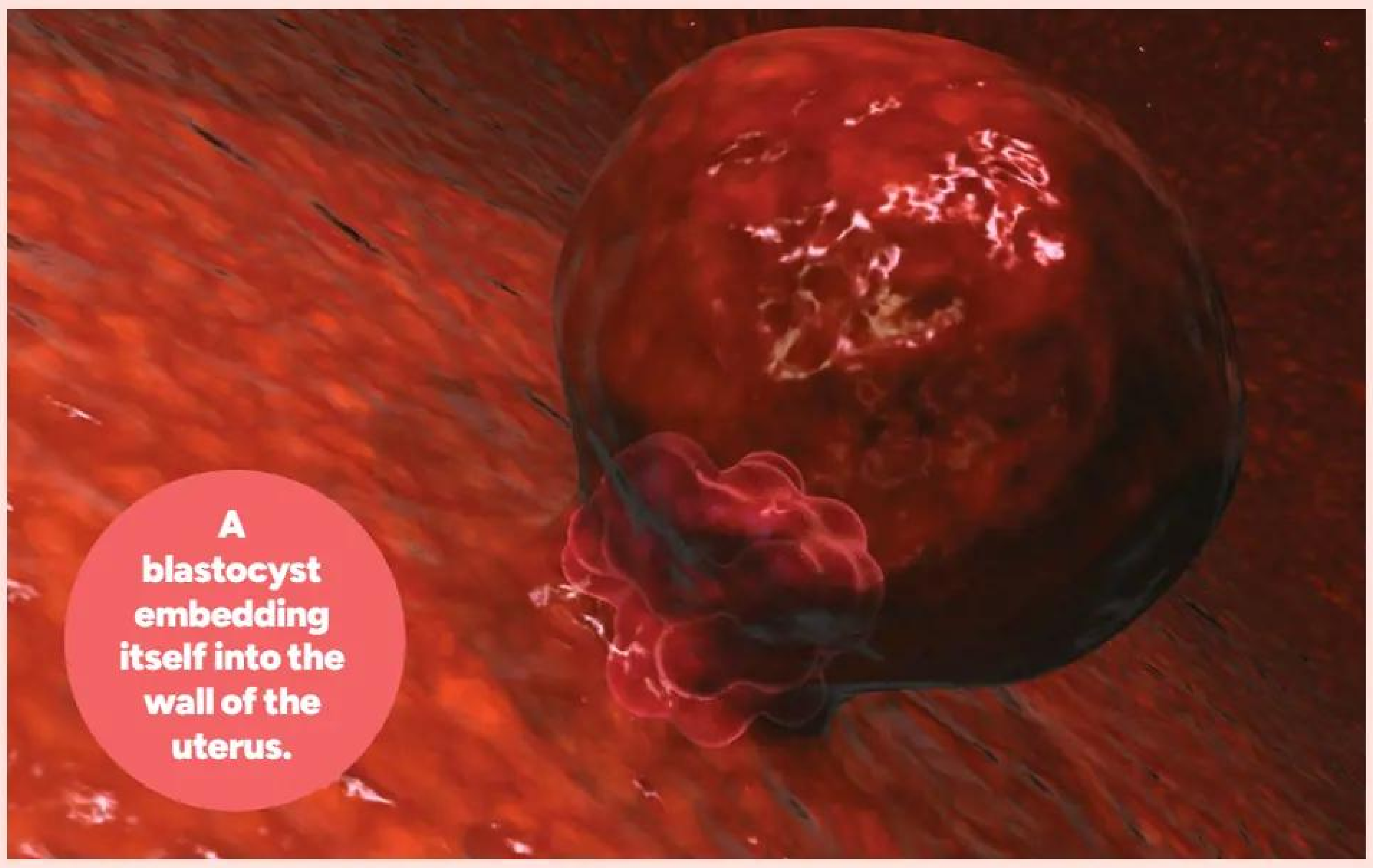
Within the egg, the DNA of sperm and egg join, producing a fertilised egg, a zygote. A new life has begun. All the possibilities inherent in that new life begin at this point. There is a direct line from fertilised egg to every person reading this, and indeed to everybody who has ever lived. Before fertilisation we did not exist: afterwards, we do. In the past, there were notions of quickening, when an animating spirit infused the developing embryo, but it is now clear that this is not the case. Life begins at conception and develops thereafter without any inflection point along the way.

Conception and the few days afterwards are the times of greatest failure. A large percentage of zygotes, possibly as many as half, do not develop further because something goes wrong: there is a fault in the sperm or egg, or the uterus does not accept them properly. In such cases, the woman will probably never even know that she has been pregnant for a little while. A small proportion of pregnancies also end because the fertilised egg implants itself in the wrong part of the uterus or, worse, in the fallopian tube, which connects the ovary to the uterus. This is known as an ectopic pregnancy and it was once tantamount to a death sentence as the embryo developed in a place where the mother's body could not support it. It's still dangerous today.

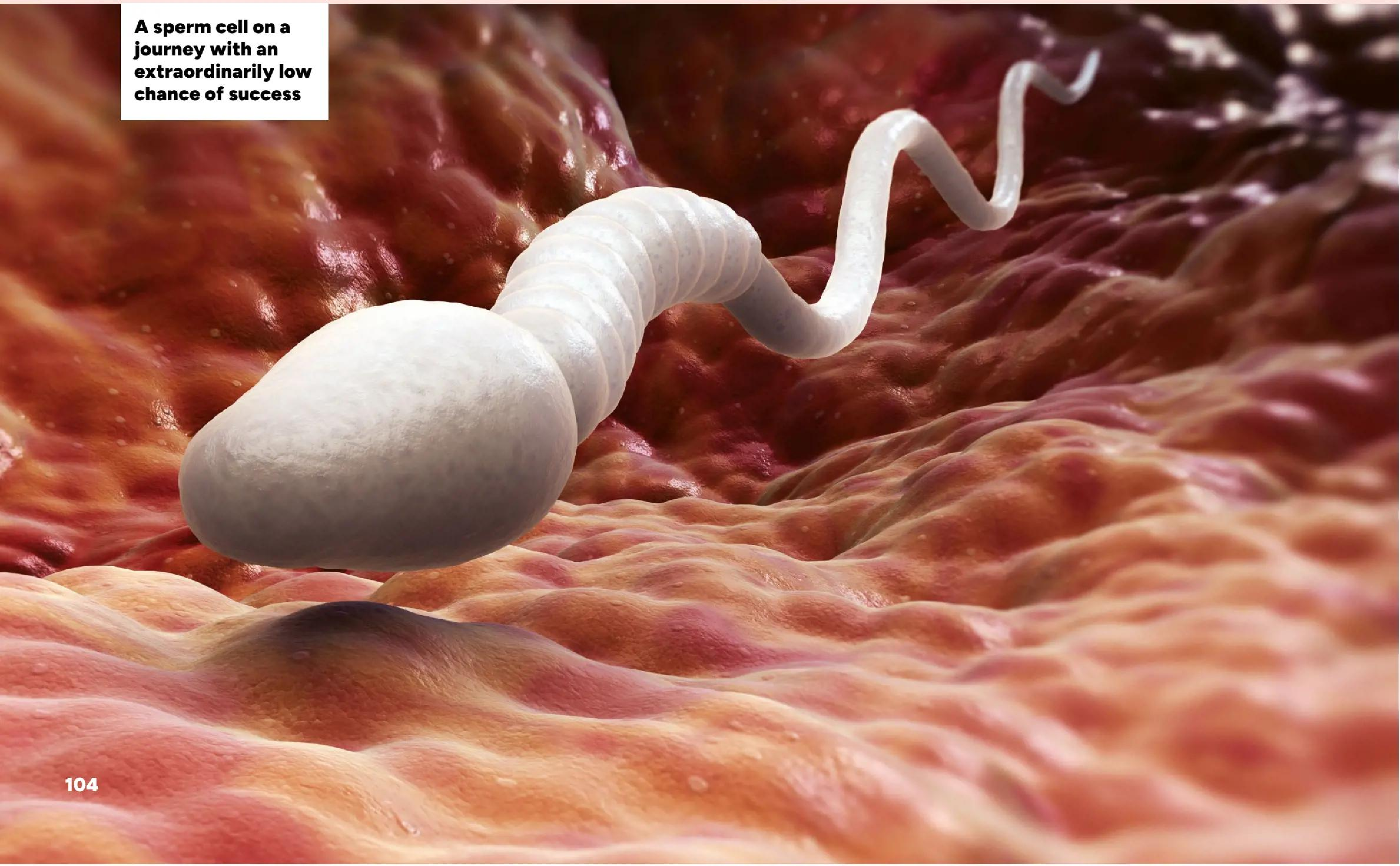
In most cases, however, the zygote implants itself properly on the wall of the uterus. It grows by dividing, although in the first few days this division is relatively slow; after a week, the single initial cell has become about ten new cells. These cells, however, are the most important we will ever have. They are called pluripotent stem cells and they are extraordinary. All the different cells in our body derive from this handful of original cells. Pluripotent stem cells are able to form cells in all three basic cell types that form the developing baby: ectodermal cells, which become the skin and nervous system; endodermal cells, which develop into digestive and respiratory organs; and mesodermal cells, the progenitors of bone, blood, muscle, heart and kidneys.

A pluripotent stem cell can produce any of these cell types, so this small group of initial cells set up the development lines that go on to produce, well, everything. At this point, the developing life is known as a blastocyst. It is only visible under a microscope. Embedded in the uterine wall, it begins to rapidly divide, producing cells destined for each of the roles mentioned. The change from zygote to blastocyst, when the cells start dividing, is called gastrulation and it's probably the single most vital moment in anyone's life.

With cell division comes acceleration. By three weeks, the new life, now formally called an embryo, has a beating heart. At nine weeks, by which point it is known



A blastocyst embedding itself into the wall of the uterus.



A sperm cell on a journey with an extraordinarily low chance of success

Two sexes

The importance of catering to men and women

Contrary to recent reports, humans are not assigned a sex at birth. In fact, everyone's sex is determined at the very moment of conception, depending upon whether the fertilising sperm is carrying an X (female) or Y (male) chromosome. From that moment on, every cell in our bodies is coded for our sex. And it does not stop at the cells. Differences between male and female are fundamental and, thankfully, these differences are now being addressed by drug companies.

For decades, drug trials were conducted almost exclusively on men because researchers did not want to have to control for the female menstrual cycle. The assumption was that male and female biology was identical, so what worked on men would work on women too – you just had to give women a smaller dose to account for lower weight. But in fact many drugs affect men and women differently, which led to women being prescribed drugs that were unsafe for them. For example, Hismanal, an antihistamine, and Pondimin, an appetite suppressant, both carried serious risks for women but this was only realised years after their approval. New regulations for drug tests now stipulate that there must be equal numbers of men and women in drug trials.

Medication can affect men and women differently

as a foetus, it has sex organs and at 16 weeks toes and fingers appear. The risk of miscarriage also drops from this point on. At 20 weeks, the baby will start to hear and at 24 weeks the lungs grow. By 32 weeks the bones have properly developed and muscles are ready by 36 weeks.

This can also be calculated in terms of cycles of cell division. From the first division to birth, 41 cycles of cell division take place, that is going from one cell to 26,000,000,000 in 280 days. (An adult has about 30 trillion cells, and extraordinarily about the same number of resident bacteria.)

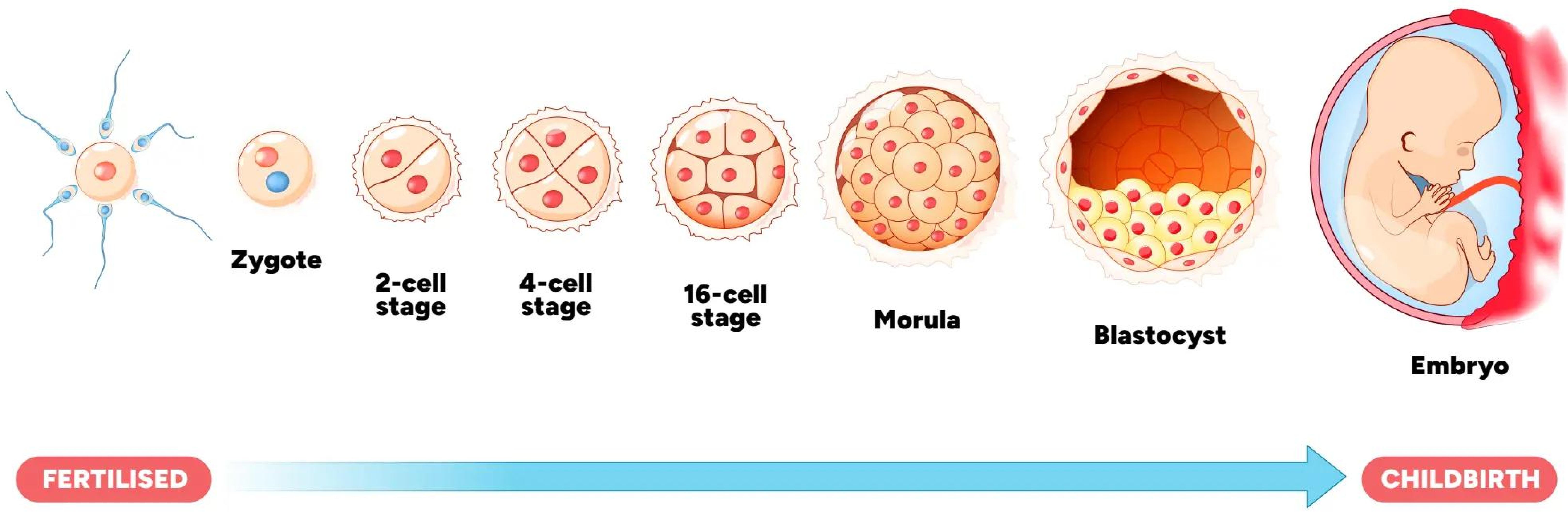
Then, it comes time for the new life to enter the world. Any mother who has gone a week past term will want to know why nothing has happened yet and the answer is that we don't know. Something trips the switch that puts the body into labour but we don't know what that is. We know the hormone prostaglandin is released, which starts the contractions, but what tells the body it's time to go remains unknown.

For women, as compared to other creatures, labour is an extraordinarily difficult process. Thankfully, the degree of danger has declined over the last century but the pain associated with it has only been a little blunted by pain relief: forgetfulness of labour pain is nature's way of getting women to go through the whole process again.

The problem arises because the baby's head is bigger than the birth canal. On average, about 2.5 centimetres (an inch) bigger. Human babies are born almost entirely helpless simply because if they grew any bigger within the womb, they could never be born. Women exchange painful but (just!) possible birth for a year of baby care after birth. The baby is not a passive participant in its birth – it has to execute a rather impressive turn in order to get through the pelvis. Some small assistance is provided to the labouring mother by the still soft skull plates of her baby's head: many a baby is born with a squashed or slightly pin-shaped head. No need to worry, though. The head will rapidly reshape itself after birth.

The moment of birth is a symphony of bodily timing. The amniotic fluid that had previously filled the new baby's lungs drains away, the lungs fill with air, and they greet the world with a cry that signifies the first breath. For the rest of us, a new life has begun but for the baby, this is just the next stage of a journey that began 40

The stages of embryo development



weeks ago, shortly after their parents engaged in the other side of the reproductive cycle: sex.

Many plants and animals manage perfectly well without sex, particularly the smaller ones. The problem with sex is that you have to find a suitable mate, and sharing genes means the children are only half yours – the other half is provided by your mate. In asexual reproduction, offspring are genetic clones of the parent. However, that does end up creating a population that can be very vulnerable to disease. The elm trees that were a feature of the English countryside spread asexually but that meant they were all vulnerable to a new infection, Dutch elm disease, which essentially wiped them out.

So we humans mate, making children whose genes are a mixture of mother and father, thereby creating a unique individual with each birth (identical twins are the rare genetic exception).

A human egg cell.

Research into human sexual behaviour has been bedevilled by more poor studies and dodgy statistics than any other branch of human knowledge. The research that made the most headlines, such as Alfred Kinsey's work in the 1940s and '50s or Shere Hite's bestselling books, the Hite Reports on female and male sexuality in the 1970s, were prime examples: apparently authoritative statistics derived from grossly unrepresentative respondents to their surveys. Kinsey, reporting what appear to have been his own sexual fantasies as science, claimed that almost 20 percent of men growing up on farms had had sex with animals, and that nearly 40 percent of men had had homosexual orgasms. The field of sexual research is still fraught with dodgy statistics: the latest census in Britain found that the area in Britain with the highest transgender population, at 1.5 percent, was Newham in London. Brighton, the gay capital of Britain, only registered one percent. Newham also has the third highest concentration of Muslims in Britain – not a population known for its high prevalence of unusual sexual identities. The moral is to treat all statistics about sexual behaviour and preference with suspicion.

Human beings are unusual in the animal kingdom in not having a specific breeding season. Evolutionary biologists theorise that this facility exists to strengthen the pair bond between female and male. In men and women, sexual intercourse goes through four stages in both sexes: excitement, plateau, orgasm and resolution.

The foetus at six months.

A sperm cell closing in on an egg cell

During the excitement phase, the heart beat speeds up and muscles tense. During this phase, for the male, the penis will swell and become rigid due to increased blood flow while in the female the clitoris also swells, secretions moisten the vagina and its inner parts grow wider. Sexual intercourse begins at this point, with the man's penis inserted into the woman's vagina. As intercourse continues, the couple reach the plateau phase. At this stage, the clitoris retracts and the vagina contracts in the woman while the man's testes and the glans of his penis swell. Upon orgasm, the tension built up during intercourse is released, with the woman experiencing contractions in the vagina while the man's penis also contracts, expelling the semen in an ejaculation. During the resolution phase, when bodies return to their normal state, men are unable to resume sexual arousal for a period between minutes and hours during a refractory period. Women have no such refractory period and can become sexually aroused again during the resolution period.

While human beings can have sexual intercourse at any time during a woman's monthly cycle, there is a window of about six or seven days when a woman may become pregnant: the five days before ovulation and one or two days after ovulation. By knowing the physical signs that accompany her fertility cycle, a woman can try to avoid becoming pregnant when she does not want to be, by avoiding intercourse during her fertile window. On the flipside, when she does want to become pregnant she will know the days when sexual intercourse is most likely to lead to conception. As a method of contraception, it can be effective when done correctly, and it leads to women having greater knowledge and understanding of their own biology. Signs of impending ovulation include a small rise of temperature and changes in cervical mucus.

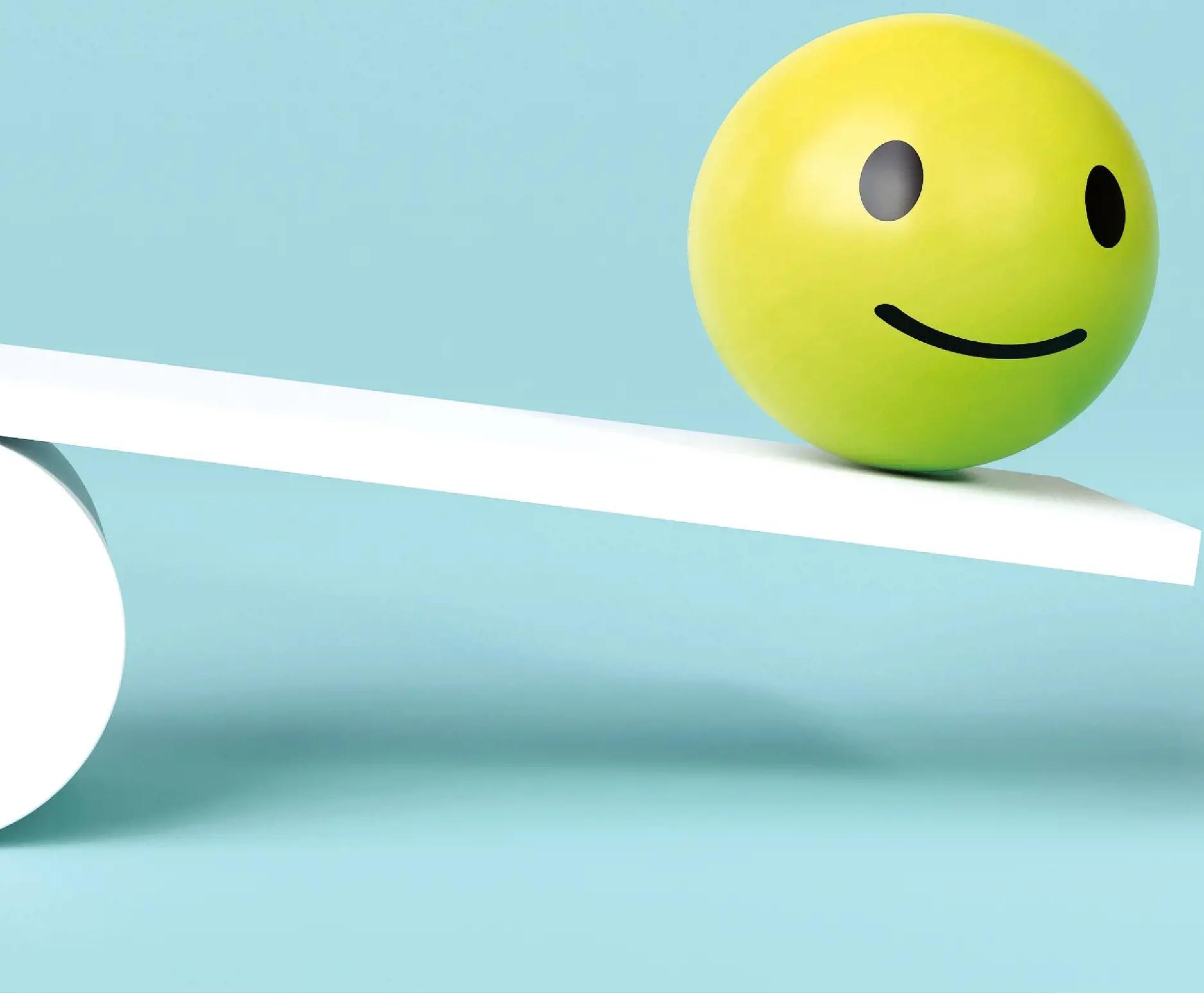
People probably spend more time agonising over this area of life than any other. Art, from epics to the most ephemeral pop, takes as its major theme love and all its difficulties. This might seem like we concentrate too much on something that is simply part of nature, but this part of nature is the most extraordinary of all: the joining together of two people to make someone entirely new, someone who has never existed before and will never exist again. It's only right that we make such a big deal about it.

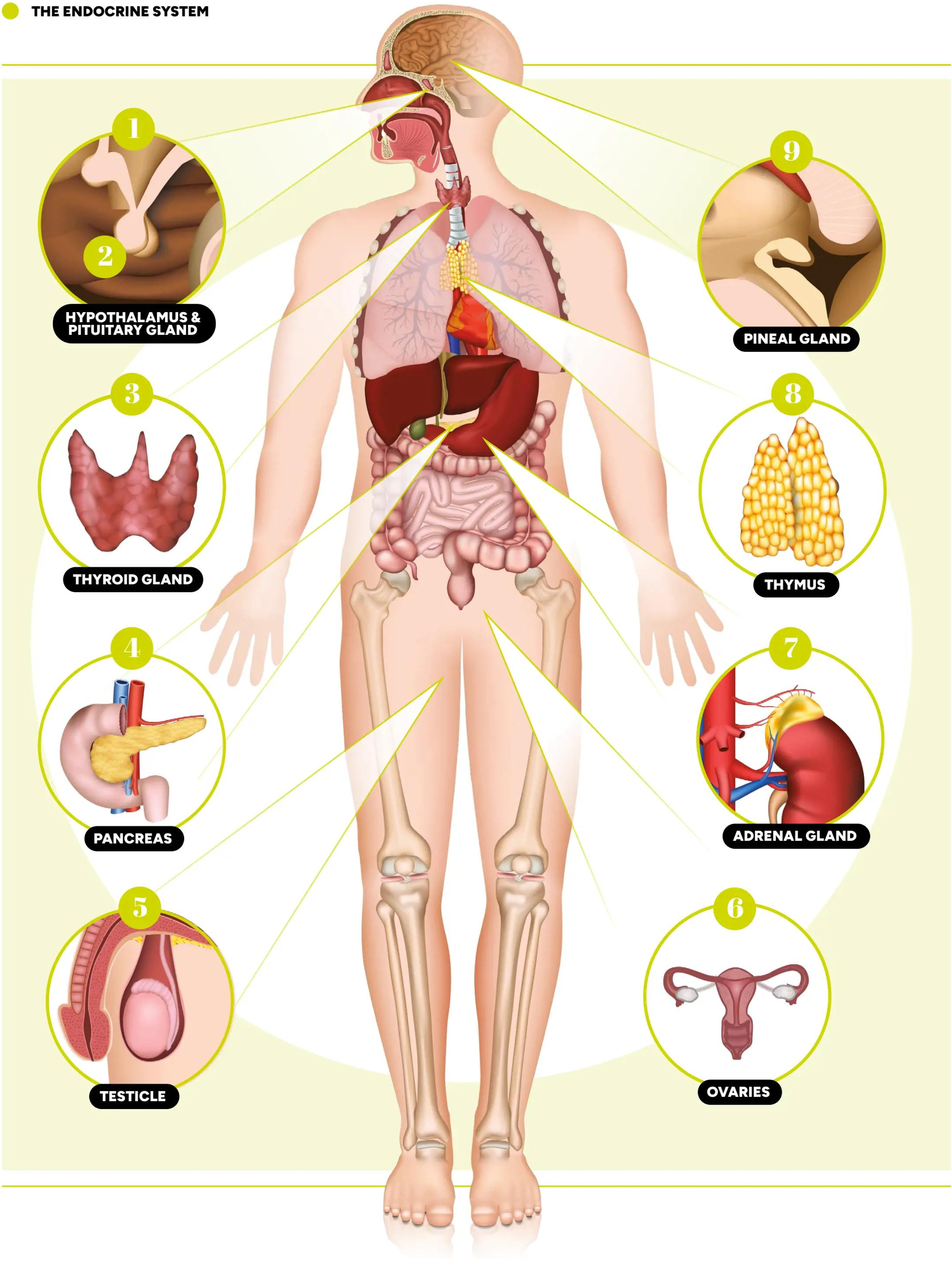
“There is a window of about six or seven days when a woman may become pregnant”

THE ENDOCRINE SYSTEM

Where the body gets chemical

WORDS BY EDOARDO ALBERT




1
2
HYPOTHALAMUS & PITUITARY GLAND
3
THYROID GLAND
4
PANCREAS
5
TESTICLE
9
PINEAL GLAND
8
THYMUS
7
ADRENAL GLAND
6
OVARIES

BREAKDOWN OF A SYSTEM

1

Hypothalamus

Regulates sleep, blood pressure, sex drive, mood, hunger, thirst and temperature.

2

Pituitary gland

Regulates growth, metabolism and reproduction.

3

Thyroid gland

Metabolic control, development and growth.

4

Pancreas

Produces insulin to control glucose levels in the blood.

5

Testicle

Produces testosterone, which regulates male development.

6

Ovaries

Produce oestrogen and progesterone, vital for the female reproductive cycle.

7

Adrenal glands

Regulate metabolism, immune system and blood pressure, and respond to stress.

8

Thymus

Vital for the immune system.

9

Pineal gland

Produces sleep hormones to regulate our circadian rhythm.

The pancreas, where insulin is produced

Fact file

Everything you need to know about the endocrine system

What does the system do?

Sends messages from one part of the body to another.

Why is it important?

It controls and regulates the fundamental processes of the body.

When does this system develop in a foetus?

The endocrine organs develop early, from the fourth week of pregnancy.

What organs are part of this system?

There's a lot! The pituitary, thalamus, hypothalamus, thyroid, parathyroids, adrenals, pineal body, testes, ovaries, pancreas, liver, kidneys – plus other parts of the body that we now know also produce hormones.

What are common conditions associated with this system?

Diabetes is by far the most common disease of the endocrine system.

Insulin injections are the main treatment for type I diabetes.

The liver is surprisingly big

You probably know someone with diabetes. According to the leading diabetes charity in the United Kingdom, more than four million people in the country have the disease. Of these, about 90 percent have type II diabetes, 8 percent have type I diabetes and the remaining two percent have rarer forms of the disease. The number of people diagnosed with diabetes has doubled in the last 15 years.

Diabetes results from a failure in insulin. Insulin is the key hormone regulating the levels of glucose in the blood. So diabetes is a disease of the body's endocrine system. The endocrine system produces the hormones that act as the body's chemical messengers. As a medical discipline, it is relatively new. The very term, 'endocrine system', was only invented in 1927.

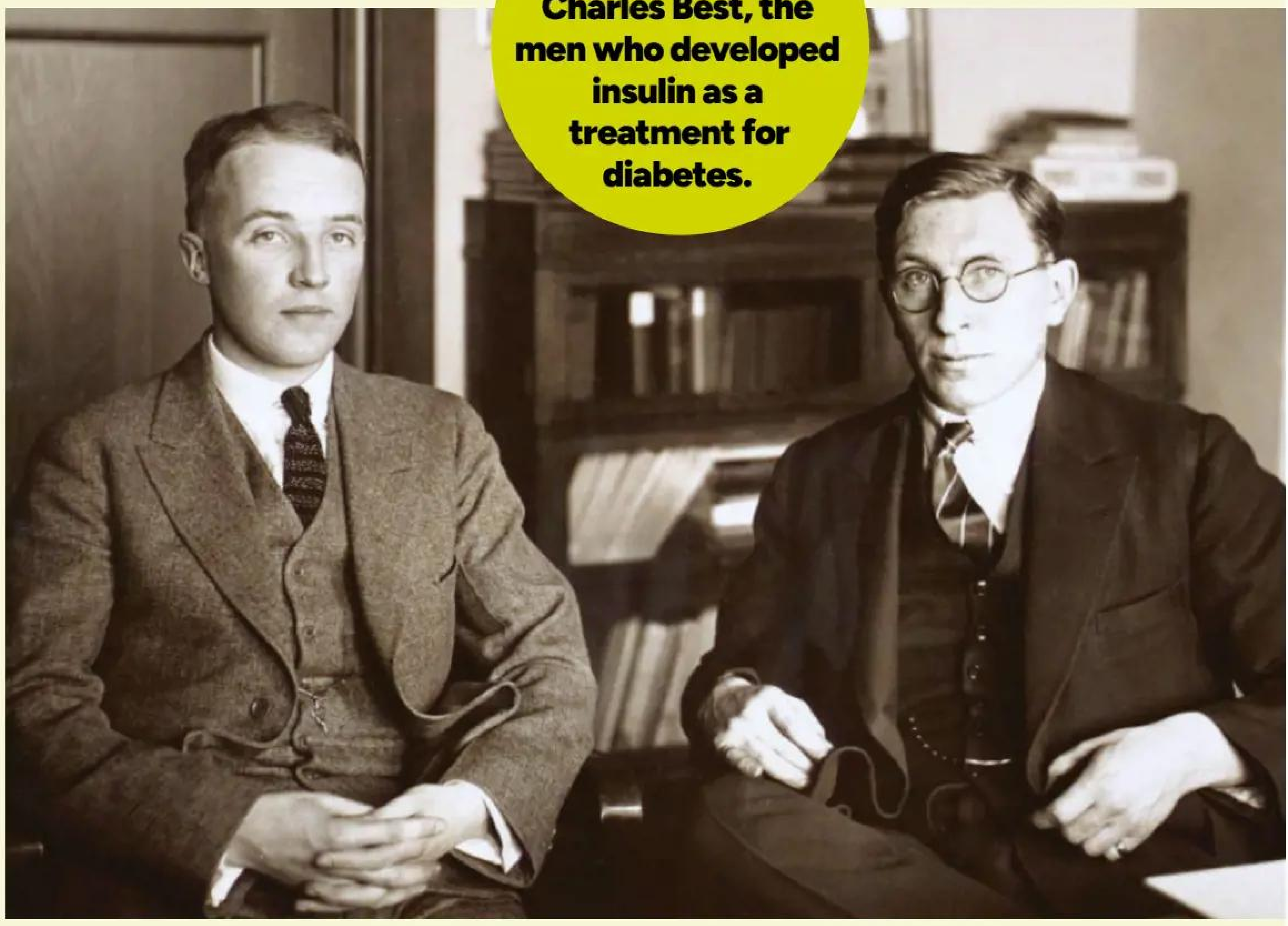
As to what hormones are, they are defined by what they do rather than what they are. A hormone is a substance made in one place of the body that produces an effect in another part of the body. Hormones can't be defined by what they are because they include such a wide group of chemicals. They can be proteins, steroids or amines. Although they are tiny molecules, our hormones wield a disproportionate influence on our health and wellbeing.

Diabetes is a good example of this. For most of history, diabetes was a death sentence. There are two types of diabetes. Type I is when the pancreas stops making insulin completely. There is a strong genetic component to type I diabetes, but not everyone with a family history develops the disease, even among identical twins, which indicates that there are other triggers to the disease's onset.

In April 1904, a widow with two young sons, John Ronald and Hilary, was diagnosed with diabetes. Her name was Mabel Tolkien and her eldest son, who was 12, was already obsessed with languages. On 14 November 1904 Mabel Tolkien died, leaving her boys orphans. There was simply no treatment for diabetes. The only way to reduce sugar levels and extend life at all was by essentially starving the patient. But the patient still died, emaciated, life prolonged at most by a few months.

Then, in 1920, a young doctor living in London, Ontario named Frederick Banting came up with an idea about how to produce insulin. The insulin molecule in

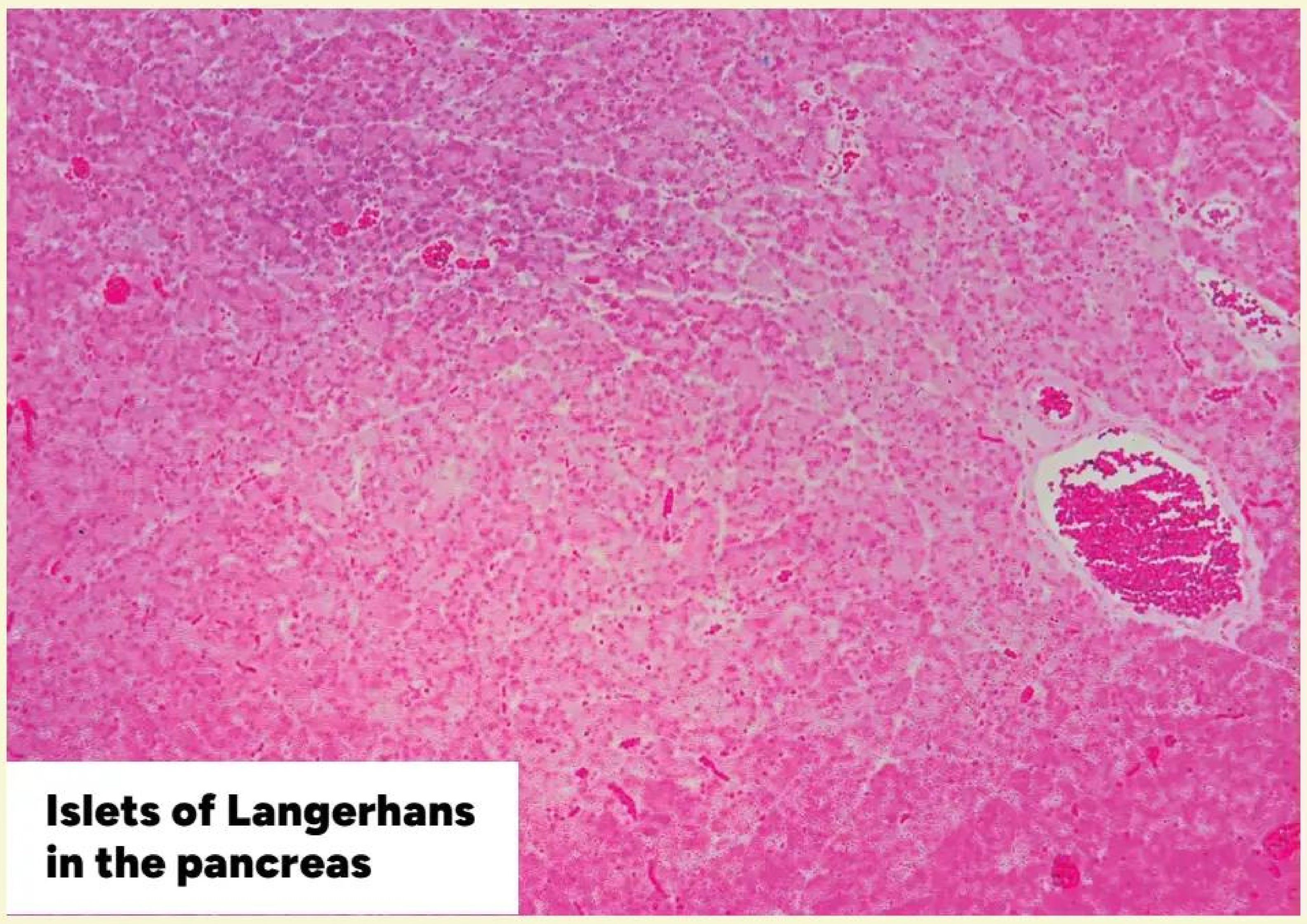
> “Insulin was the first of the 20th century’s wonder drugs. But it was not a medicine, it was a hormone”



Frederick Banting and Charles Best, the men who developed insulin as a treatment for diabetes.

the body is short lasting, at somewhere between five and 15 minutes, so the pancreas has to produce a lot of it. By the 1920s, doctors knew that insulin was the key to controlling glucose levels but the problem was separating the insulin from the other products of the pancreas: digestive enzymes.

Within the pancreas, insulin is produced by groups of cells that have possibly the most delightful name of any body part: the islets of Langerhans. They sound like mystical islands in a mythical sea but the Langerhans are named after their discoverer, Paul Langerhans, who identified the cells in 1869. Although Langerhans named the cells he did not have the faintest idea as to what they actually did. It took 20 years for doctors to isolate insulin. Fifty years later, Frederick Banting, working on an inspired hunch, sealed the pancreas from the pancreatic duct. This destroyed the enzymes that broke down insulin but left the islets of Langerhans intact – and still producing insulin. With his colleagues, Charles Best and James Collip, Banting worked on producing sufficient quantities of insulin and, on 11 January 1922, he gave the first insulin injection to a 14-year-old boy,



Islets of Langerhans in the pancreas

Leonard Thompson. Insulin wasn’t just saving lives, it was changing lives. Patients who could barely move were, within a matter of minutes, talking and walking. Insulin was the first of the 20th century’s wonder drugs. But it was not a medicine, it was a hormone.

Today, insulin is produced by genetically engineered bacteria. For people with type I diabetes it remains a lifesaver. While not perfect as a treatment, because it can’t be taken orally but has to be injected, it is better than the alternative, which remains death.

Type II diabetes is diagnosed when insulin, while still being produced by the pancreas, becomes less good at doing its job. This is normally because the pancreas produces less insulin while at the same time the body’s cells respond more weakly to the insulin that is being produced. Type II diabetes also has a genetic component but it’s just as strongly associated with obesity and lack of exercise. The genetic component is exacerbated by ancestry. People from Africa and south Asia are at greater risk of type II diabetes, for reasons that remain unknown. What is also unknown is exactly why the incidence of type II diabetes has increased so much over the last few decades, although the fact that an increasing proportion of the population is obese is clearly a key factor.

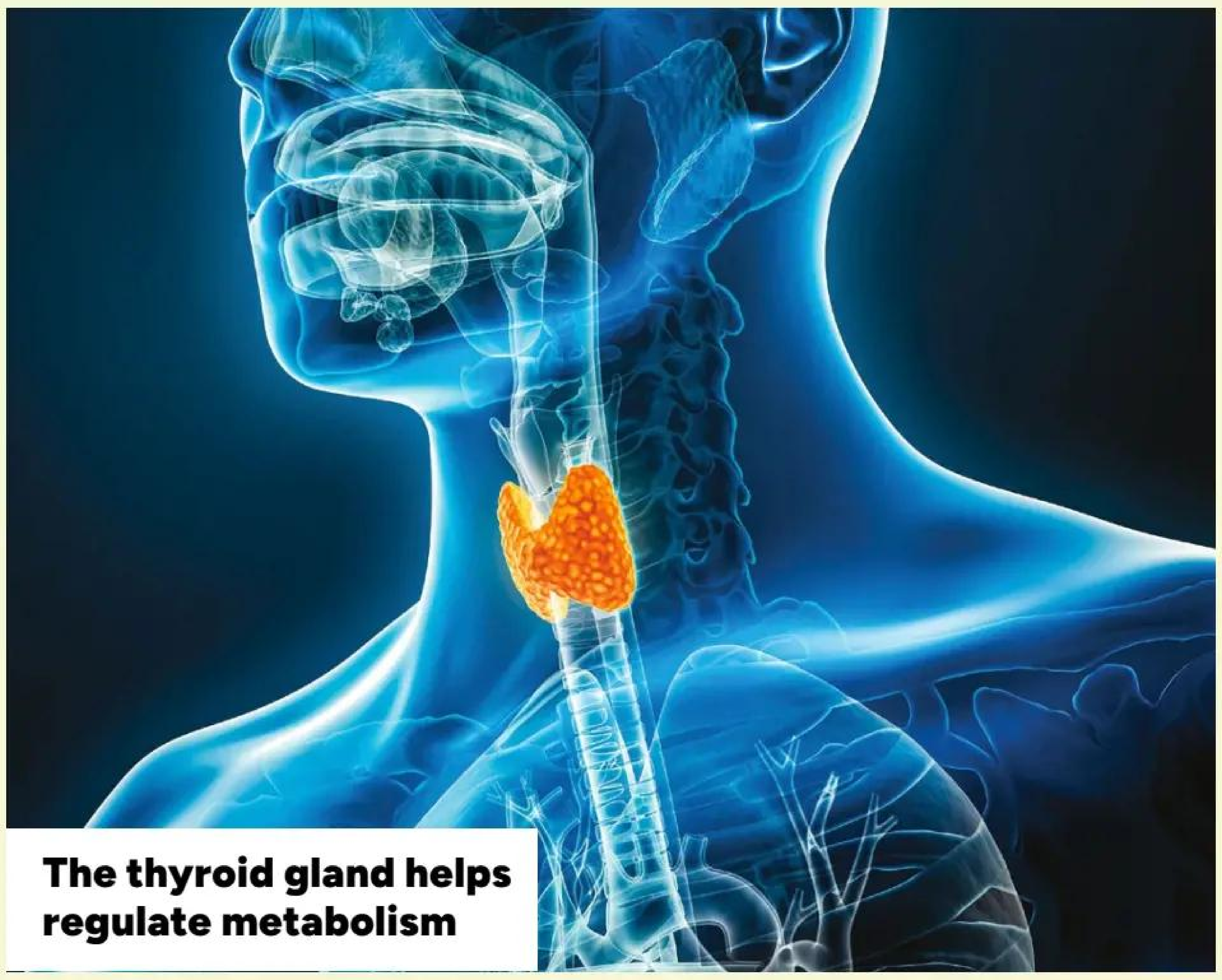
The good news so far as type II diabetes is concerned is that the measures that can improve, or even put it into remission, are generally good for health: lose weight, exercise more and eat better. Do these, and type II diabetes can often be controlled without the need of insulin injections. However, as things stand, the NHS spends ten percent of its whole budget treating diabetes, mostly dealing with complications from diabetes, which can include blindness, kidney failure and amputation of the legs. A healthy weight, an active life and good food is therefore a bit of a no-brainer: diabetes is no respecter of body positivity.

While insulin is the best known of our hormones it's by no means the only one. In fact, doctors don't know how many hormones the body produces. Estimates range between 50 and 100 but new hormones continue to be discovered, so the number is likely to rise.

While we know now that hormones are produced all over the body, the major endocrine glands (pituitary, thyroid, parathyroids, thalamus, hypothalamus, pineal, thymus, pancreas and the testes in men and the ovaries in women) are responsible for many of the key hormones produced by the body. These hormones regulate aspects of the body from the short-term, such as insulin and glucose levels, to the long-term: the pituitary gland regulates growth, starting and stopping it.

The pituitary gland, which is about the size of a baked bean, sits right behind your eyes deep inside the brain. It produces or regulates the growth hormone, cortisol (the stress hormone), testosterone, oestrogen, adrenalin, oxytocin and endorphins. That's a king-size influence for something so small.

For most of the 20th century, endocrinologists assumed that hormones were only produced in dedicated endocrine glands, such as the pituitary. They are called endocrine glands because they secrete their products into the bloodstream as opposed to exocrine glands, such as the salivary and tear glands, that excrete their products on to the surface of the body.



The thyroid gland helps regulate metabolism

“The major endocrine glands are responsible for many of the key hormones”

But then, in 1994, geneticist Jeffrey Friedman discovered a hormone, leptin, that was not produced in any of the dedicated hormonal glands but by fat cells. Since that discovery, endocrinologists have realised that hormones are produced all over the body and by almost every bit of the body. Friedman's discovery of leptin was hailed not only for the fact that he had found a hormone synthesised in fat cells, but also for what the hormone did: regulate appetite. With obesity a massive and growing problem, drug companies and medical researchers jumped upon the leptin bandwagon, hoping to discover a miracle drug that would enable people to lose weight simply by popping a few pills. If they had succeeded, it would have been one of the most profitable developments in pharmaceutical history.

The initial trials on rats raised hopes even higher. Scientists found that by adjusting the levels of leptin in rats they could make thin rats or fat rats and any rat in between. With so much riding on being first to market, clinical trials on human beings began quickly, with groups of overweight volunteers being given injections of leptin every day for a year.

But at the end of that year, they were still as fat as they had been at the start of the trial. Leptin, as least for people, was not a wonder weight loss drug. It turns out that our endocrine system is much more complicated than that. Hormones act in concert, and sometimes in opposition, to other hormones. Thus tweaking the levels of one hormone will not necessarily produce the desired results, while the interplay between different hormones makes it much more difficult to tease out how particular hormones function. What's worse, many hormones have multiple functions. Without knowing all the roles a hormone has, it is difficult to use it therapeutically.

The problem of modern weight gain is also hindered by our evolutionary past. Sometime shortly before 2016,

Robert Wadlow in New York in 1937. He grew another 7 inches before his death.

When hormones go wrong

If your glands malfunction, the effects can be extraordinary

The pituitary gland is tiny but among the suite of hormones it produces is human growth hormone. In most people, that results in an adult somewhere in the normal band of height, at which point the pituitary stops pumping out growth hormone. However, in the case of Robert Wadlow of Alton, Illinois, the pituitary gland didn't stop. It kept right on producing human growth hormone, and large amounts of it. As a result, when he was eight Wadlow was taller than his father, and when he was 12 he was 2.13-metres (7-feet) tall. Although nowhere near fat, Wadlow's weight matched his height: at 2.13 metres he weighed 130 kilograms (286 pounds). As he aged, Wadlow's pituitary gland kept on producing growth hormone. When he reached his late teens, when other people stop growing, he kept getting taller and taller. As an adult, Wadlow appeared at Madison Square Garden in New York with the Ringling Brothers circus and went on a promotional tour around America on behalf of the International Shoe Company, who provided him with his outsize shoes free of charge. The strain Wadlow's height placed on his body meant that he had to wear leg braces but he was nevertheless exceptionally strong and never used a wheelchair. Sadly, aged just 22, Wadlow's leg became infected from chafing by the leg brace, the infection spread and despite attempts to save him, Wadlow died on 15 July 1940. There was no sign he had stopped growing because he was measured on 27 June 1940 at 2.72 metres (8 feet 11 inches): the tallest man to have ever lived. And all because of the tiny pituitary gland.

There are now more obese people than starving people in the world

the human population passed a major milestone: for the first time in our whole history there were more obese people in the world than starving people. For all the thousands of years of history and tens of thousands of years before history, the great problem we faced was starvation, not abundance. Our bodies are programmed to binge eat in times of plenty in order to store up fat for the times when there will not be enough to eat. We have systems in the body to enable us to store this excess as fat but essentially nothing to say, you've had enough, you're getting too fat because, in the past, fat was insurance against famine. Now we live in a world of permanent abundance, a world that our bodies did not evolve to cope with. It will take some getting used to.

To do that, we may have to look to other things apart from our hormone-producing glands. There may be help elsewhere. For while the endocrine system was traditionally identified with its small endocrine glands, such as the pituitary, we now know there are others which are downright large, and none more so than the liver. In adults the liver weights about the same as the brain, 1.5 kilograms (3.3 pounds). It sits just below the diaphragm and at any one moment it holds about 25 percent of your blood.

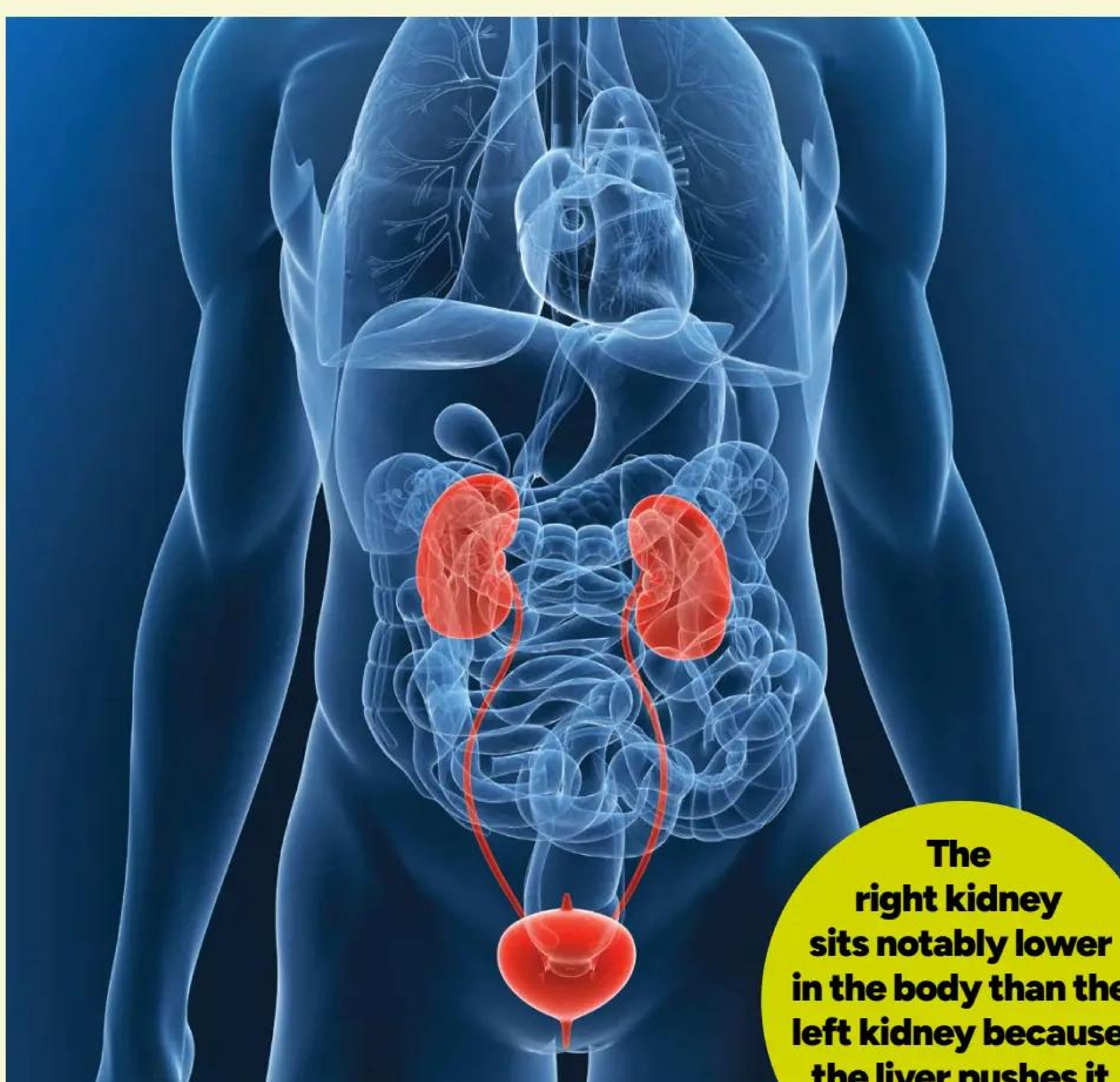
So much blood flows to the liver because it does so much. About 500 body processes take place in whole or in part in the liver. Liver failure is a shortcut to death. While the liver is an endocrine gland, producing at least four important hormones, it also produces bile, which is important for digestion; acts as a filter to remove toxins; changes fat and carbohydrates into glucose; stores glycogen, minerals and vitamins; activates enzymes; produces proteins for blood – and that's just some of its functions.

Given that the liver plays such a key role in the body's metabolism, it's just as well that it's considerably more resilient than other organs. Specifically, the liver can regrow if it is damaged or removed so long as one third of it remains alive and healthy. What's more, it will regrow the missing liver quickly, in about a month.

Being so central to our wellbeing means that diseases of the liver are a serious business. The best known of these is cirrhosis. Cirrhosis of the liver is popularly associated with alcoholism but it actually results from scarring of the tissue of the liver. Alcohol abuse can certainly produce this, but so can diseases such as hepatitis C. A liver can continue to work even when cirrhosis has occurred, but obviously its efficiency deteriorates and worsening cirrhosis can result in liver failure. In such cases, a liver transplant becomes the only treatment option.

Besides the liver, there are other organs in the abdominal cavity that play large parts in the endocrine system. We have already talked about the role the pancreas plays in insulin production but the pancreas produces glucagon, also important for glucose regulation, as well as digestive enzymes. The pancreas is a hardworking organ, producing up to three litres (101 fl oz) of pancreatic juices every day.

The spleen sits next to the pancreas in the abdomen. It's one of those organs that can be removed without killing the patient. You might ask what it does then – particularly as a small number of babies are born each year without a spleen at all and generally survive. However, it does play an important role in the immune system, as well as controlling the levels of red and white blood cells, and platelets, and removing damaged blood cells in the blood. We can make do without a spleen, however, because the liver, that great multitasking organ, steps up and takes over the spleen's function should it be damaged or removed. Still, it's undoubtedly better to have a spleen than not to have one.



The right kidney sits notably lower in the body than the left kidney because the liver pushes it downwards.

"The spleen is one of the organs that can be removed without killing the patient"

Luckily for us, the other important endocrine organ in the abdominal cavity has a spare: the kidneys. The kidneys sit under the ribcage, although the right kidney is lower than the left kidney because the liver pushes it downwards. Doctors did not actually know whether we could manage with just one kidney until 2 August 1869, when the German surgeon Gustav Simon removed an infected kidney from a woman patient. Luckily for the lady concerned, it turns out we can survive with just one kidney. Given that we only have one liver, heart, and most other major organs, it's a mystery why we should have two kidneys. However, this duplication has allowed kidney transplants to become one of the most common and successful of transplant surgeries.

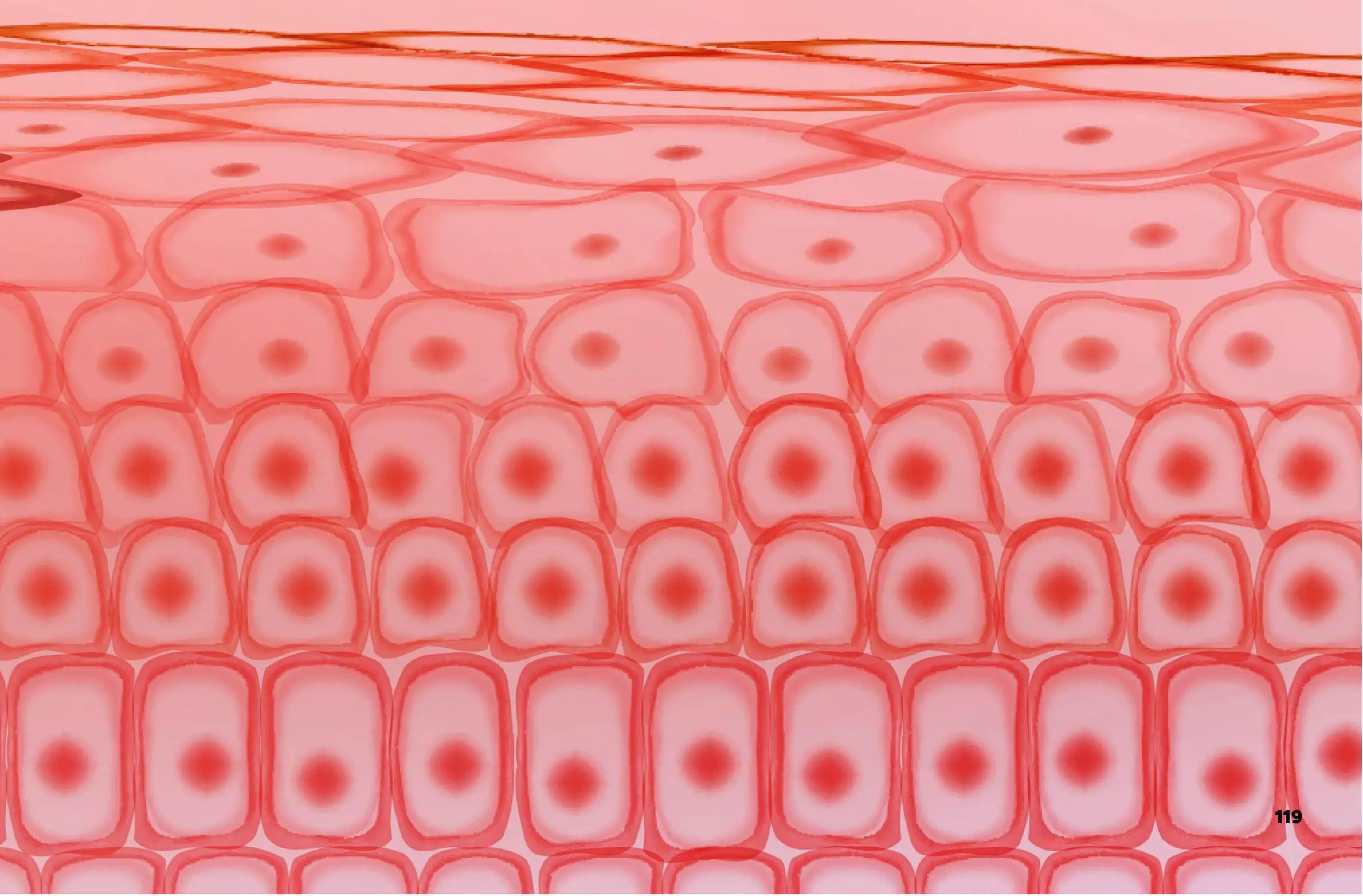
Our kidneys are surprisingly small for the work they do – 10-13 centimetres (3.9-5.1 inches) long and 5-7.5 centimetres (1.9-2.9 inches) wide. During a normal day about 180 litres (6,086 fl oz) of water flows through the kidneys. They filter the water for impurities, monitor and regulate blood pressure, stimulate the production of red blood cells using the hormone erythropoietin, produce vitamin D, balance calcium and phosphorous, and regulate internal pH levels. That's a lot.

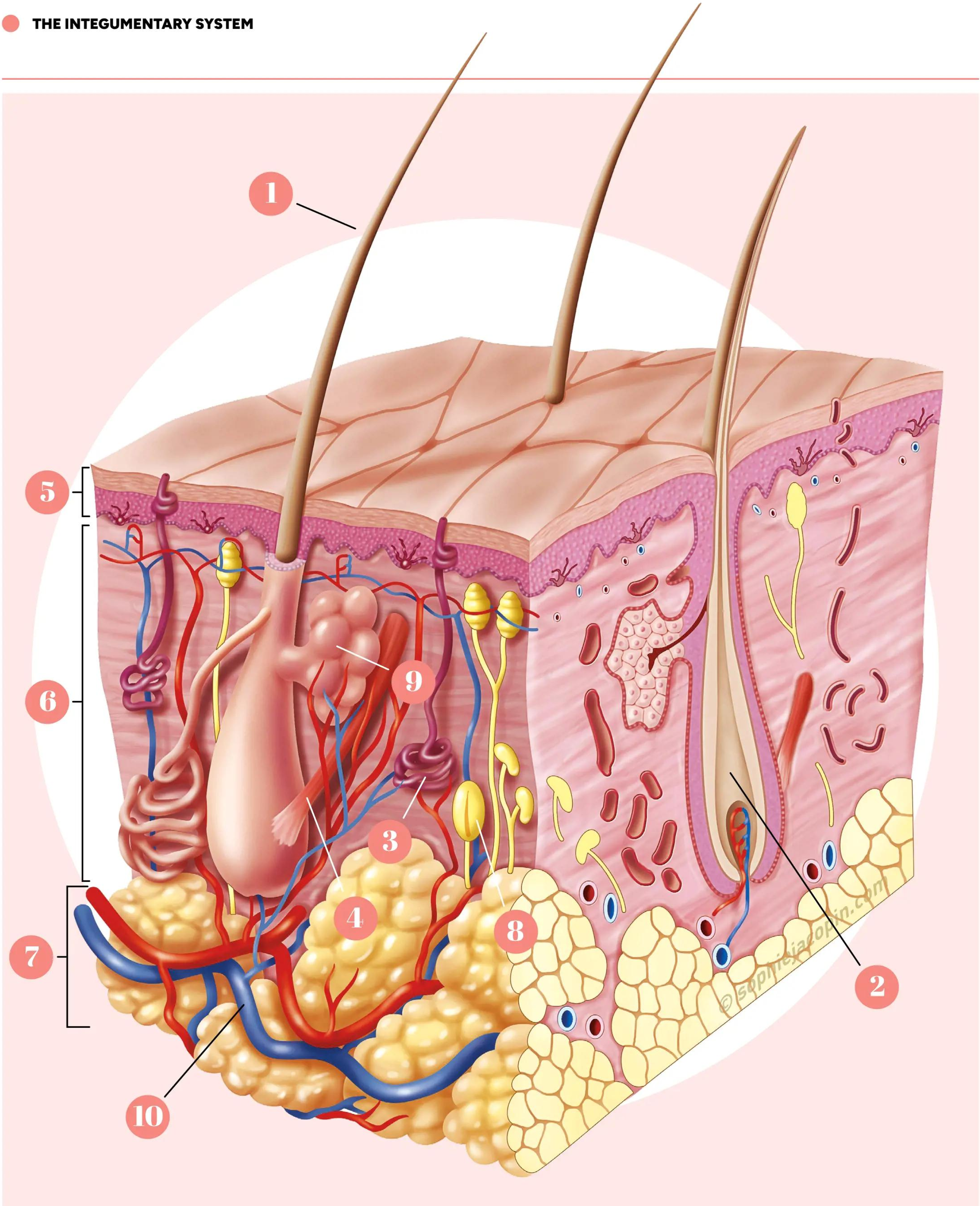
But this workload is typical for the endocrine system. The organs of the endocrine system do the heavy lifting of communication around the human body where rapid communication is not vital and the system has to work without conscious control. Many of the mysteries of the endocrine system remain to be unlocked, in particular the interaction between different hormones. What is becoming clear is that hormones generally do not act alone, but with a suite of their fellow hormones, making disentangling their effects much more difficult for researchers. However, with the discovery of hormone production by so many different organs in the body, we may begin to find out exactly how the body communicates with itself.

THE *INTEGUMENTARY SYSTEM*

How does the body's largest organ system serve as a shield, sense pain and control temperature?

WORDS BY AILSA HARVEY

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BREAKDOWN OF A SYSTEM

1
Hair strand
Over five million hairs cover the human body, trapping air for insulation and protecting the skin.

2
Hair root
Nutrients from the body's blood supply is delivered to hair through the hair follicle.

3
Sweat gland pore
Sweat is mostly water and waste products from the blood. The gland releases sweat onto the skin, cooling the body as it evaporates.

4
Arrector pili muscle
A tiny muscle connects to each hair. When they contract, hairs are pulled upright, causing goosebumps.

5
Epidermis
The outer layer of skin is a waterproof barrier and contains the skin's colour pigment, melanin.

6
Dermis
The large, middle section of the skin feels temperature and pain through nerve endings. It contains blood vessels, glands and fat cells.

7
Hypodermis
The skin's bottom layer connects it to muscle and other tissue beneath. It enables the skin to move smoothly over body tissue.

8
Pacinian corpuscle
This connective tissue forms around nerve endings to process pressure and vibration.

9
Sebaceous oil gland
An oily substance called sebum is produced here and released onto the skin to prevent it from drying out.

10
Blood vessels
The circulatory system delivers five per cent of its blood to the skin.

> **"Without the integumentary system, disease and damage in internal organs would occur"**

Fact file

Everything you need to know about the integumentary system

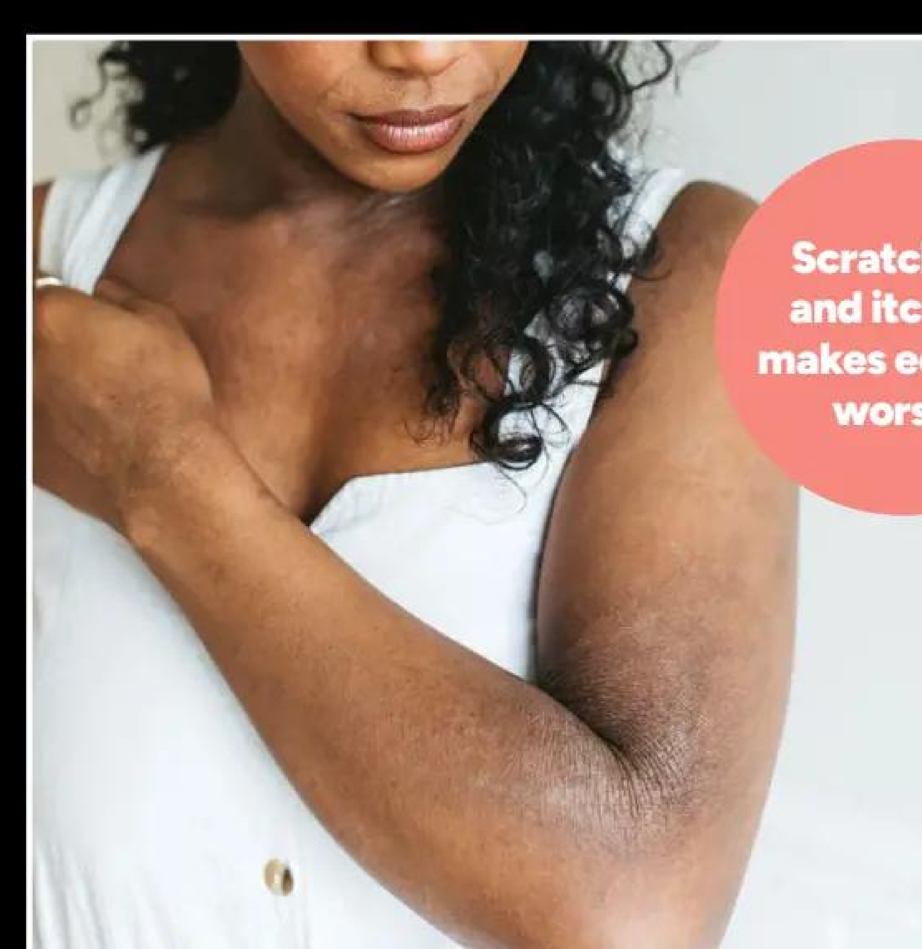
What does the system do?
The cells of the integumentary system fight against bacteria, shield tissue from UV light, heal wounds and regulate body temperature.

Why is it important?
Without the integumentary system, disease and damage in internal organs would occur. Changing environments would drastically impact body temperature and prevent most body processes.

When does this system develop in a foetus?
The skin develops between five and eight weeks. At this stage, it only has two layers.

What organs are part of this system?
The skin, hair, nails, sweat glands, sebaceous glands, ceruminous (ear wax) glands, and mammary (milk producing) glands make up the system.

What are common conditions associated with this system?
Acne, eczema, skin cancer, burns, bacterial infections, rosacea and alopecia are the main conditions impacting the skin and hair.



Scratching and itching makes eczema worse.

In the first few months of life, a baby's skin is thinner and more sensitive

The integumentary system is the most visible of all body systems. Its main, extensive organ – the skin – serves as biological armour, covering almost the entire body from the top of your head to the soles of your feet. It keeps the 60,000 types of germs that you come into contact with on a daily basis on the surface of the skin. Unless it is damaged, skin prevents germs from entering the body and blood stream, where they can spread quickly through the body, attacking different organs and becoming more dangerous and lethal. Within the skin are pathogen-fighting cells, which reduce the chance of infection spreading when the inevitable small cuts rupture the armour.

Protruding from the skin are the body hair and nails, the other organs of this system. When your body gets cold, the hairs that cover the body stand up straight, trapping air and causing an insulating layer between them. The densely packed hair that most have on the top of their heads also protects the skin closest to the sun from ultraviolet (UV) light exposure. Just as the protein making up hair is produced below the skin and grows outwards, your nails' protein forms and grows from deep folds in the skin of the fingers and toes.

What happens when the armour ages?

Although your skin armour stays with you and continues to regenerate its cells continuously throughout your lifetime, the speed of regeneration becomes slower over time. Babies' skin cells can regenerate in 14 days. By the time these children become teenagers, this time has already doubled. Middle-aged skin requires between 28 and 42 days to make new skin cells, and for people aged 50 years old and above this time can escalate to 84 days.

As the human body ages, the skin becomes thinner and less protective, so to maximise its ability to protect your other internal systems, you might choose to alter your skincare routine to keep it as strong and healthy as you can. The dermis and epidermis layers of skin thin out, along with the layer of fat at the base of the skin. With less skin space comes a lower production of the body's essential oils and sweat. The skin becomes drier and the body can't regulate heat as well. Due to the breakdown of skin structure, the skin creases and folds, creating wrinkles that are often an early indication of ageing.

Some of the changes you can make to support changes in the skin are the temperature of the water used to wash in, and using fragrance-free moisturisers and ointments. When the skin starts to become dry due to oil reduction, warm water is much better than hot water, as too much heat strips the natural hydration from the skin. Moisturisers help to soothe dryness in the skin, while ointments are better for very dry skin as they hold water in the skin more effectively. Products that list glycerin, hyaluronic acid and lanolin as ingredients generally do this well.

One of the physical changes many people notice as they age is that their pain tolerance increases. This is because you lose some of the nerve endings in your skin over time. It may seem like a perk to feel less pain, but more caution should be taken when handling hot, cold or dangerous items. When you rely less on the integumentary system alerting you to harm, you need to take on this role more consciously.

Finally, one of the most important types of cells for skin protection decreases in number when the human body ages. These are melanocytes, which contain the skin's pigment. Melanocytes are essential in preventing DNA damage, as the pigment blocks harmful UV light.

As the human body ages, the skin becomes thinner

> **"One physical change as you age is that your pain tolerance increases because you lose some of the nerve endings in your skin"**

The more exposed the skin is to this radiation, combined with the weakness of the skin, the more wrinkly and unevenly pigmented the skin becomes. Elderly people are far more at risk of developing skin cancer because of this, so should be wary of spending too much time in the sun with unprotected skin.

All about hair

Your hairstyle choices can drastically shape your appearance, so when many people consider these shiny strands, they focus on its role in looks first and foremost. But, hair has a few far more important roles as part of the integumentary system.

The main purpose of hair cover is to respond to external temperatures. As well as the hairs standing up to trap insulating air, they respond opposingly in hot weather. High temperatures cause the small hair muscles to relax, making the strands of hair lie flat and releasing heat away from the body. Without these vital processes, all of the body's biological systems would suffer. Enzymes and other cells that carry out chemical reactions within the body require a specific temperature range of 36.1°C to 37.2°C, and the heat lost from the body needs to be equal to the heat being produced within the body. If the temperature fluctuates above this range for too long, a person can develop hyperthermia. If the temperature spikes the other way, dropping below 36.1°C, hypothermia becomes the danger. Aggressive and continual shivering is the first sign of hypothermia, followed by slurred speech when the condition gets worse. On the contrary, hyperthermia is recognised by excessive sweating, fatigue and headaches. When action isn't taken to bring these symptoms back into control, those in shock from hyperthermia or hypothermia can slip into unconsciousness as their body's usual processes begin shutting down.

The dispersal of body hair isn't entirely even. On the palms of your hands, lips and soles of your feet, you will notice it is completely naked of hair. Yet, on your face above your eyes and on your eyelids are neat lines of small, dense hairs. These hairs work as filters to keep dust, sweat and other irritants out of your eyes. Nose hairs that are concealed inside your nostrils play a similar role in capturing allergens, but these serve the respiratory system, which would otherwise have to deploy the local immune response far more often.

Goosebumps help to conserve heat when you feel cold.

What is alopecia?

The integumentary system doesn't always work as it's supposed to. One disease that prevents some of this system's work is caused by the immune system attacking the skin's hair follicles. The autoimmune disease, called alopecia, is the complete or partial loss of hair. As the immune system persistently attacks the follicles, they become inflamed and damaged and can't hold onto hair.

After this disease makes patches of skin completely bald, the hair can grow back later, as the follicles aren't destroyed in the process. Most incidences of alopecia target the hair, but because nails are made of the same protein, keratin, some sufferers of alopecia experience changes in their nail structure also. In the nails, the symptoms include dents, thinning, brittleness and white dots. This can turn usually smooth nails into rough, sandpaper-like protrusions.

Vitiligo is a skin condition that causes patches of the skin to lose pigment

More commonly, alopecia causes hair from the head and face to fall out in small circles (patchy alopecia areata). But, in more extreme cases, large volumes of hair are lost. Alopecia totalis is the name of the type of alopecia that affects all the hair on a person's scalp, while alopecia universalis can strip all the hair from the body.

Hair loss is also a side effect of cancer treatment. Chemotherapy uses power medication to attack growing tumours. The medication usually fulfils this task, but unfortunately isn't localised at one site. Because the drugs target rapidly growing cells, chemotherapy tends to result in hair cell loss post-treatment, too. In the majority of cases, balding is temporary and hair begins to grow back a few months later. Sometimes, patients are surprised to find that their hair has taken on new textures and a darker shade. This is because the medication sometimes alters the hair follicles, including their shape, and the new hair emerges in curls.

Never-ending nails

If you have developed the habit of nail biting, you are probably relieved that you don't have a limited supply of nails to grow. Nails are a highly practical element of the integumentary system as they help the hand to scratch, grab, climb and dig.

For the average person, it will take their body six months to grow an entirely new fingernail, from the base of the finger nail to the top of the finger. It's unlikely that you'll need to clip your toenails as often as your fingernails, as it takes longer to grow a toenail by two millimetres per month. To achieve the same growth, from the base to the tip of the toe takes between 12 and 18 months.

How the epidermis renews

New layers of skin cells form at the bottom of the epidermis, forcing all the layers above it to be pushed outwards. As the outermost layer of skin reaches the outside of the body, it is exposed to the air. When skin cells are between other layers, they are densely packed, so they hold onto their water concentration. But when they become the exposed layer, before long, this skin begins to harden. Harder cells separate from the surrounding cells and fall off in small flakes as the skin rubs against objects.

It takes up to four weeks for newly made epidermal cells to rise to the surface of the body. However, the rate of growth isn't consistent. The rate of new generation is dependent on the conditions faced by the surface layer. When there is pressure on the skin, or it is being more regularly rubbed on another object, the integumentary system is activated to make new cells. Although the outer cells are facing these forces, they still flake away at the same rate. Instead of forming an evenly circulating system, the skin instead becomes harder and thicker. This patch of hard skin is called a callus, and is a defence mechanism by the skin. People who go climbing regularly develop calluses so that their palms can better withstand the friction of the sport.

Varied skin textures and thicknesses don't just change based on individual activities. Due to the long term uses of different parts of the body, some areas are more likely to develop thick skin than others. The sole of your foot is one place where thick, hardened skin grows. For mobile people, this skin is in contact with a surface most often, so needs to be stronger to prevent skin breaking apart while walking. The epidermis on your elbows and at the back of your knees is only 0.3 millimetres thick, while that on the palm of your hands and soles of your feet is around four millimetres thick.

Glands in the largest organ

The skin is classed as the largest organ. No other organ compares to the weight of the skin, which makes up 15 per cent of your total body weight. But, aside from its skin cells, your skin hosts other essential structures that

How to keep your nails healthy

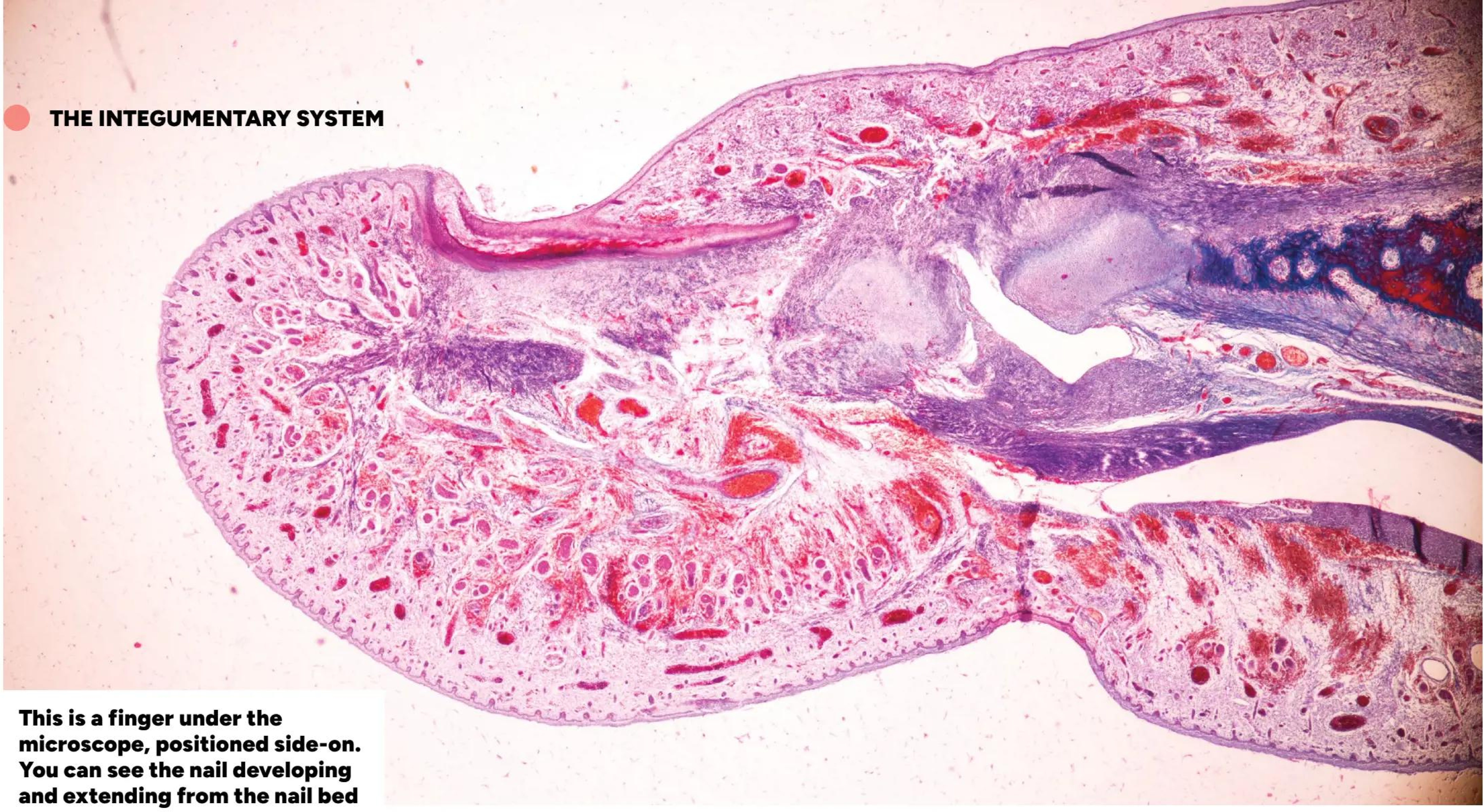
Nail cells are continually being produced, but what are the best steps to keep these digit protectors robust?

The keratin in your fingernails and toenails is the same substance that is produced in the hair and the top layer of your skin, just with laminated layers and less elasticity. These hard, digit extensions can be used as tools and contribute to the tactile sensations felt in the hands and feet. Fingernails should be smooth and consistent in colouring.

To reduce the chance of infection and keratin breakdown, you should attempt to keep nails in a clean, dry state. Regularly washing your hands and feet, and scrubbing under the nails, prevents bacteria from becoming trapped there. Meanwhile, nails that remain wet for long periods of time can split and weaken, as minerals in the water break down the keratin structure.

Biting fingernails or picking at the cuticles can also reduce nail health. Nails should be left to grow just beyond the tip of the fingers and toes. This optimises their protective purpose while reducing the chance of an excess of trapped bacteria and nail breakage. Picking at the nails' cuticles can cause breakage in skin and access for harmful microorganisms. Finally, you should limit your nails' exposure to harsh chemicals. A common culprit in causing brittle nails is acetone-containing nail polish remover. This clear solvent is very effective at stripping nail polish from painted nails, but it also strips away the natural oils that keeps keratin strong, stimulates nail growth and hydrates nails and skin. Too much of this product can cause brittle nails that crack more easily.

A vitamin E deficiency can lead to yellow-coloured nails.



This is a finger under the microscope, positioned side-on. You can see the nail developing and extending from the nail bed

help to bulk out the organ, such as blood vessels, nerve endings and glands.

On average, an adult human has a skin surface area between 1.5 and 2 metres squared (16 and 22 feet squared). Beneath every 2.5 centimetres squared, the skin contains 650 sweat glands, also known as sudoriferous glands. There are three other gland types within the integumentary system: sebaceous glands, ceruminous glands and mammary glands. All of these glands are classed as exocrine glands, which means they release their substances outside of the skin cells and out onto the surface of the body.

Sebaceous glands release an oil called sebum, which is a slightly acidic substance. This pH level isn't favoured by pathogens such as bacteria and viruses. So, the presence of these glands serve as security guards filtering out what can enter the deeper layers of skin. If any pathogens infiltrate into the skin, the role is passed onto the immune system.

The second role of sebum is to keep the skin waterproof. Lipids that are released from skin cells make up part of the sebum and create a waterproof coating. Without this vital property of skin, your body would take on a soggy texture if you were to get caught out in the rain.

Ceruminous glands are specifically located in the skin around the eardrum. Earwax is produced in this gland to keep the eardrum flexible, so that it can vibrate and enable the ear to process sounds. Mammary glands are specialised sweat glands that produce milk when a woman begins breastfeeding. All of these glands consist of a series of cells that react to external stimuli to produce and release their substances. When they do so, the substance is secreted through passages called ducts onto the body's surfaces.

This cross section of the skin shows a round sweat gland with a sweat duct connecting it to the skin's surface.

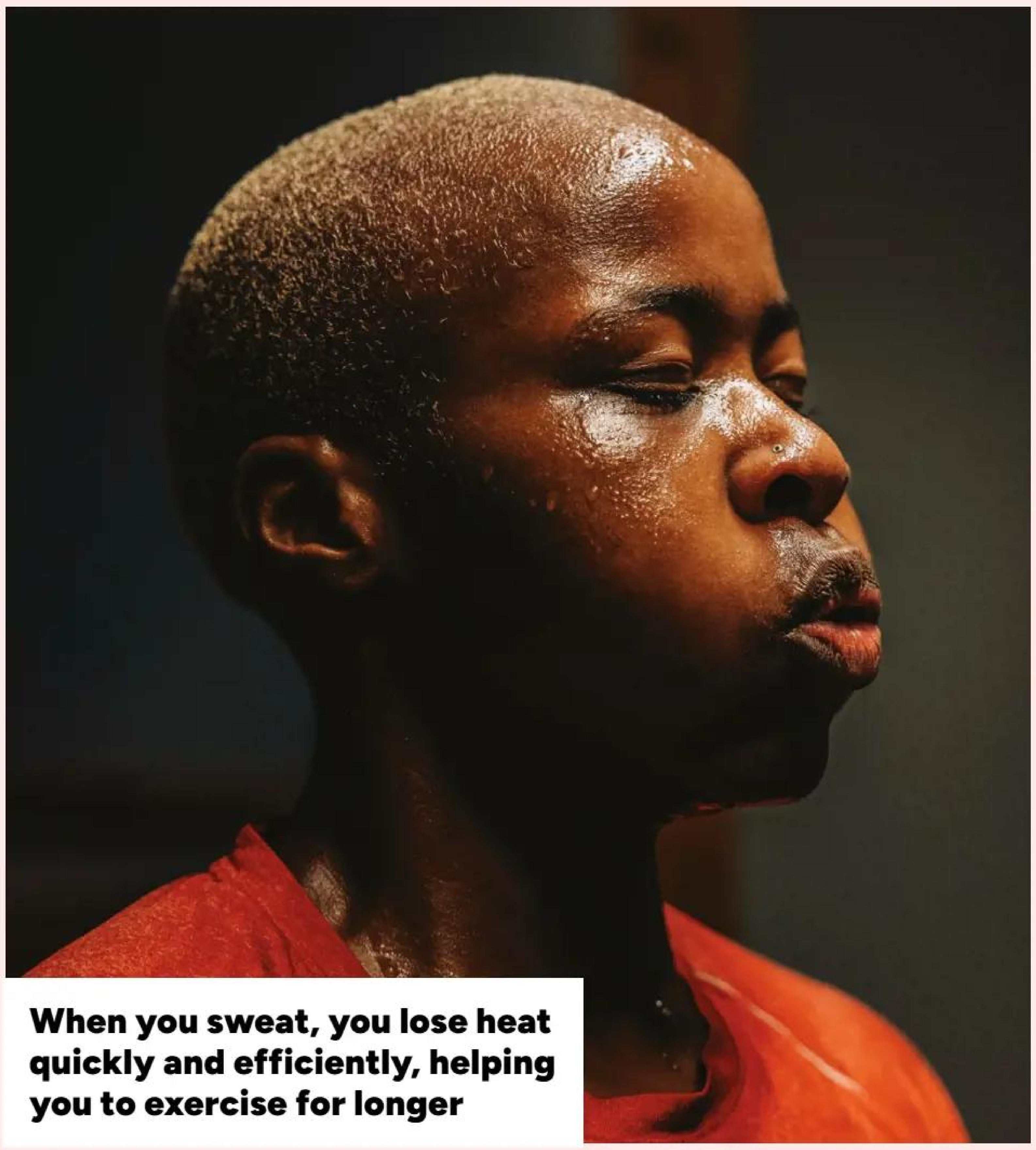
> The cause of eczema is a lack of fats and oils being produced in the skin

Sweat and thermoregulation

The role of the sudoriferous glands in releasing sweat onto the skin's surface is a widespread and essential function of the integumentary system. There are sweat glands in all areas of skin, but areas such as the forehead, armpits and palms of the hands have a higher concentration of them congregating. Sweat is mostly water and salt.

When your body temperature begins to rise, sensory neurons in the skin detect these changes and fire a message to the brain. This information is instantly processed by the brain and it sends a signal to sweat glands to increase activity. This causes the glands to make and release more sweat onto the skin. When the sweat exits the skin and comes into contact with the air, the water content evaporates, carrying some body heat with it and reducing the overall body temperature. This continues until the body temperature is back within the optimal range.

To make thermoregulation as efficient as possible, the skin has a layer of fat at the base layers. These insulate organs and make it more difficult for heat to escape the body. If the body wasn't built like this, to keep temperature stable, you would be shivering and sweating much more regularly in a constant cycle.



When you sweat, you lose heat quickly and efficiently, helping you to exercise for longer

Skin conditions and reactions

The complex cellular biology of skin has evolved to be an adaptable, sturdy yet soft organ that separates your internal and external environments. But, thousands of skin conditions have been described, impacting how well the integumentary system functions.

The most common skin conditions are acne and eczema. Acne is the clogging of the skin's pores, which can cause the separating skin cells, hairs and sebum to stick together. This prevents the sebum from reaching the skin's surface and inhibits the shedding cycle of the skin.

Eczema presents a far opposite problem of dry skin and presents as a series of itchy, red or dark rashes across the body. The cause of eczema is a lack of fats and oils being produced in the skin. The dry skin is filled with gaps between skin cells in place of the moisture, creating gateways in the armour for irritants. As the immune system reacts to irritants, the skin becomes discoloured and inflamed, leaving a sore rash across the skin.

Being the most exposed of the body's systems means the integumentary system faces the brunt of most injuries, from cuts to burns. The immune and circulatory systems are called to any skin site that requires immediate healing and to prevent the loss of blood. Meanwhile, burns can kill a large number of skin cells due to intense heat, chemical irritation or electricity. This can cause severe dehydration as bodily fluids are lost. First degree burns only impact the epidermis, but second degree burns affect part of the dermis; third degree damage the entire dermis, and fourth degree burns impact the tissue beneath the skin.

The most severe burns remove the repair cells, so the skin can't regrow. Instead, skin grafts can be added to replace the lost tissue. This shows that although the integumentary system serves as a sturdy and flexible shield, springing back from most flare-ups and injuries, the skin should be protected as much as possible to ensure its longevity as your body's first defence.

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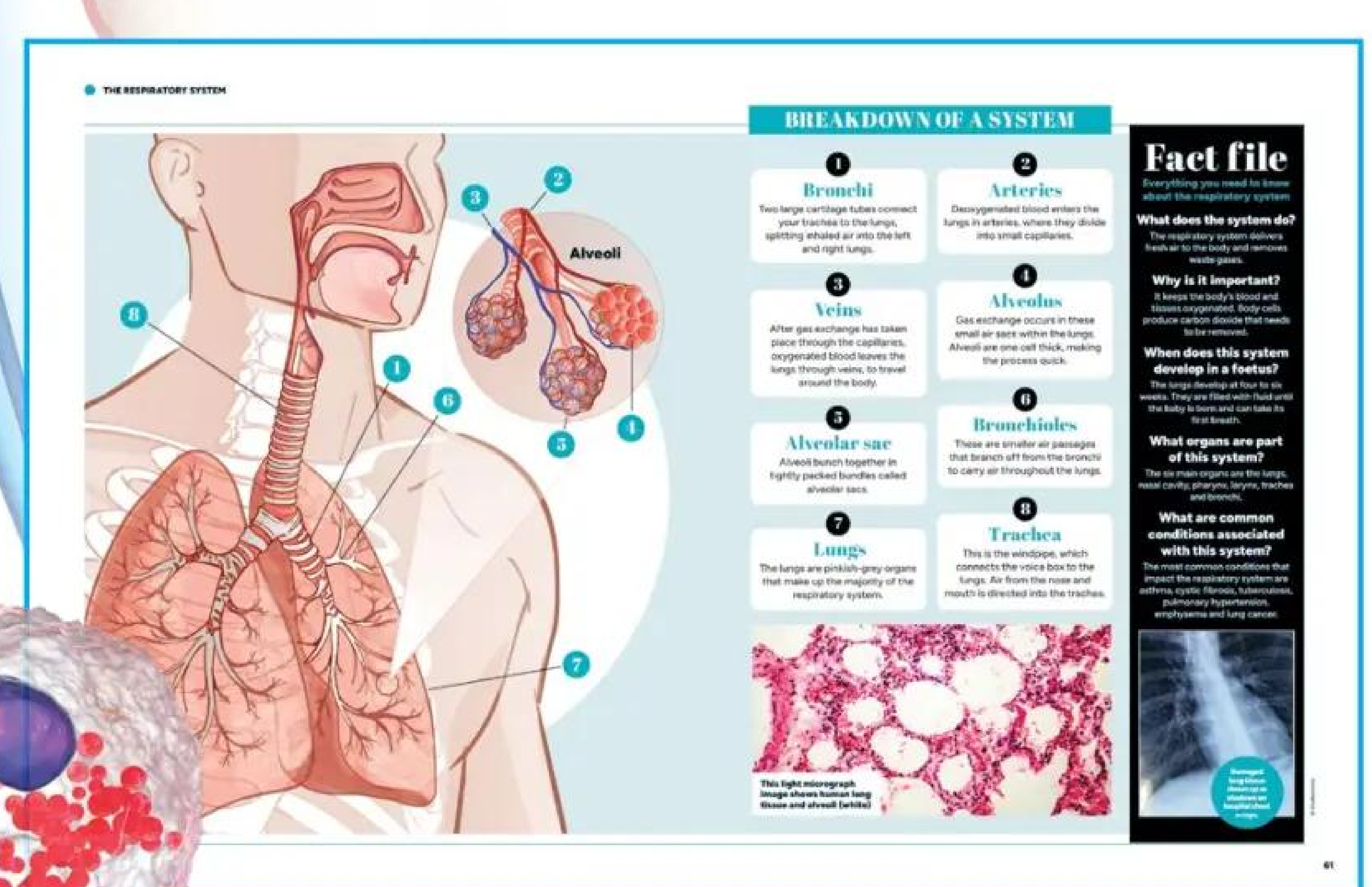

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