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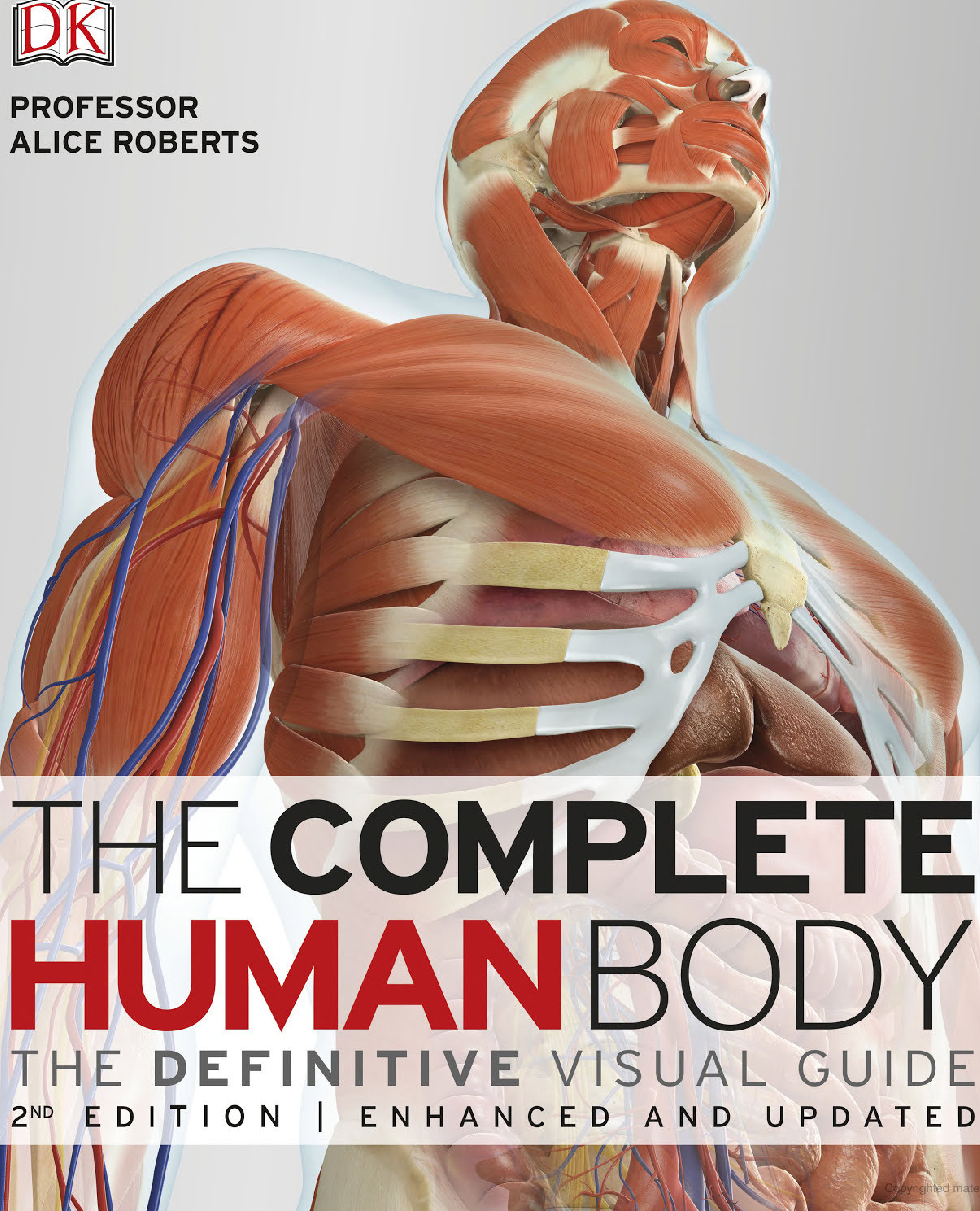
PROFESSOR ALICE ROBERTS



THE COMPLETE HUMAN BODY

THE DEFINITIVE VISUAL GUIDE

2ND EDITION | ENHANCED AND UPDATED

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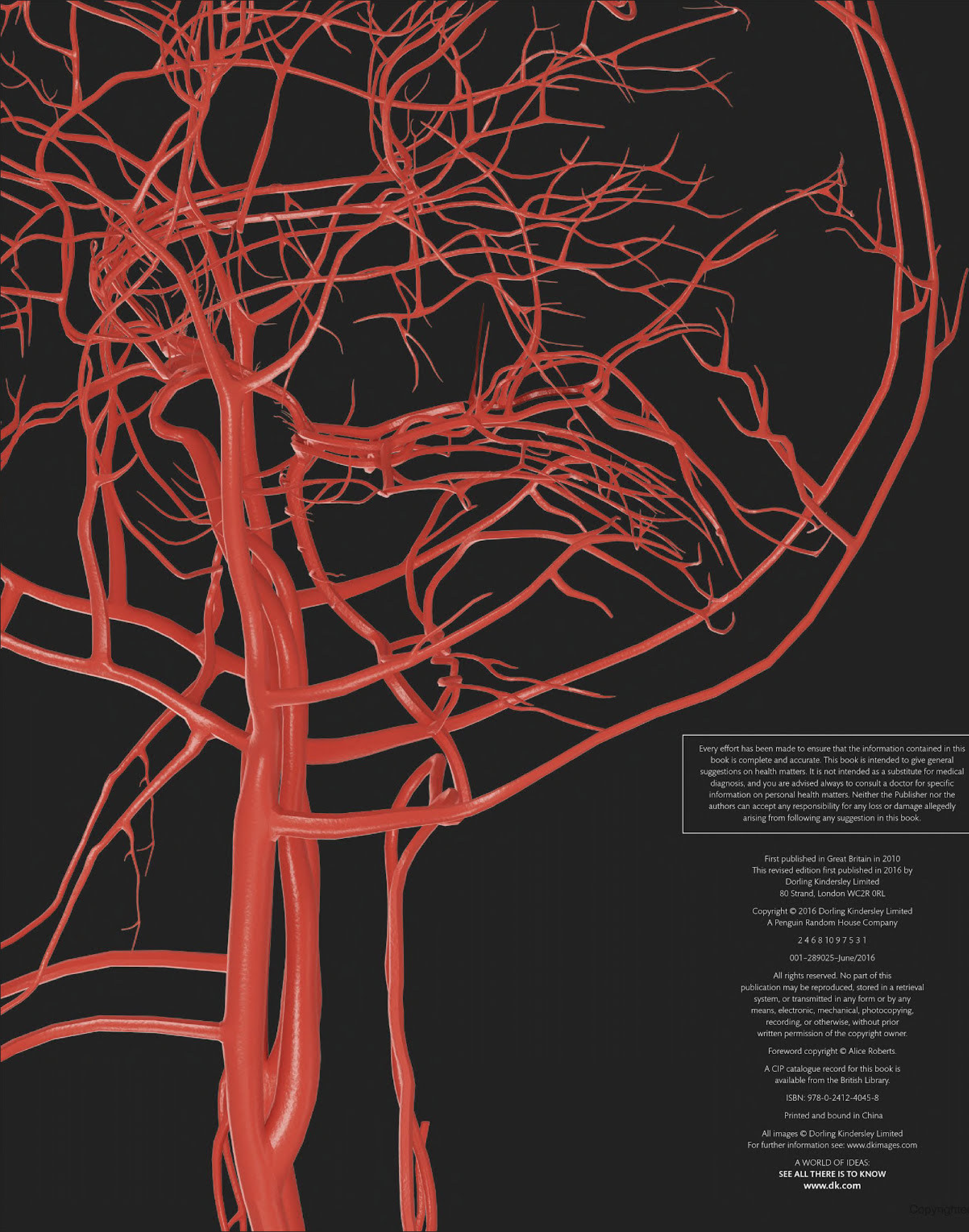

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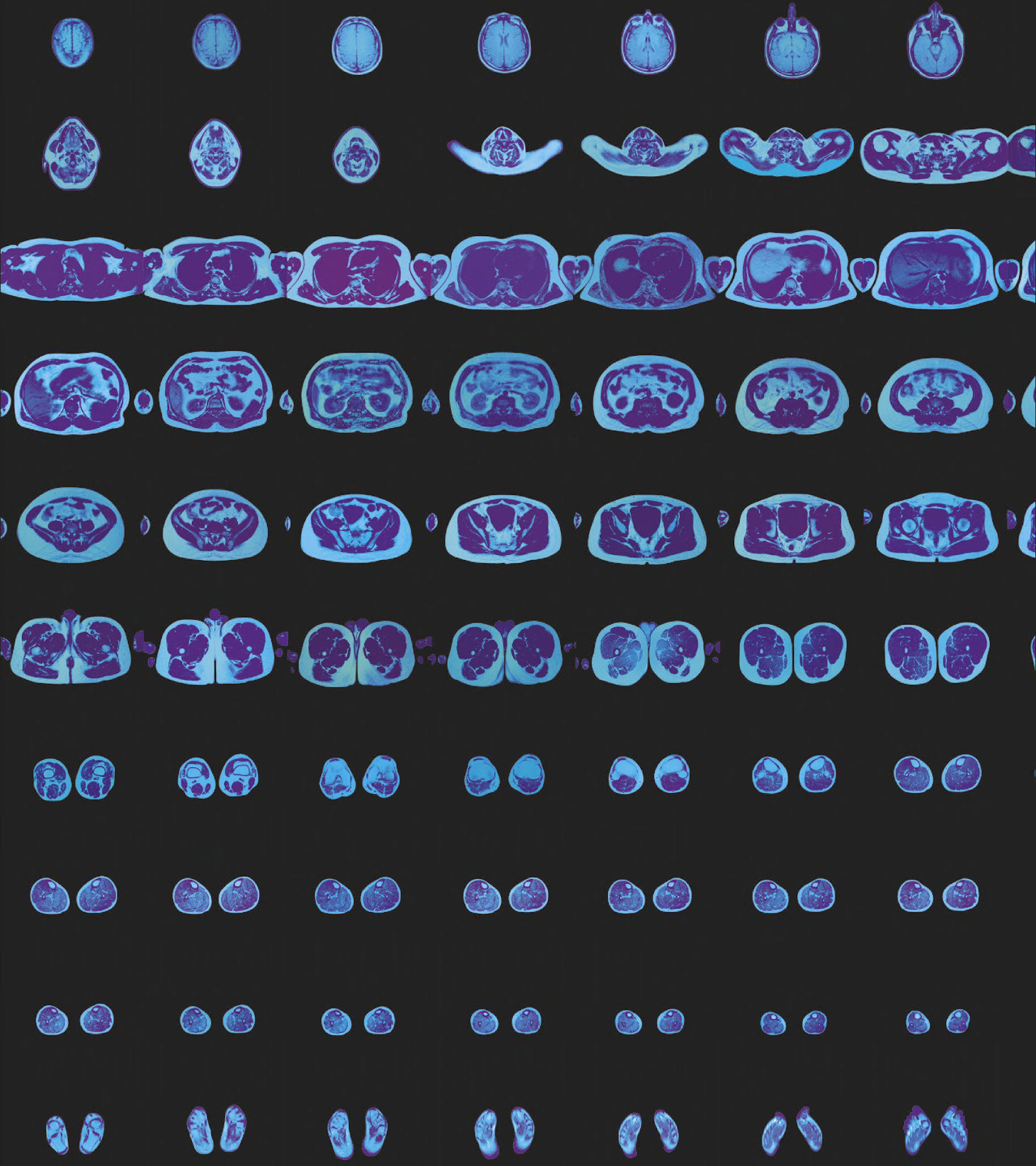

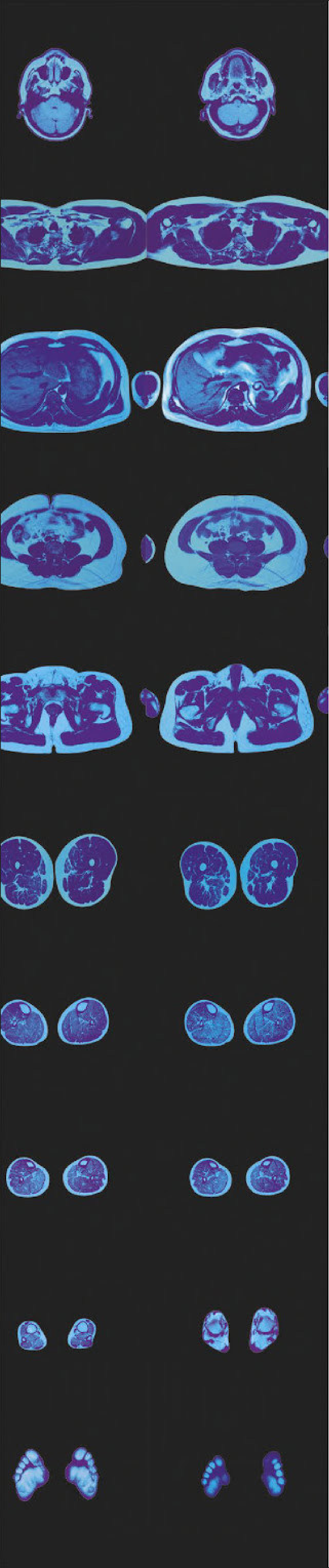

FOREWORD

The study of the human body has an extremely long history. The Edwin Smith papyrus, dating to around 1600BCE, is the earliest known medical document. It's a sort of early surgical textbook, listing various afflictions and ways of treating them. Even if those are treatments that we wouldn't necessarily recommend today, the papyrus shows us that the ancient Egyptians had some knowledge of the internal structure of the body – they knew about the brain, heart, liver, and kidneys, even if they didn't understand how these organs functioned.

Historically, finding out about the structure of the human body involved dissection; the word "anatomy" literally means "to cut up". After all, when you're trying to find out how a machine works, it's not particularly helpful just to look at the outside of it and try to imagine the machinery inside. I remember a physics practical at school, when we were tasked with finding out how a toaster worked. We found out by taking it apart – although I must admit that we miserably failed to put it back together again (so it's probably a good thing that I ended up as an anatomist rather than a surgeon). Most medical schools still have dissection rooms, where medical students can learn about the structure of the body in a practical, hands-on way. Being able to learn in this way is a great privilege and depends entirely on the generosity of people who bequeath their bodies to medical science. But as well as dissection, we now have other techniques with which to explore the structure of the human body: cutting it up virtually using X-rays, computed tomography (CT) and magnetic resonance imaging (MRI), or studying the minute detail of its architecture using electron microscopy.

The first section of this book is an atlas of human anatomy. The body is like a very complicated jigsaw, with organs packed closely together and nestled into cavities, with nerves and vessels twisting around each other, branching inside organs or piercing through muscles. It can be very hard to appreciate the way that all these elements are organized, but the illustrators have been able to strip down and present the anatomy in a way that is not really possible in the dissection room – showing the bones, muscles, blood vessels, nerves, and organs of the body in turn.

Of course, this isn't an inanimate sculpture, but a working machine. The function of the body becomes the main theme of the second part of the book, as we focus on physiology. Many of us only start to think about how the human body is constructed, and how it works, when something goes wrong with it. The final section looks at some of the problems that interfere with the smooth running of our bodies.

This book – which is a bit like a user's manual – should be of interest to anyone, young or old, who inhabits a human body.

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The body piece by piece
A series of magnetic resonance imaging (MRI) scans show horizontal slices through the body, starting with the head and working downwards, through the thorax and upper limbs, to the lower limbs and finally the feet.

the integrated body

The human body comprises trillions of cells, each one a complex unit with intricate workings in itself. Cells are the building blocks of tissues, organs, and eventually, the integrated body systems that all interact – allowing us to function and survive.

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THE INTEGRATED BODY

HUMAN EVOLUTION

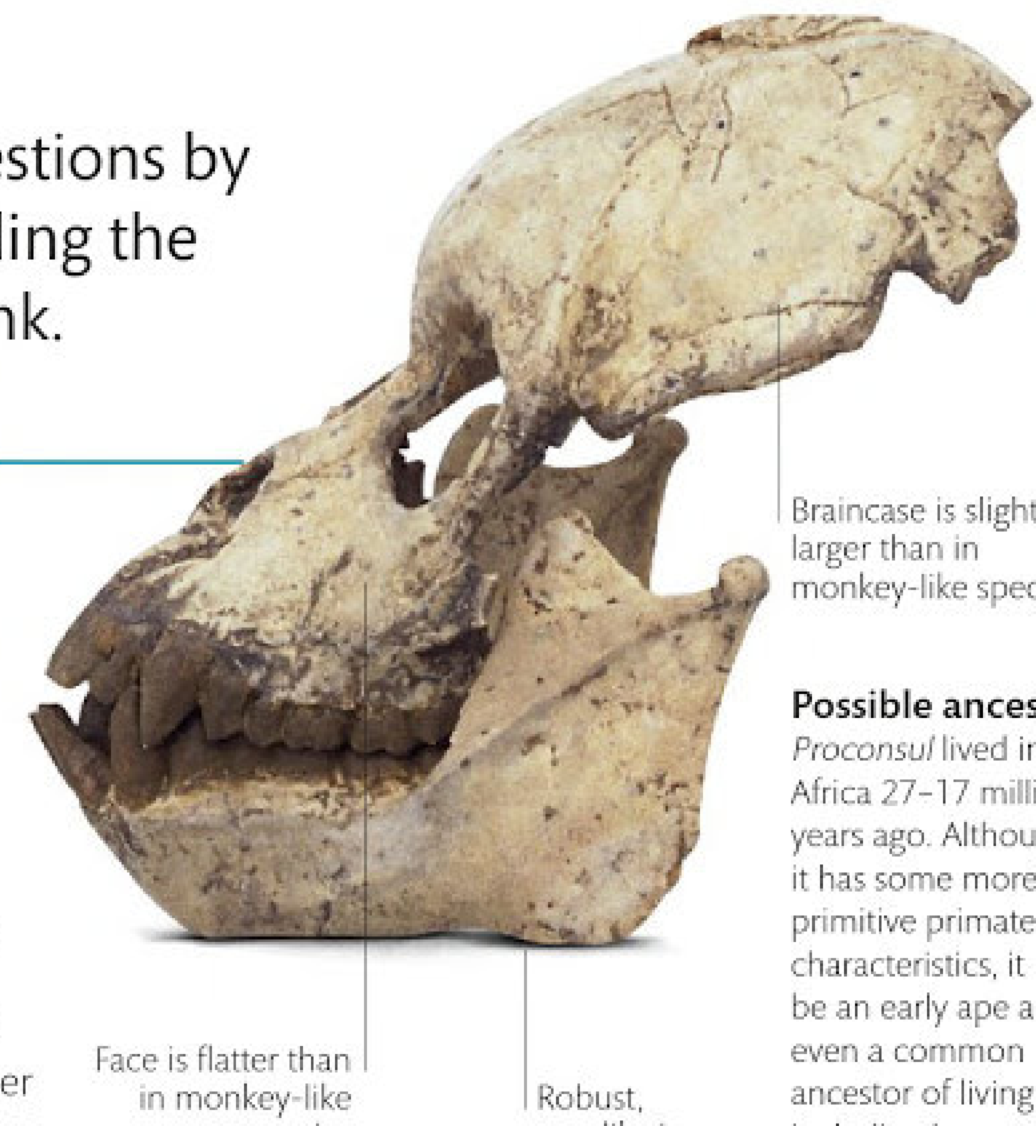
Who are we? Where are we from? We can attempt to answer these questions by studying human evolution. Evolution provides a context for understanding the structure and function of our bodies, and even how we behave and think.

ANCIENT ORIGINS

In placing our species within the animal kingdom, it is clear that we are primates – mammals with large brains compared to other mammals, good eyesight, and, usually, opposable thumbs. Primates diverged, or branched off, from other mammal groups on the evolutionary tree at least 65 million years ago, and possibly as far back as 85 million years ago (see below).

Within the primates, we share with a clutch of other species – the apes – a range of anatomical features: a large body with a chest that is flattened front-to-back; shoulder blades on the back of the chest, supported by long collarbones; arms and hands designed for swinging from branches; and the lack of a tail.

The earliest apes emerged in East Africa at least 20 million years ago, and for the following 15 million years a profusion of ape species existed across Africa, Asia, and Europe. The picture today is very different: humans represent one populous, globally distributed species, contrasting with very small populations of other apes, which are threatened with habitat loss and extinction.



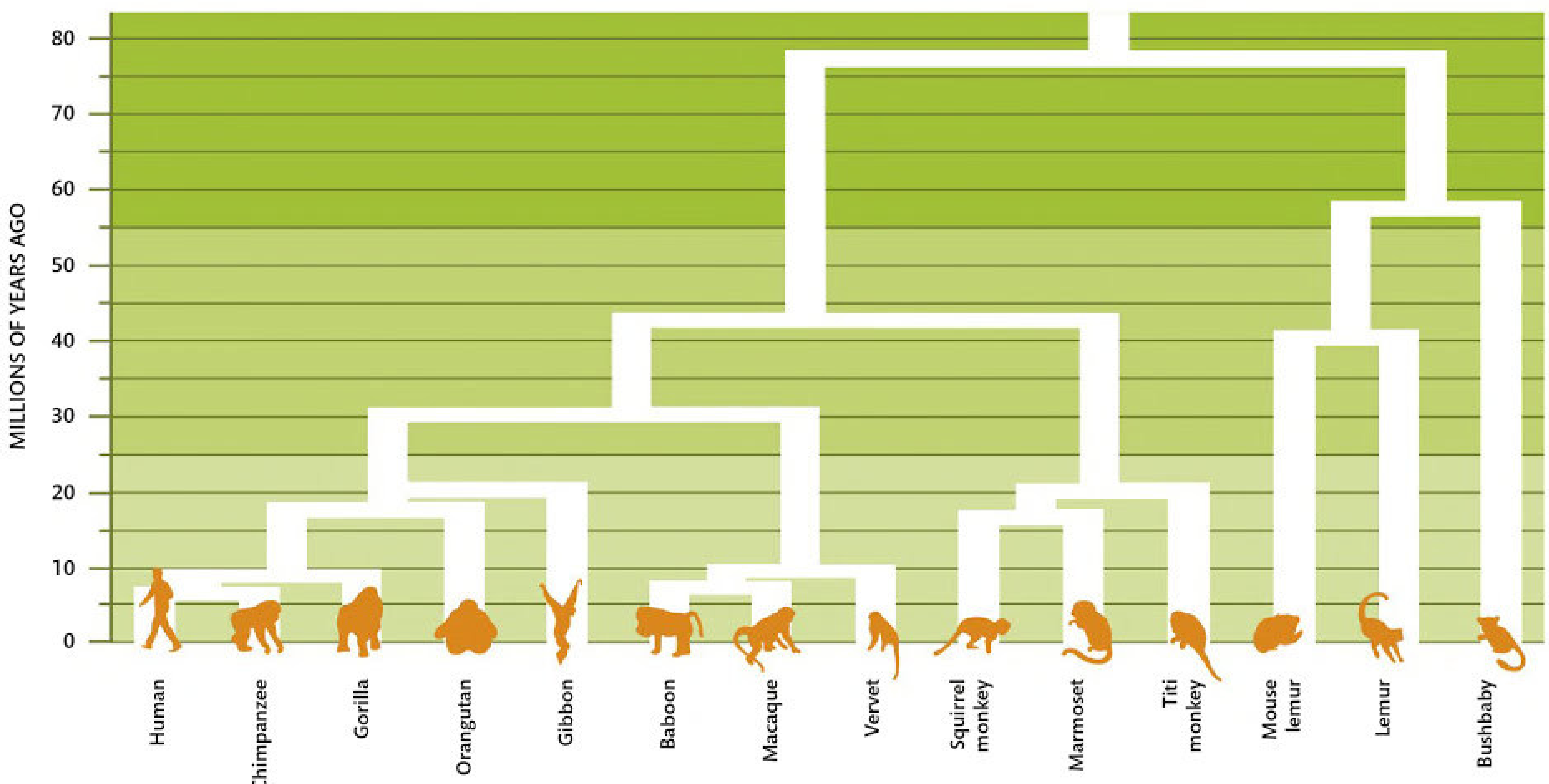
Possible ancestor
Proconsul lived in Africa 27–17 million years ago. Although it has some more primitive primate characteristics, it may be an early ape and even a common ancestor of living apes, including humans.

UNUSUAL PRIMATE

From bushbabies to bonobos, lorises and lemurs to gibbons and gorillas, primates are a diverse bunch of animals, bound together by a common ancestral heritage (see below) and a penchant for living in trees. Humans are unusual primates, having developed a new way of getting around – on two legs, on the ground. However, we still share many characteristics with the other members of the wider primate family tree: five digits on our hands and feet; opposable thumbs, which can be brought into contact with the tips of the fingers (other primates have opposable big toes as well); large, forward-facing eyes, which allow good depth perception; nails rather than claws on our fingers and toes; year-round breeding and long gestation periods, with only one or two offspring produced per pregnancy; and flexible behaviour with a strong emphasis on learning.

SCIENCE
DATING SPECIES DIVERGENCE

Historically, working out evolutionary relationships between living species depended on comparing their anatomy and behaviour. Recently, scientists began to compare species' proteins and DNA, using differences in these molecules to construct family trees. Assuming a uniform rate of change, and calibrating the tree using dates from fossils, the dates of divergence of each branch or lineage can be calculated.



Primate family tree
This diagram explains the evolutionary relationships between living primates. It shows how humans are most closely related to chimpanzees, and that apes are more closely related to Old World monkeys (including baboons) than New World monkeys (including squirrel monkeys). All monkeys and apes are shown to be more closely related to each other than to prosimians (including lemurs and bushbabies).

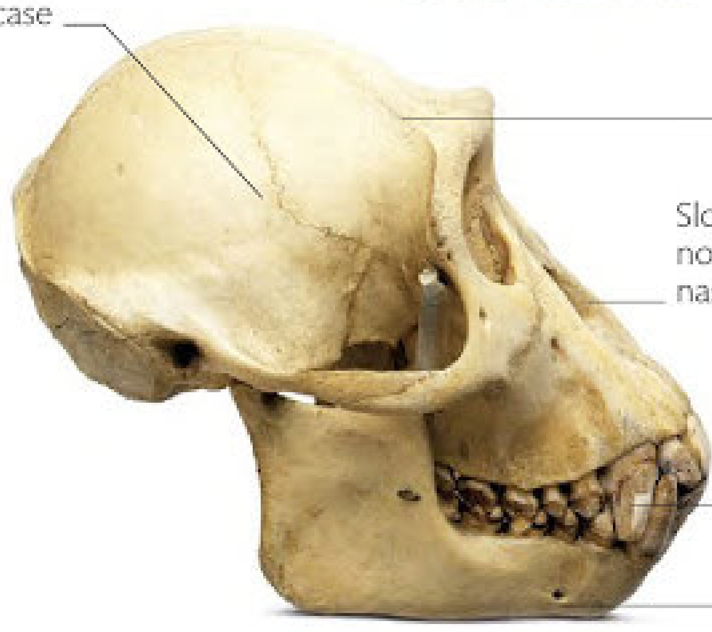
GREAT APE

Although we might like to think of ourselves as separate from other apes, our anatomy and genetic make-up places us firmly in that group. Classically, the apes have been divided into two families: lesser apes (gibbons and siamangs) and great apes (orangutans, gorillas, and chimpanzees), with humans and their ancestors placed in a separate family: hominids. But, as genetic studies have shown such a close relationship between the African apes and humans, it makes more sense to group humans, chimpanzees, and gorillas together as hominids. Humans and their ancestors are then known as hominins.

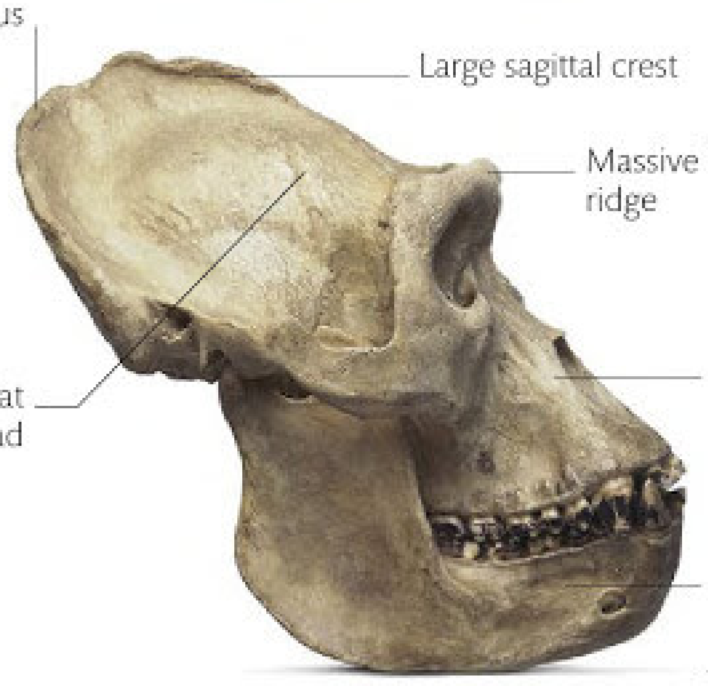
Not only that, but humans are genetically closer to chimpanzees than either humans or chimpanzees are to gorillas. It's not surprising that humans have been called the "third chimpanzee".

Human skull
The skull in humans is dominated by a massive braincase, with a volume of 1,100–1,700 cubic centimetres (cc). Its teeth, jaws, and areas of attachment for chewing muscles are small in comparison with other apes. The brow ridges over the eye sockets are subtle and the face is relatively flat.

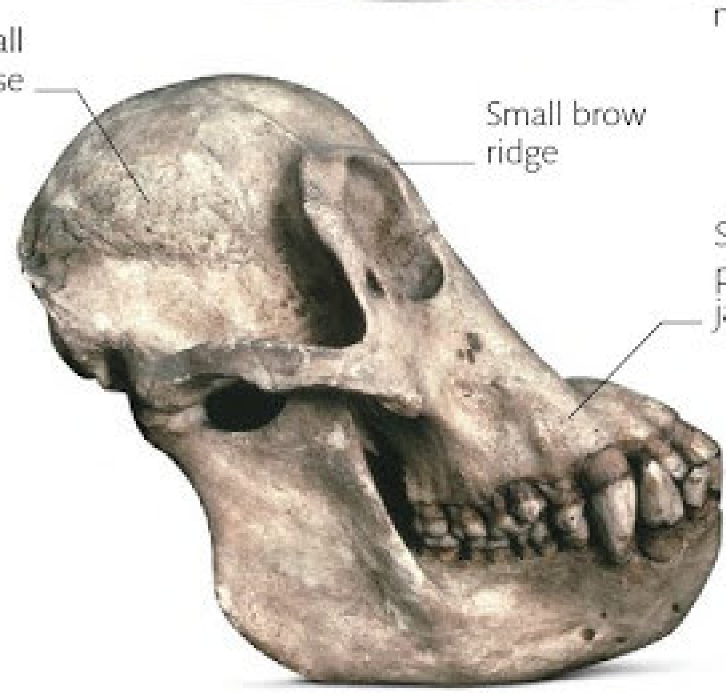
Chimpanzee skull
Chimpanzees have a relatively small, rounded braincase, accommodating a brain of 300–500 cubic centimetres in volume. The face is relatively large, with a fairly prominent brow ridge and jaws that project forwards.



Gorilla skull
The occipital torus is high on the skull, with a large area for the attachment of strong neck muscles below it. The male gorilla has a massive brow ridge and a large sagittal crest for the attachment of strong jaw muscles. The size of the braincase is 350–700 cubic centimetres.



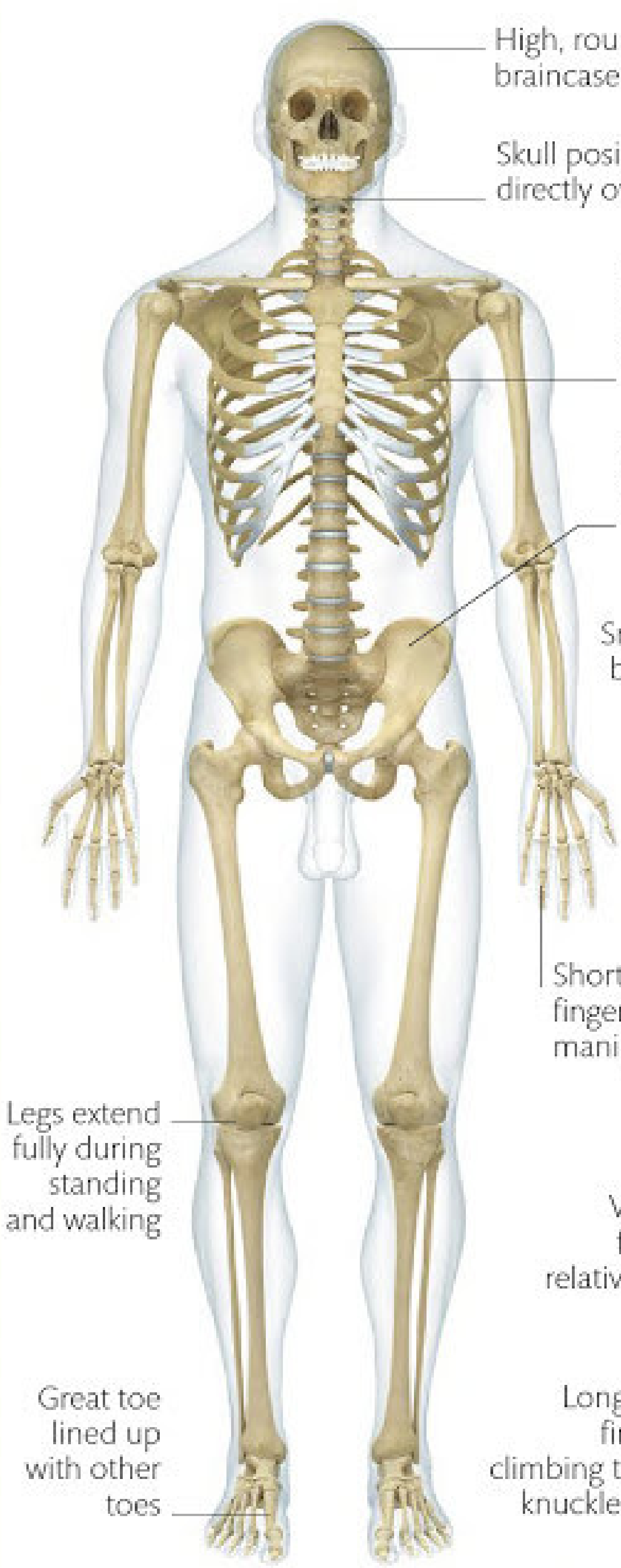
Orangutan skull
Like the chimpanzee, the orangutan has a relatively small braincase, with a volume of 300–500 cubic centimetres, and a large face. The skull is extremely prognathic, with strongly projecting jaws. The brow ridge is much smaller than in gorillas or chimpanzees.



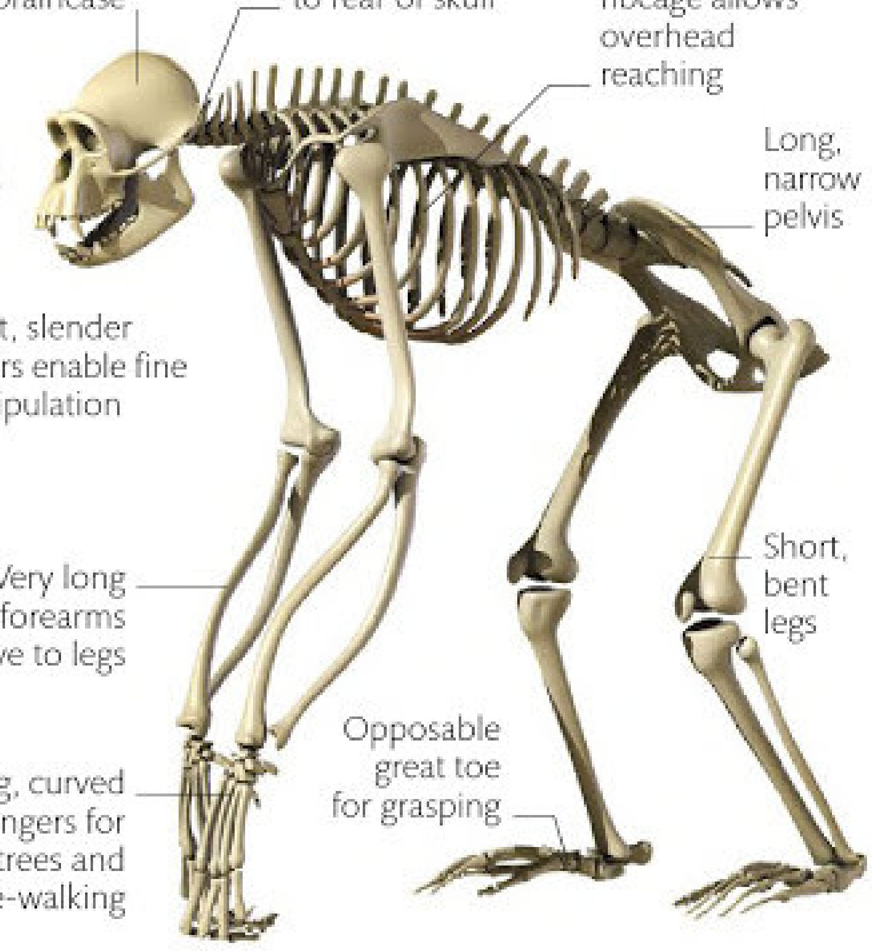
OUR CLOSEST RELATIVE

Science has shown that humans and chimpanzees shared a common ancestor some 5–8 million years ago. Comparing ourselves with our closest relative gives us an opportunity to identify the unique features that make us human.

Humans have developed two major defining characteristics – upright walking on two legs, and large brains – but there are many other differences between us and chimpanzees. The human population is huge and globally distributed, but we are, in fact, less genetically diverse than chimpanzees, probably because our species is much younger. Reproduction is quite similar, although human females reach puberty later, and also live for a long time after the menopause. Humans live up to 80 years, while chimpanzees may live up to 40 or 50 years in the wild. Chimpanzees live in large, hierarchical social groups, with relationships strengthened by social grooming; humans have even more complex social organization. Furthermore, although chimpanzees can be taught to use sign language, humans are uniquely adept at communicating thoughts and ideas through complex language systems.



Comparing cousins
Some parts of the human skeleton are remarkably similar to that of the chimpanzee: the shoulder and upper arm are almost the same size and shape. Chimpanzees walk on four legs, which makes their lower skeletons quite different from a human's, with a long pelvis and short, bent legs.



Dependent young
A human baby is born at an earlier stage of brain development than a chimpanzee baby, and is more helpless and dependent on carers. Even so, the human baby's head is relatively large at birth, making for a longer and more difficult delivery.

HUMAN ANCESTORS

Humans and their ancestors are known as hominins. The hominin fossil record begins in East Africa, with many finds from the Rift Valley. Early species walked upright, but large brains and tool-making came along later, with the appearance of our own genus, *Homo*.

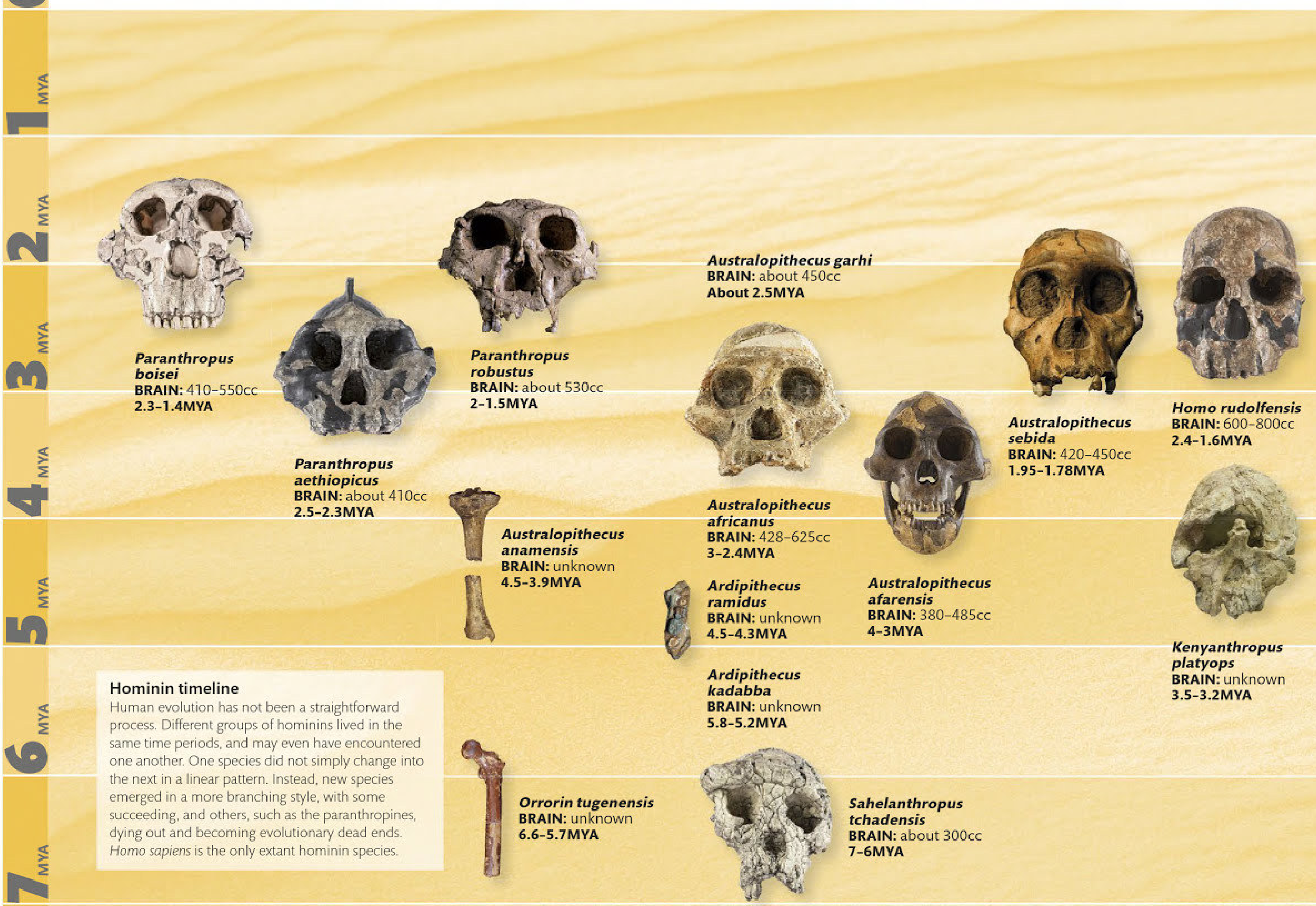
THE FOSSIL RECORD

In the last two decades, exciting discoveries have pushed back the dates of the earliest hominin ancestors, and provoked controversy over when humans first left Africa.

Fossils of a few possible early hominins have been found in East and Central Africa, dating to more than 5 million years ago. The oldest of these is *Sahelanthropus tchadensis*, which, from the position of the foramen magnum (the large hole where the spinal cord exits) on its fossil skull, appears to have stood upright on two legs. Fossilized limb bones of *Ardipithecus ramidus* suggest that it clambered around in trees as well as being able to walk on two legs on the ground. From 4.5 million years ago, a range of fossil species known collectively as australopithecines emerged. These hominins were well adapted to upright walking, but did not have the long legs and large brains of the *Homo* genus.

Until recently, it was thought that *Homo erectus* was the first hominin to leave Africa, and its fossils are found as far east as China. However, discoveries of small hominins in Indonesia suggest that there may have been an earlier expansion out of Africa.

We are the only hominin species on the planet today, but this is unusual: for most of human evolutionary history, there have been several species overlapping with each other.



MODERN HUMANS

From around 600,000 years ago, a species called *Homo heidelbergensis* existed in Africa and Europe. This ancestral species may have evolved into Neanderthals (*Homo neanderthalensis*) in Europe, about 400,000 years ago, and anatomically modern humans (*Homo sapiens*) in Africa, around 200,000 years ago. Although it is difficult to draw a line between the later fossils of *Homo heidelbergensis* and the earliest fossils of *Homo sapiens,* the rounded cranium of Omo II, discovered by the renowned Kenyan paleoanthropologist Richard Leakey and his team in southern Ethiopia, and now dated to around 195,000 years ago, is accepted by many to be the earliest fossil of a modern human (see below).

The fossil, archaeological, and climatic evidence suggests that modern humans expanded out of Africa between 50,000 and 80,000 years ago. People spread out of Africa along the rim of the Indian Ocean to Australia, and northwards, into Europe, northeast Asia, and later, into the Americas.

Modern behaviour
This piece of ochre found at Pinnacle Point, South Africa, suggests that humans were using pigment more than 160,000 years ago.

EXTINCT COUSINS

Neanderthals lived in Europe for hundreds of thousands of years before modern humans arrived on the scene some 40,000 years ago. The last known evidence of Neanderthals is from Gibraltar, around 25,000 years ago. The question of whether Neanderthals and modern humans met and interacted is hotly debated. There are a few fossils that some anthropologists believe show features of both species, leading to the controversial suggestion that modern humans and Neanderthals interbred with each other. Analysis of DNA from Neanderthal fossils has not shown any genetic evidence for interbreeding.

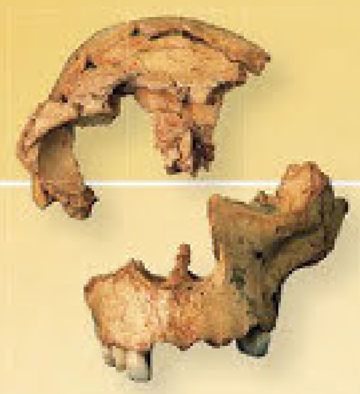
Varied diets
Archaeological evidence from Gibraltar suggests that, like humans, Neanderthals were eating a varied diet including shellfish, small animals and birds, and possibly even dolphins.

Homo habilis
BRAIN: 500–650cc
2.4–1.4MYA

Homo ergaster
BRAIN: 600–910cc
1.9–1.5MYA

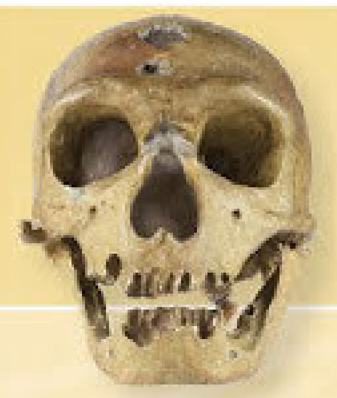
Homo erectus
BRAIN: 750–1,300cc
1.8MYA–30,000YA

Homo floresiensis
BRAIN: about 400cc
95,000–12,000YA



Homo antecessor
BRAIN: about 1,000cc
780,000–500,000YA

Homo heidelbergensis
BRAIN: 1,100–1,400cc
600,000–100,000YA



Homo neanderthalensis
BRAIN: about 1,412cc
400,000–28,000YA

Homo sapiens
BRAIN: 1,000–2,000cc
200,000YA–present

OUR OLDEST REMAINS

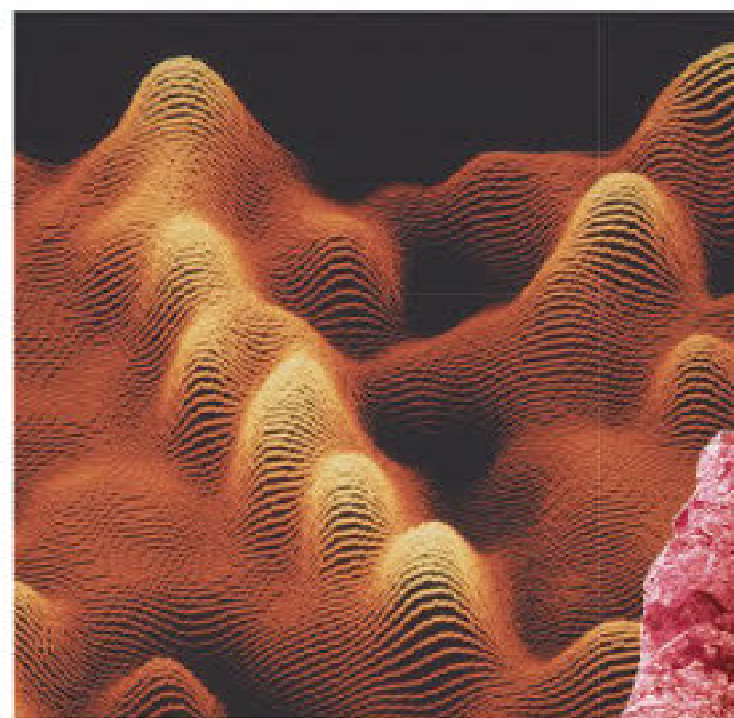
In 1967, a team led by the paleoanthropogist Richard Leakey discovered fossils of our own species in the dune-like hills of the Kibish formation near the Omo River in Ethiopia (shown here). The fossils were found sandwiched between layers of ancient volcanic rock. In 2005, scientists applied new dating techniques to these volcanic layers, and pushed back the date of the fossils to around 195,000 years old. This makes them the oldest known remains of *Homo sapiens* in the world.

HUMAN GENETIC FORMULA

DNA (deoxyribonucleic acid) is the blueprint for all life, from the humblest yeast to the human being. It provides a set of instructions on how to assemble the many thousands of different proteins that make us who we are. It also tightly regulates this assembly, ensuring that it does not run out of control.

THE MOLECULE OF LIFE

Although we all look different, the basic structure of our DNA is identical. It consists of chemical building blocks called bases, or nucleotides. What varies between individuals is the precise order in which these bases are connected into pairs. When base pairs are strung together they can form functional units called genes, which "spell out" the instructions for making a protein. Each gene encodes a single protein, although some complex proteins are encoded by more than one gene. Proteins have a wide range of vital functions in the body. They form structures such as skin or hair, they carry signals around the body, and they fight off infectious agents such as bacteria. Proteins also make up cells, the basic units of the body, and carry out the thousands of basic biochemical processes needed to sustain life. However, only about 1.5 per cent of our DNA encodes genes. The rest consists of regulatory sequences, structural DNA, or has no obvious purpose – so-called "junk DNA".

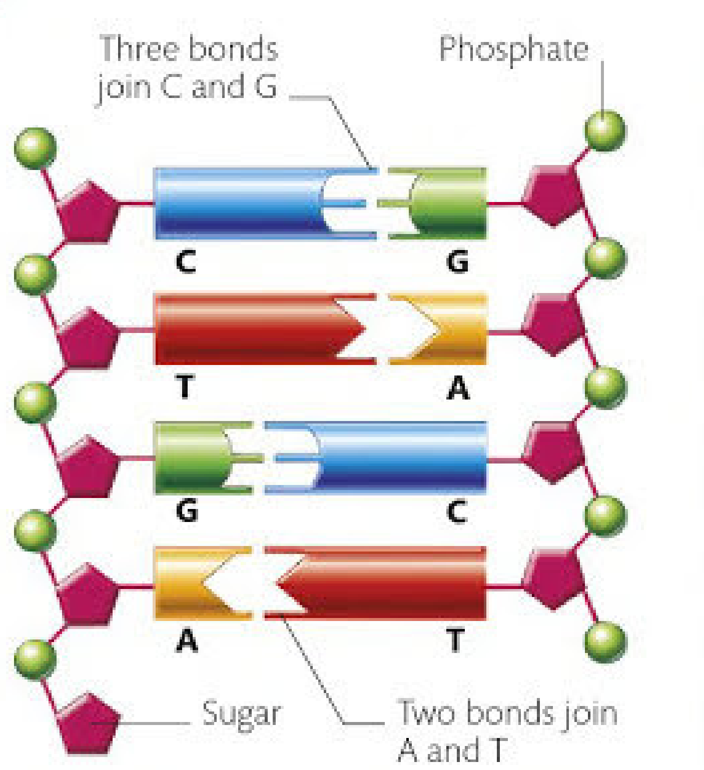


DNA micrograph
Although DNA is extremely small, its structure can be observed by using a scanning tunnelling microscope, which has magnified this image around two million times.

DNA double helix
In the vast majority of organisms, including humans, long strands of DNA twist around each other to form a right-handed spiral structure called a double helix. The helix consists of a sugar (deoxyribose) and phosphate backbone and complementary base pairs that stick together in the middle. Each twist of the helix contains around ten base pairs.

BASE PAIRS

DNA consists of building blocks called bases. There are four types: adenine (A), thymine (T), cytosine (C), and guanine (G). Each base is attached to a phosphate group and a deoxyribose sugar ring to form a nucleotide. In humans, bases pair up to form a double-stranded helix in which adenine pairs with thymine, and cytosine with guanine. The two strands are "complementary" to each other. Even if they are unwound and unzipped, they can realign and rejoin.

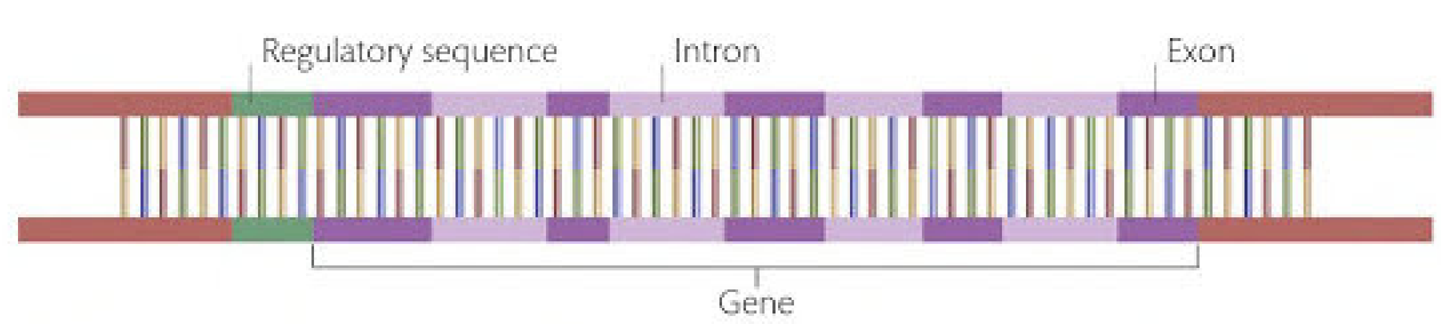


Forming bonds
The two strands of the double helix join by forming hydrogen bonds. When guanine binds with cytosine, three bonds are formed, and when adenine binds with thymine, they form two.

GENES

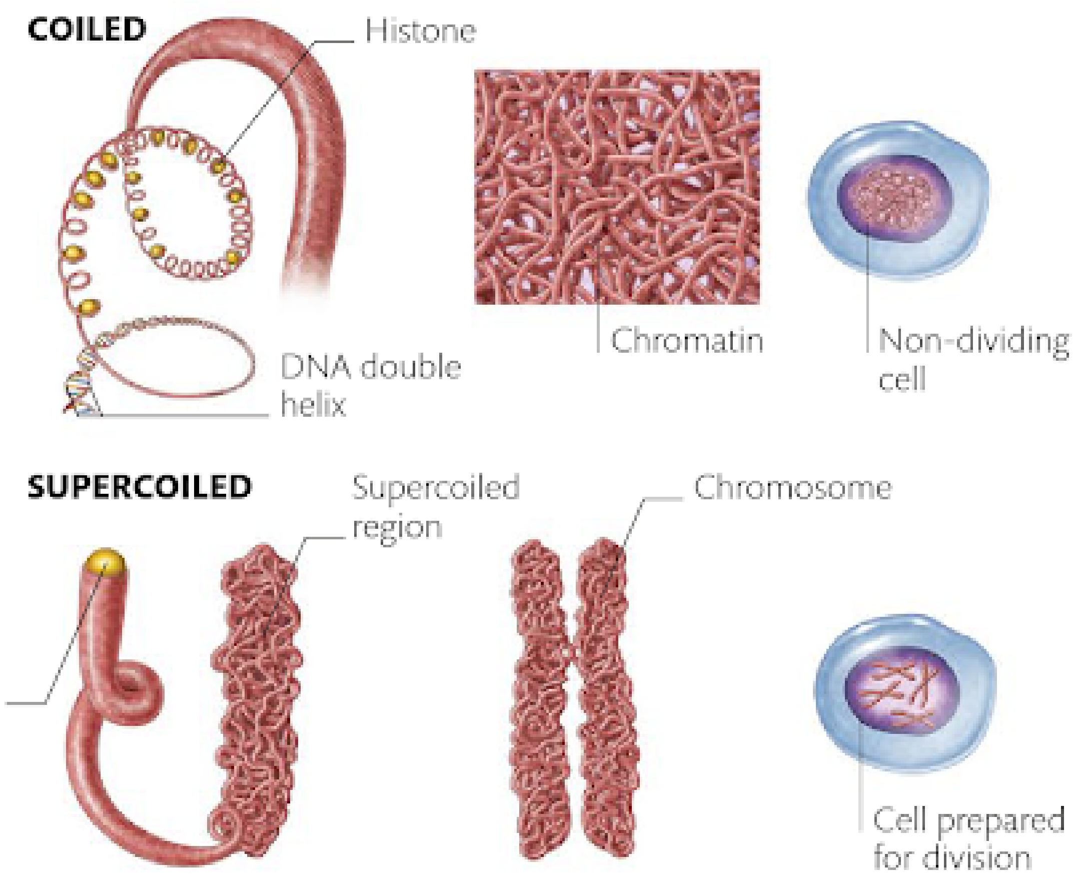
A gene is a unit of DNA needed to make a protein. Genes range in size from just a few hundred to millions of base pairs. They control our development, but are also switched on and off in response to environmental factors. For example, when an immune cell encounters a bacterium, genes are switched on that produce antibodies to destroy it. Gene expression is regulated by proteins that bind to regulatory sequences within each gene. Genes contain regions that are translated into protein (exons) and non-coding regions (introns).

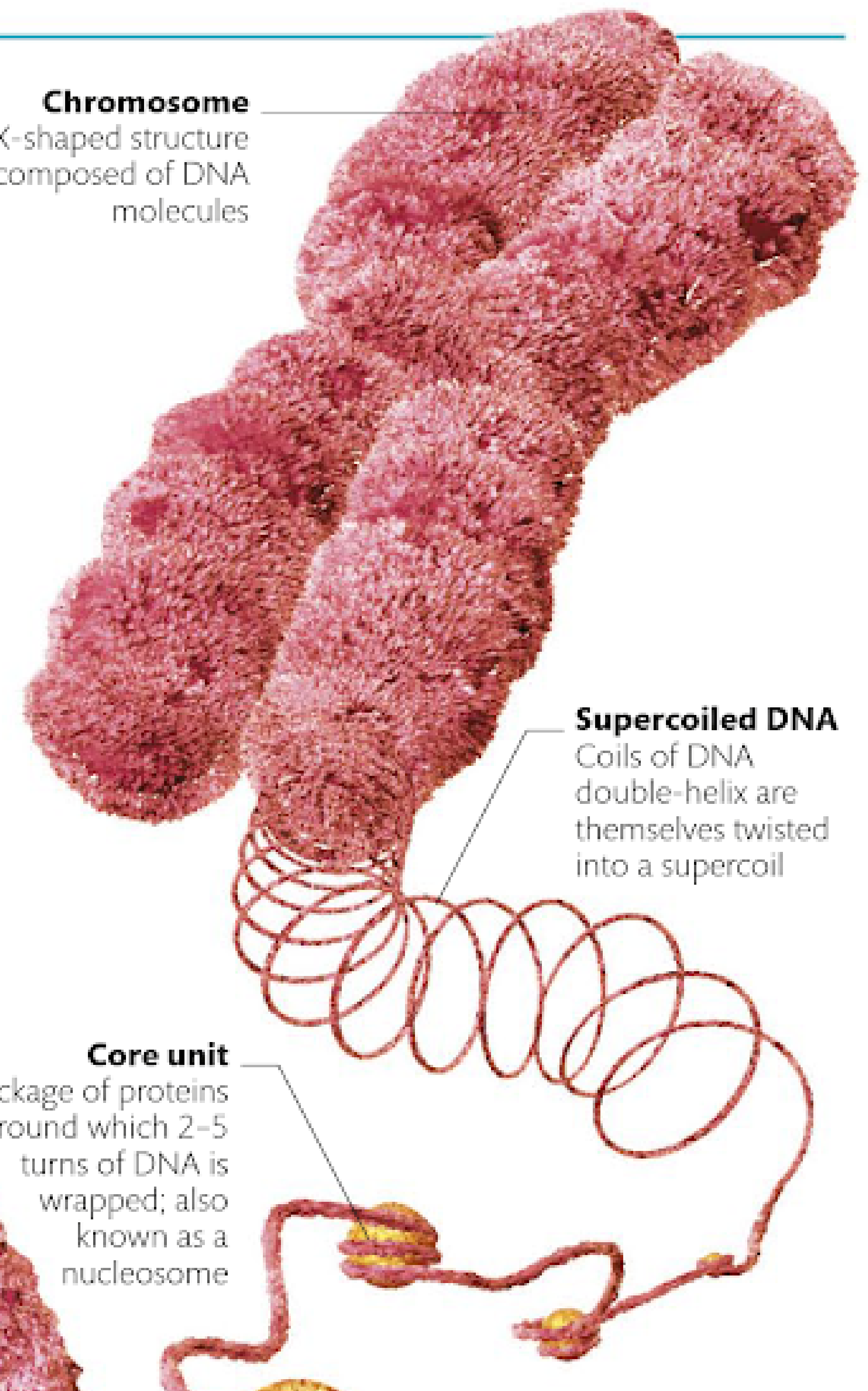
Eye colour
The genetics of eye colour are incredibly complex, and many different genes are involved.

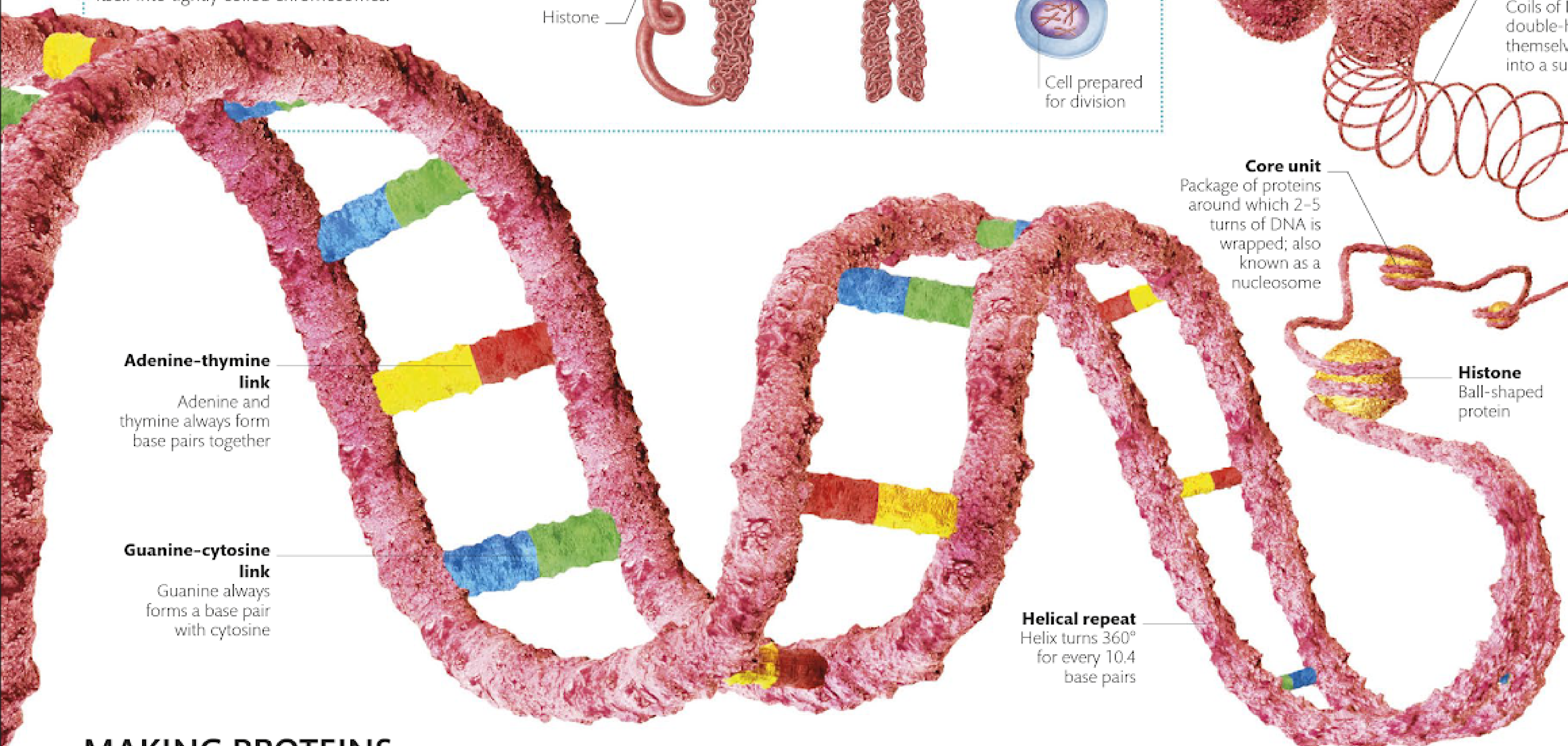


PACKAGING DNA

The human genome is composed of approximately 3 billion bases of DNA – about 2m (6½ft) of DNA in every cell if it was stretched from end to end. Therefore, our DNA must be packaged up in order to fit inside each tiny cell. DNA is concentrated into dense structures called chromosomes, and each cell contains 23 pairs of chromosomes (46 in total) – one set from the mother and another set from the father. To package up DNA, the double helix must first be coiled around histone proteins, forming a structure that looks a little like beads on a string. These histone "beads" then wind up and lock together into densely coiled "chromatin", which, when a cell prepares to divide, further winds back on itself into tightly coiled chromosomes.

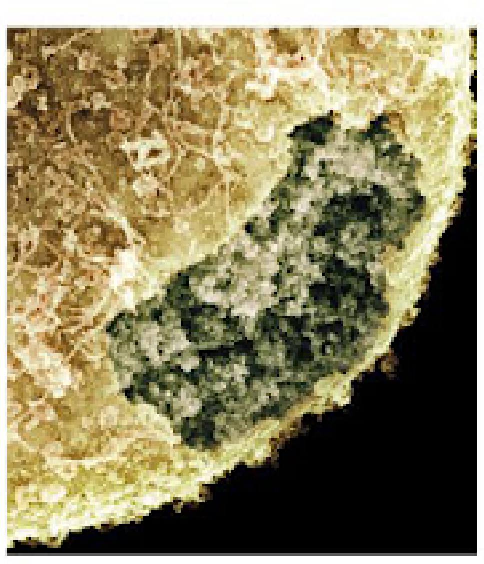






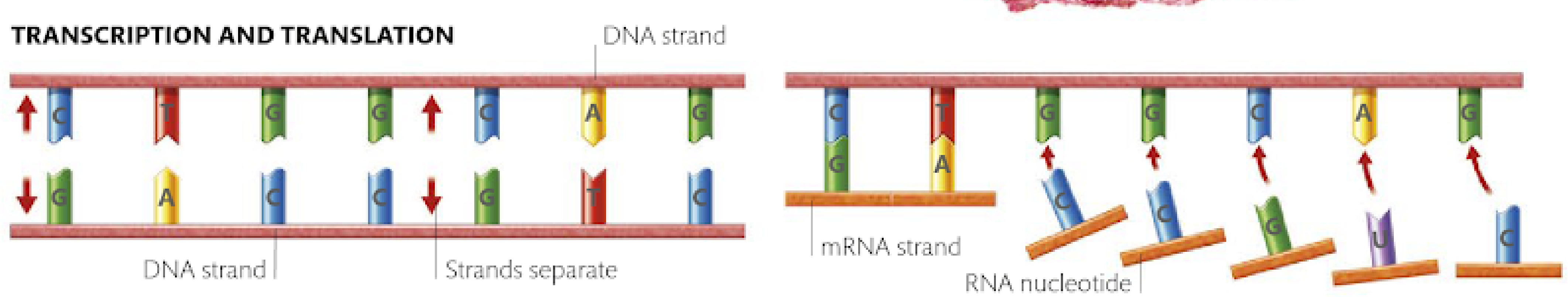
MAKING PROTEINS

Proteins consist of building blocks called amino acids, strung together in chains and folded. Every three base pairs of DNA codes for one amino acid, and the body makes 20 different amino acids – others are obtained from the diet. Protein synthesis occurs in two steps: transcription and translation. In transcription, the DNA double helix unwinds, exposing single-stranded DNA. Complementary sequences of a related molecule called RNA (ribonucleic acid) then create a copy of the DNA sequence that can be translated into protein. This "messenger RNA" travels to ribosomes, where it is translated into strings of amino acids. These are then folded into the 3-D structure of a protein.



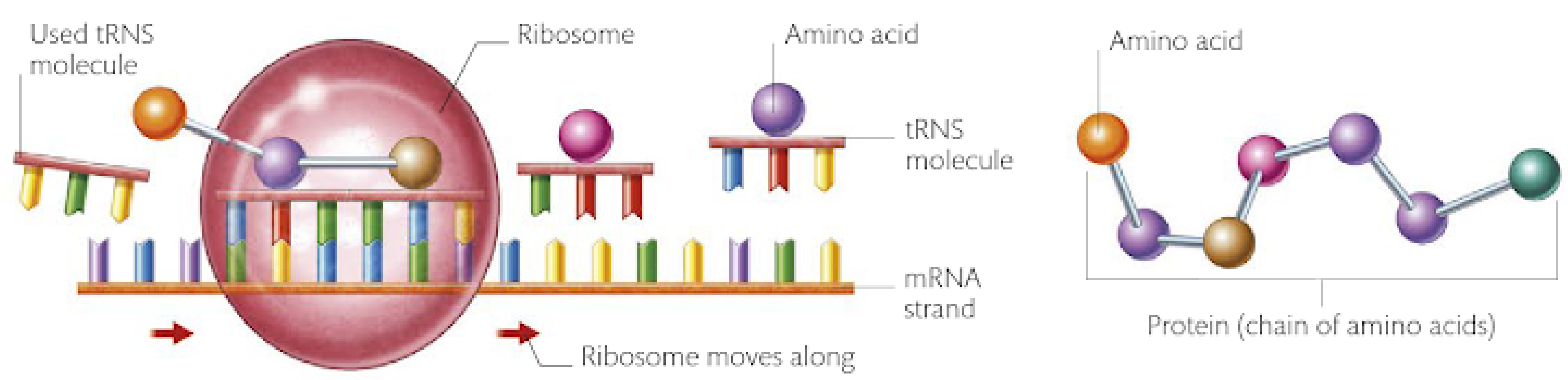
Cell nucleus
DNA is found in a structure at the centre of the cell called the nucleus. The first stage of protein synthesis takes place here.

TRANSCRIPTION AND TRANSLATION



1 Inside the nucleus of the cell, the DNA strands temporarily separate. One will act as a template for the formation of mRNA (messenger ribonucleic acid).

2 RNA nucleotides with correctly corresponding bases lock onto the exposed DNA bases and join to form a strand of mRNA. In this process, thymine bases are replaced by uracil bases.



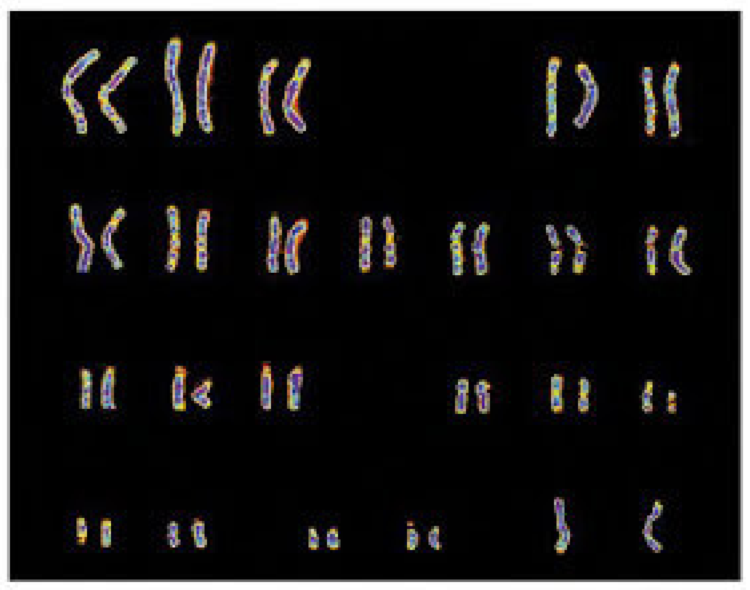
3 The mRNA strand attaches to a ribosome, which passes along the strand. Within the ribosome, individual tRNS (transfer ribonucleic acid) molecules, each carrying an amino acid, slot onto the mRNA.

4 As the ribosome moves along the mRNA, it produces a specific sequence of amino acids, which combine to form a particular protein.

THE HUMAN GENOME

Different organisms contain different genes, but a surprisingly large proportion of genes are shared between organisms. For example, roughly half of the genes found in humans are also found in bananas. However, it would not be possible to substitute the banana version of a gene for a human one because variations in the order of the base pairs within each gene also distinguish us. Humans all possess more or less the same genes, but many of the differences between individuals can be explained by subtle variations within each gene. The extent of these variations is smaller than between humans and animals, and smaller still than the differences between humans and plants. In humans, DNA differs by only around 0.2 per cent, while human DNA differs from chimpanzee DNA by around 5 per cent.

Human genes are divided unevenly between 23 pairs of chromosomes, and each chromosome consists of gene-rich and gene-poor sections. When chromosomes are stained, differences in these regions show up as light and dark bands, giving chromosomes a striped appearance. We still don't know exactly how many protein-coding genes there are in the human genome, but researchers currently estimate between 20,000 and 25,000.



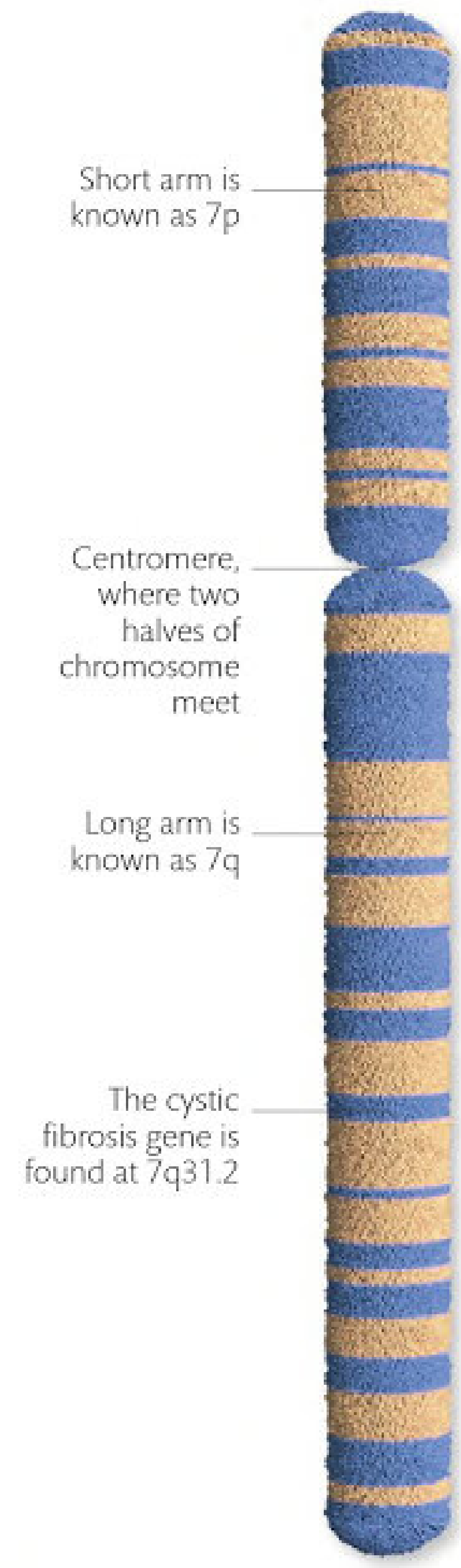
Karyotype
This is an organized profile of the chromosomes in someone's cells, arranged by size. Studying someone's karyotype enables doctors to determine whether any chromosomes are missing or abnormal.

GENETIC PROFILING

Apart from subtle genetic variations, humans also vary in their non-coding DNA. This so-called "junk DNA" accounts for vast tracts of our genetic material, and we still have little understanding of what it does. However, that does not make it useless. Forensic scientists look at variations in non-coding DNA to match criminal suspects to crime scenes. To do this, they analyse short, repeating sequences of DNA within non-coding regions, called short-tandem-repeats (STRs). The precise number of repeats is highly variable between individuals. In one method, forensic scientists compare ten of these repeating regions, chopping them up and then separating them on the basis of their size to generate a series of bands called a DNA profile or fingerprint.

Shared characteristics
Genetic profiling can also be used to prove family relationships. Here, two children are shown to share bands with each parent, proving they are related.

Chromosome banding
Each chromosome has two arms, and staining reveals that these are divided into bands. Each band is numbered, making it possible to locate a specific gene if you know its address. These are the bandings on chromosome 7.



Chromosome complement
The human genome is stored on 23 pairs of chromosomes – 46 in total. Of these, 22 pairs store general genetic information and are called autosomes, while the remaining pair determines whether you are male or female. There are two types of sex chromosome: X and Y. Men have one X and one Y, while women have two X chromosomes.

There is **no known function** for **97 per cent** of the DNA in the human genome – sometimes known as **junk DNA**.

1
Number of genes: 4,234
Associations and conditions: Alzheimer's disease; Parkinson's disease; glaucoma; prostate cancer; brain size

2
Number of genes: 3,078
Associations and conditions: Colour-blindness; red hair; breast cancer; Crohn's disease; amyotrophic lateral sclerosis (ALS); high cholesterol

3
Number of genes: 3,723
Associations and conditions: Deafness; autism; cataracts; susceptibility to HIV infection; diabetes; Charcot-Marie-Tooth disease

4
Number of genes: 542
Associations and conditions: Blood vessel growth; immune system genes; bladder cancer; Huntington's disease; deafness; haemophilia; Parkinson's disease

5
Number of genes: 737
Associations and conditions: DNA repair; nicotine addiction; Parkinson's disease; Cri du Chat syndrome; breast cancer; Crohn's disease

6
Number of genes: 2,277
Associations and conditions: Cannabis receptor; cartilage strength; immune system genes; epilepsy; type 1 diabetes; rheumatoid arthritis

7
Number of genes: 4,171
Associations and conditions: Pain perception; muscle, tendon and bone formation; cystic fibrosis; schizophrenia; Williams syndrome; deafness; type 2 diabetes

8
Number of genes: 1,400
Associations and conditions: Brain development and function; cleft lip and palate; schizophrenia; Werner syndrome

9
Number of genes: 1,931
Associations and conditions: Blood group; albinism; bladder cancer; porphyria

10
Number of genes: 1,776
Associations and conditions: Inflammation; DNA repair; breast cancer; Usher's syndrome

11
Number of genes: 546
Associations and conditions: Sense of smell; haemoglobin production; autism; albinism; sickle cell anaemia; breast cancer; bladder cancer

12
Number of genes: 1,698
Associations and conditions: Cartilage and muscle strength; narcolepsy; stuttering; Parkinson's disease

THE SUM OF ONE'S GENES

At the simplest level, each gene encodes a protein, and each protein results in a distinct trait or phenotype. In humans, this is best illustrated by inherited diseases like cystic fibrosis. Here, a mutation in the CFTR gene, which makes a protein found in mucus, sweat, and digestive juices, results in the accumulation of thick mucus in the lungs, leaving carriers of the defective gene more susceptible to lung infections. If we know what a specific gene looks like in a healthy person, and how it looks if it has gone wrong, it may be possible to devise a genetic test to find out whether someone is at risk of disease. For example, mutations in a gene called BRCA1 can predict if a woman is at high risk of developing one form of breast cancer. However, many traits – such as height or hair colour – are influenced by several genes working together. And genes are only part of the equation. In the case of personality or lifespan, multiple genes interact with environmental factors, such as upbringing and diet, to shape who we are and who we will become (see p.410).

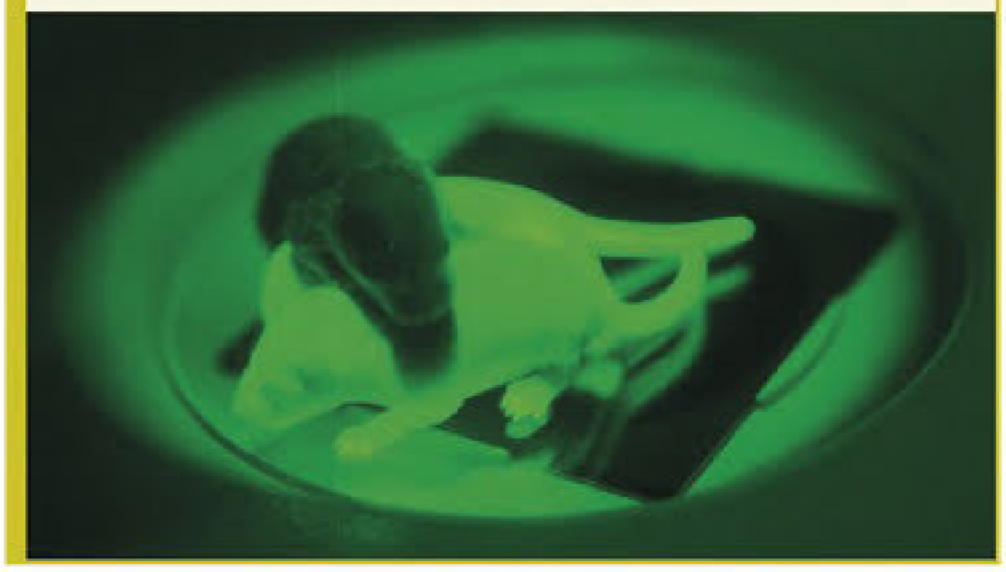
Human diversity
Although all humans carry more or less the same genes in terms of the proteins they manufacture, the vast number of possible combinations of genes, and the ways they are expressed, explains the huge diversity in the human body across the world's population.

Inherited traits
Humans possess two copies of each gene, but not all genes are equal. Dominant genes show their effect even if there is only one in a pair, while recessive genes need two copies (see p.411). Free-hanging earlobes are caused by the dominant form of a gene, while attached earlobes are recessive.

BREAKTHROUGHS

GENETIC ENGINEERING

This form of gene manipulation enables us to substitute a defective gene with a functional one, or introduce new genes. Glow-in-the-dark mice were created by introducing a jellyfish gene that encodes a fluorescent protein into the mouse genome. Finding safe ways of delivering replacement genes to the correct cells in humans could lead to cures for many types of inherited diseases – so-called gene therapy.



13
Number of genes: 925
Associations and conditions: LSD receptor; breast cancer (BRCA2 gene); bladder cancer; deafness; Wilson's disease

14
Number of genes: 1,887
Associations and conditions: Antibody production; Alzheimer's disease; amyotrophic lateral sclerosis (ALS); muscular dystrophy

15
Number of genes: 1,377
Associations and conditions: Eye colour; skin colour; Angelman syndrome; breast cancer; Tay-Sachs disease; Marfan syndrome

16
Number of genes: 1,561
Associations and conditions: Red hair; obesity; Crohn's disease; breast cancer; trisomy 16 (most common chromosomal cause of miscarriage)

17
Number of genes: 2,417
Associations and conditions: Connective tissue function; early onset breast cancer (BRCA1); brittle bone disease; bladder cancer

18
Number of genes: 756
Associations and conditions: Edward's syndrome; Paget's disease; porphyria; selective mutism

19
Number of genes: 1,984
Associations and conditions: Cognition; Alzheimer's disease; cardiovascular disease; high cholesterol; hereditary stroke

20
Number of genes: 1,019
Associations and conditions: Coeliac disease; type 1 diabetes; prion diseases

21
Number of genes: 595
Associations and conditions: Down Syndrome; Alzheimer's disease; amyotrophic lateral sclerosis (ALS); deafness

22
Number of genes: 1,841
Associations and conditions: Antibody production; breast cancer; schizophrenia; amyotrophic lateral sclerosis (ALS)

X
Number of genes: 1,860
Associations and conditions: Breast cancer; colour blindness; haemophilia; fragile X syndrome; Turner syndrome; Klinefelter's syndrome

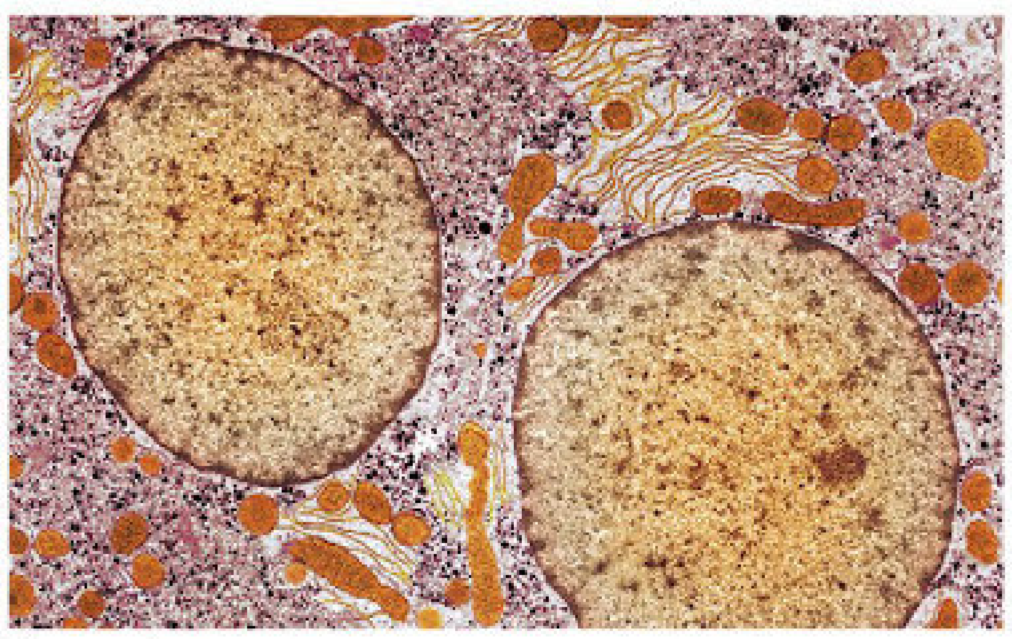
Y
Number of genes: 454
Associations and conditions: Male fertility and testicular development

THE CELL

It is hard to comprehend what 75 trillion cells looks like, but observing yourself in a mirror would be a good start. That is how many cells exist in the average human body – and we replace millions of these cells every single day.

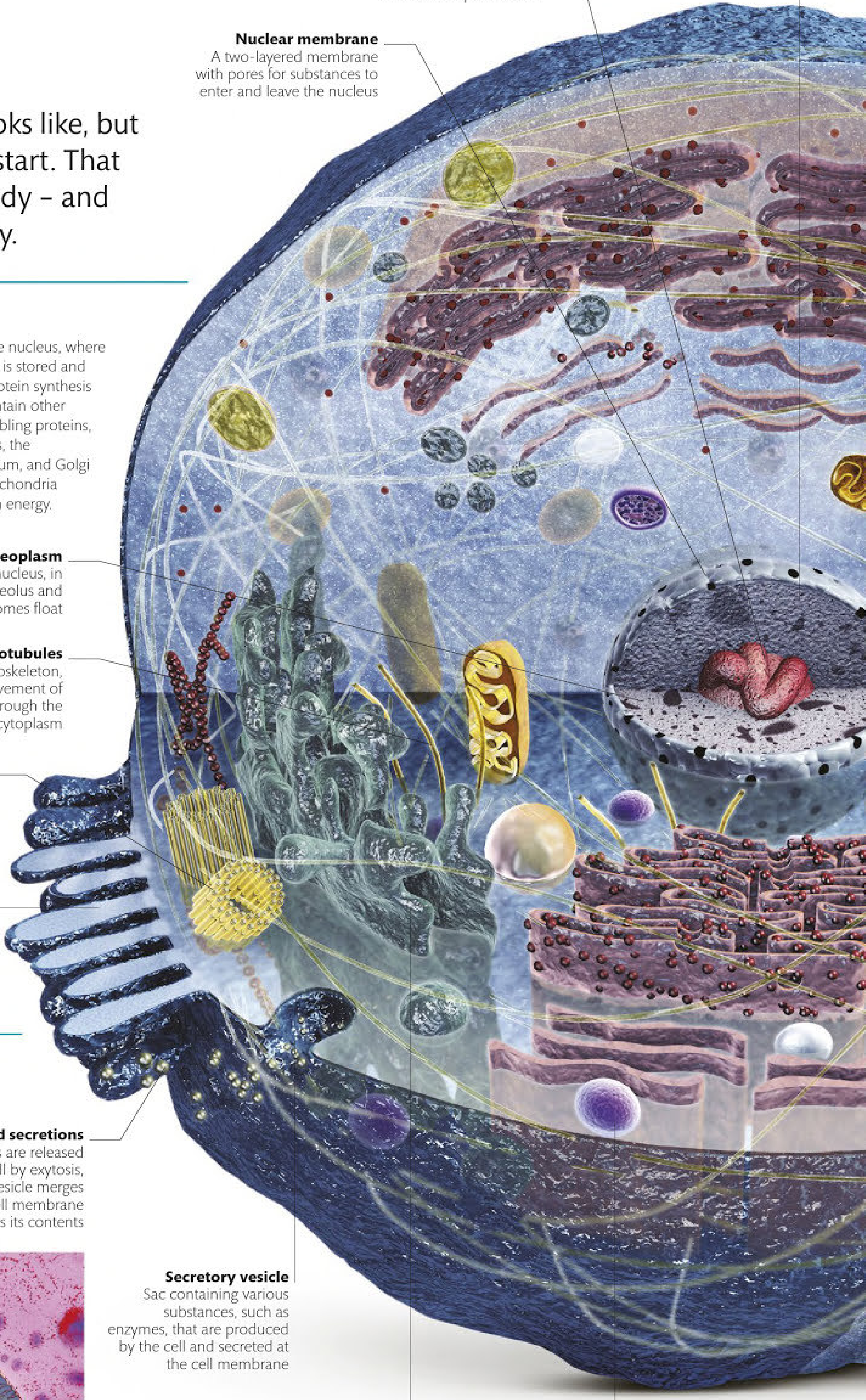
CELL ANATOMY

The cell is the basic functional unit of the human body. Cells are extremely small, typically only about 0.01mm across – even our largest cells are no bigger than the width of a human hair. They are also immensely versatile: some can form sheets like those in your skin or lining your mouth, while others can store or generate energy, such as fat and muscle cells. Despite their amazing diversity, there are certain features that all cells have in common, including an outer membrane, a control centre called a nucleus, and tiny powerhouses called mitochondria.



Liver cell
These cells make protein, cholesterol, and bile, and detoxify and modify substances from the blood. This requires lots of energy, so liver cells are packed with mitochondria (orange).

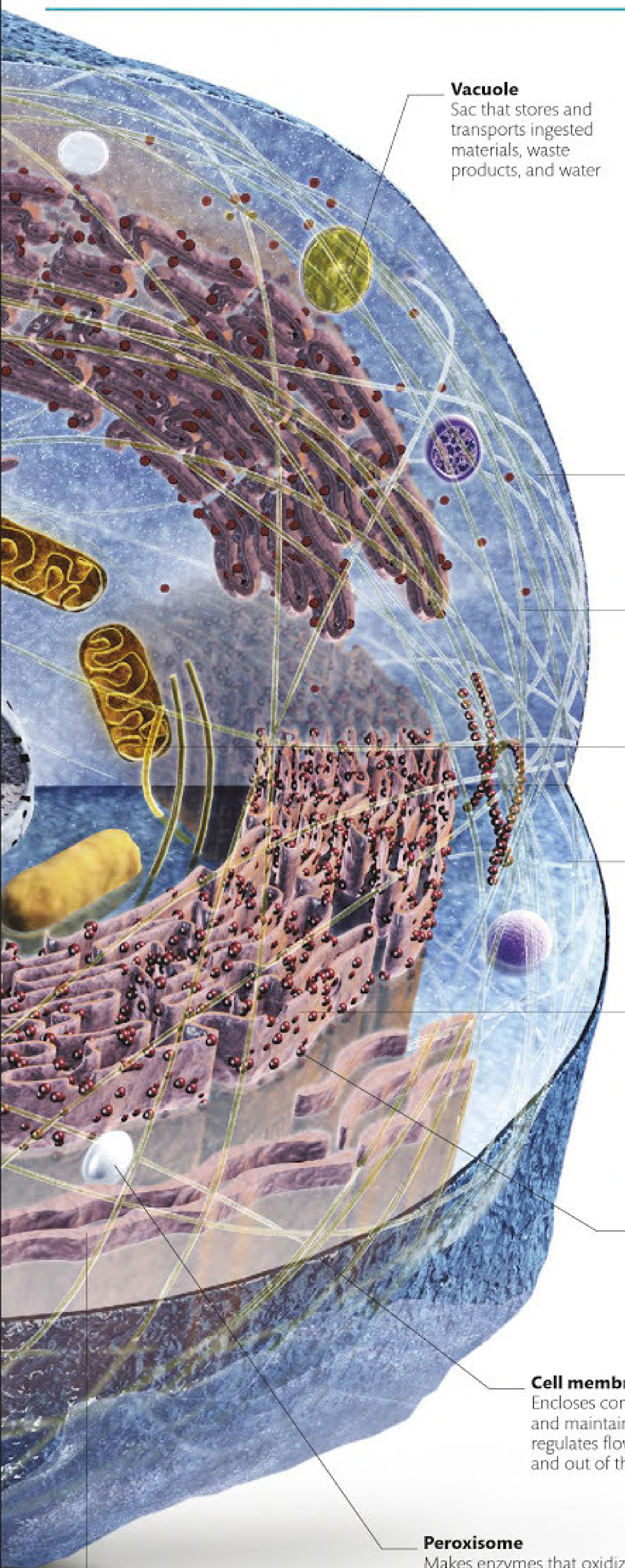
Generic cell
At a cell's heart is the nucleus, where the genetic material is stored and the first stages of protein synthesis occur. Cells also contain other structures for assembling proteins, including ribosomes, the endoplasmic reticulum, and Golgi apparatus. The mitochondria provide the cell with energy.



CELL METABOLISM

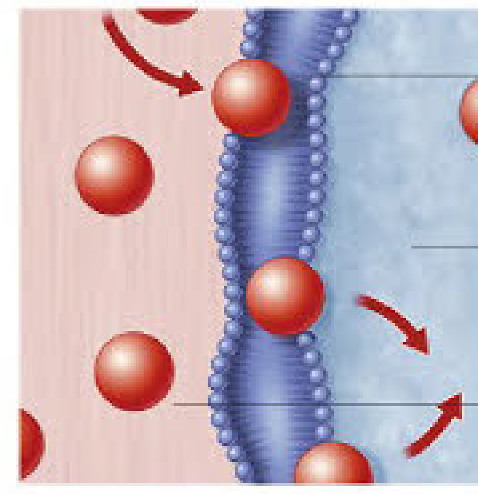
When individual cells break down nutrients to generate energy for building new proteins or nucleic acids, it is known as cell metabolism. Cells use a variety of fuels to generate energy, but the most common one is glucose, which is transformed into adenosine triphosphate (ATP). This takes place in structures called mitochondria through a process called cellular respiration: enzymes within the mitochondria react with oxygen and glucose to produce ATP, carbon dioxide, and water. Energy is released when ATP is converted into adenoside diphosphate (ADP) via the loss of a phosphate group.

Mitochondrion
While the number of mitochondria varies between different cells, all have the same basic structure: an outer membrane and a highly folded inner membrane, where the production of energy actually takes place.

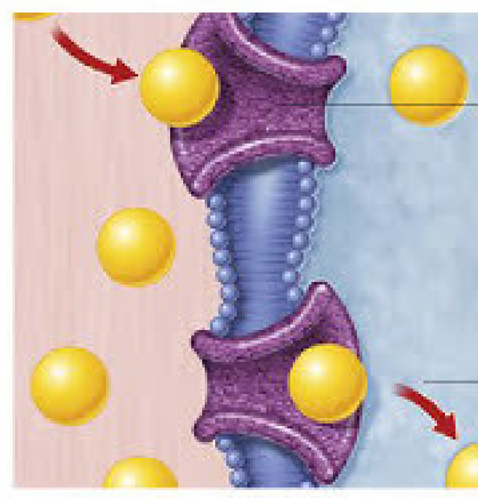


CELL TRANSPORT

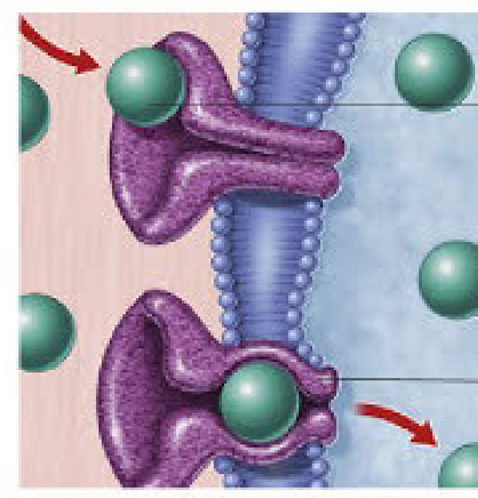
Materials are constantly being transported in and out of the cell via the cell membrane. Such materials could include fuel for generating energy, or building blocks essential for protein assembly, such as amino acids. Some cells can secrete signalling molecules to communicate with neighbouring cells or the rest of the body. The cell membrane is largely composed of phospholipids, but it is also studded with proteins that facilitate transport, enable cells to communicate with one another, and identify a cell to other cells. The membrane is permeable to some molecules, but other molecules need active transport through special channels in the membrane. Cells have three main methods of transport: diffusion, facilitated diffusion, and active transport (the last requires energy).



Diffusion
Molecules passively cross the membrane from areas of high to low concentration. Water and oxygen both cross by diffusion.



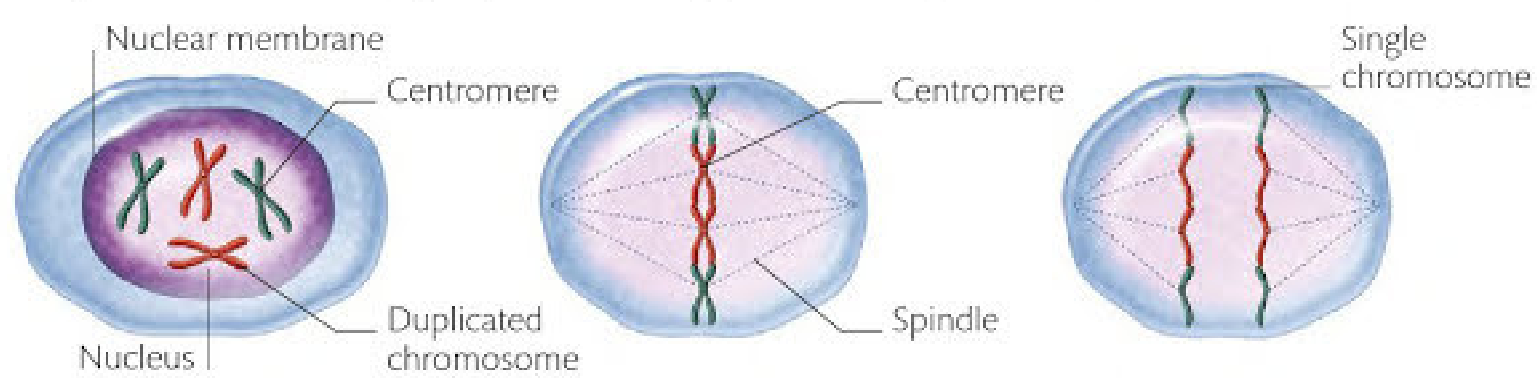
Facilitated diffusion
A carrier protein, or protein pore, binds with a molecule outside the cell, then changes shape and ejects the molecule into the cell.



Active transport
Molecules bind to a receptor site on the cell membrane, triggering a protein, which changes into a channel that molecules travel through.

MAKING NEW BODY CELLS

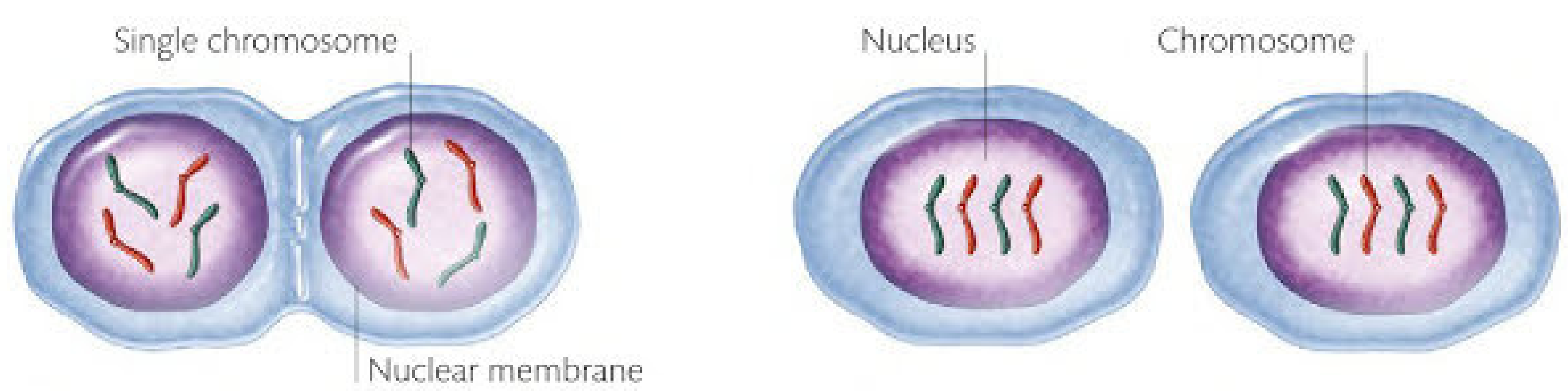
Some cells are constantly replacing themselves; others last a lifetime. While the cells lining the mouth are replaced every couple of days, some of the nerve cells in the brain have been there since before birth. Stem cells are specialized cells that are constantly dividing and giving rise to new cells, such as blood cells, immune cells, or fat cells. Cell division requires that a cell's DNA is accurately copied and then shared equally between two "daughter" cells, by a process called mitosis. The chromosomes are first replicated before being pulled to opposite ends of the cell. The cell then divides to produce two daughter cells, with the cytoplasm and organelles being shared between the two cells.



1 Preparation
The cell produces proteins and new organelles, and duplicates its DNA. The DNA condenses into X-shaped chromosomes.

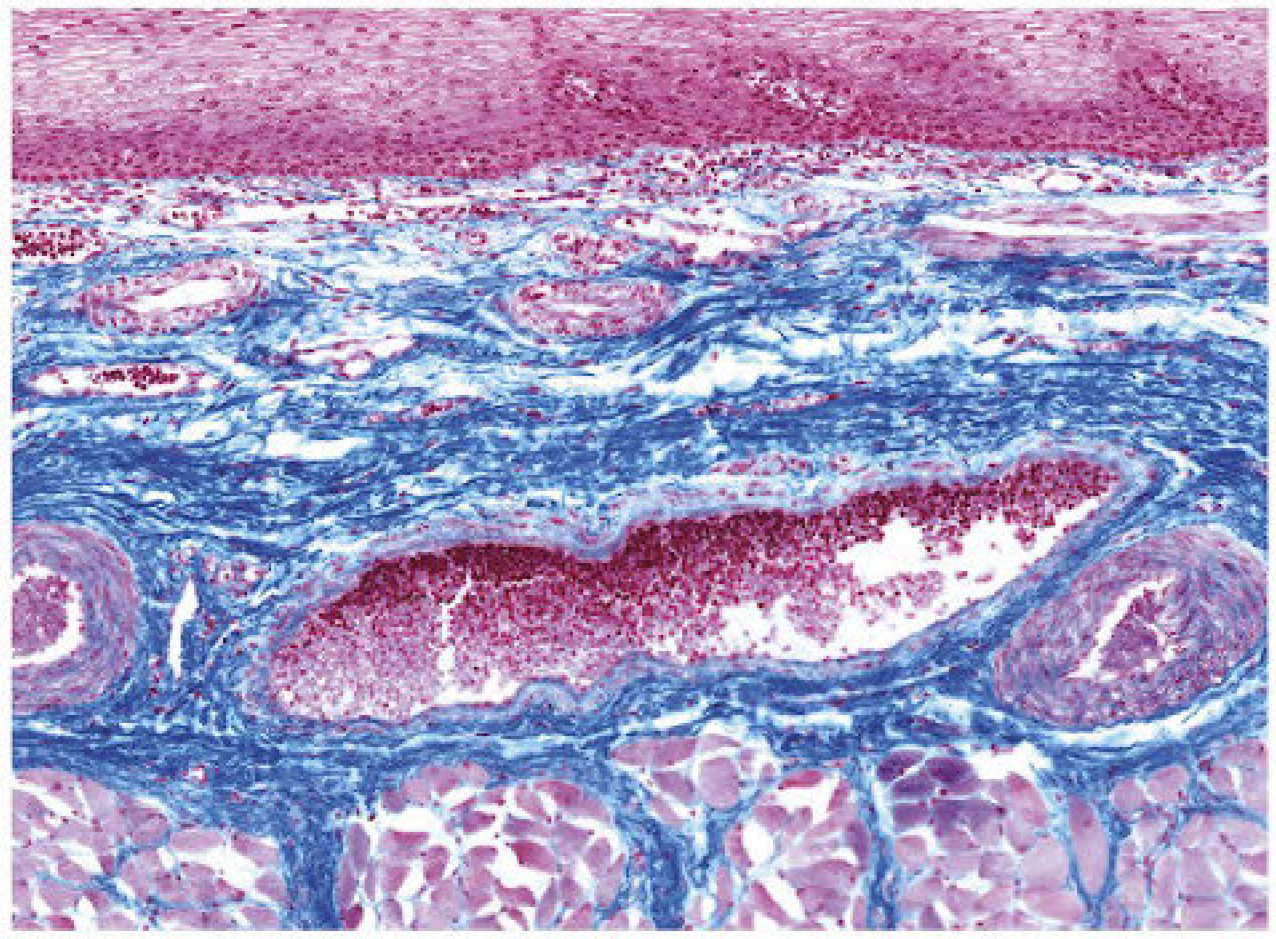
2 Alignment
The chromosomes line up along a network of filaments called the spindle. This is linked to a larger network called the cytoskeleton.

3 Separation
The chromosomes are pulled apart and move to opposite ends of the cell. Each end has an identical set of chromosomes.



4 Splitting
The cell now splits in two, with the cytoplasm, cell membrane, and remaining organelles being shared roughly equally between the two daughter cells.

5 Offspring
Each daughter cell contains a complete copy of the DNA from the parent cell; this enables it to continue growing, and eventually divide itself.



Integrated tissues
This section through the wall of the oesophagus shows a combination of different tissues: lining epithelium (pink, top); collagen connective tissue (blue); blood vessels (circular); skeletal muscle fibres (purple, bottom).

CELLS AND TISSUES

Cells are the building blocks from which the human body is made. Some cells work alone – such as red blood cells, which carry oxygen around the body, or sperm, which fertilize egg cells – but many are organized into tissues, where cells with different functions join forces to accomplish one or more specific tasks.

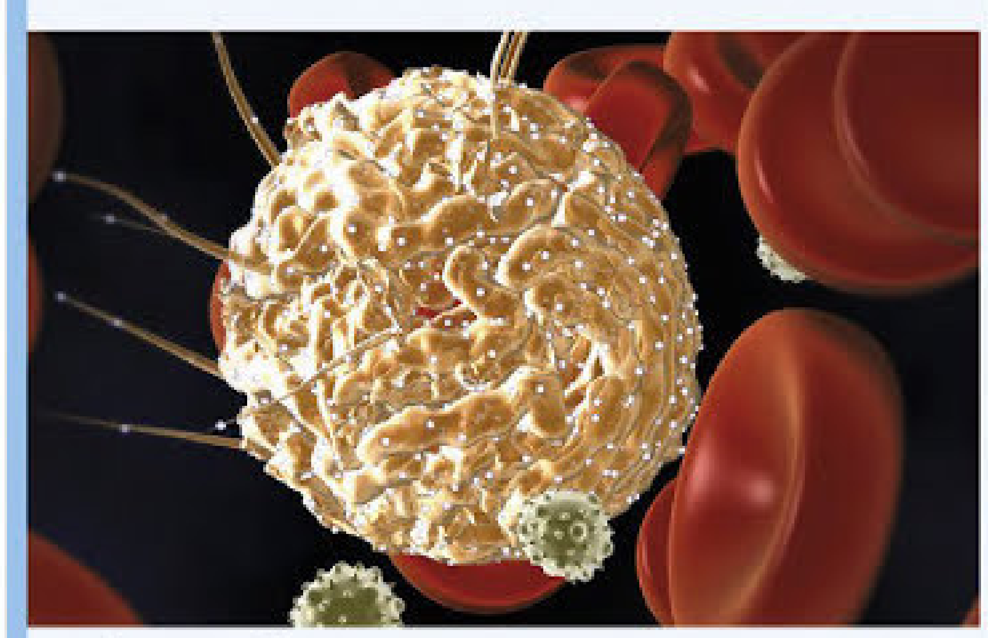
CELL TYPES

There are more than 200 different types of cell in the body, each type specially adapted to its own particular function. Every cell contains the same genetic information, but not all of the genes are "switched on" in every cell. It is this pattern of gene expression that dictates what the cell looks like, how it behaves, and what role it performs in the body. A cell's fate is largely determined before birth, influenced by its position in the body and the cocktail of chemical messengers that it is exposed to in that environment. Early during development, stem cells begin to differentiate into three layers of more specialized cells called the ectoderm, endoderm, and mesoderm. Cells of the ectoderm will form the skin and nails, the epithelial lining of the nose, mouth, and anus, the eyes, and the brain and spinal cord. Cells of the endoderm become the inner linings of the digestive tract, the respiratory linings, and glandular organs including the liver and pancreas. Mesoderm cells develop into the muscles, circulatory system, and the excretory system, including the kidneys.

SCIENCE

STEM CELLS

A few days after fertilization, an embryo consists of a ball of "embryonic stem cells" (ESCs). These cells have the potential to become any type of cell in the body. Scientists are trying to harness this property to grow replacement body parts. As the embryo grows, the stem cells become increasingly restricted in their potential. By the time we are born most of our cells are fully differentiated, but a small number of adult stem cells remain in parts of the body, including in bone marrow. While not as universal in their potential as ESCs, they do have some flexibility in terms of what they can become. Scientists believe that these cells could also be used to help cure disease.

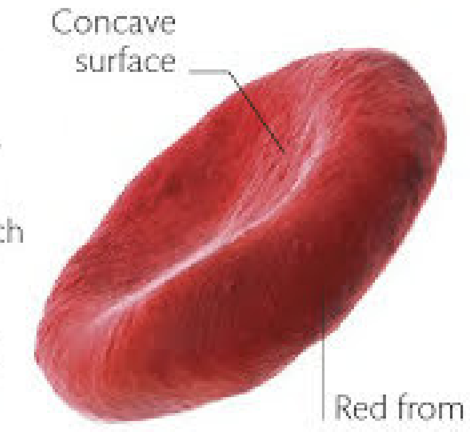


Adult stem cells
Adult stem cells, such as the large white cell in this image, are present in bone marrow, where they multiply and produce millions of blood cells, including red blood cells, also seen here.

200

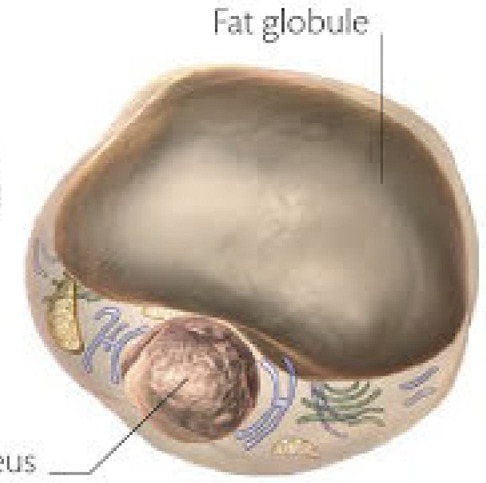
The number of different **types of cell** in the human body. Most are **organized in groups** to form tissues.

Red blood cells
Unlike all other human cells, red blood cells lack a nucleus and most organelles. Instead, they are packed with an oxygen-carrying protein called haemoglobin, which gives blood its red colour. Red blood cells develop in the bone marrow and circulate for around 120 days, before being broken down and recycled.

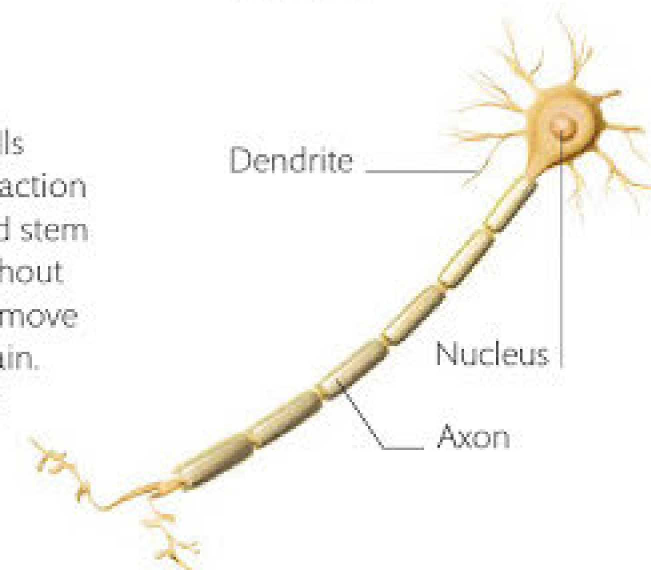


Epithelial cells
These cells are barrier cells lining the cavities and surfaces of the body. They include skin cells and the cells lining the lungs and reproductive tracts. Some epithelial cells have finger-like projections called "cilia" that can waft eggs down the fallopian tubes, or push mucus out of the lungs, for example.

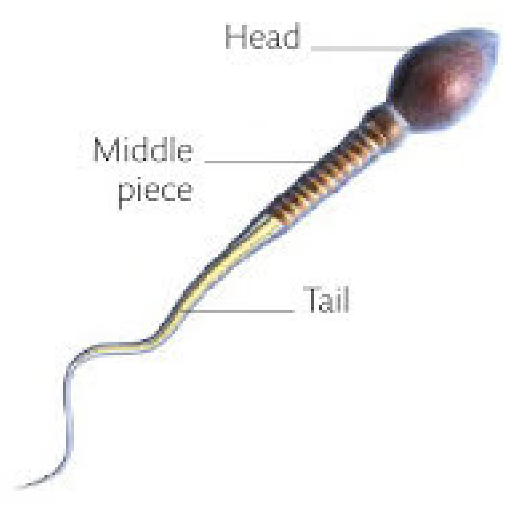
Adipose (fat) cells
These cells are highly adapted for the storage of fat, and the bulk of their interior is taken up by a large droplet of semi-liquid fat. When we gain weight, our adipose cells swell up and fill with even more fat, though eventually they also start to increase in number.



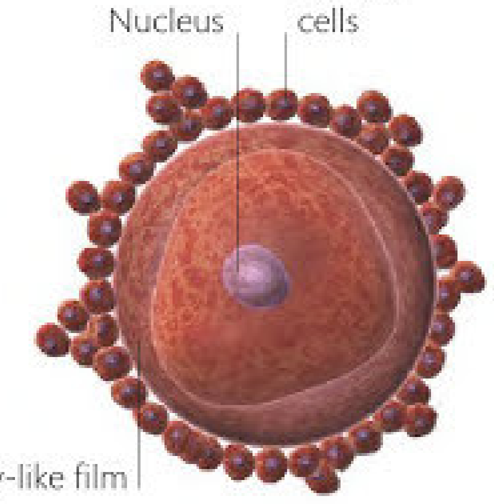
Nerve cells
These electrically excitable cells transmit electrical signals, or "action potentials", down an extended stem called an axon. Found throughout the body, they enable you to move and feel sensations such as pain. They communicate with each other across connections called synapses.



Sperm cells
Sperm are male reproductive cells with a tail that enables them to swim up the female reproductive tract and fertilize an egg. Sperm contain just 23 chromosomes; in fertilization, these pair up with an egg's 23 chromosomes to create an embryo with the normal 46 chromosomes per cell.

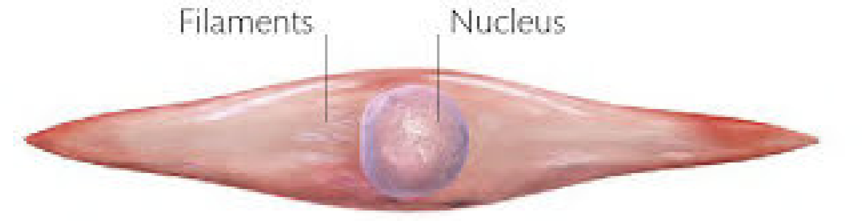


Ovum (egg) cells
One of the largest cells in the body, a human egg is still only just visible to the naked eye. Eggs are the female reproductive cells and, like sperm, they contain just 23 chromosomes. Every woman is born with a finite number of eggs, which decreases as she ages.



Photoreceptor cells
These occur at the back of the eye. They contain a light-sensitive pigment and generate electrical signals when struck by light, enabling us to see. There are two main photoreceptor types: rods (below) see in black and white, and work well in low light; cones work better in bright light, and are able to detect colours.

Smooth muscle cells
One of three types of muscle cell, smooth muscle cells are spindle-shaped cells found in the arteries and the digestive tract that produce long, wave-like contractions. To do this, they are packed with contractile filaments, and large numbers of mitochondria that supply the energy they need.



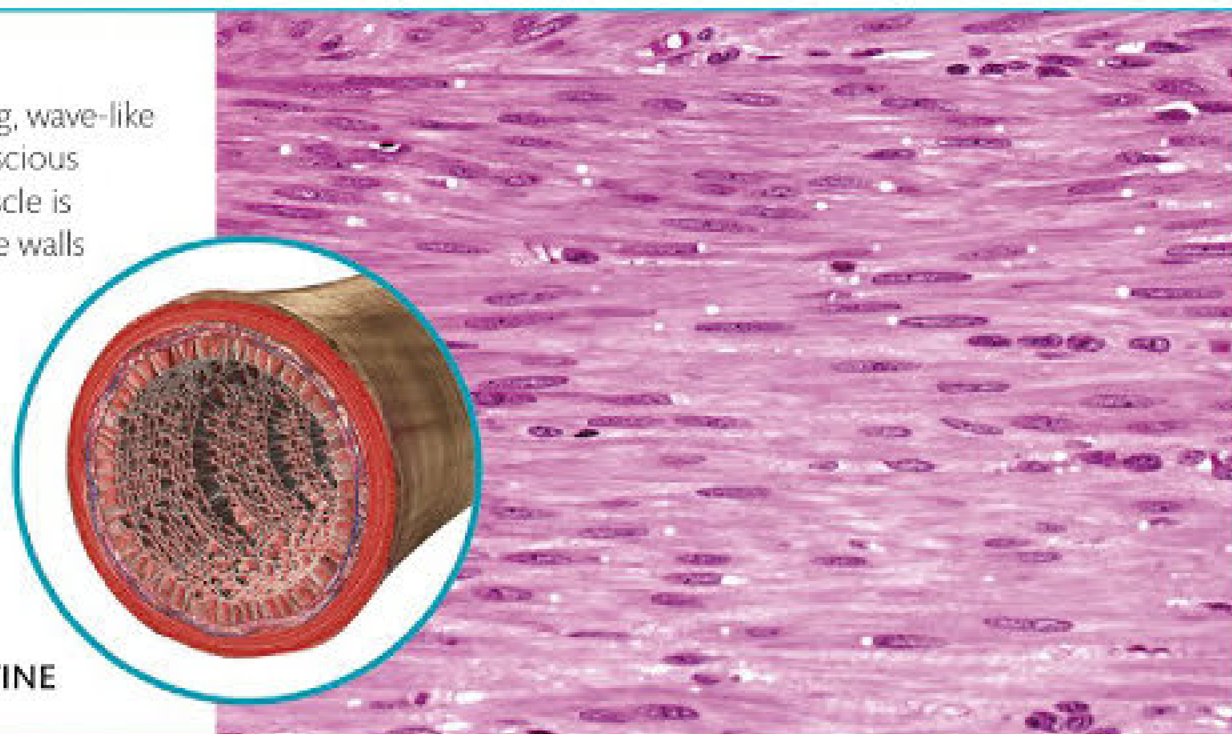
TISSUE TYPES

Cells often group together with their own kind to form tissues that carry out a specific function. However, not all cells within a tissue are necessarily identical. The four main types of tissue in the human body are muscle, connective tissue, nervous tissue, and epithelial tissue. Within these groups, different forms of these tissues can have very different appearances and functions. For example, blood, bone, and cartilage are all types of connective tissue, but so are fat layers, tendons, ligaments, and the fibrous tissue that holds organs and epithelial layers in place. Organs such as the heart and lungs are composed of several different kinds of tissue.

Skeletal muscle

This tissue performs voluntary movements of the limbs. Unlike smooth muscle, skeletal muscle cells are arranged into bundles of fibres, which connect to bones via tendons. They are packed with highly organized filaments that slide over one another to produce contractions.

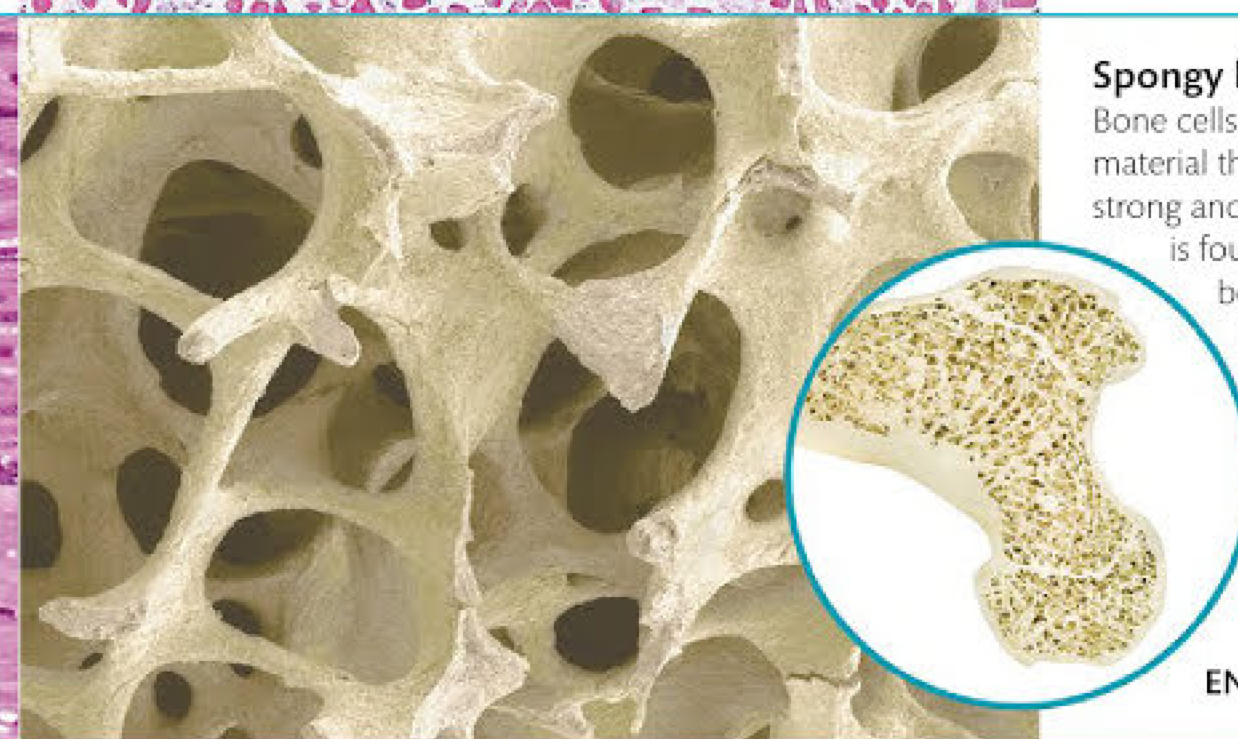
MUSCLE FIBRES



Smooth muscle

Able to contract in long, wave-like motions without conscious thought, smooth muscle is found in sheets on the walls of the blood vessels, stomach, intestines, and bladder. It is vital for maintaining blood pressure and for pushing food through the digestive system.

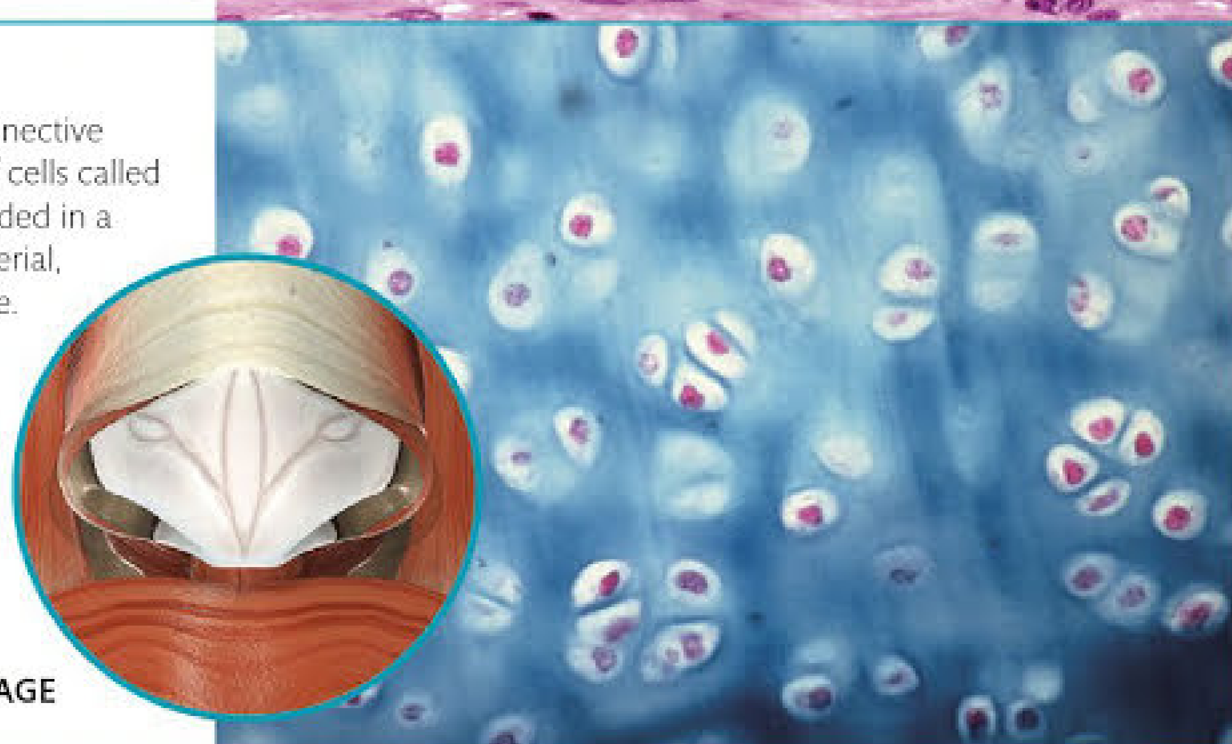
SMALL INTESTINE



Spongy bone

Bone cells secrete a hard material that makes bones strong and brittle. Spongy bone is found in the centre of bones, and is softer and weaker than the compact bone. The lattice-like spaces in spongy bone are filled with bone marrow or connective tissue.

END OF THE FEMUR



Cartilage

This stiff, rubbery, connective tissue is composed of cells called chondrocytes embedded in a matrix of gel-like material, which the cells secrete. Cartilage is found in the joints between bones, and in the ear and nose. The high water-content of cartilage makes it tough but flexible.

NOSE CARTILAGE

Loose connective tissue

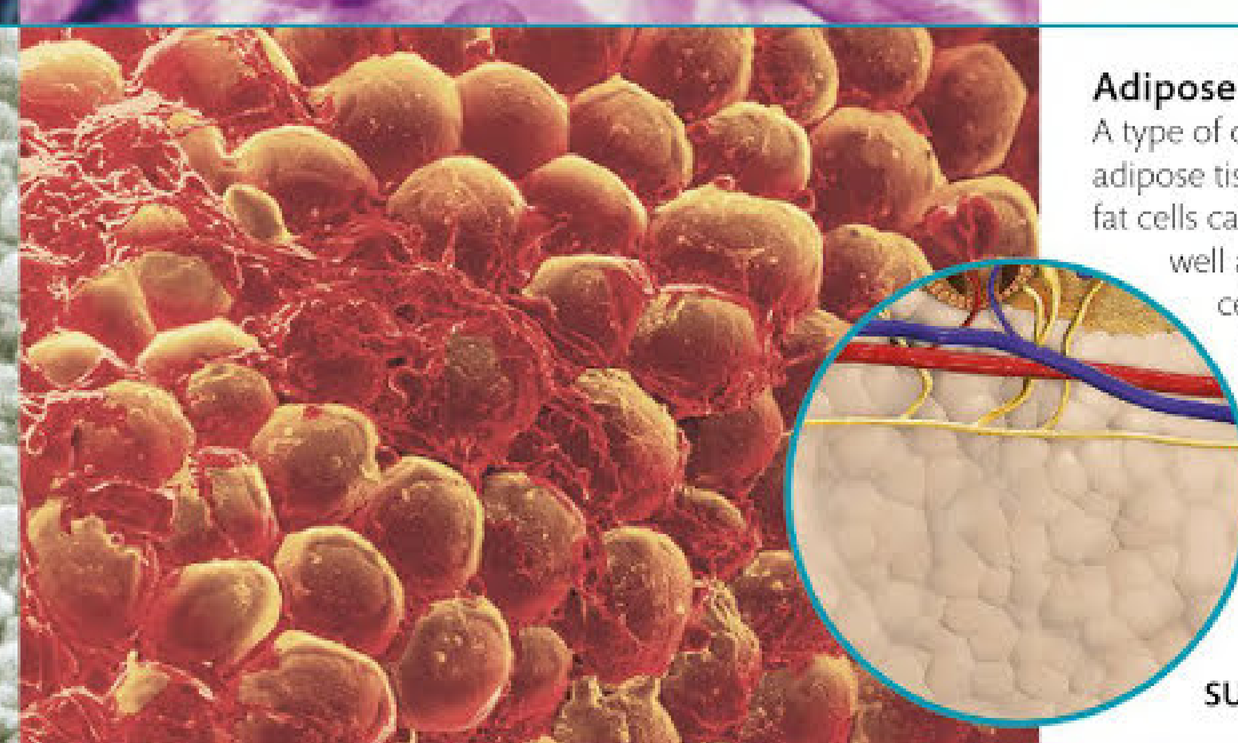
This type of tissue also contains cells called fibroblasts, but the fibres they secrete are loosely organized and run in random directions, making the tissue quite pliable. Loose connective tissue holds organs in place, and provides cushioning and support.

DERMAL TISSUE

Dense connective tissue

This contains fibroblast cells, which secrete the fibrous protein called type 1 collagen. The fibres are organized into a regular parallel pattern, making the tissue very strong. Dense connective tissue occurs in the base layer of skin, and forms structures such as ligaments and tendons.

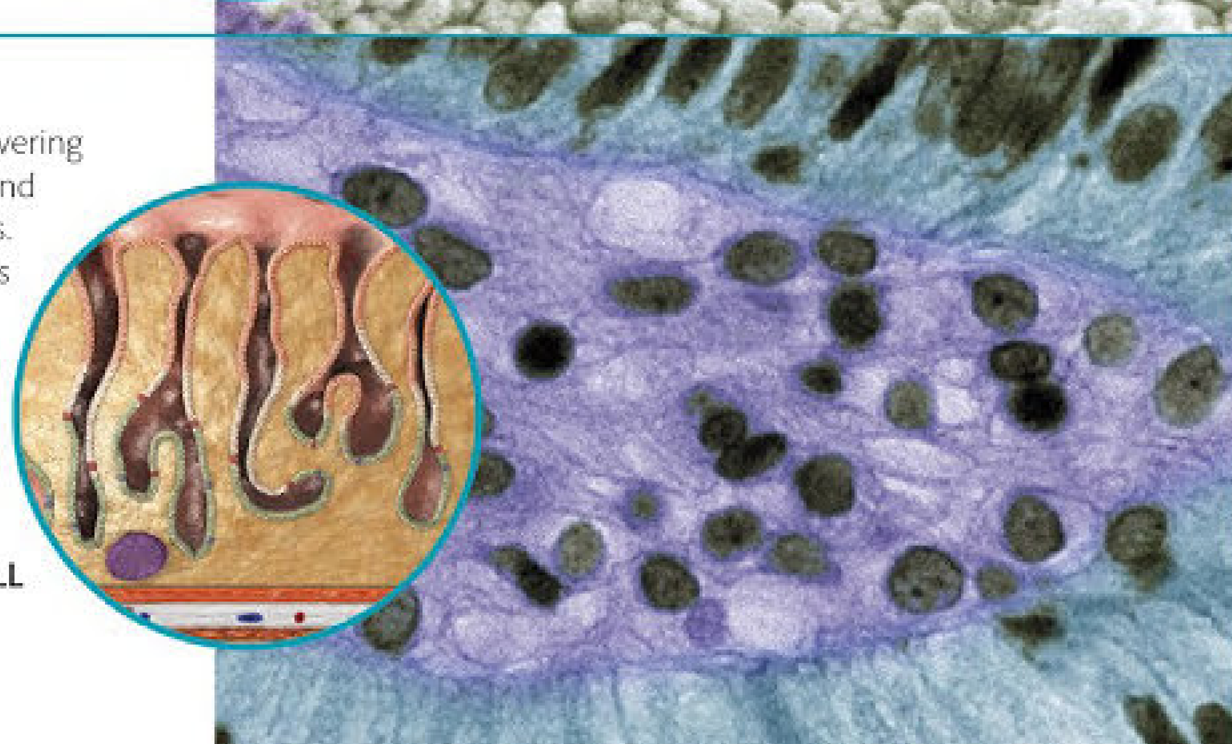
KNEE LIGAMENTS



Adipose tissue

A type of connective tissue, adipose tissue is composed of fat cells called adipocytes, as well as some fibroblast cells, immune cells, and blood vessels. Its main function is to act as an energy store, and to cushion, protect, and insulate the body.

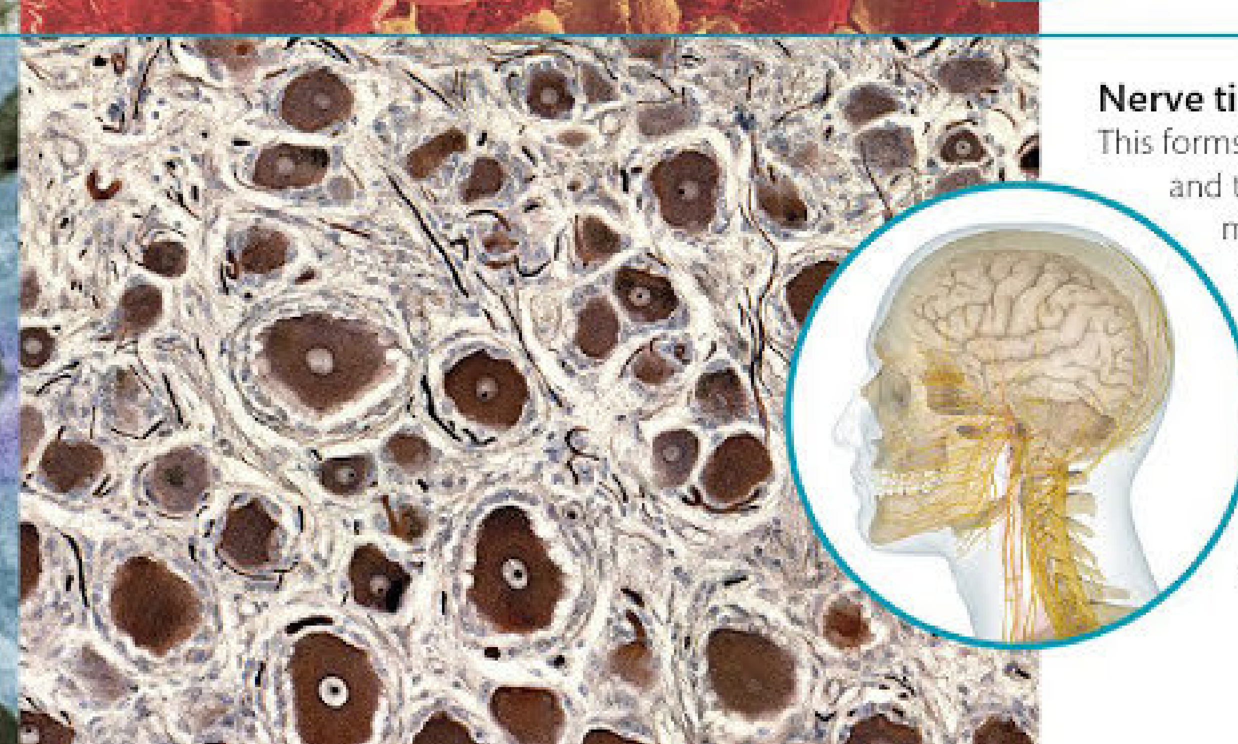
SUBCUTANEOUS FAT



Epithelial tissue

This tissue forms a covering or lining for internal and external body surfaces. Some epithelial tissues can secrete substances such as digestive enzymes; others can absorb substances like food or water.

STOMACH WALL



Nerve tissue

This forms the brain, spinal cord, and the nerves that control movement, transmit sensation, and regulate many body functions. It is mainly made up of networks of nerve cells (see opposite).

UPPER SPINAL CORD

BODY COMPOSITION

If the 75 trillion cells that make up the human body led an isolated, anarchic existence, it would be no more than a shapeless mass. Instead, those cells are precisely organized, taking their place within the hierarchical structure that is a fully functioning human being.

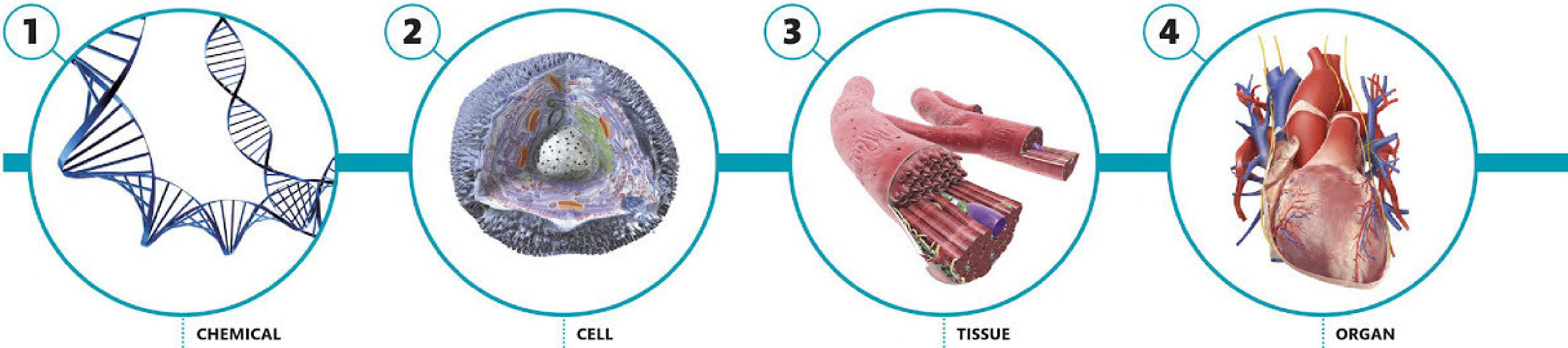
LEVELS OF ORGANIZATION

The overall organization of the human body can be visualized in the form of a hierarchy of levels, as shown below. At its lowest level are the body's basic chemical constituents. As the hierarchy ascends, the number of components in each of its levels – cells, tissues, organs, and systems – decreases progressively, culminating in a single organism at its apex.

More than 20 chemical elements are found in the body, with just four – oxygen, carbon, hydrogen, and nitrogen – comprising around 96 per cent of body mass. Each element is composed of atoms, the tiny building blocks of matter, of which there are quadrillions in the body. Atoms of different elements generally combine with others to form molecules such as water (hydrogen and oxygen atoms), and the many organic molecules, including proteins and DNA. These organic molecules are constructed around a "skeleton" of linked carbon atoms.

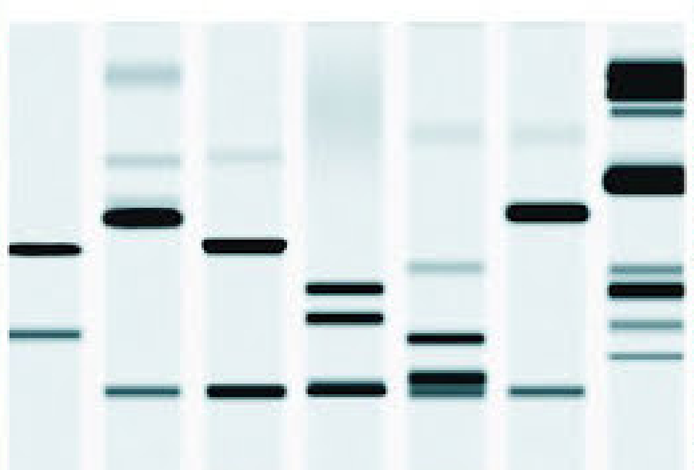
Cells are the smallest of all living units. They are created from chemical molecules, which shape their outer covering and inner structures, and drive the metabolic reactions that keep them alive. There are more than 200 types of cell in the human body, each adapted to carry out a specific role, but not in isolation (see p.22). Groups of similar cells with the same function form and cooperate within communities called tissues. The body's four basic tissue types are epithelial, which covers surfaces and lines cavities; connective, which supports and protects body structures; muscular, which creates movement; and nervous, which facilitates rapid internal communication (see p.23).

Organs, such as the liver, brain, and heart are discrete structures built from at least two types of tissue. Each has a specialized role or roles that no other organ can perform. Where organs collectively have a common purpose, they are linked together within a system, such as the cardiovascular system, which transports oxygen and nutrients around the body, and which is overviewed here. Integrated and interdependent, the body's systems combine to produce a complete human (see pp.26–27).



CHEMICALS

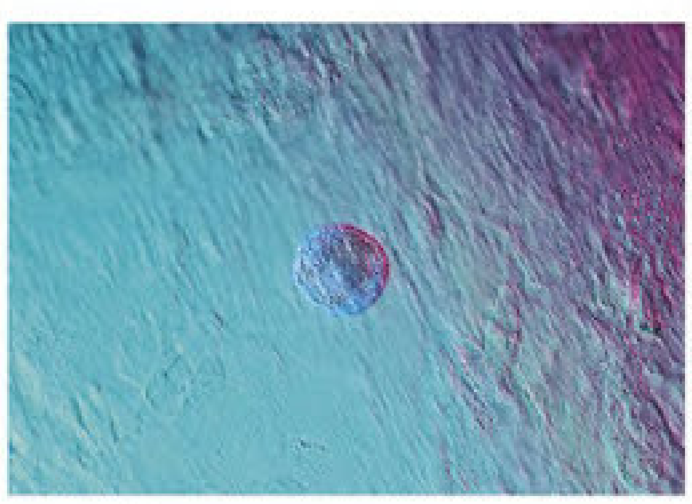
Key among the chemicals inside all cells is DNA (see pp.16–17). Its long molecules resemble twisted ladders, their "rungs" made from bases that provide the instructions for making proteins. These, in turn, perform many roles, from building cells to controlling chemical reactions.



DNA sequencing
The bases of DNA can be isolated and separated by scientists. Such sequencing allows them to "read" the instructions coded within the molecules.

CELLS

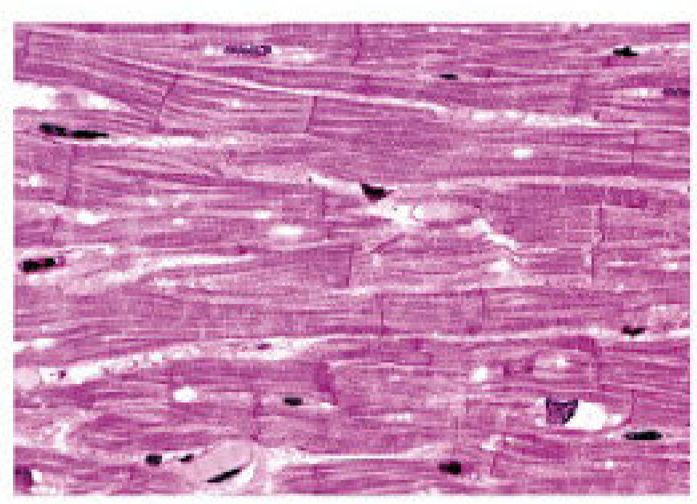
While cells may differ in size and shape according to their function (see p.22), all possess the same basic features: an outer boundary membrane; organelles, floating within a jelly-like cytoplasm; and a nucleus, which contains DNA (see pp.20–21). Cells are the body's most basic living components.



Stem cells
These unspecialized cells have the unique ability to differentiate, or develop, into a wide range of specialized tissue cells such as muscle, brain, or blood cells.

HEART TISSUE

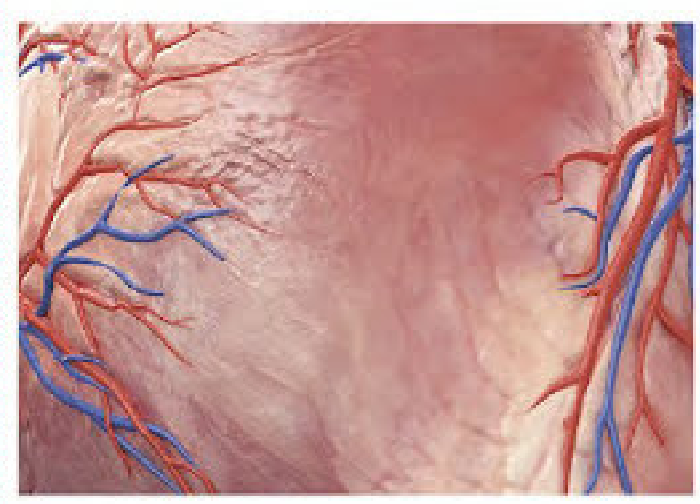
One of three types of muscle tissue, cardiac muscle is found only in the walls of the heart. Its constituent cells contract together to make the heart squeeze and pump, and, working as a network, conduct the signals that ensure that the pumping is precisely coordinated.



Muscle fibres
The cells, or fibres, in cardiac tissue are long and cylindrical and have branches that form junctions with other cells to create an interconnected network.

HEART

Like other organs, the heart is made of several types of tissue, including cardiac muscle tissue. Among the other types present are connective tissues, which protect the heart and hold the other tissues together, and epithelial tissues, which line its chambers and cover its valves.

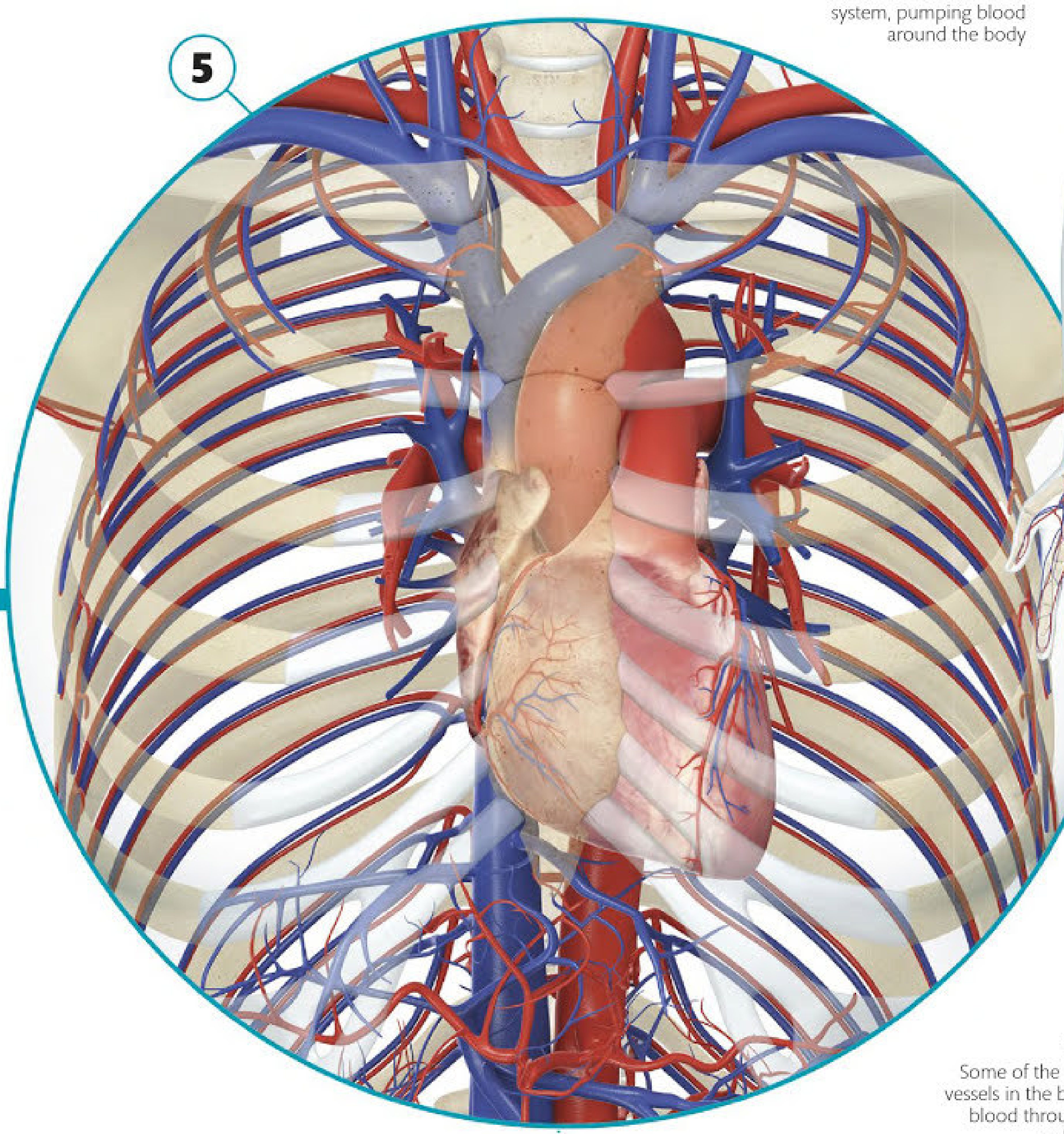


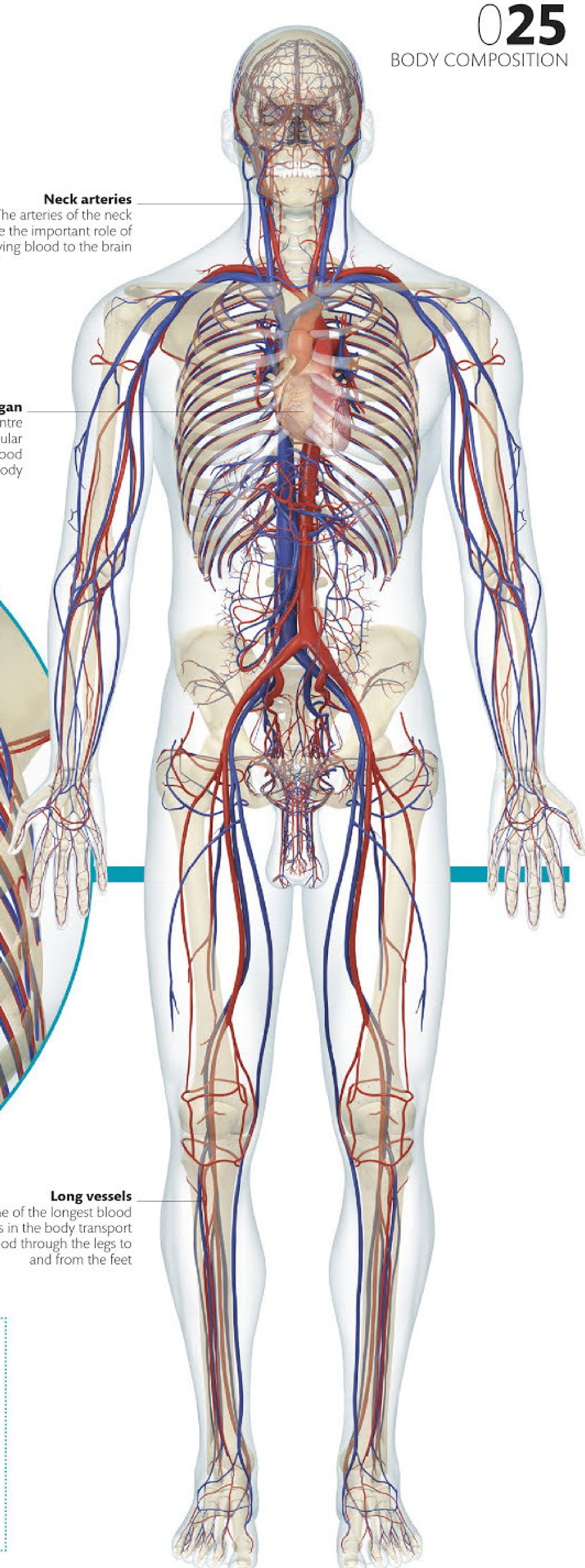
Complex structure
The heart has a complex structure. Internally it has four chambers through which blood is pumped by its muscular walls. It is connected to a vast network of veins and arteries.

75 trillion

The total **number of cells** that make up the average **human body**.

5





BODY SYSTEM

CARDIOVASCULAR SYSTEM

The heart, blood, and the blood vessels – arteries (shown in red) and veins (blue) – that carry blood, make up the cardiovascular system. As the body's key transport system, its basic function is to pump blood around the body, delivering essentials to, and removing waste from, the tissue cells that comprise the body's other ten systems: the integumentary (skin, nails, and hair), skeletal, muscular, nervous, endocrine (hormonal), lymphatic, respiratory, digestive, urinary, and reproductive systems. At the same time, the cardiovascular system depends on those other systems to function normally. The respiratory system, for example, provides the blood with oxygen, the nervous system regulates the rate at which the heart beats, and the digestive system supplies the body with energy-rich fuel (see pp.26–27).

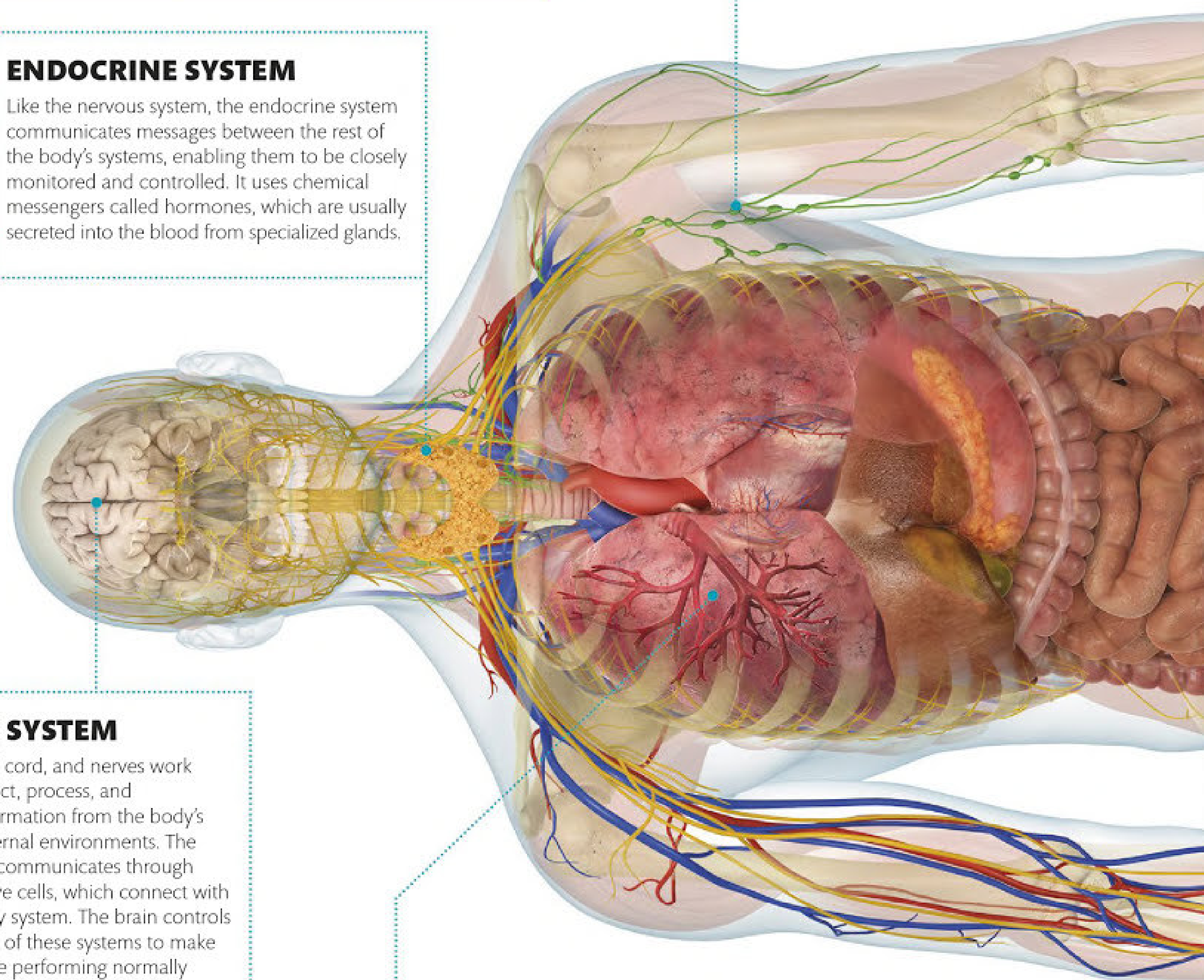
BODY SYSTEMS

The human body can do many different things. It can digest food, think, move, even reproduce and create new life. Each of these tasks is performed by a different body system – a group of organs and tissues working together to complete that task. However, good health and body efficiency rely on the different body systems working together in harmony.

SYSTEM INTERACTION

Think about what your body is doing right now. You are breathing, your heart is beating, and your blood pressure is under control. You are also conscious and alert. If you were to start running, specialized cells called chemoreceptors would detect a change in your body's metabolic requirements and signal to the brain to release adrenaline. This would in turn signal to the heart to beat faster, boosting blood circulation and enabling more oxygen to reach the muscles. After a while, cells in the hypothalamus might detect an increase in body temperature and send a signal to the skin to produce sweat, which would evaporate and cool you down.

The individual systems of the body are linked together by a vast network of positive and negative feedback loops. These use signalling molecules such as hormones and electrical impulses from nerves to communicate and maintain a state of equilibrium. Here, the basic components and functions of each system are described, and examples of system interactions are examined.



LYMPHATIC SYSTEM

The lymphatic system is composed of a network of vessels and nodes, which drain fluid from blood capillaries and return it to the veins. Its main functions are to maintain fluid balance within the cardiovascular system and to distribute immune cells from the immune system around the body. Movement of lymph fluid relies on the contraction and relaxation of smooth muscles within the muscular system.

ENDOCRINE SYSTEM

Like the nervous system, the endocrine system communicates messages between the rest of the body's systems, enabling them to be closely monitored and controlled. It uses chemical messengers called hormones, which are usually secreted into the blood from specialized glands.

NERVOUS SYSTEM

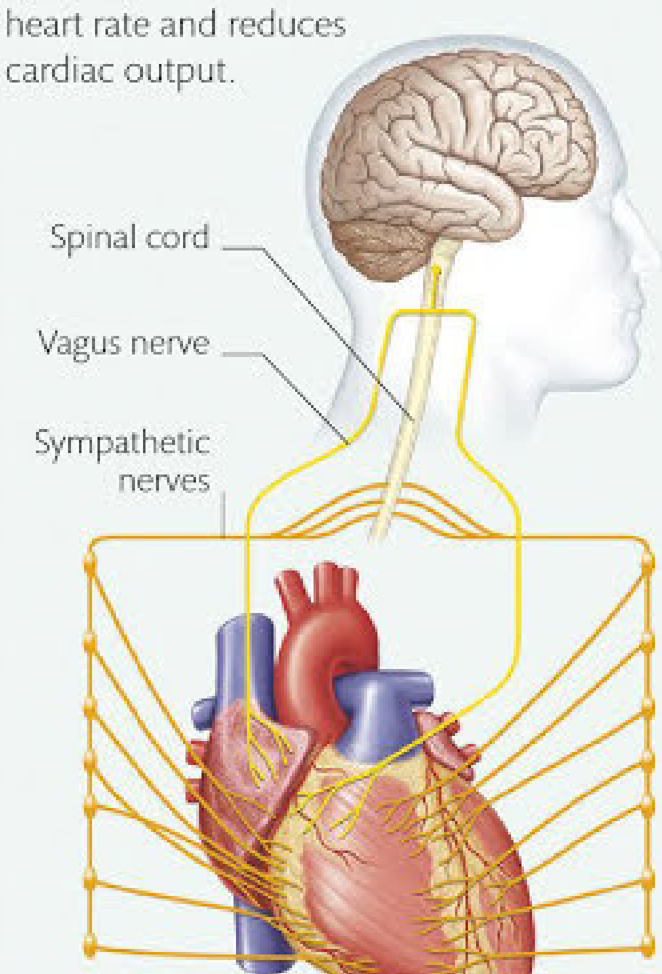
The brain, spinal cord, and nerves work together to collect, process, and disseminate information from the body's internal and external environments. The nervous system communicates through networks of nerve cells, which connect with every other body system. The brain controls and monitors all of these systems to make sure that they are performing normally and receiving everything they need.

RESPIRATORY SYSTEM

Every cell in the body needs oxygen and must get rid of the waste product carbon dioxide in order to function – regardless of which body system it belongs to. The respiratory system allows this to happen by breathing air into the lungs, where the passive exchange of these molecules occurs between the air and blood. The cardiovascular system transports oxygen and carbon dioxide between the cells and the lungs.

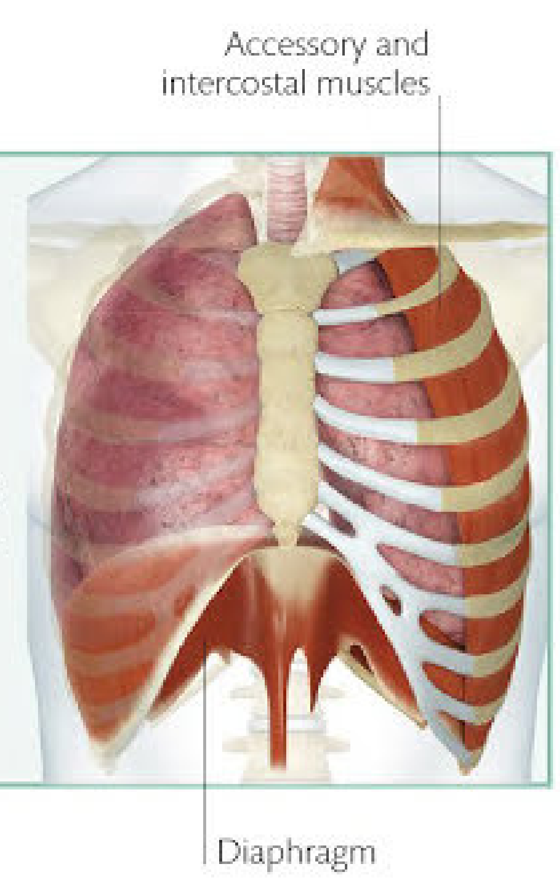
CONTROLLING THE HEART

Working together, nerves of the sympathetic and parasympathetic nervous systems regulate the heart and cardiac output (see p.353). Sympathetic nerves release chemicals that increase heart rate and the force of cardiac muscle contractions. The vagus nerve, from the parasympathetic system, releases a chemical that slows the heart rate and reduces cardiac output.



BREATHING IN AND OUT

The mechanics of breathing rely upon an interaction between the respiratory and muscular systems. Together with three accessory muscles, the intercostal muscles and the diaphragm contract to increase the volume of the chest cavity (see pp.342–43). This forces air down into the lungs. A different set of muscles is used during forced exhalation. These rapidly shrink the chest cavity, forcing air out of the lungs.



DIGESTIVE SYSTEM

As well as oxygen, every cell needs energy in order to function. The digestive system processes and breaks down the food we eat so that a variety of nutrients can be absorbed from the intestines into the circulatory system. These are then delivered to the cells of every body system in order to provide them with energy.

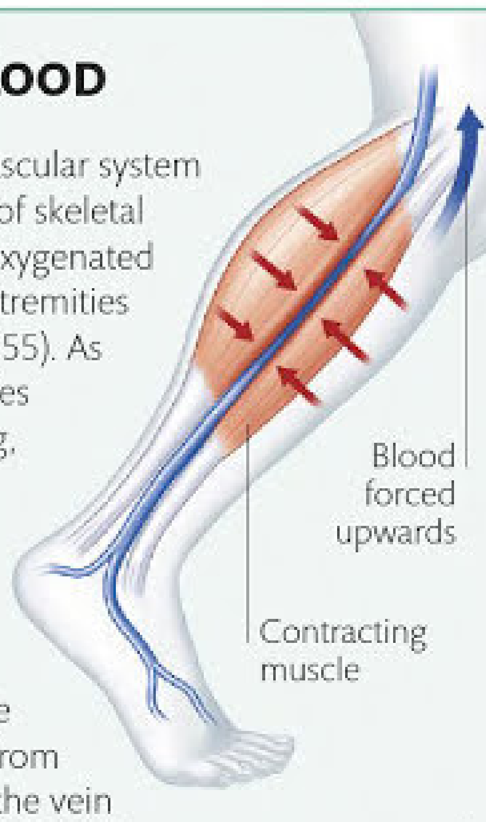
MUSCULAR SYSTEM

The muscular system is made up of three types of muscle: skeletal, smooth, and cardiac. It is responsible for generating movement – both of the limbs and within the other body systems. For example, smooth muscle aids the digestive system by helping to propel food down the oesophagus and through the stomach, intestines, and rectum. And the respiratory system could not function without the muscles of the thorax contracting to fill the lungs with air (see opposite).

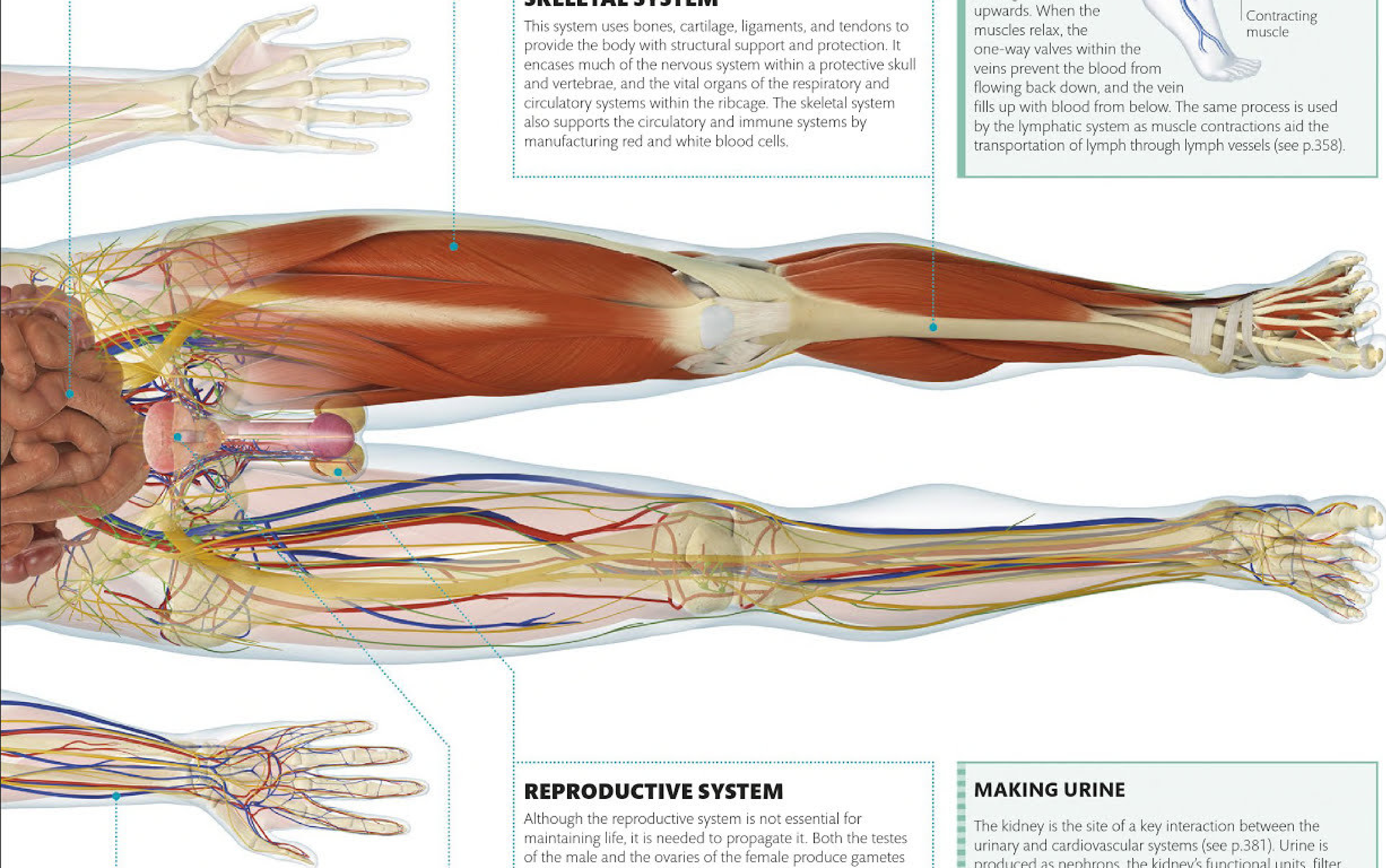
SKELETAL SYSTEM

This system uses bones, cartilage, ligaments, and tendons to provide the body with structural support and protection. It encases much of the nervous system within a protective skull and vertebrae, and the vital organs of the respiratory and circulatory systems within the ribcage. The skeletal system also supports the circulatory and immune systems by manufacturing red and white blood cells.

CIRCULATING BLOOD



The veins of the cardiovascular system rely on the direct action of skeletal muscles to transport deoxygenated blood from the body's extremities back to the heart (see p.355). As shown here, in the muscles and veins of the lower leg, muscle contractions compress nearby veins, forcing the blood upwards. When the muscles relax, the one-way valves within the veins prevent the blood from flowing back down, and the vein fills up with blood from below. The same process is used by the lymphatic system as muscle contractions aid the transportation of lymph through lymph vessels (see p.358).



CARDIOVASCULAR SYSTEM

The cardiovascular system uses blood to carry oxygen from the respiratory system and nutrients from the digestive system to cells of all the body's systems. It also removes products from these cells. At the centre of the cardiovascular system lies the muscular heart, which pumps the blood through the blood vessels.

REPRODUCTIVE SYSTEM

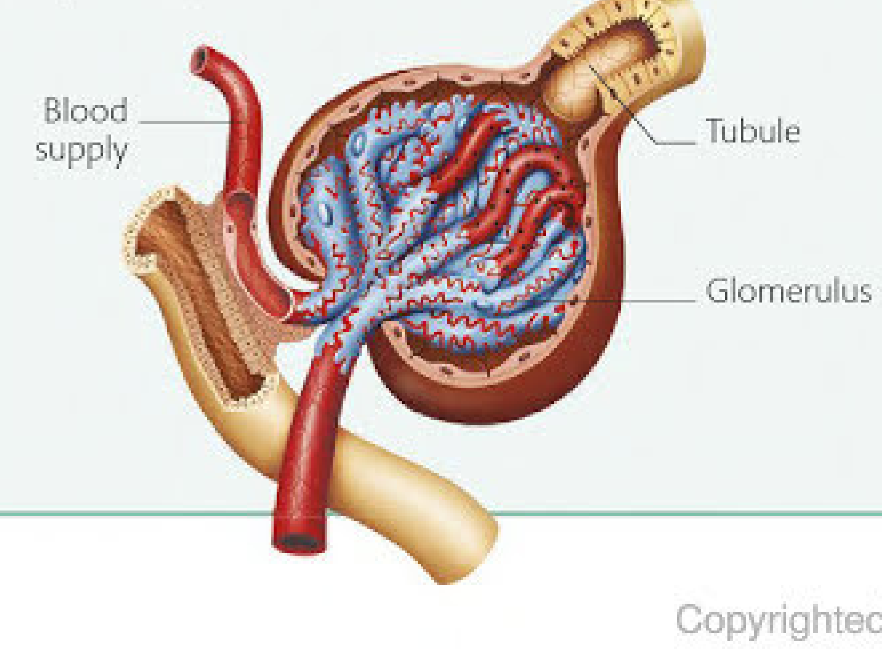
Although the reproductive system is not essential for maintaining life, it is needed to propagate it. Both the testes of the male and the ovaries of the female produce gametes in the form of sperm and eggs, which fuse to create an embryo. The testes and ovaries also produce hormones including oestrogen and testosterone, so also form part of the endocrine system.

URINARY SYSTEM

The urinary system filters and removes many of the waste products generated by the other body systems, such as the digestive system. It does this by filtering blood through the kidneys and producing urine, which is collected in the bladder and then excreted through the urethra (see right). The kidneys also help maintain blood pressure within the cardiovascular system by ensuring that the correct amount of water is reabsorbed by the blood.

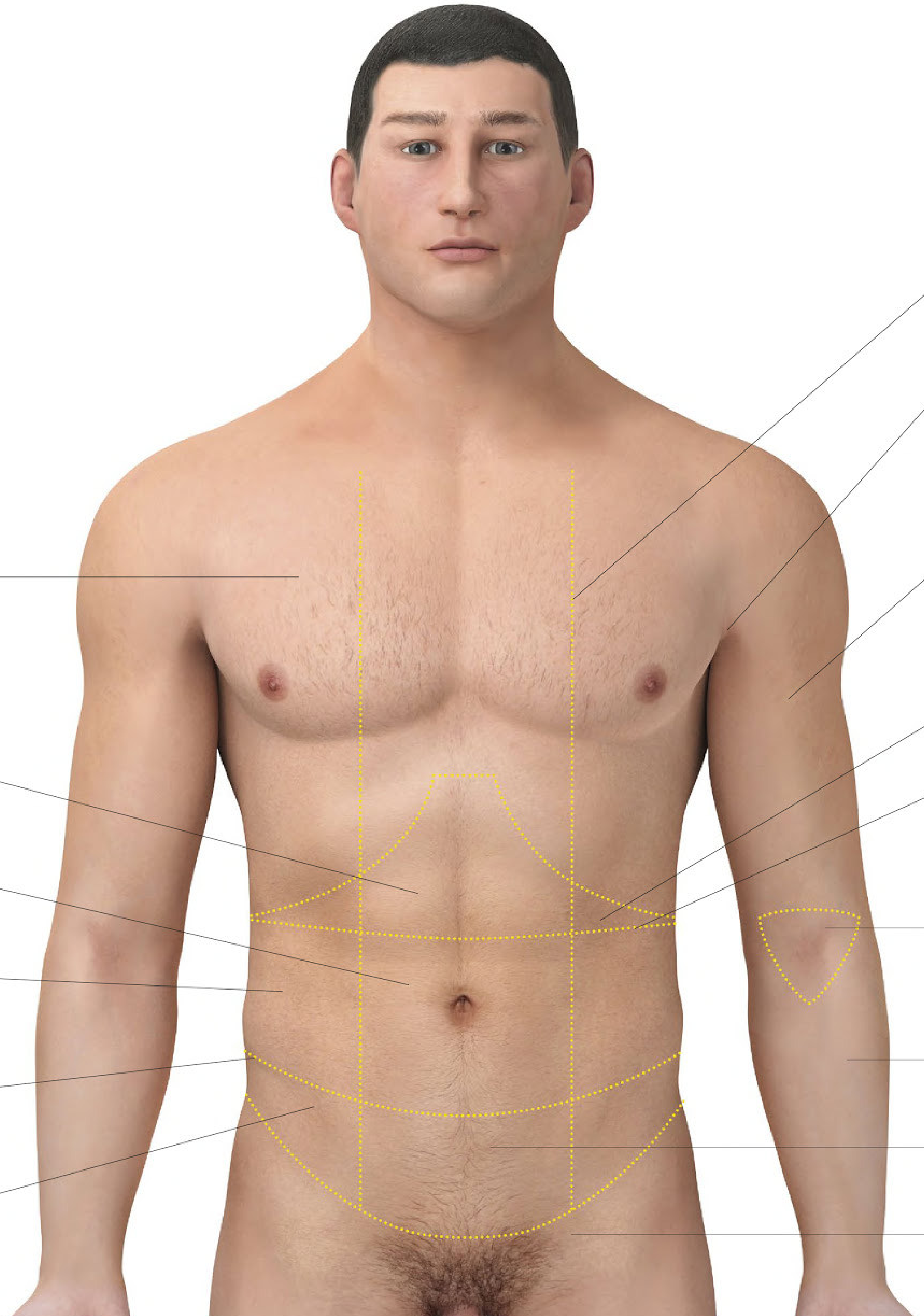
MAKING URINE

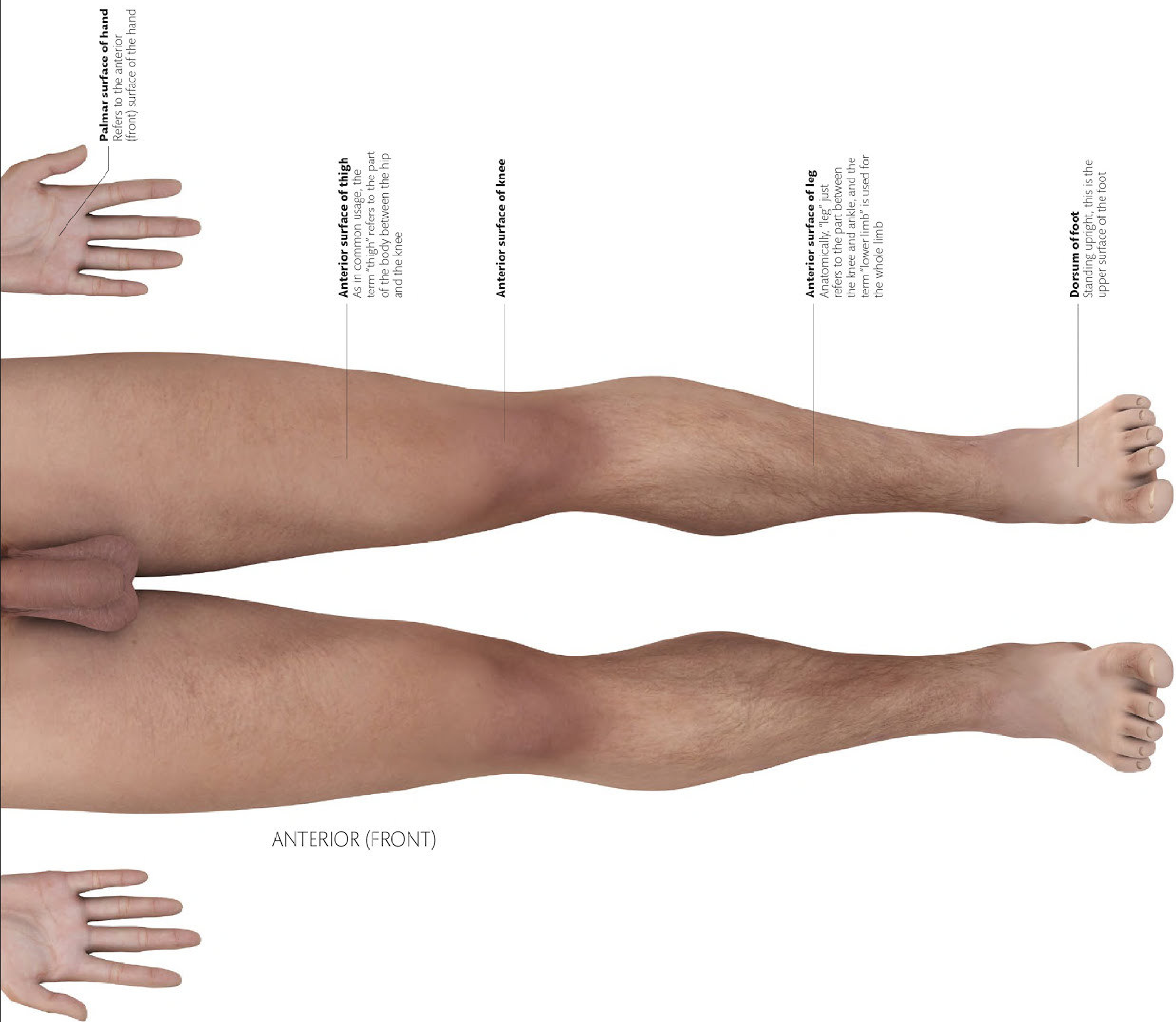
The kidney is the site of a key interaction between the urinary and cardiovascular systems (see p.381). Urine is produced as nephrons, the kidney's functional units, filter the blood. Within each nephron, blood is forced through a glomerulus (cluster of capillaries) and filtered by its sieve-like membranes. The filtrate passes through a series of tubules through which some glucose, salts, and water are reabsorbed into the blood stream. What remains, including urea and waste products, is excreted as urine.



anatomy

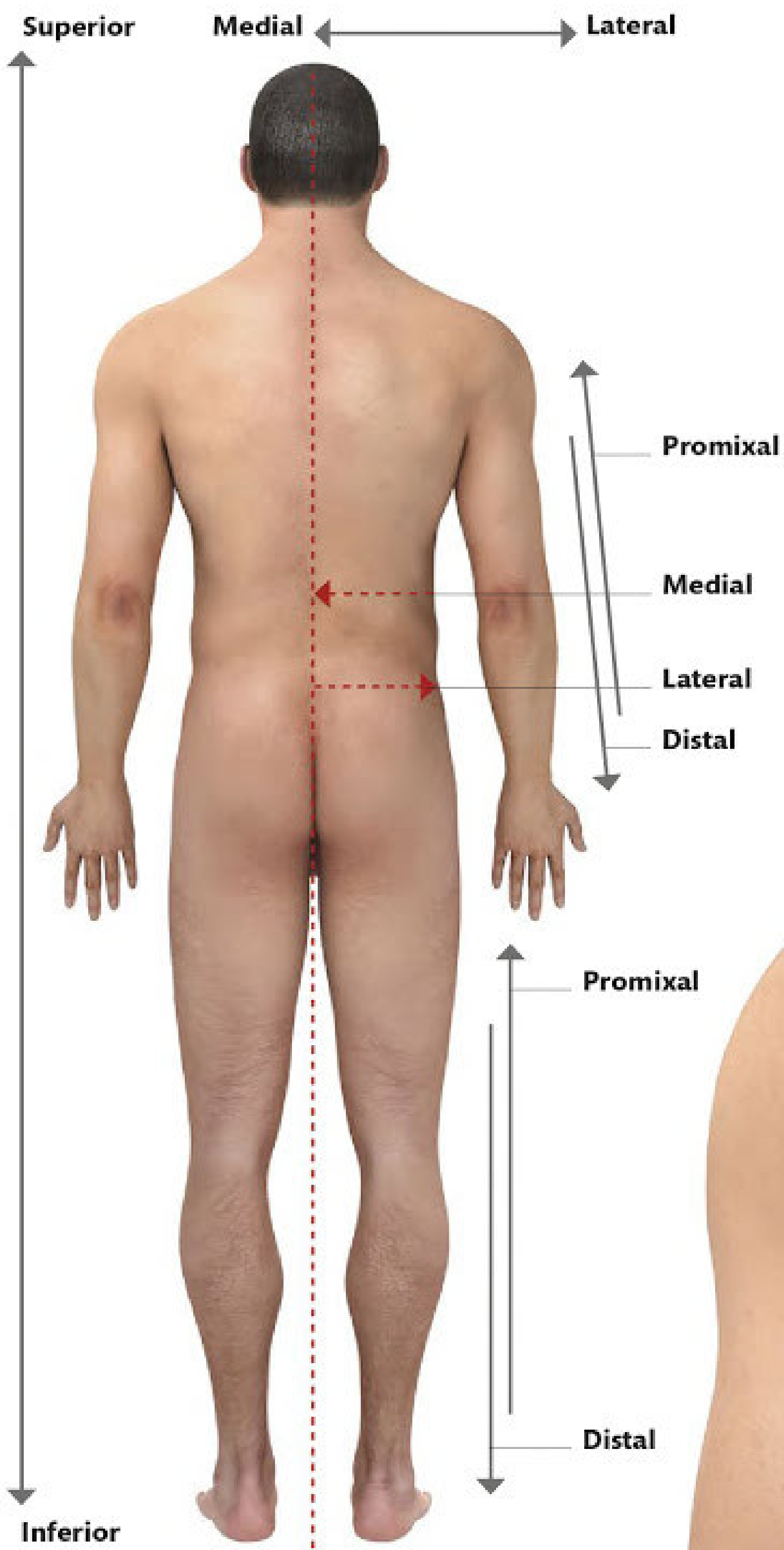
The human body is a "living machine" with many complex working parts. To understand how the body functions it is vital to know how it is assembled. Advances in technology allow us to strip back the outer layers and reveal the wonders inside.


Midclavicular line
A vertical line running down from the midpoint of each clavicle
Axilla
Loosely, the armpit; more precisely, the pyramid-shaped part of the body between the upper arm and the side of the thorax. Floored by the skin of the armpit, it reaches up to the level of the clavicle, top of the scapula, and first rib
Anterior surface of arm
"Anterior" means front, and always refers to the body when it is in the "anatomical position" shown here. Strictly speaking, "arm" only relates to the part of the upper limb between the shoulder and the elbow
Hypochondrial region
The abdominal region under the ribs on each side
Transpyloric plane
Horizontal plane joining the tips of the ninth costal cartilages, at the margins of the ribcage; also level with the first lumbar vertebra and the pylorus of the stomach
Cubital fossa
Triangular area anterior to (in front of) the elbow, bounded above by a line between the bony epicondyles of the humerus on each side, and framed below by the pronator teres and brachioradialis muscles
Anterior surface of forearm
Anatomically – and colloquially – the forearm is the part of the body between the elbow and the wrist
Suprapubic region
The part of the abdomen that lies just above the pubic bones of the pelvis
Inguinal region
Refers to the groin area, where the thigh meets the trunk
Pectoral region
The chest; sometimes used to refer to just the upper chest, where the pectoral muscles lie
Epigastric region
Area of the abdominal wall above the transpyloric plane, and framed by the diverging margins of the ribcage
Umbilical region
Central region of the abdomen, around the umbilicus (navel)
Lumbar region
Refers to the sides of the abdominal wall, between the transpyloric and intertubercular planes
Intertubercular plane
This plane passes through the iliac tubercles – bony landmarks on the pelvis – and lies at the level of the fifth lumbar vertebra
Iliac region
The area below the intertubercular plane and lateral to (to the side of) the midclavicular line; may also be referred to as the "iliac fossa"



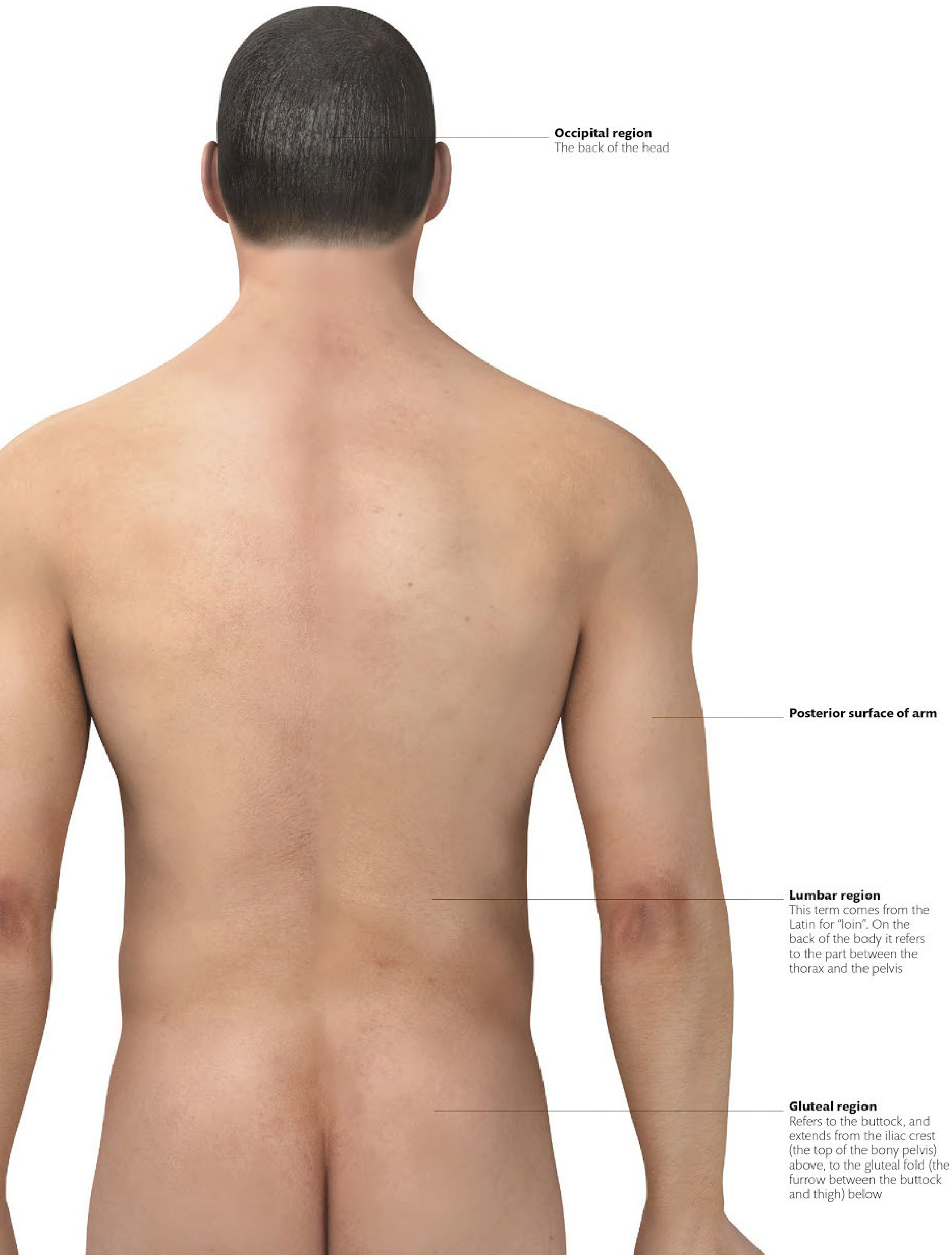
ANATOMICAL TERMINOLOGY

Anatomical language allows us to describe the structure of the body clearly and precisely. It is useful to be able to describe areas and parts, as well as the planes and lines used to map out the body, in much more accurate and detailed terms than would be possible colloquially. Rather than recording that a patient had a tender area "somewhere on the left side of the belly", a doctor can be more precise and say that the patient's painful area was "the left lumbar region", and other doctors will know exactly what is meant.



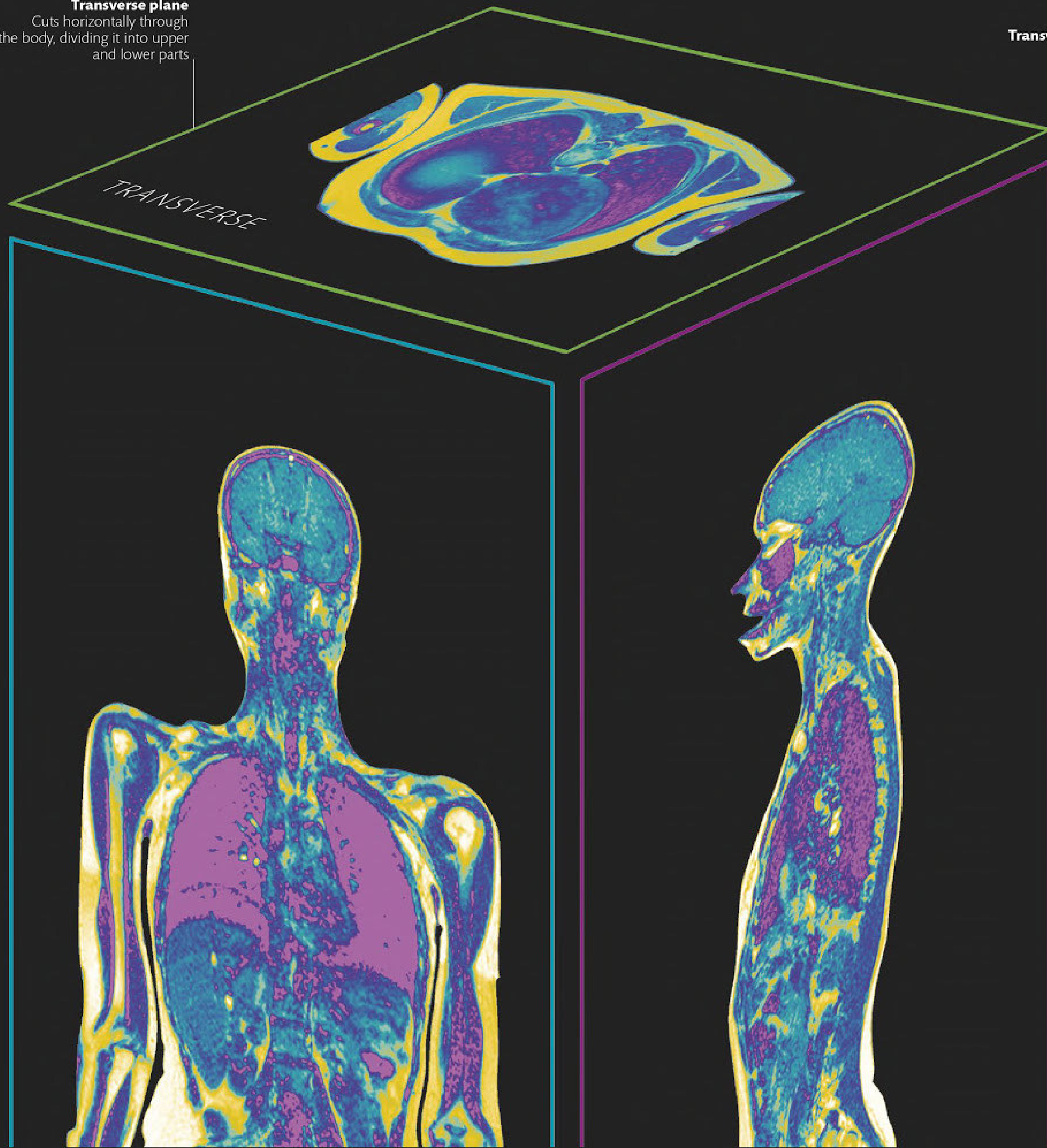
Relative terms

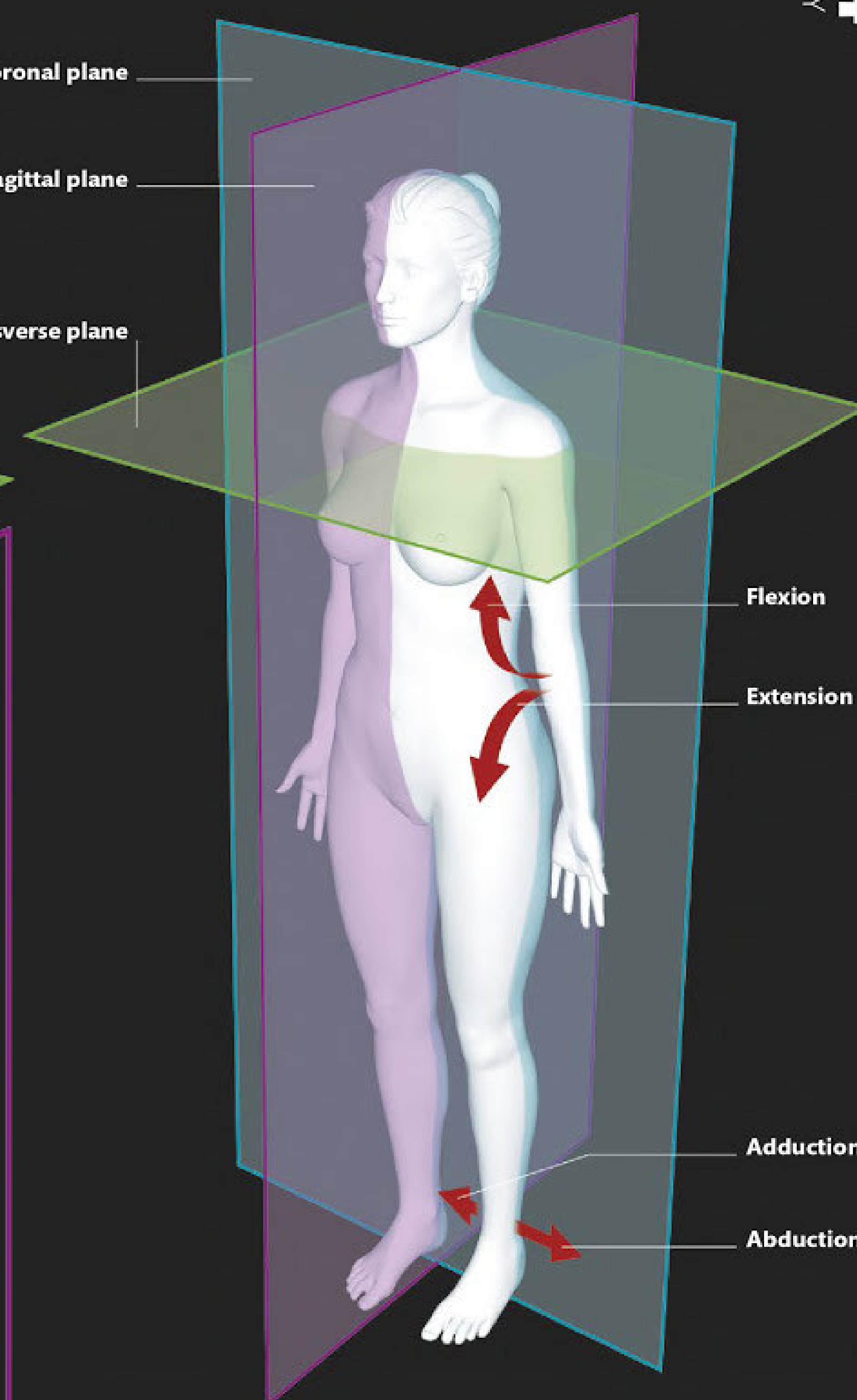
As well as defining parts of the body, anatomical terminology also allows us to precisely and concisely describe the relative positions of various structures. These terms always refer back to relative positions of structures when the body is in the "anatomical position" (shown above). Medial and lateral describe positions of structures towards the midline, or towards the side of the body, respectively. Superior and inferior refer to vertical position – towards the top or bottom of the body. Proximal and distal are useful terms, describing a relative position towards the centre or periphery of the body.



ANATOMICAL TERMINOLOGY

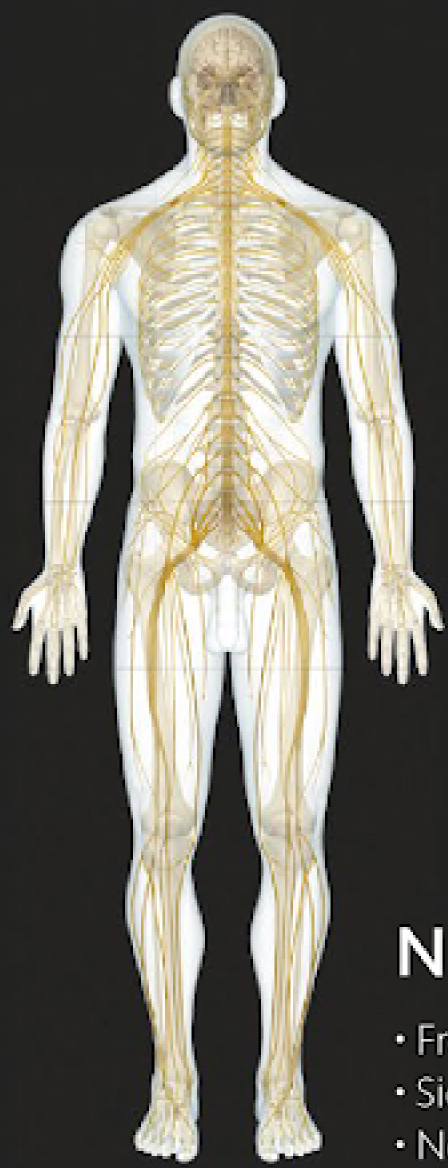
The illustration shows some of the terms used for the broader regions of the back of the body, and those used to describe relative position. Where our everyday language may have names for larger structures – such as the shoulder or hip – it soon runs out when it comes to finer detail. So anatomists have created names for specific structures, usually derived from Latin or Greek. The pages that follow show the detailed structure of the head and neck, thorax, abdomen, and limbs. The anatomical language is there to illuminate rather than confuse. Some of the terms may seem unfamiliar and even unnecessary at first, but they enable precise description and clear communication.





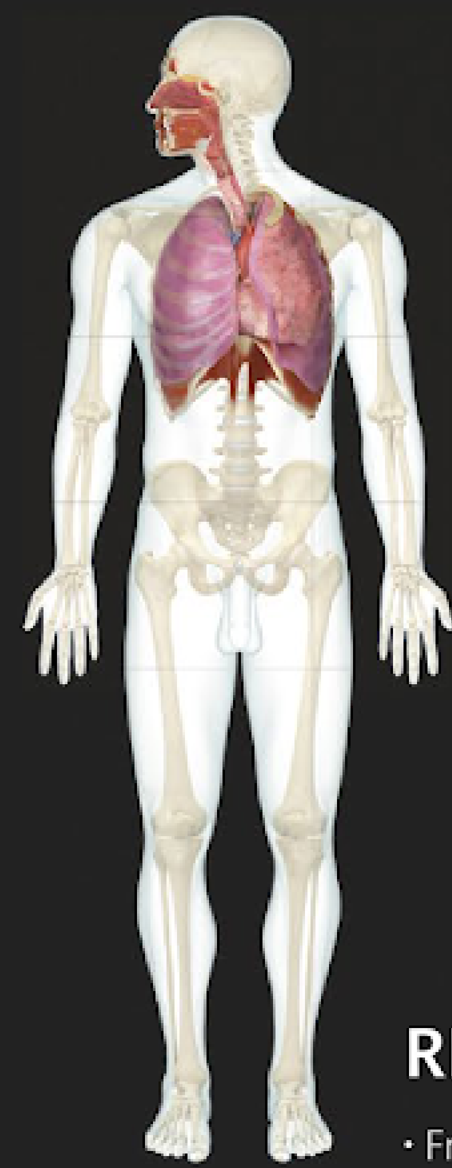
Anatomical terms for movement
The diagram above shows the three planes – sagittal, coronal, and transverse – cutting through a body, and to the left are examples of real MRI scans demonstrating views along those planes. The above image also illustrates some medical terms that are used to describe certain movements of body parts: flexion decreases the angle of a joint, such as the elbow, while extension increases it; adduction draws a limb closer to the sagittal plane, while abduction moves it further away from that plane.

BODY SYSTEMS



NERVOUS

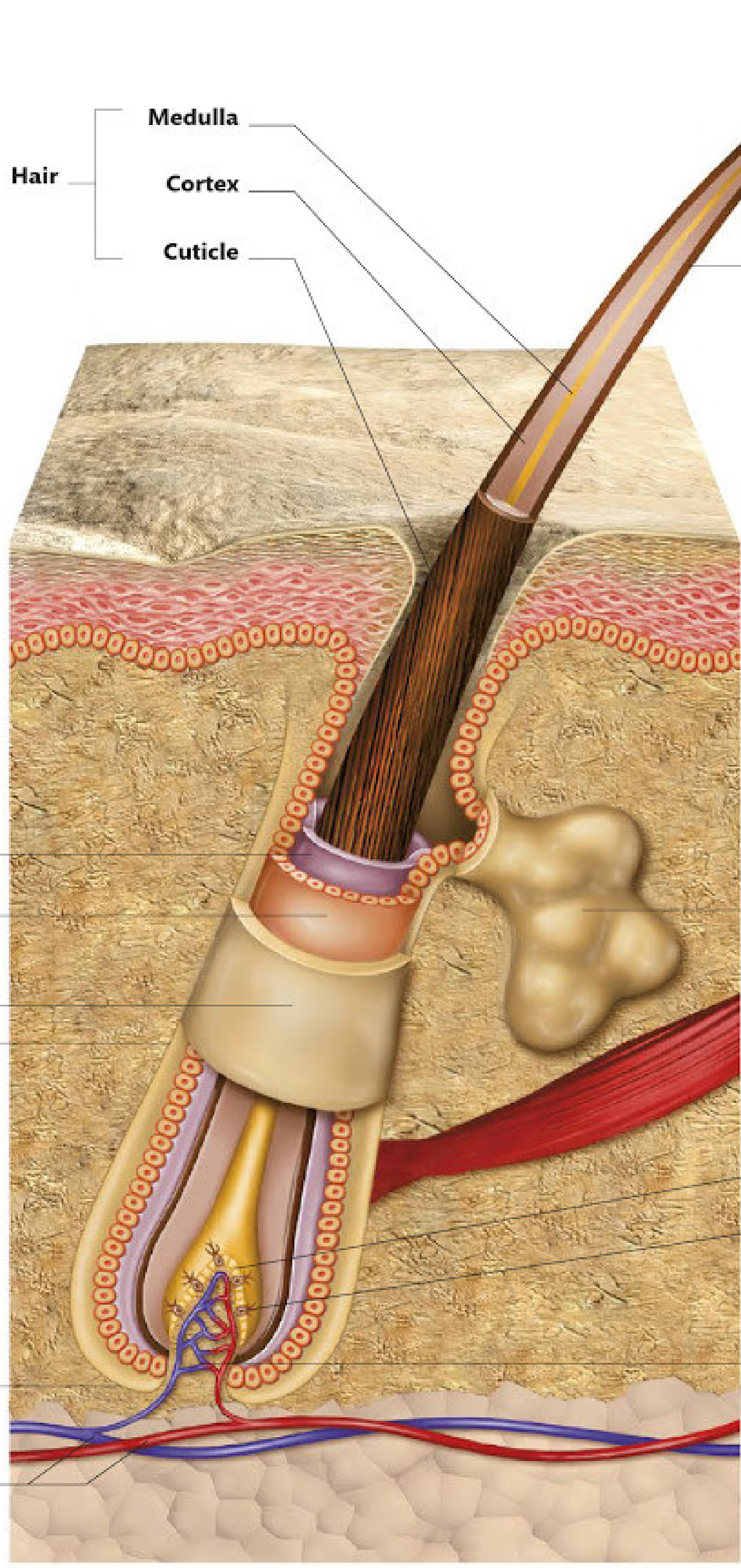
- Front pp.60–61
- Side pp.62–63
- Nerve structure pp.64–65



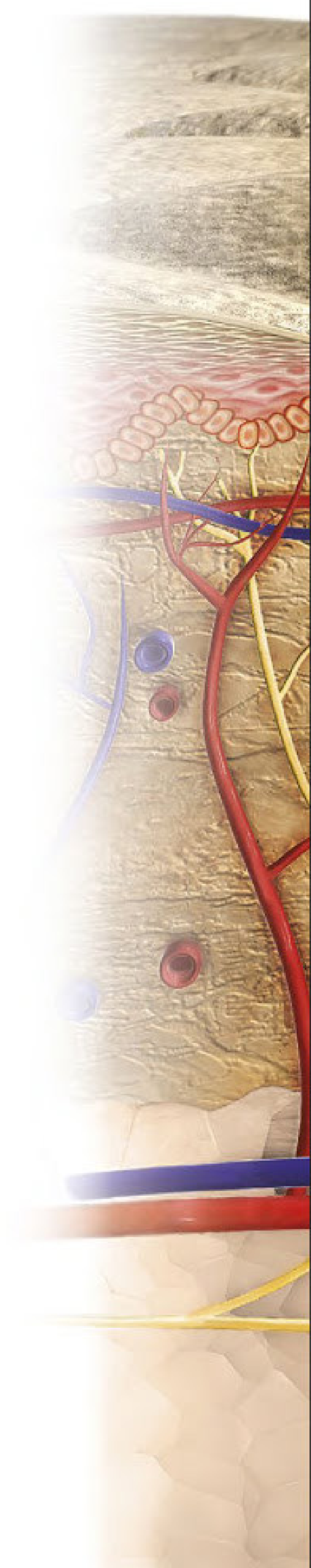
RESPIRATORY

- Front pp.66–67

The body has 11 main body systems. None of these works in isolation, for example the endocrine and nervous systems work together closely, as do the respiratory and cardiovascular systems. However, in order to understand how the body is put together, it helps to break it down system by system. In this part of the **Anatomy** chapter, an overview of the basic anatomy of each of the 11 systems is given before being broken down into more detail in the **Anatomy Atlas**.



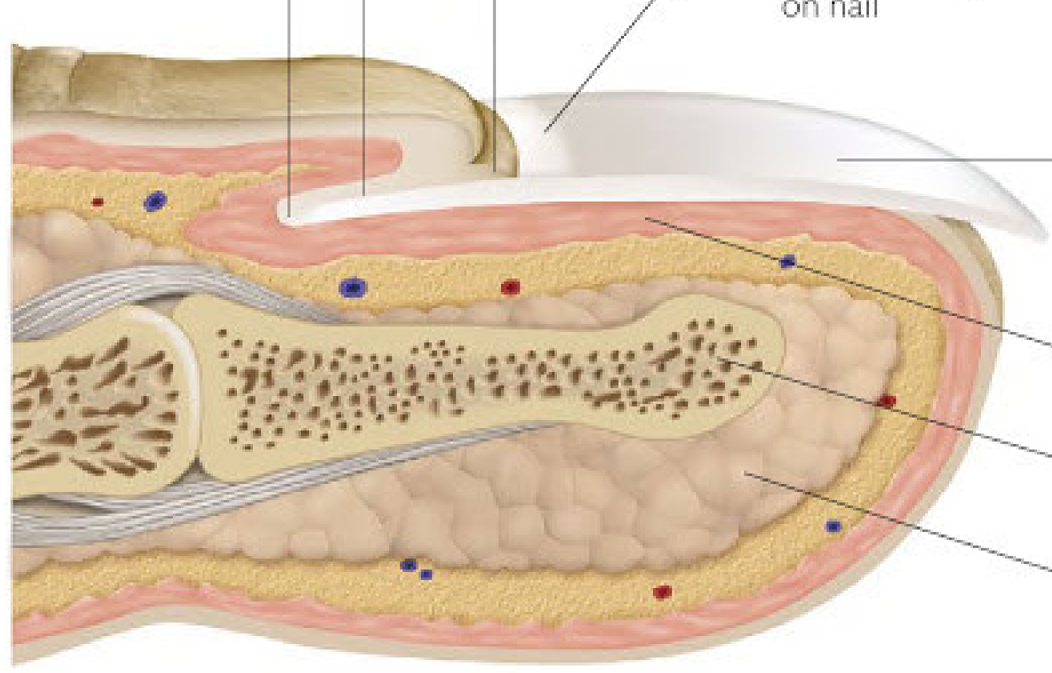
SECTION THROUGH A HAIR



SKIN, HAIR, AND NAIL STRUCTURE

The skin is our largest organ, weighing about 4kg (9lb) and covering an area of about 2 square metres (21 square feet). It forms a tough, waterproof layer, which protects us from the elements. However, it offers much more than protection: the skin lets us appreciate the texture and temperature of our environment; it regulates body temperature; it allows excretion in sweat, communication through blushing, gripping due to ridges on our fingertips, and vitamin D production in sunlight.

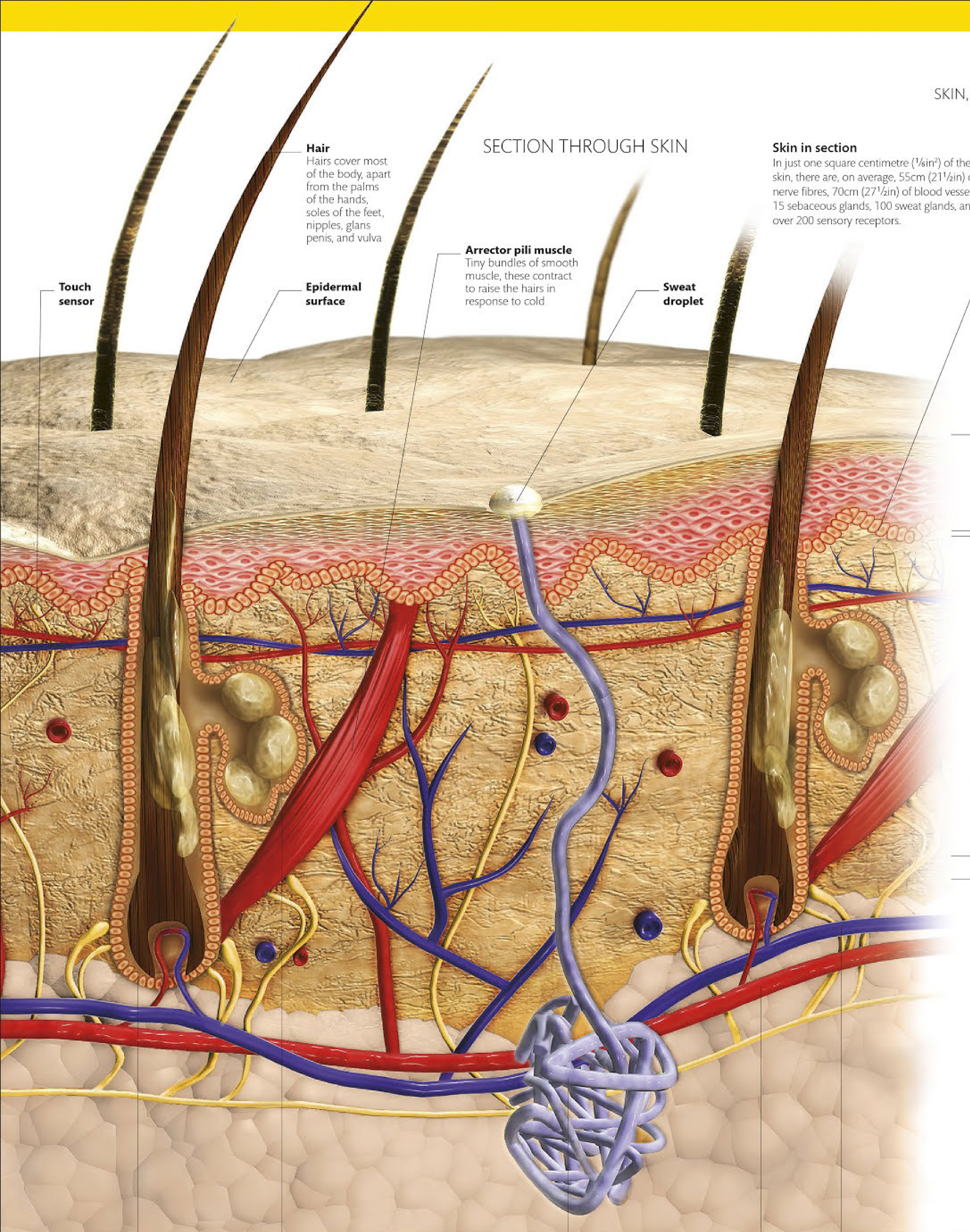
Thick head hairs and fine body hairs help to keep us warm and dry. All visible hair is in fact dead; hairs are only alive at their root. Constantly growing and self-repairing, nails protect fingers and toes but also enhance their sensitivity.



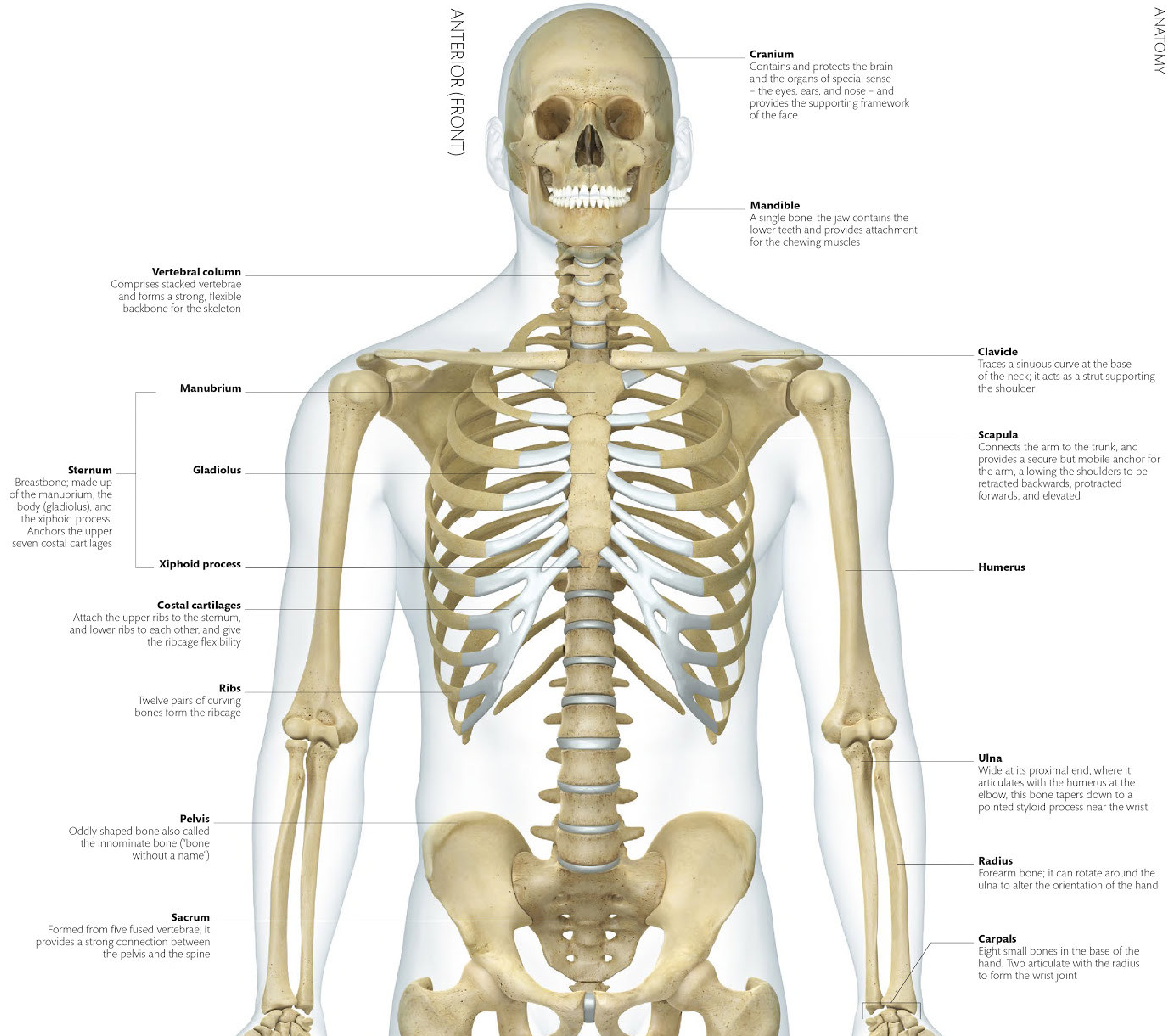
SECTION THROUGH A NAIL

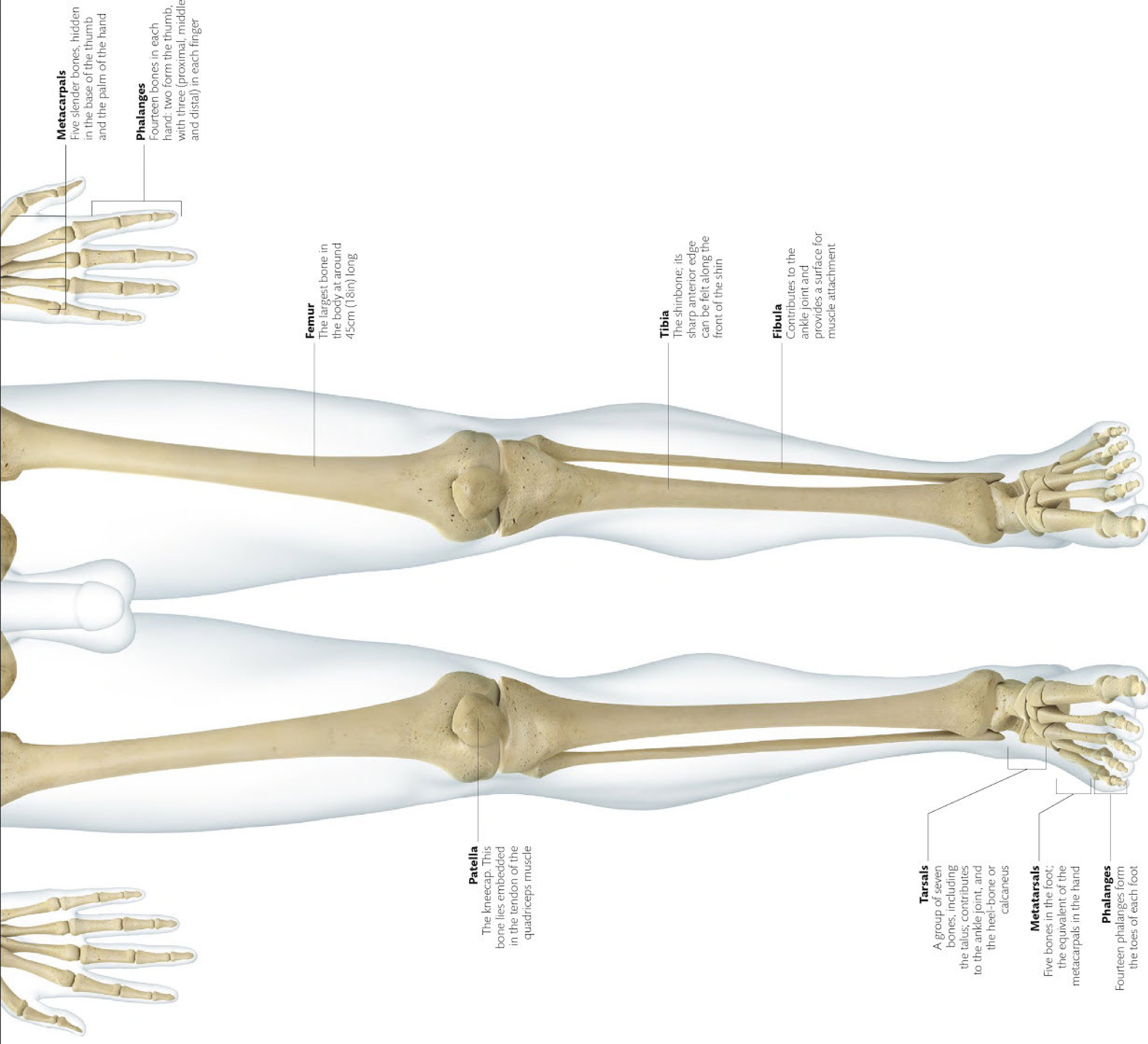
SECTION THROUGH SKIN

Skin in section
In just one square centimetre ($\frac{1}{6}$in^2) of the skin, there are, on average, 55cm (21½in) of nerve fibres, 70cm (27½in) of blood vessels, 15 sebaceous glands, 100 sweat glands, and over 200 sensory receptors.



ANTERIOR (FRONT)





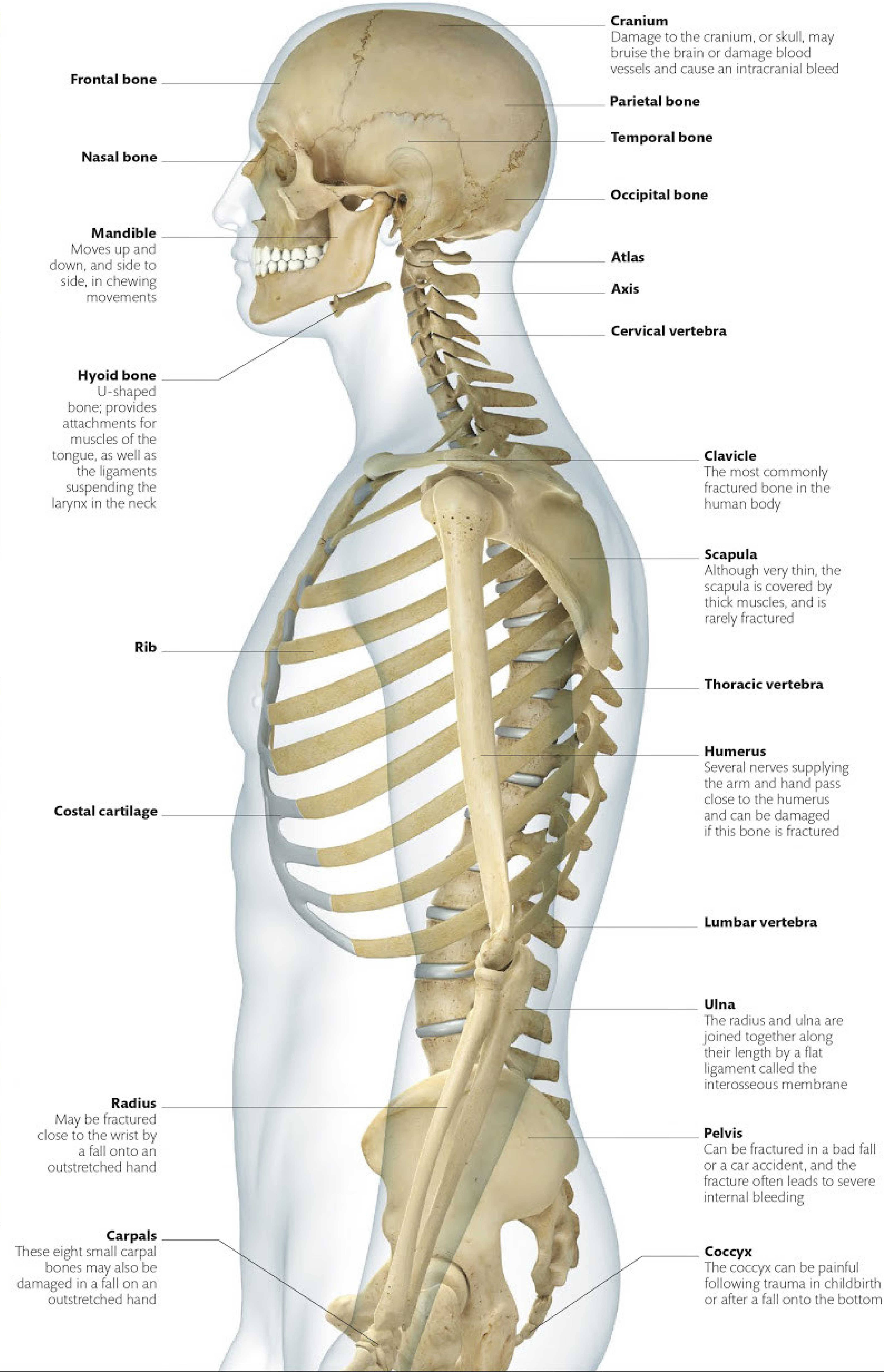
SKELETAL SYSTEM

The skeleton gives the body its shape, supports the weight of all our other tissues, provides attachment for muscles, and forms a system of linked levers that the muscles can move. The skeleton also plays an important role in protecting delicate organs and tissues, such as the brain within the skull, the spinal cord within the protective arches of the vertebrae, and the heart and lungs within the ribcage.

The human skeleton differs between the sexes. This is most obvious in the pelvis, which must form the birth canal in a woman; the pelvis of a woman is usually wider than that of a man. The skull also varies: men tend to have a larger brow and more prominent areas for muscle attachment on the back of the head. The entire skeleton tends to be larger and more robust in a man.

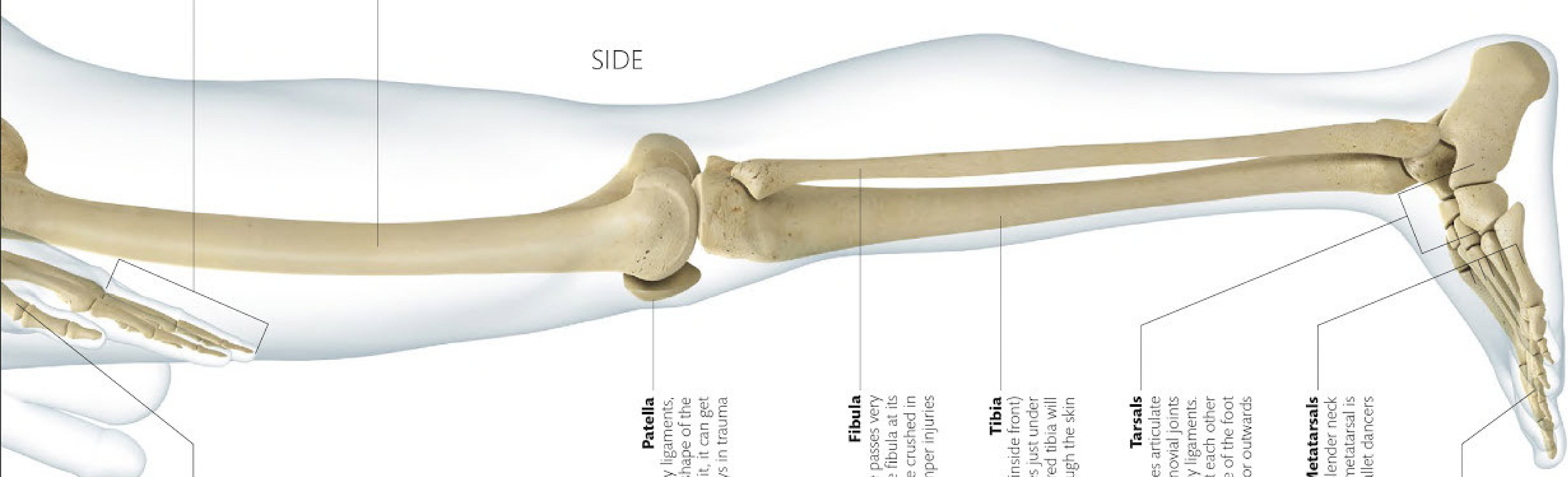
Lateral radiograph of a skull and cervical spine
On radiographs – images produced using X-rays – bone appears bright, while air spaces are dark. The part of the skull just above the spine looks very bright here – this is the extremely dense petrous, or "stony", part of the temporal bone.

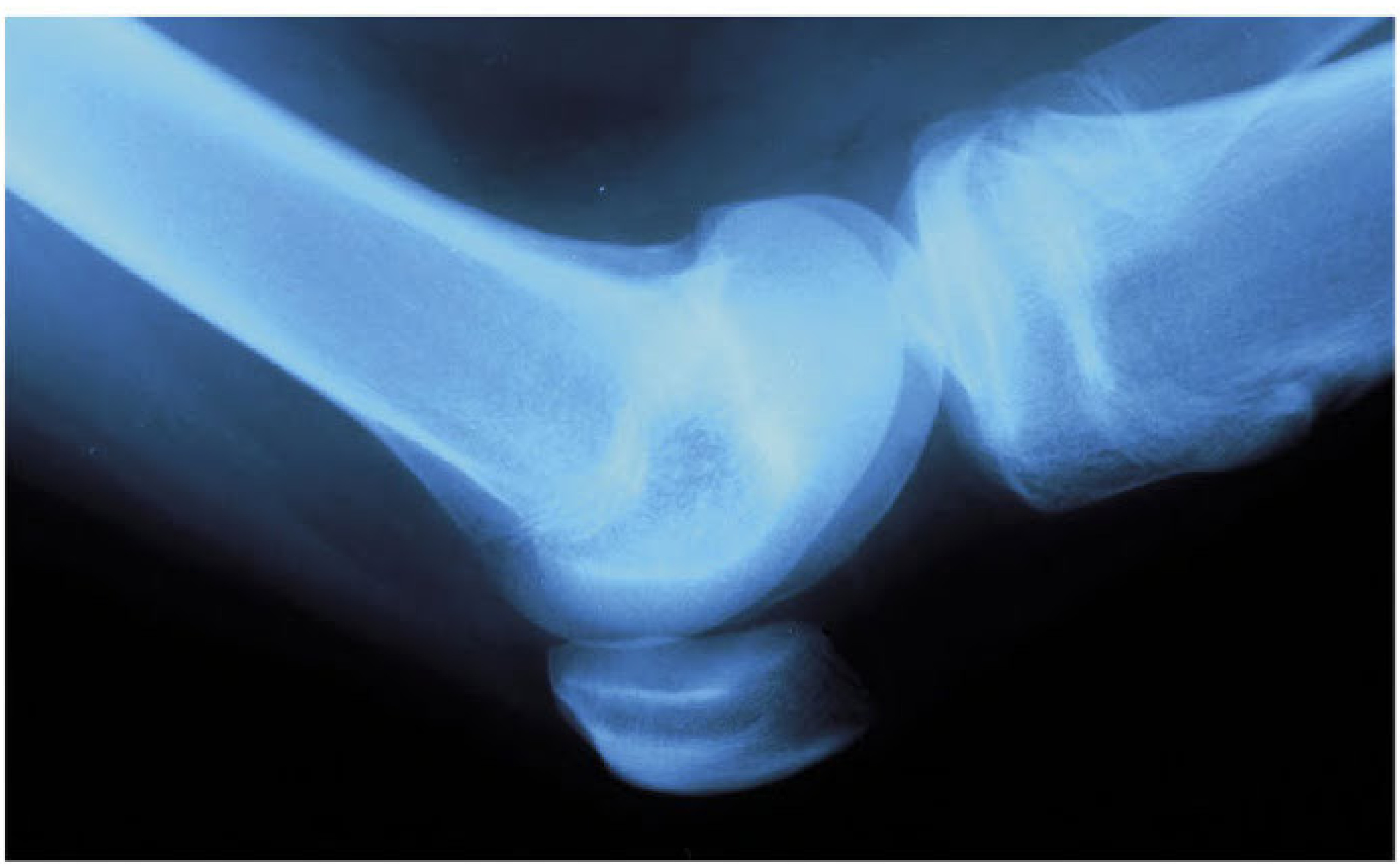
MRI of a lumbar spine
Protected within the vertebral column, the tapering tail-end of the spinal cord can be seen, in blue. The fluid and fat around the cord appears white.



SKELETAL SYSTEM

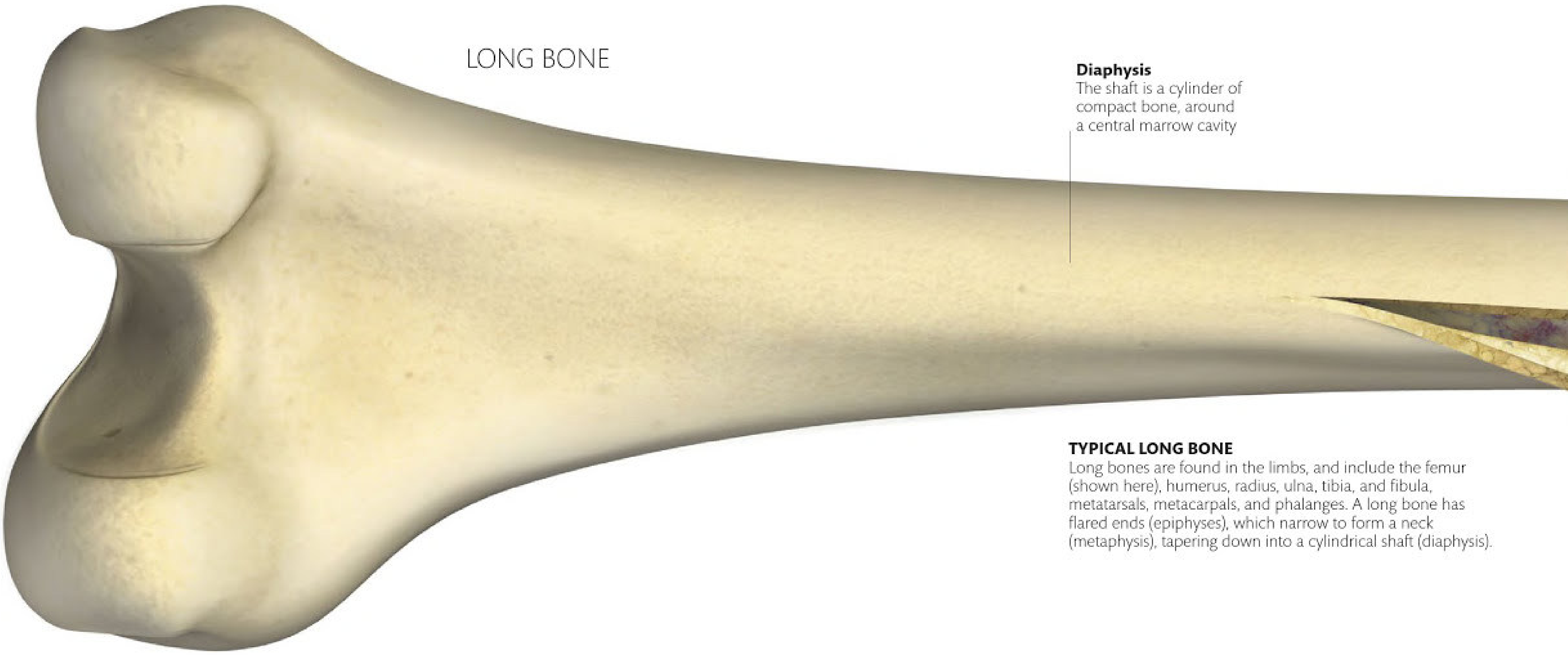
After teeth, bone is the hardest material in the human body. Bone mineral – made of calcium and phosphate salts – gives bone its hardness and rigidity. It also acts as the body's calcium store: if the level of calcium in the blood drops, calcium will be freed from the bones. Cartilage is another component of the skeleton. Many bones develop as cartilage "models" in the embryo, and later ossify, or turn to bone. But cartilage persists into adulthood at certain sites, such as at the surfaces of joints and as the costal cartilages that join the ribs to the sternum. Cartilage is not as hard as bone, but it has other useful properties. The costal cartilages give the ribcage some flexibility, and the cartilage lining the surface of joints resists compression well and provides a smooth, low-friction surface.



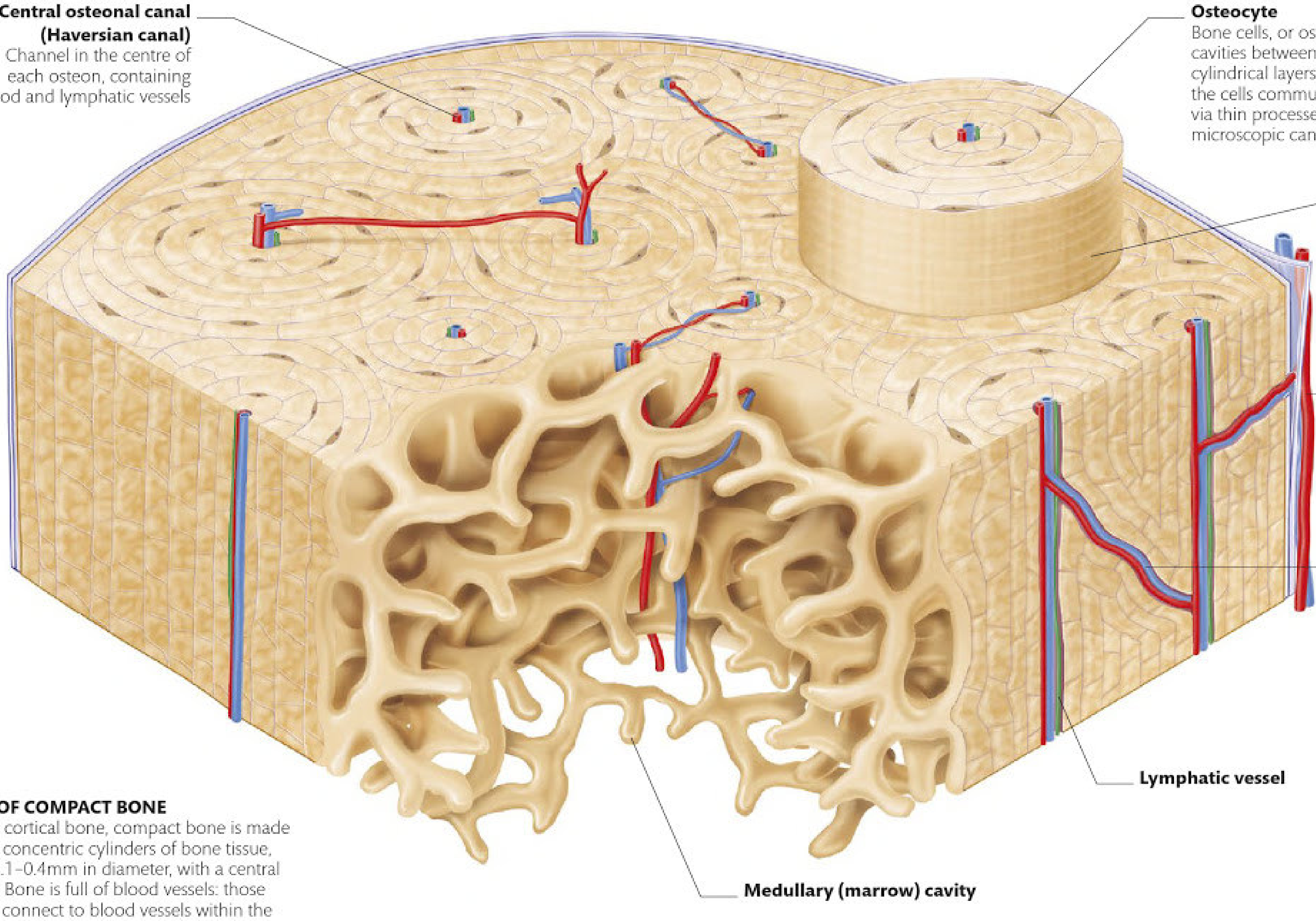


Lateral radiograph of a knee The knee is half-flexed here, showing how the curved condyles of the femur rotate on the tibia below. The patella is embedded in the quadriceps tendon (invisible on a radiograph), which runs over the front of the knee.

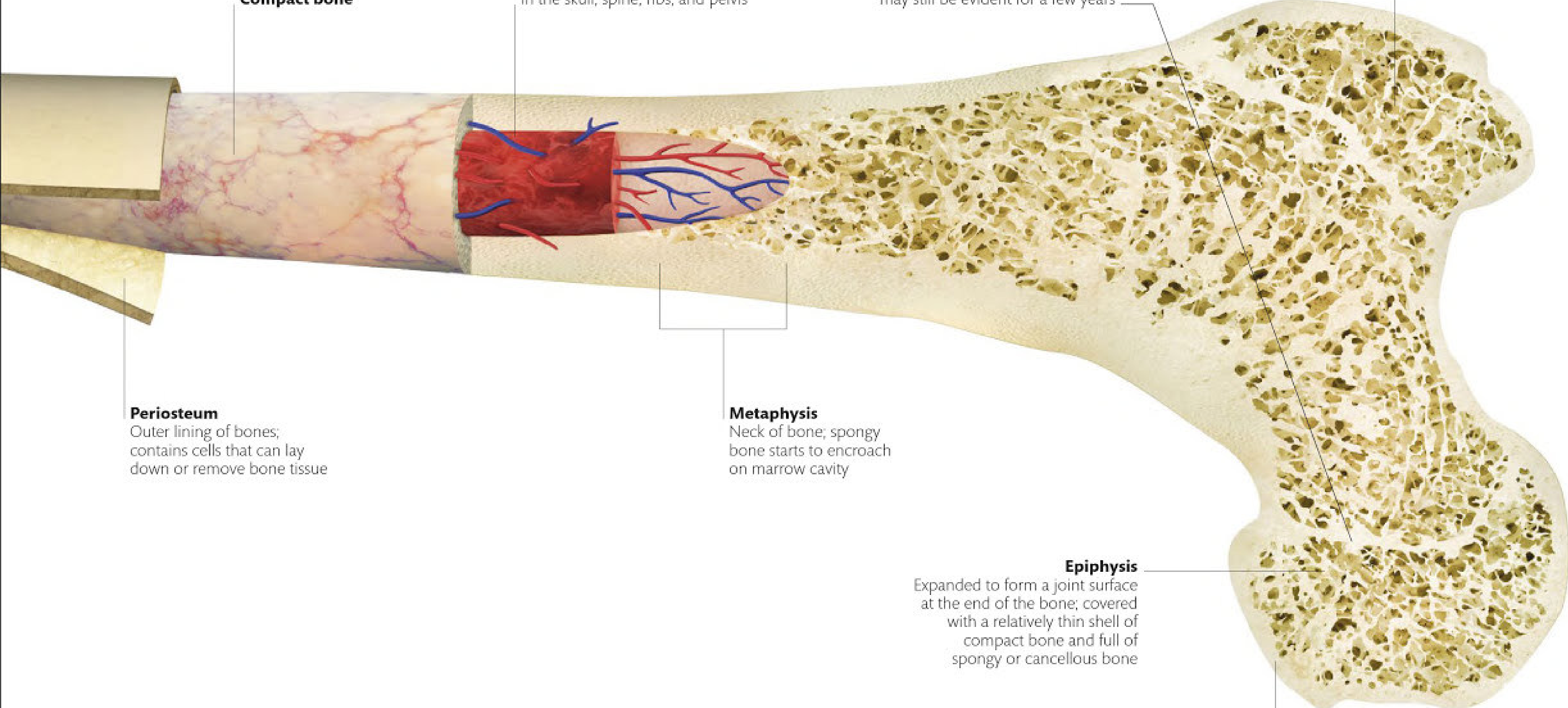
Lateral radiograph of a foot The hinge joint that forms the ankle can be clearly seen here – between the tibia and fibula of the leg and the uppermost tarsal bone, the talus. The bones of the foot can be seen to form an arch, which is supported by tendons and ligaments.



TYPICAL LONG BONE
Long bones are found in the limbs, and include the femur (shown here), humerus, radius, ulna, tibia, and fibula, metatarsals, metacarpals, and phalanges. A long bone has flared ends (epiphyses), which narrow to form a neck (metaphysis), tapering down into a cylindrical shaft (diaphysis).

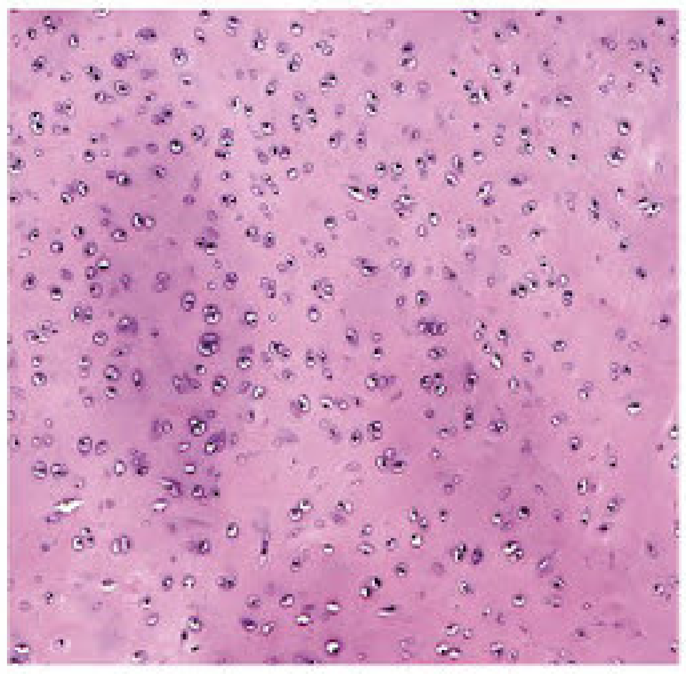


STRUCTURE OF COMPACT BONE
Also known as cortical bone, compact bone is made up of osteons: concentric cylinders of bone tissue, each around 0.1–0.4mm in diameter, with a central vascular canal. Bone is full of blood vessels: those in the osteons connect to blood vessels within the medullary cavity of the bone as well as to vessels in the periosteum on the outside.

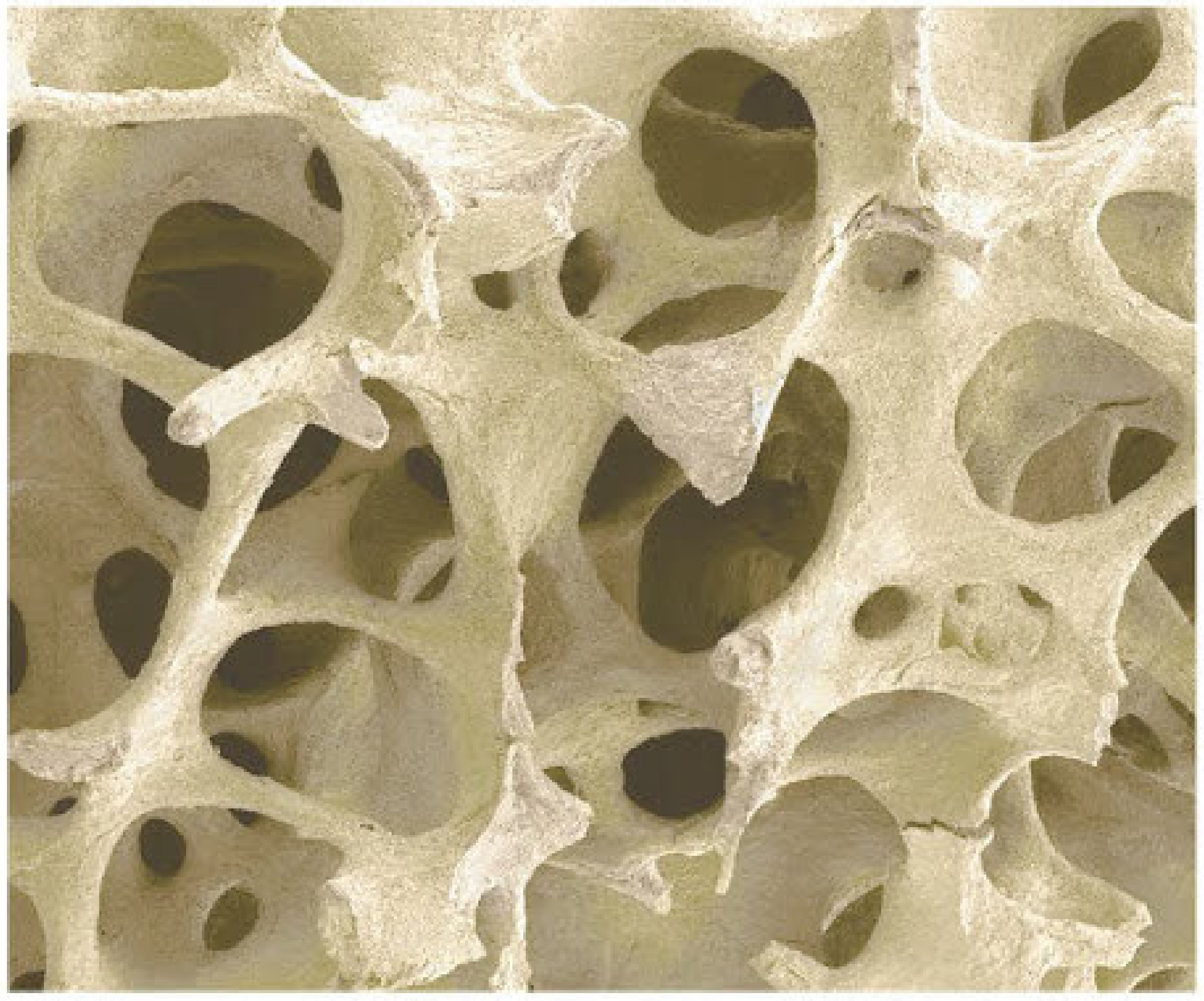


BONE AND CARTILAGE STRUCTURE

The adult skeleton is mainly made of bone, with just a little cartilage in some places – such as the costal cartilages which complete the ribs. Most of the human skeleton develops first as cartilage, which is later replaced by bone (see pp.300–01). At just 8 weeks, a fetus already has cartilage models of almost all the components of the skeleton, some of which are just starting to transform into bone. This transformation continues during fetal development and throughout childhood. But there are still cartilage plates near the end of the bones in an adolescent's skeleton, enabling rapid growth. When growth is finally complete, those plates close and become bone. Bone and cartilage are both connective tissues, with cells embedded in a matrix, but they have different properties. Cartilage is a stiff but flexible tissue and good at load-bearing, which is why it is involved in joints. But it has virtually no blood vessels and is very bad at self-repair. In contrast, bone is full of blood vessels and repairs very well. Bone cells are embedded in a mineralized matrix, creating an extremely hard, strong tissue.



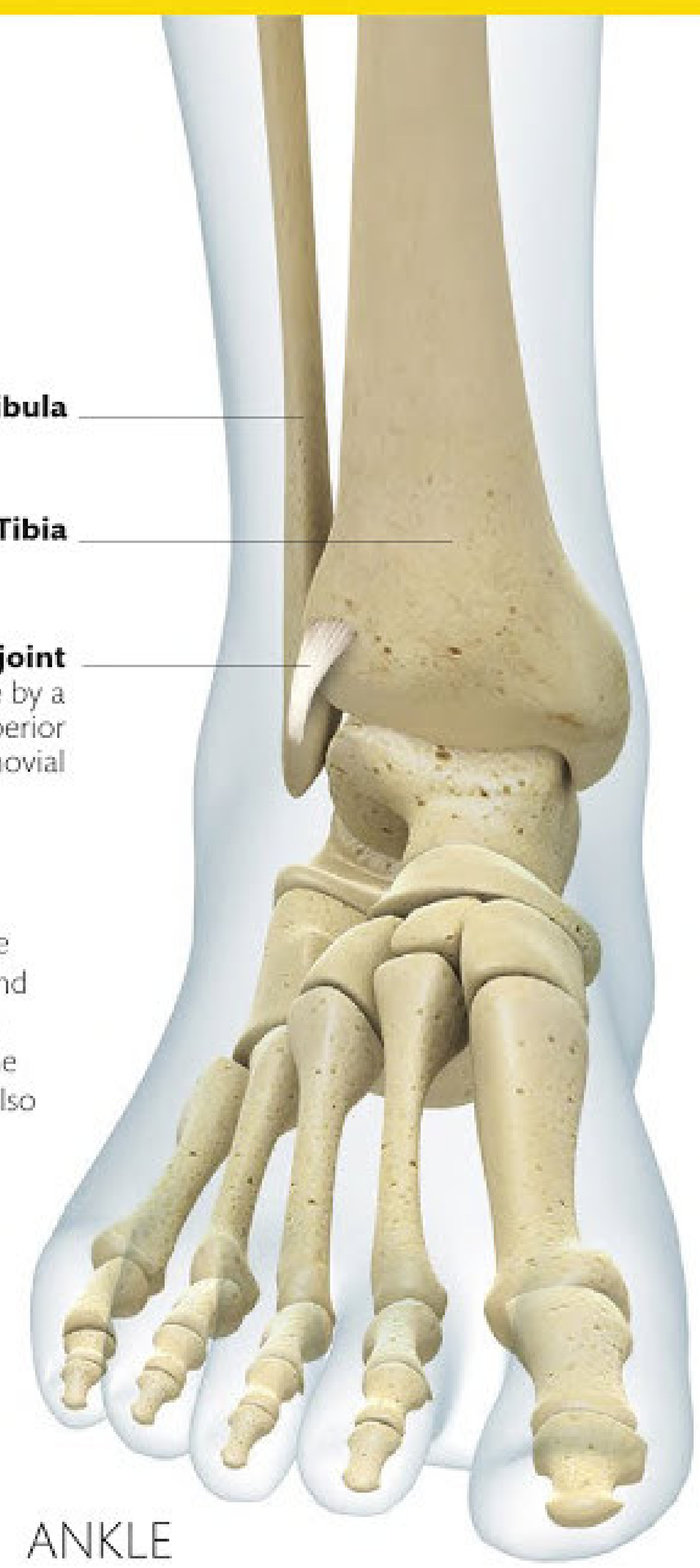
CARTILAGE
This tissue is made up of specialized cells called chondrocytes (seen clearly here) contained within a gel-like matrix embedded with fibres, including collagen and elastin. The different types of cartilage include hyaline, elastic, and fibrocartilage, which differ in the proportion of these constituents.



SPONGY BONE
Also known as cancellous bone, this is found in the epiphyses of long bones, and completely fills bones such as the vertebrae, carpals, and tarsals. It is made of minute interlinking struts or trabeculae (seen in this magnified image), giving it a spongy appearance, with bone marrow occupying the spaces between the trabeculae.

JOINT AND LIGAMENT STRUCTURE

During development of the embryo, the connective tissue between developing bones forms joints – either remaining solid, creating a fibrous or cartilaginous joint, or creating cavities, to form a synovial joint. Fibrous joints are linked by microscopic fibres of collagen. They include the sutures of the skull, the teeth sockets (gomphoses), and the lower joint between the tibia and fibula. Cartilaginous joints include the junctions between ribs and costal cartilages, joints between the components of the sternum, and the pubic symphysis. The intervertebral discs are also specialized cartilaginous joints. Synovial joints contain lubricating fluid, and the joint surfaces are lined with cartilage to reduce friction. They tend to be very mobile joints (see pp.302–03).

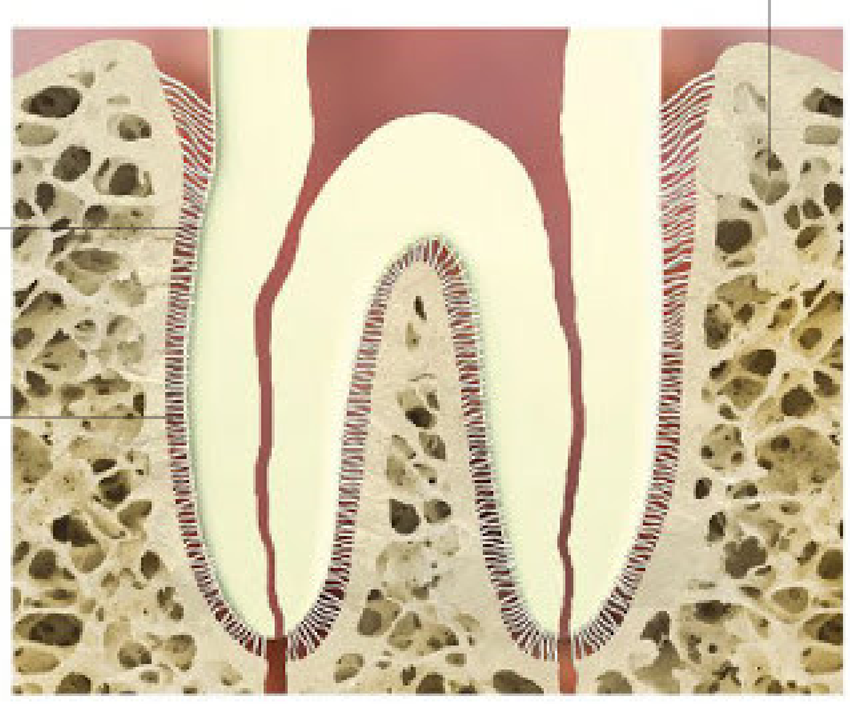


Syndesmosis
From the Greek for joined together; the lower ends of the tibia and fibula are firmly bound together by fibrous tissue. The interosseous membranes of the forearm and lower leg could also be described as syndesmoses.

ANKLE

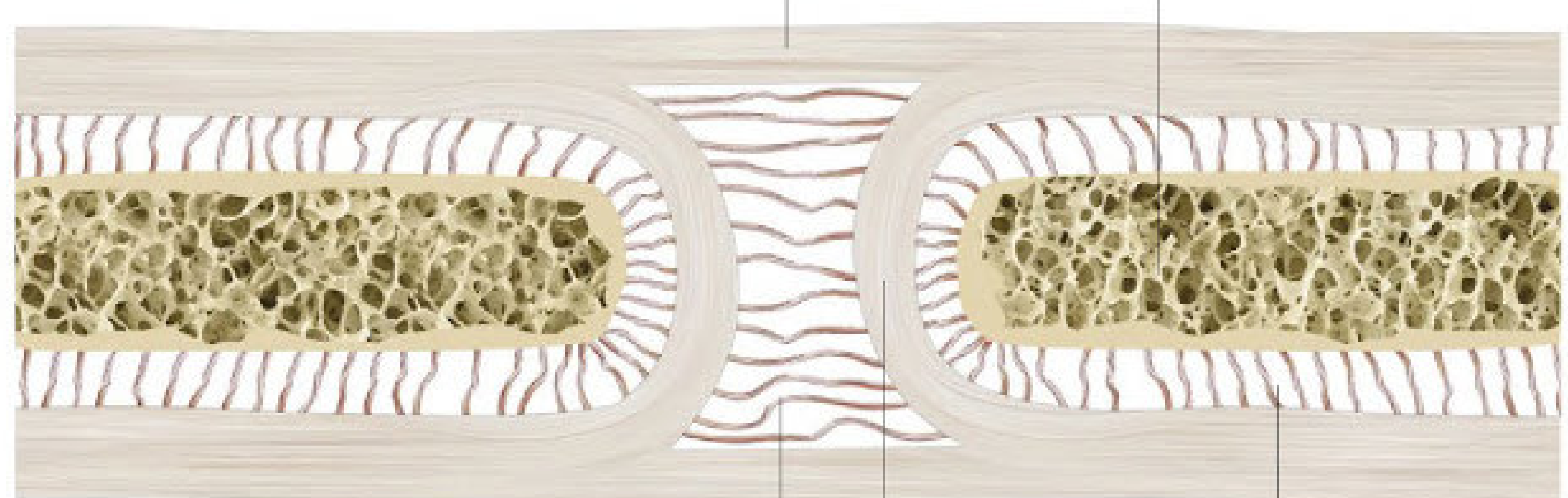
FIBROUS JOINTS

Gomphosis
This name comes from the Greek word for bolted together. The fibrous tissue of the periodontal ligament connects the cement of the tooth to the bone of the socket.



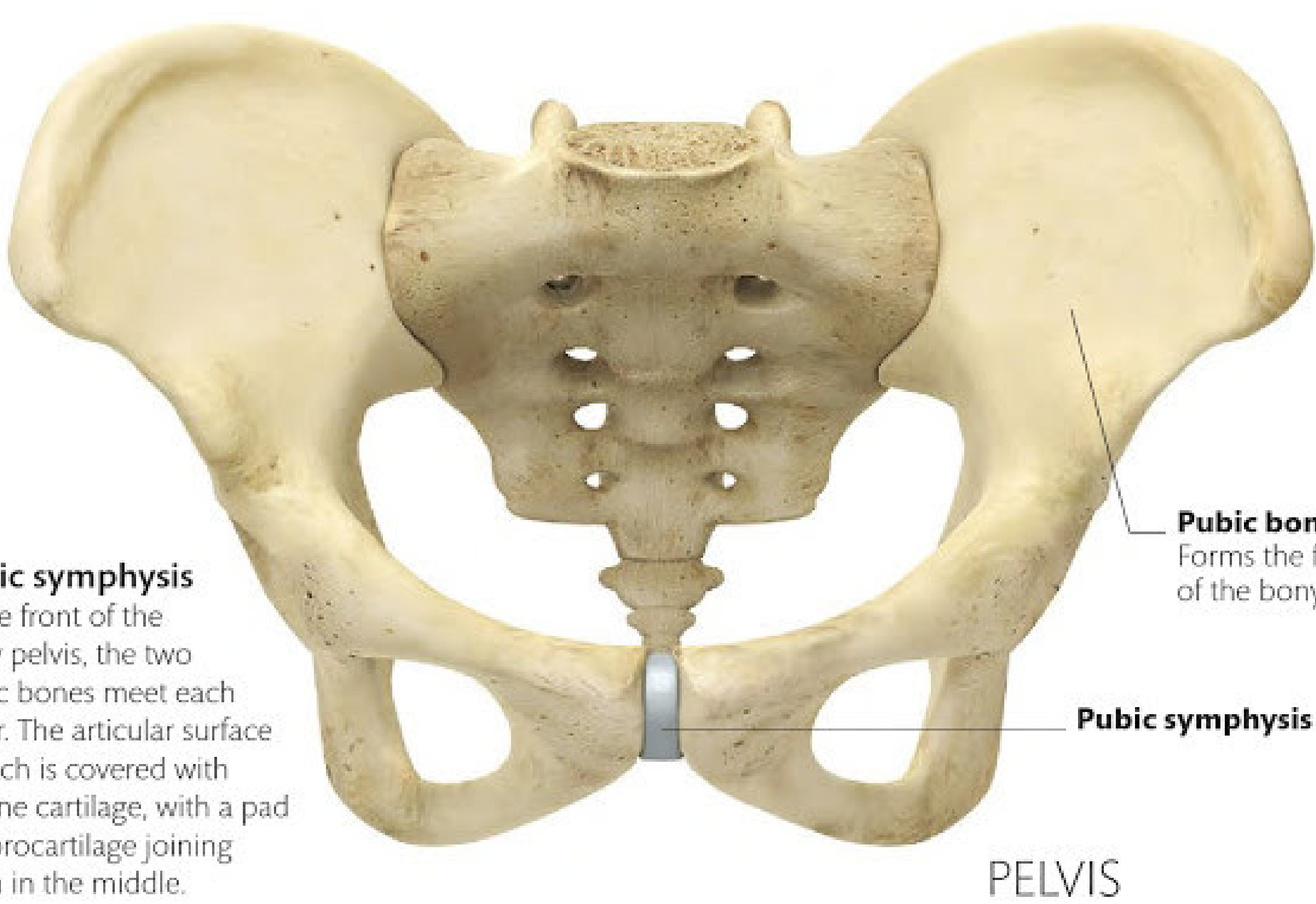
TOOTH

Suture
These joints exist between flat bones of the skull. They are flexible in the skull of a newborn baby, and allow growth of the skull throughout childhood. The sutures in the adult skull are interlocking, practically immovable joints, and eventually fuse completely in later adulthood.



SKULL

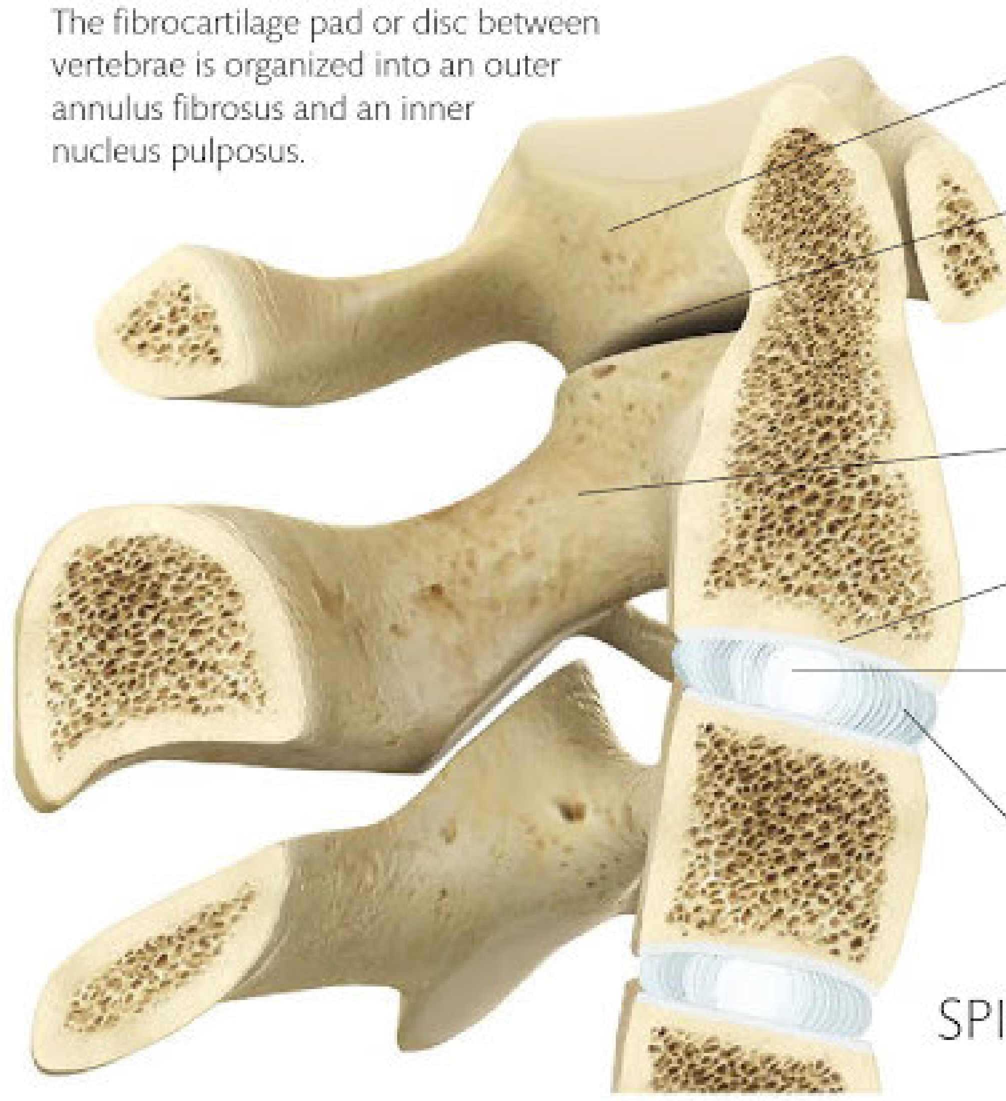
CARTILAGINOUS JOINTS



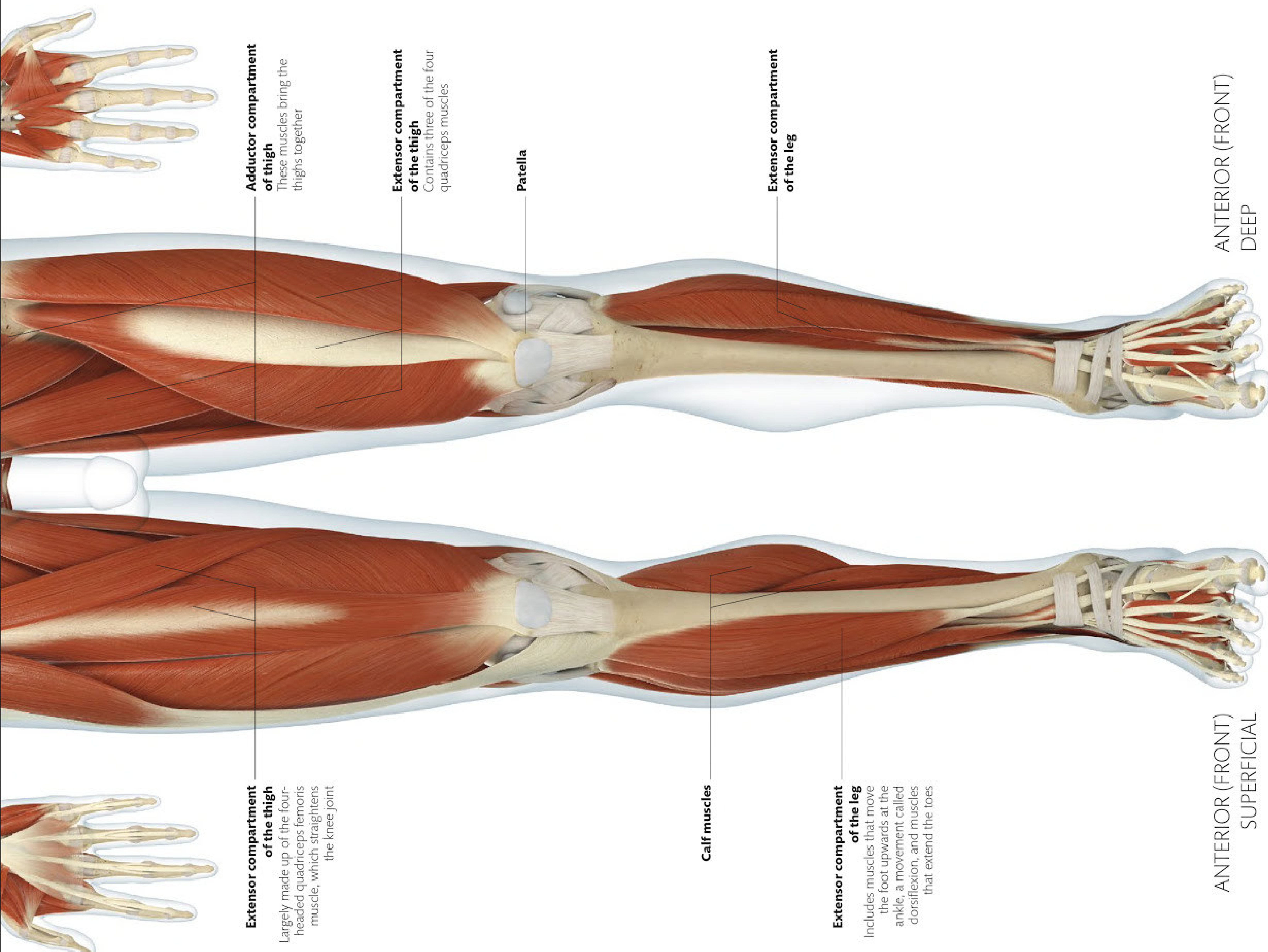
Pubic symphysis
At the front of the bony pelvis, the two pubic bones meet each other. The articular surface of each is covered with hyaline cartilage, with a pad of fibrocartilage joining them in the middle.

PELVIS

Intervertebral disc
The fibrocartilage pad or disc between vertebrae is organized into an outer annulus fibrosus and an inner nucleus pulposus.

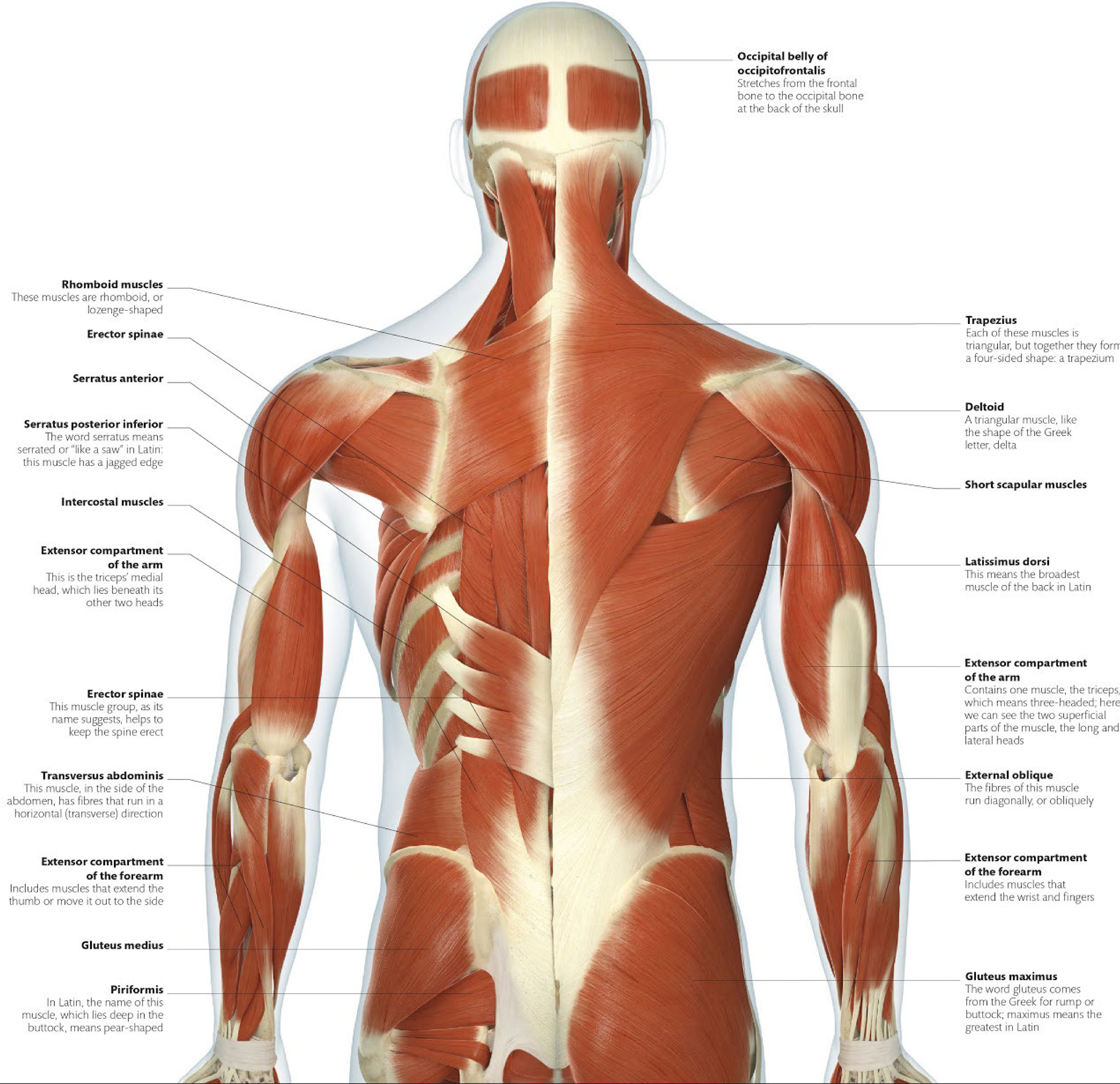


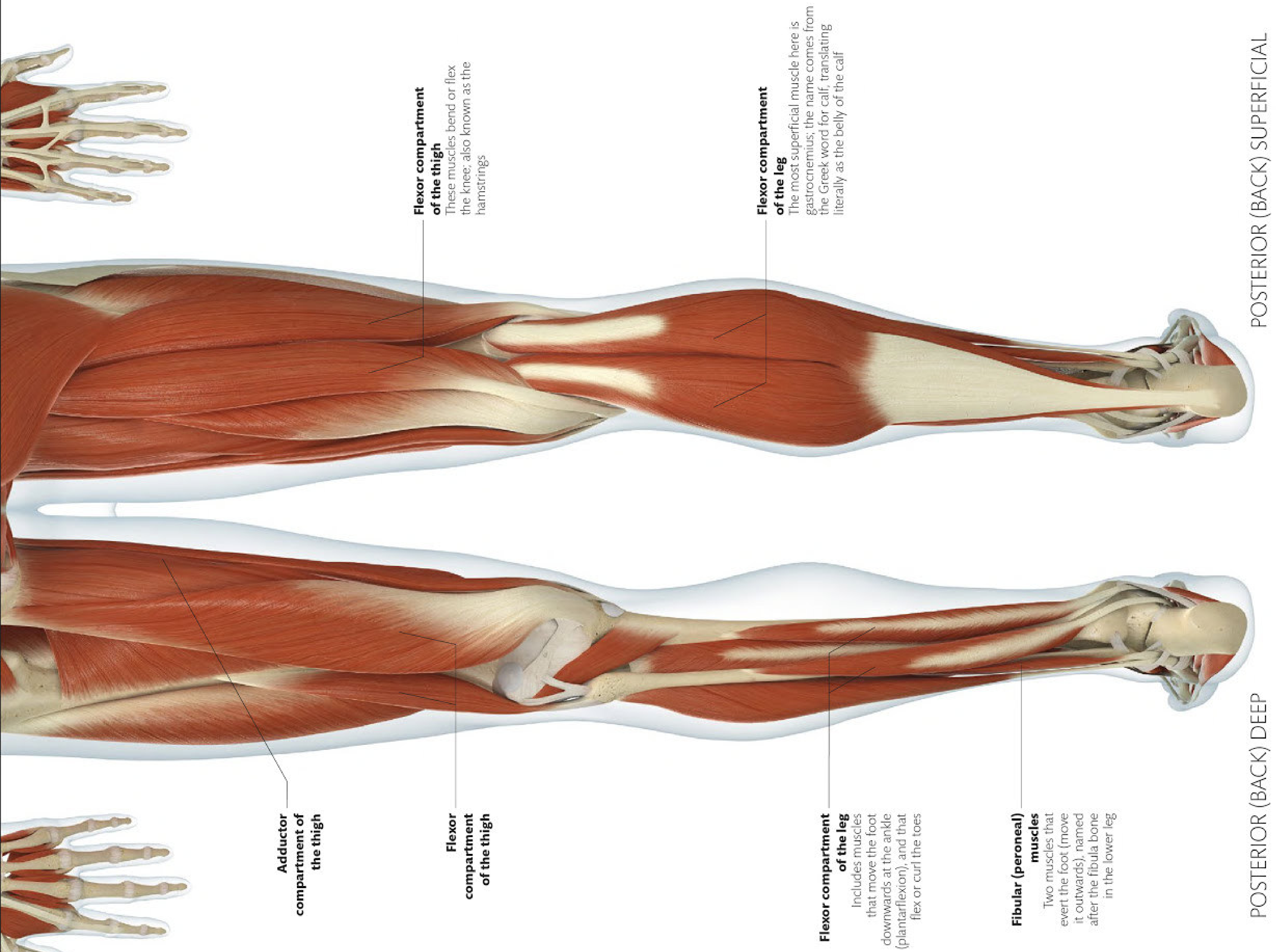
SPINE



MUSCULAR SYSTEM

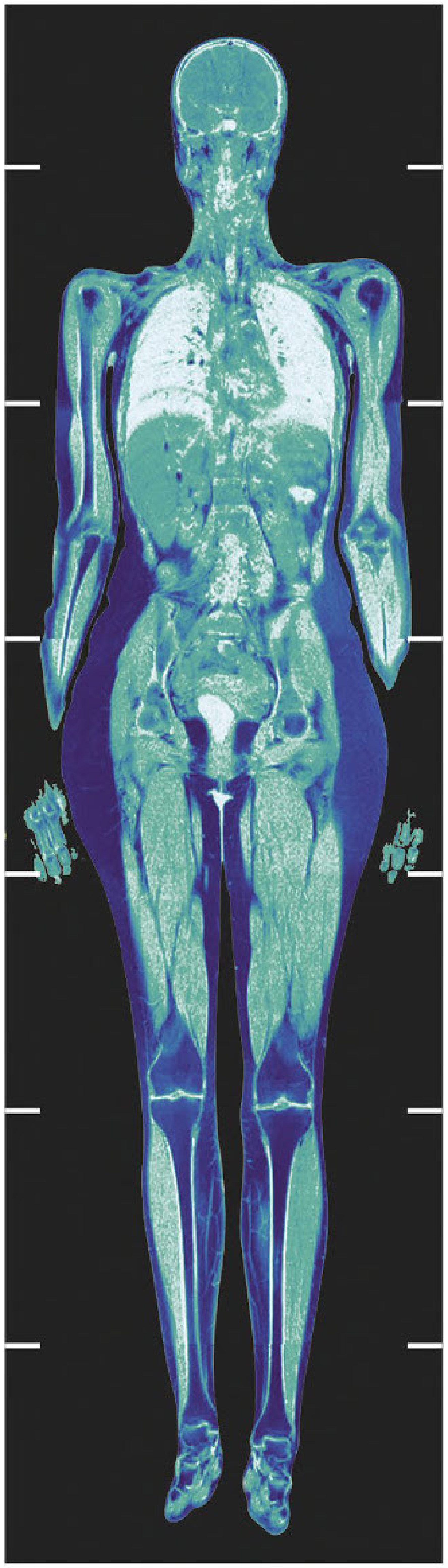
Muscles attach to the skeleton by means of tendons, aponeuroses (flat, sheet-like tendons), and bands of connective tissue called fascia. Muscles are well supplied with blood vessels and appear reddish; tendons have a sparse vascular supply and look white. The "action" of a muscle refers to the movement it produces as it contracts. Muscle action has been investigated both by observing living people and by dissection of cadavers to pinpoint the precise attachments of muscles. Electromyography (EMG) – using electrodes to detect the electrical activity that accompanies muscle contraction – has proved invaluable in revealing which muscles act to produce a specific movement.


Occipital belly of occipitofrontalis
Stretches from the frontal bone to the occipital bone at the back of the skull
Rhomboid muscles
These muscles are rhomboid, or lozenge-shaped
Erector spinae
Serratus anterior
Serratus posterior inferior
The word serratus means serrated or "like a saw" in Latin: this muscle has a jagged edge
Intercostal muscles
Extensor compartment of the arm
This is the triceps' medial head, which lies beneath its other two heads
Erector spinae
This muscle group, as its name suggests, helps to keep the spine erect
Transversus abdominis
This muscle, in the side of the abdomen, has fibres that run in a horizontal (transverse) direction
Extensor compartment of the forearm
Includes muscles that extend the thumb or move it out to the side
Gluteus medius
Piriformis
In Latin, the name of this muscle, which lies deep in the buttock, means pear-shaped
Trapezius
Each of these muscles is triangular, but together they form a four-sided shape: a trapezium
Deltoid
A triangular muscle, like the shape of the Greek letter, delta
Short scapular muscles
Latissimus dorsi
This means the broadest muscle of the back in Latin
Extensor compartment of the arm
Contains one muscle, the triceps, which means three-headed; here we can see the two superficial parts of the muscle, the long and lateral heads
External oblique
The fibres of this muscle run diagonally, or obliquely
Extensor compartment of the forearm
Includes muscles that extend the wrist and fingers
Gluteus maximus
The word gluteus comes from the Greek for rump or buttock; maximus means the greatest in Latin

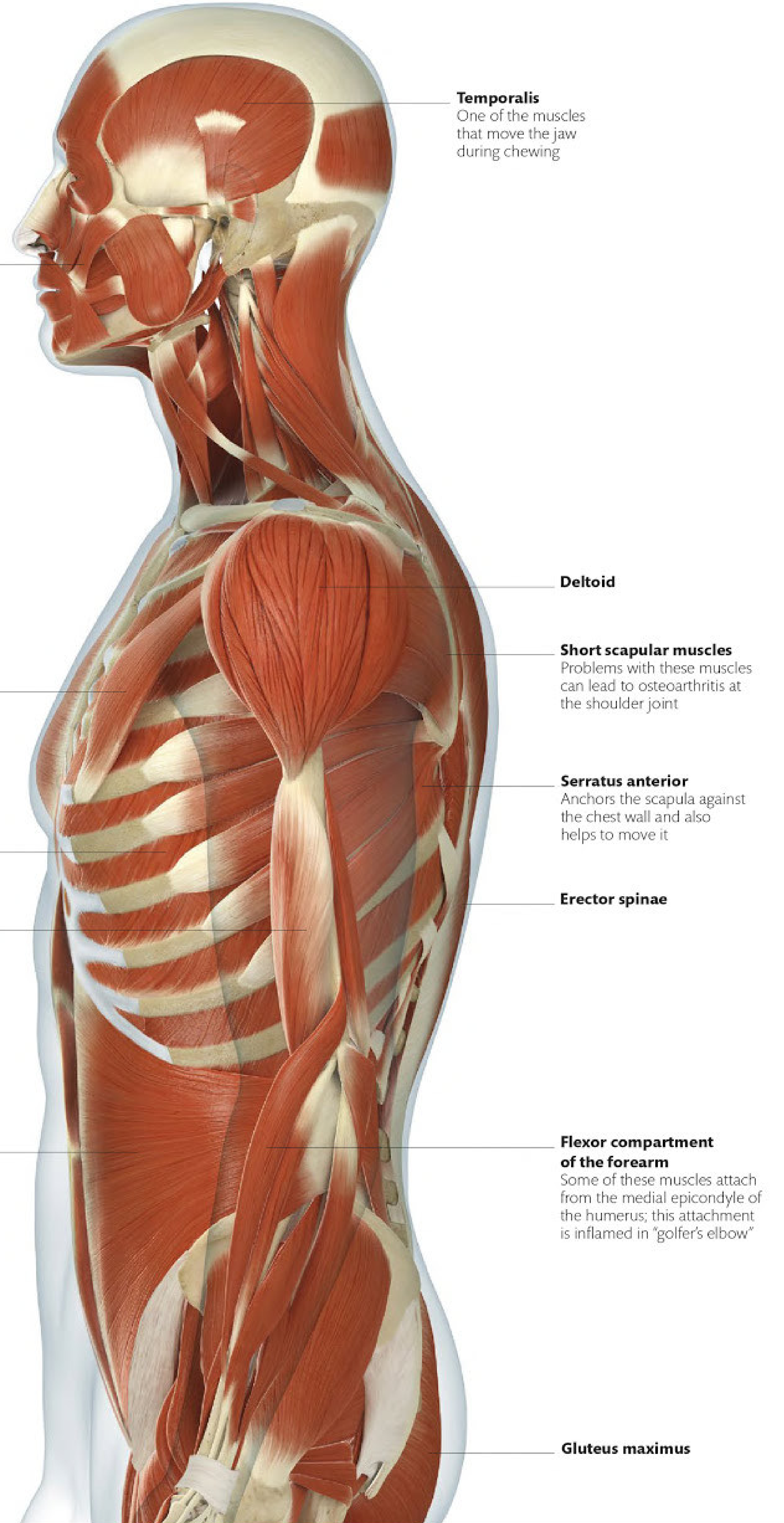


MUSCULAR SYSTEM

Most muscle names are derived from Latin or Greek. They can refer to a muscle's shape, size, attachments, number of heads, position or depth in the body, or the action it produces when it contracts. Names that end in -oid refer to the shape of the muscle. Deltoid, for example, means triangle-shaped, and rhomboid means diamond-shaped. Many muscles have two-part names. These names often refer to both a characteristic of the muscle and the muscle's position in the body. Rectus abdominis, for example, means straight [muscle] of the abdomen, and biceps brachii means two-headed [muscle] of the arm. Some muscles have names that describe their action, such as flexor digitorum, which simply means flexor of the fingers.

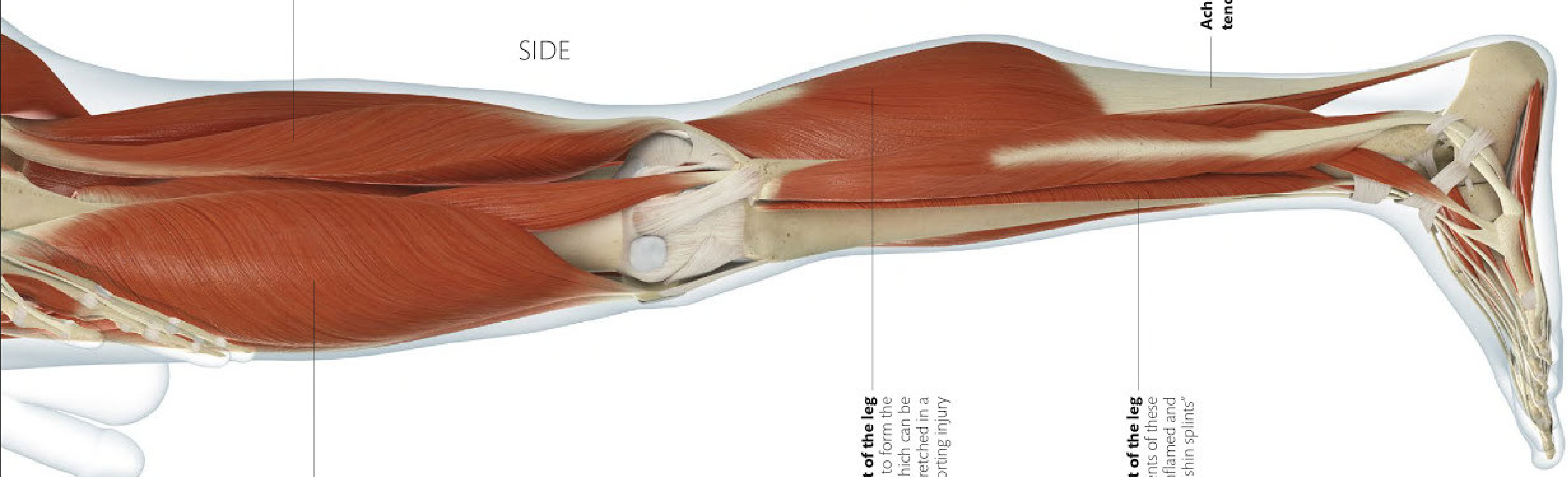


Coloured MRI scan: coronal section
Unlike plain radiographs, MRI and CT scans show soft tissue detail, including muscles. In the limbs, the bones and subcutaneous fat are here coloured purple, with muscles in green.

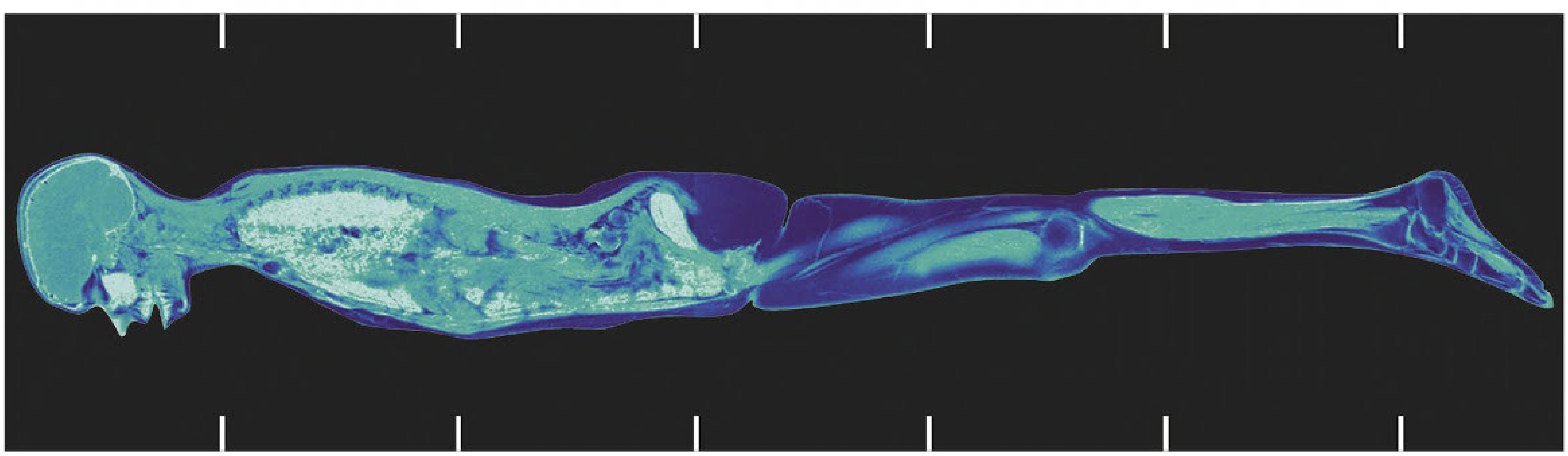


MUSCULAR SYSTEM

The force produced by muscles of different shapes varies. Long, thin muscles tend to contract a lot but exert low forces. Muscles with many fibres attaching to a tendon at an angle, such as the deltoid, shorten less during contraction but produce greater forces. Although the shape of muscles varies, there is a general rule that the force generated by the contracting muscle fibres will be directed along the line of the tendon. Muscle fibres will enlarge in response to intense exercise. Conversely, if muscles are unused for just a few months, they start to waste away. Consequently, physical activity is very important in maintaining muscle bulk.

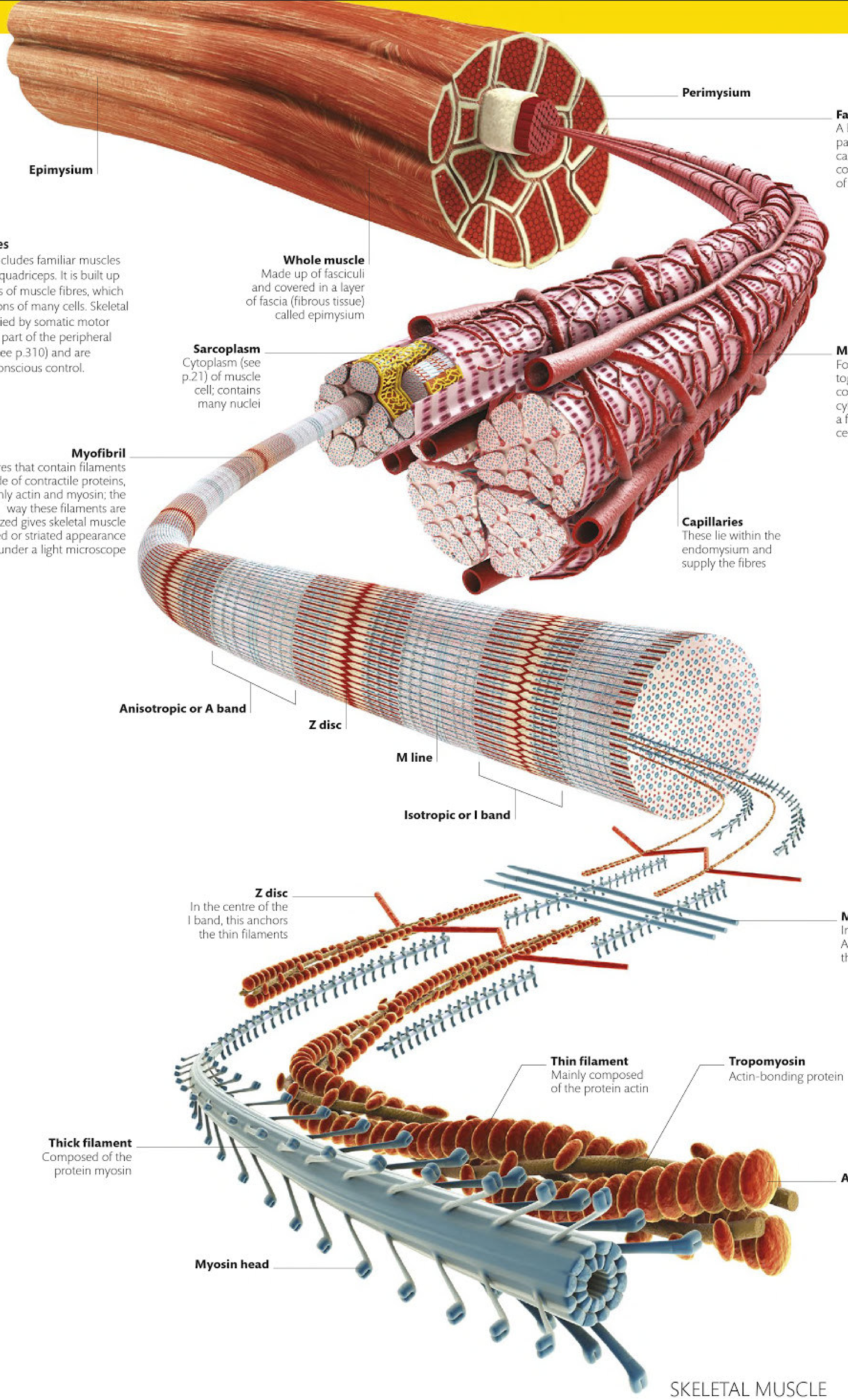


Coloured MRI scan: parasagittal section
This section through the body is to the side of the midline, so we see a slice through the leg. The muscles of the back – mainly erector spinae – are coloured green, lying behind the spine.



Parallel bundles

Skeletal muscle includes familiar muscles such as biceps or quadriceps. It is built up of parallel bundles of muscle fibres, which are conglomerations of many cells. Skeletal muscles are supplied by somatic motor nerves, which are part of the peripheral nervous system (see p.310) and are generally under conscious control.

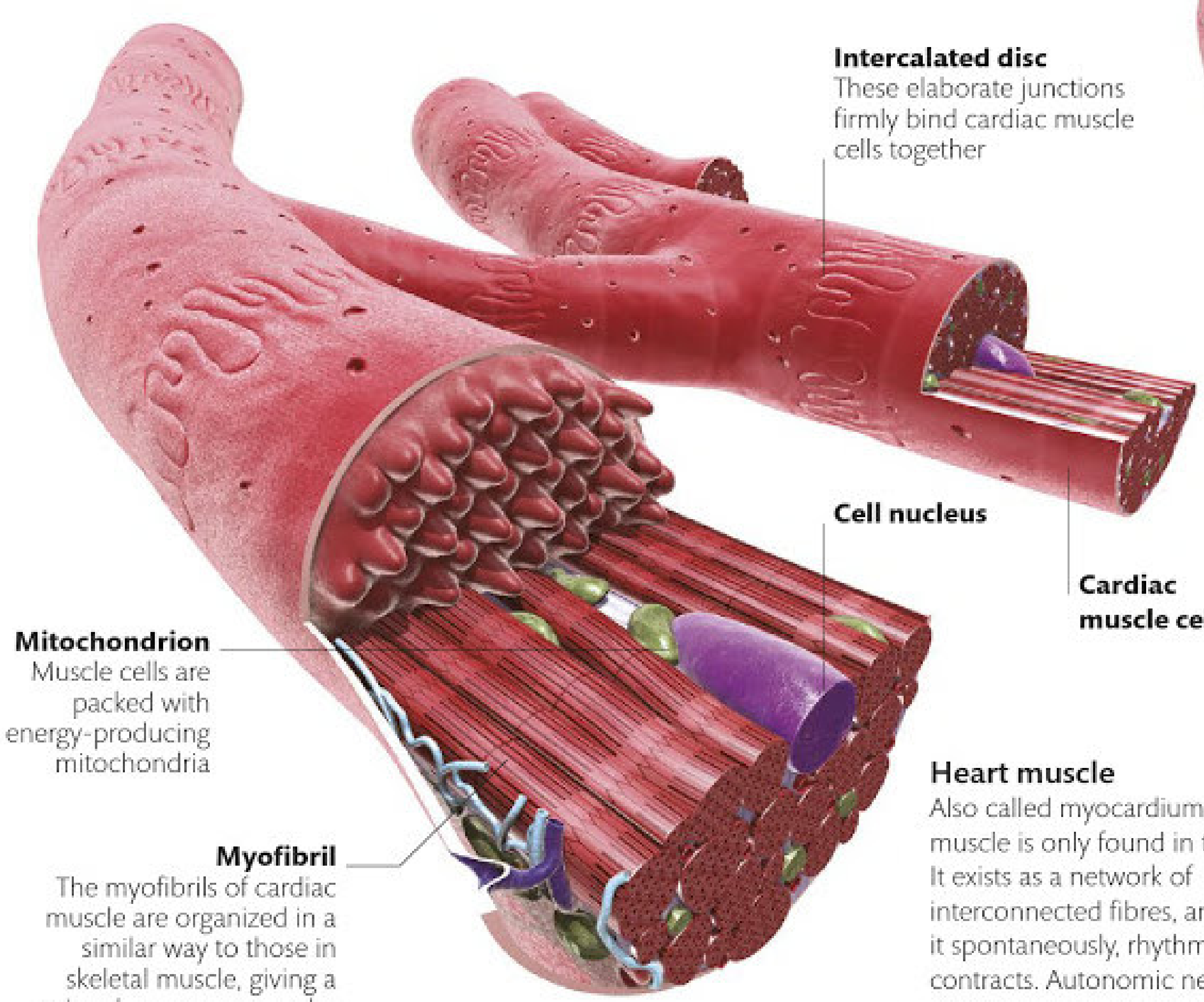


SKELETAL MUSCLE

MUSCLE STRUCTURE

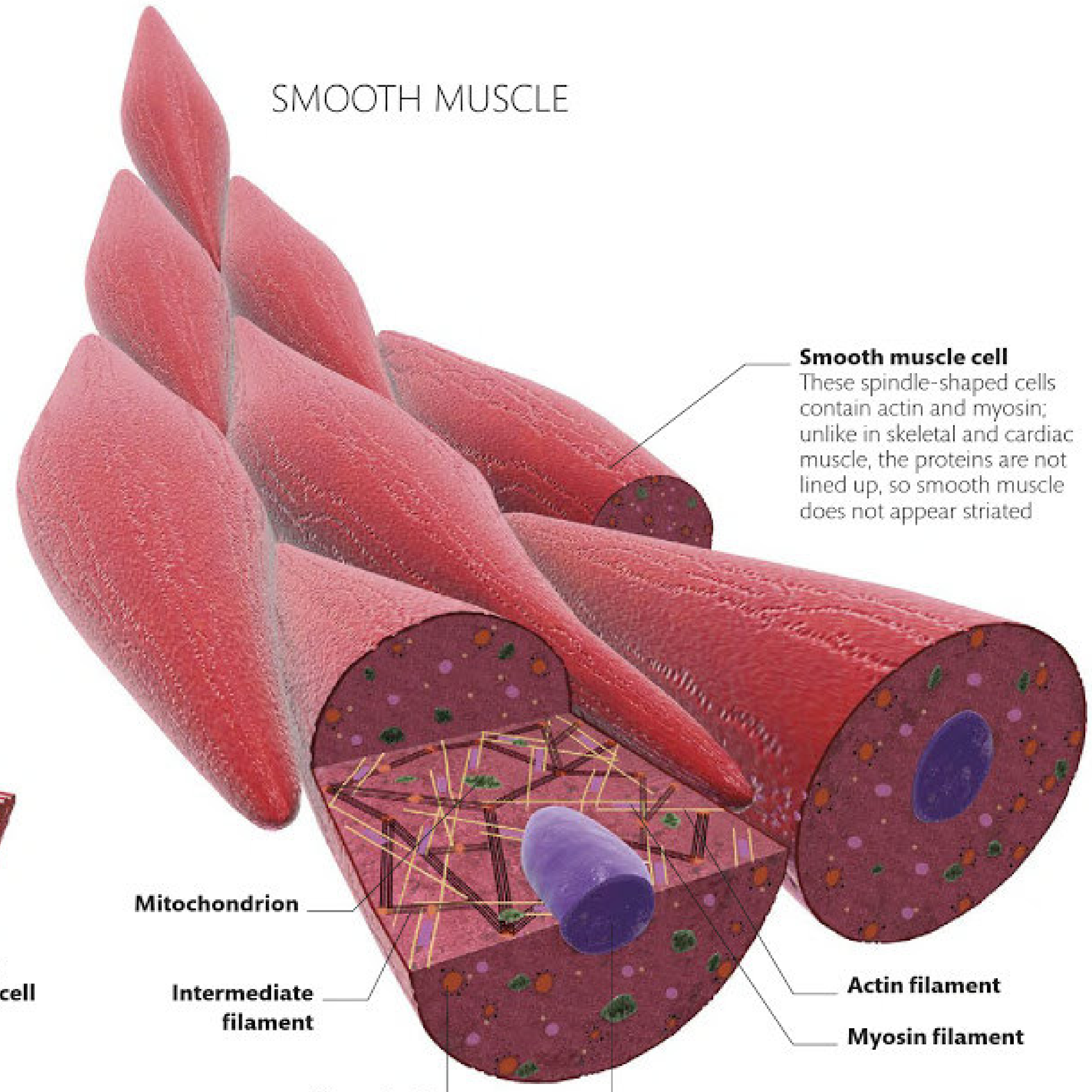
Muscle cells possess a special ability to contract. Also called myocytes, muscle cells are packed full of the long, filamentous proteins actin and myosin, which ratchet past each other to change the length of the cell itself (see p.304). There are three main types of muscle in the human body: skeletal or voluntary muscle, cardiac muscle, and smooth or involuntary muscle. Each of these hasa distinctive microscopic structure. Skeletal muscle also varies in its overall shape and structure, depending on its function.

CARDIAC MUSCLE



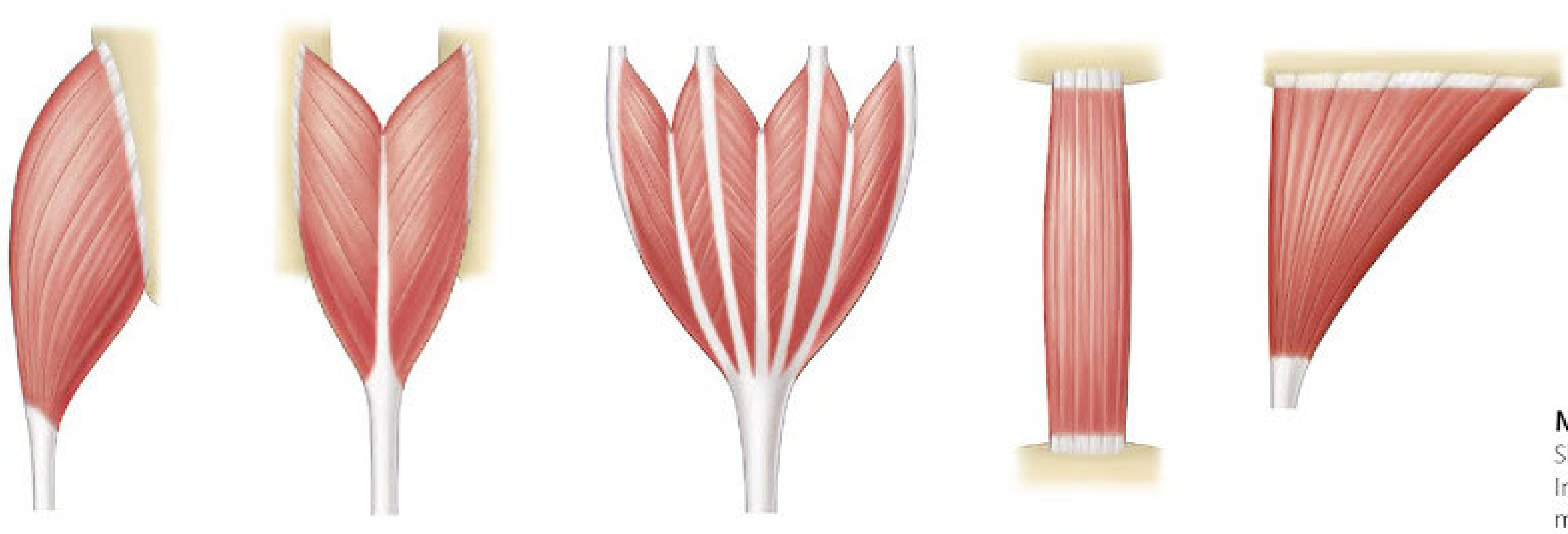
Heart muscle
Also called myocardium, cardiac muscle is only found in the heart. It exists as a network of interconnected fibres, and it spontaneously, rhythmically contracts. Autonomic nerves can increase or reduce the rate of contraction, matching the heart's output to the body's needs.

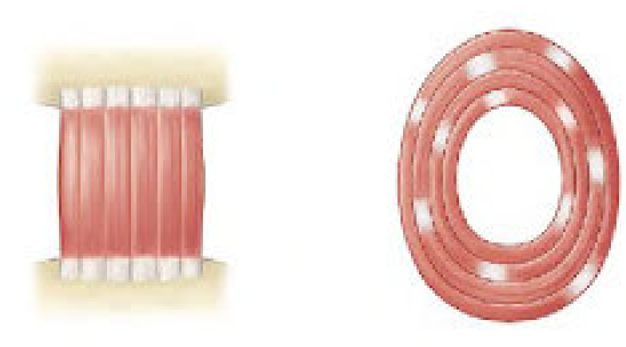
SMOOTH MUSCLE



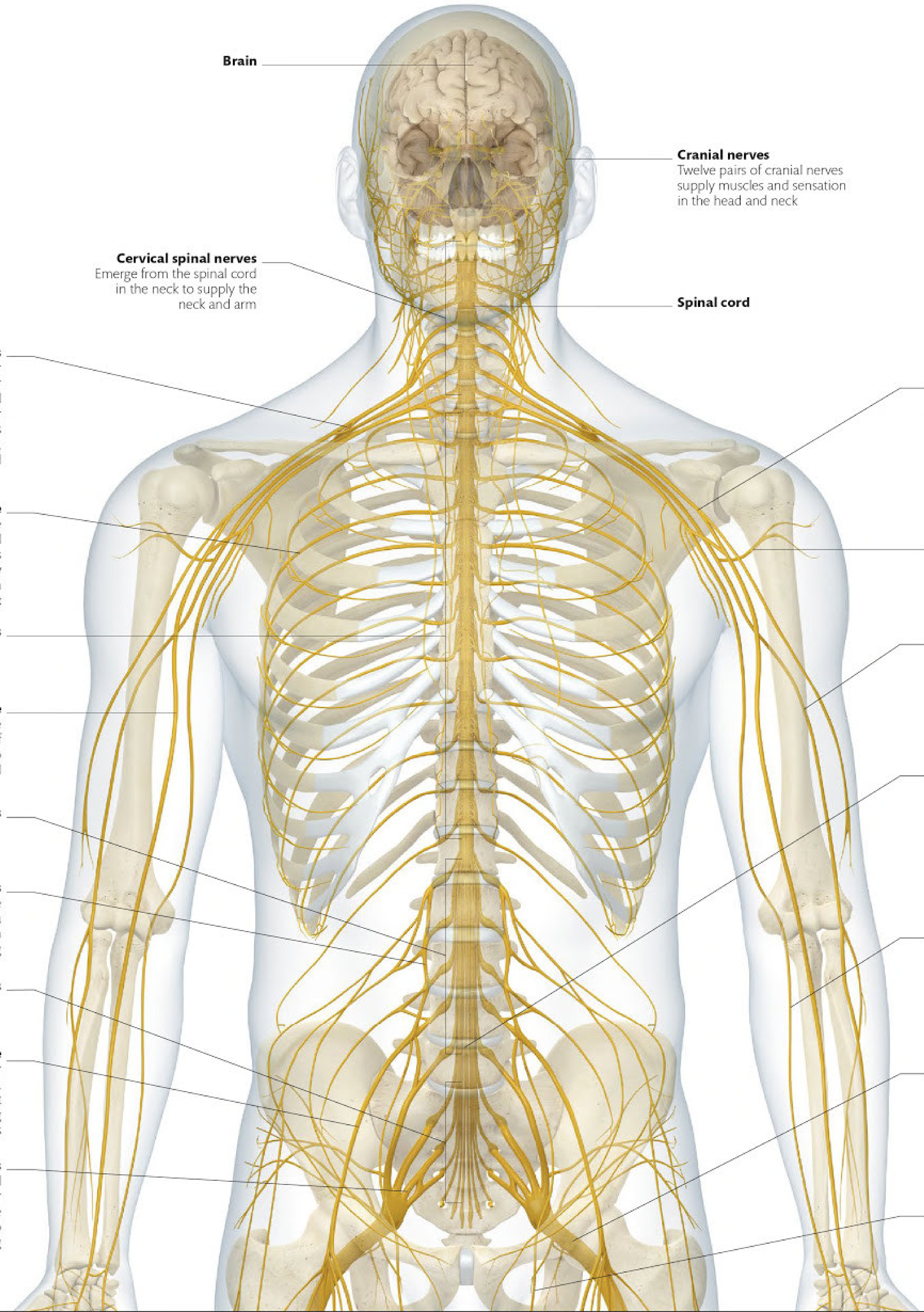
Tapering cells
This type of muscle is made of individual, tapering cells and is supplied by autonomic motor nerves, which control the operation of body systems, usually at a subconscious level. It is found in the organs of the body, particularly in the walls of tubes such as the gut, blood vessels, and the respiratory tract.

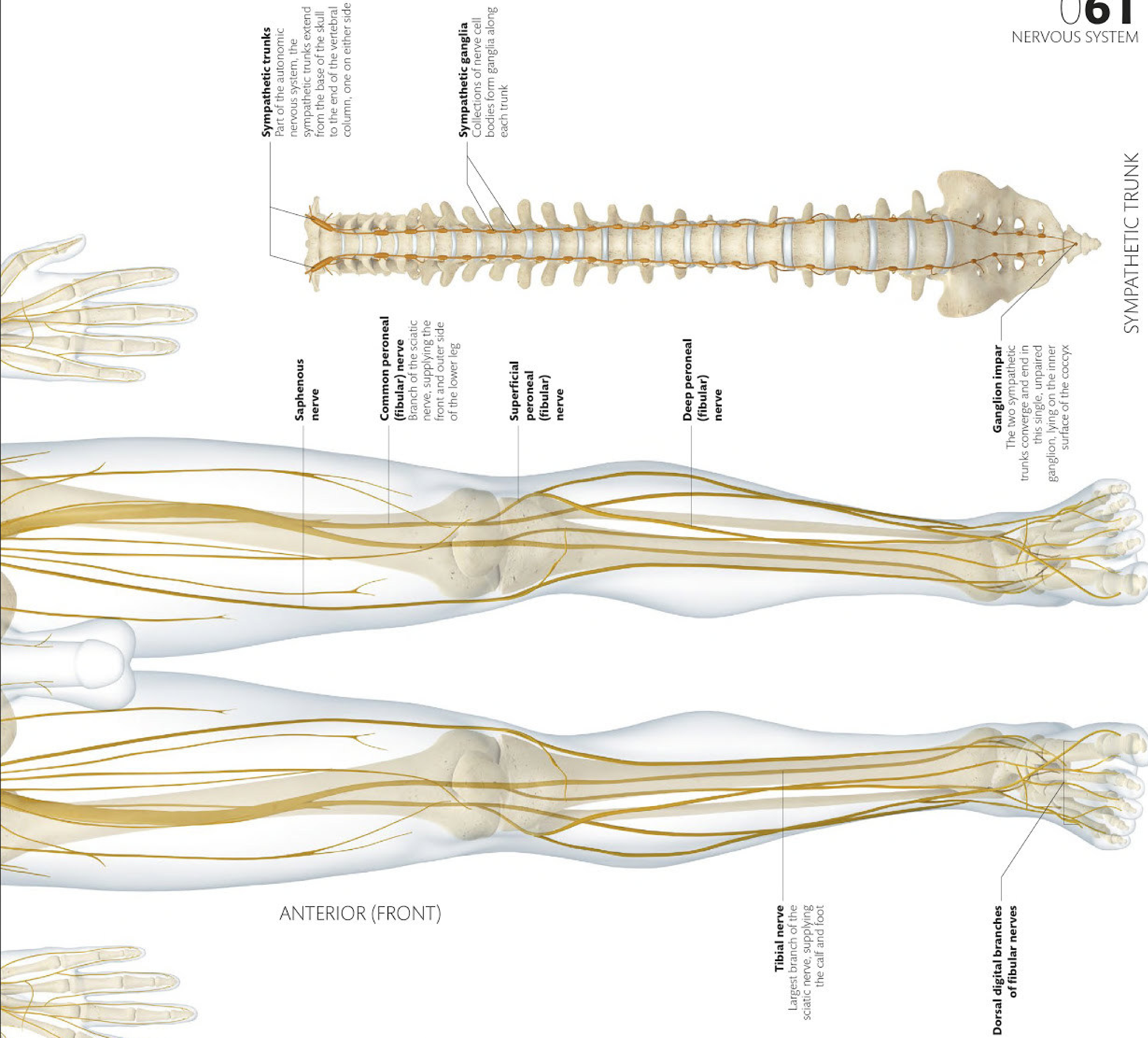
MUSCLE SHAPES





Muscular variation
Skeletal muscles vary hugely in size and shape. In some, such as strap or quadrate muscles, the muscle fibres are parallel with the direction of pull. In others, the fibres are obliquely oriented – as in triangular or pennate (feather-like) muscles.

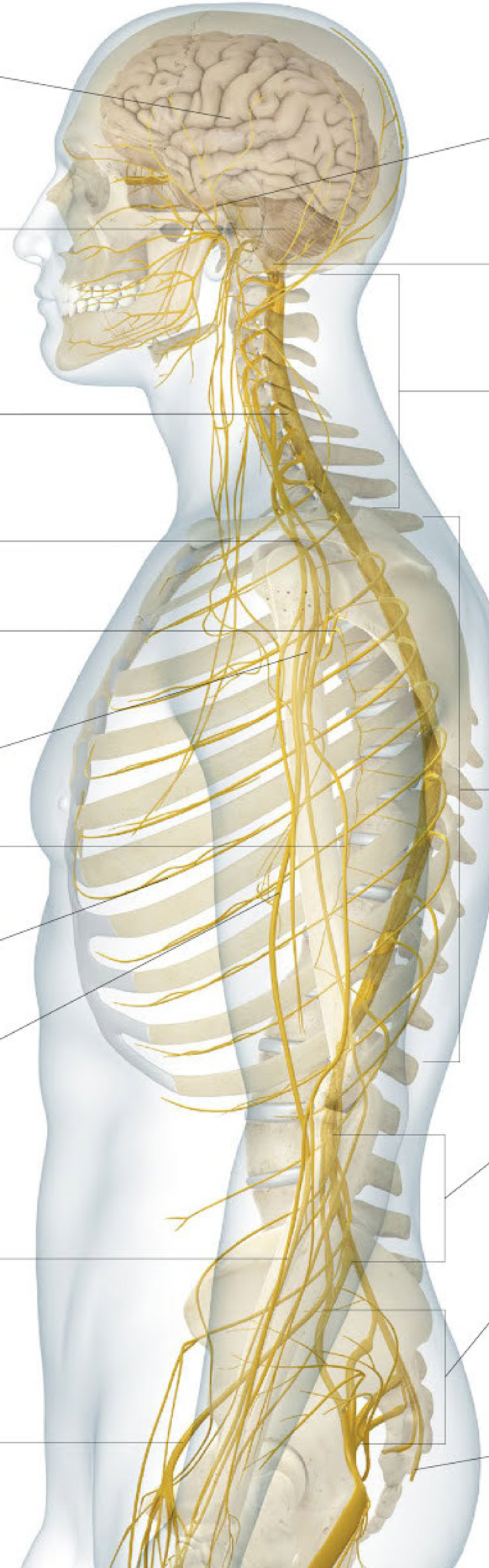

Brain
Cranial nerves
Twelve pairs of cranial nerves supply muscles and sensation in the head and neck
Cervical spinal nerves
Emerge from the spinal cord in the neck to supply the neck and arm
Spinal cord
Brachial plexus
Anterior branches of the lower cervical spinal nerves, together with the first thoracic spinal nerve, form a network, or plexus, from which branches emerge to supply the arm, forearm, and hand
Musculocutaneous nerve
Supplies the muscles in the front of the upper arm, including the biceps, as well as sensation to the skin of the outer (lateral) side of the forearm
Intercostal nerve
Anterior branches of the thoracic spinal nerves travel forwards between the ribs as intercostal nerves; they supply the muscles and skin of the thorax
Axillary nerve
Supplies muscles and sensation around the shoulder
Thoracic spinal nerves
Radial nerve
Supplies muscles and sensation on the back of the arm, (including the triceps, forearm, and hand)
Median nerve
Supplies most of the muscles in the front of the forearm, and also some in the hand
Cauda equina
Below the end of the spinal cord, the lumbar and sacral nerve roots continue for some way inside the vertebral canal, before emerging from the spine
Lumbar spinal nerves
Lumbar plexus
Anterior branches of the lumbar spinal nerves form a network here, from which nerves emerge to supply the leg
Ulnar nerve
Supplies two muscles in the forearm, and many of the small muscles in the hand
Sacral spinal nerves
Femoral nerve
Supplies sensation over the thigh and inner leg, and muscles in the front of the thigh, including the quadriceps
Sciatic nerve
Largest nerve in the body, which supplies the hamstrings in the back of the thigh; its branches supply muscles and sensation in the lower leg and foot
Sacral plexus
Anterior branches of sacral spinal nerves come together here as a network; the network provides nerves to the buttock and leg
Obturator nerve
Supplies the muscles and skin of the inner thigh

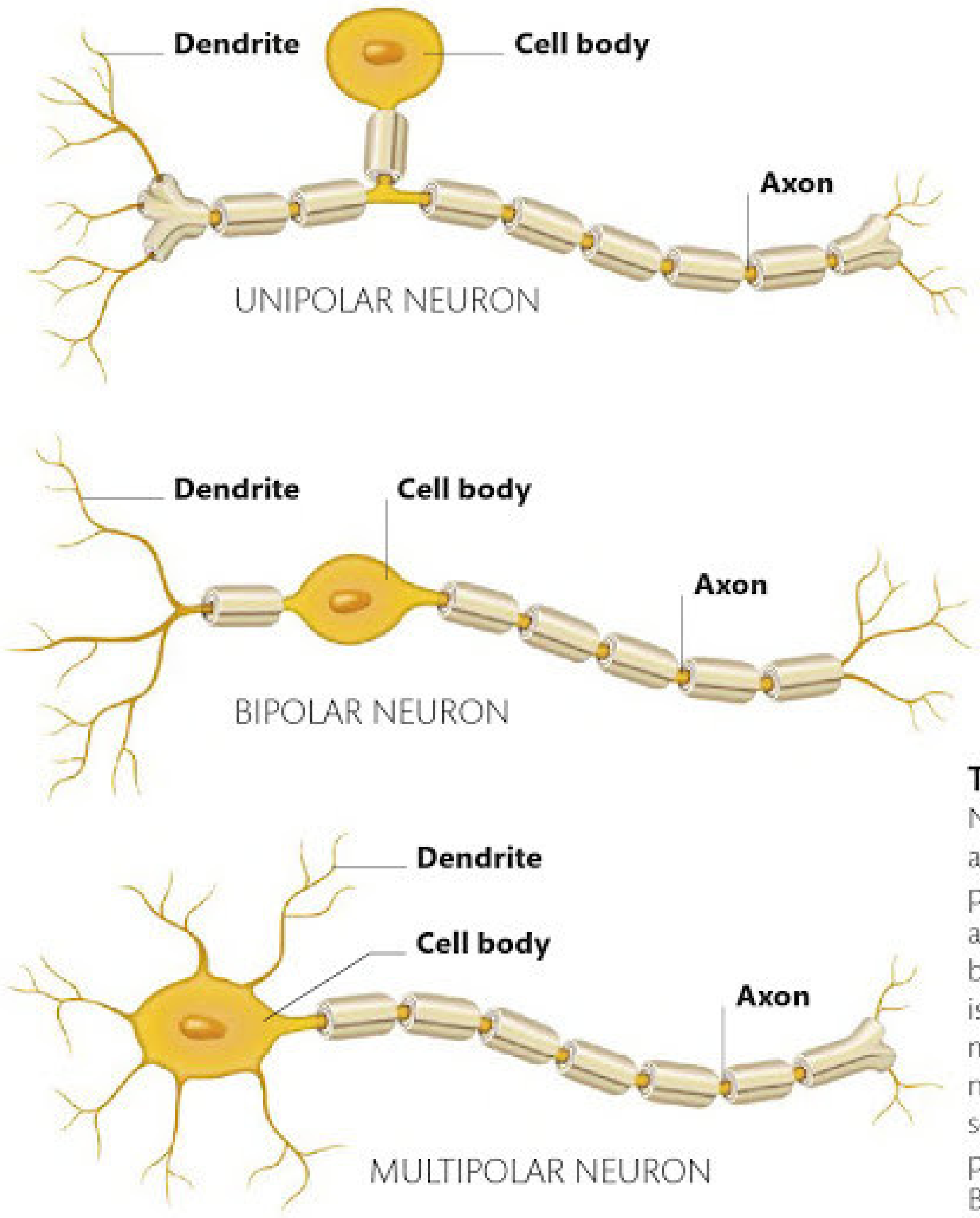


NERVOUS SYSTEM

The nervous system contains billions of intercommunicating nerve cells, or neurons. It can be broadly divided into the central nervous system (brain and spinal cord) and the peripheral nervous system (cranial and spinal nerves and their branches). The brain and spinal cord are protected by the skull and vertebral column respectively. Cranial nerves exit through holes in the skull to supply the head and neck; spinal nerves leave via gaps between vertebrae to supply the rest of the body. You can also divide the nervous system by function. The part that deals more with the way we sense and interact with our surroundings is called the somatic nervous system. The part involved with sensing and controlling our internal environments – affecting glands or heart rate, for example – is the autonomic nervous system.

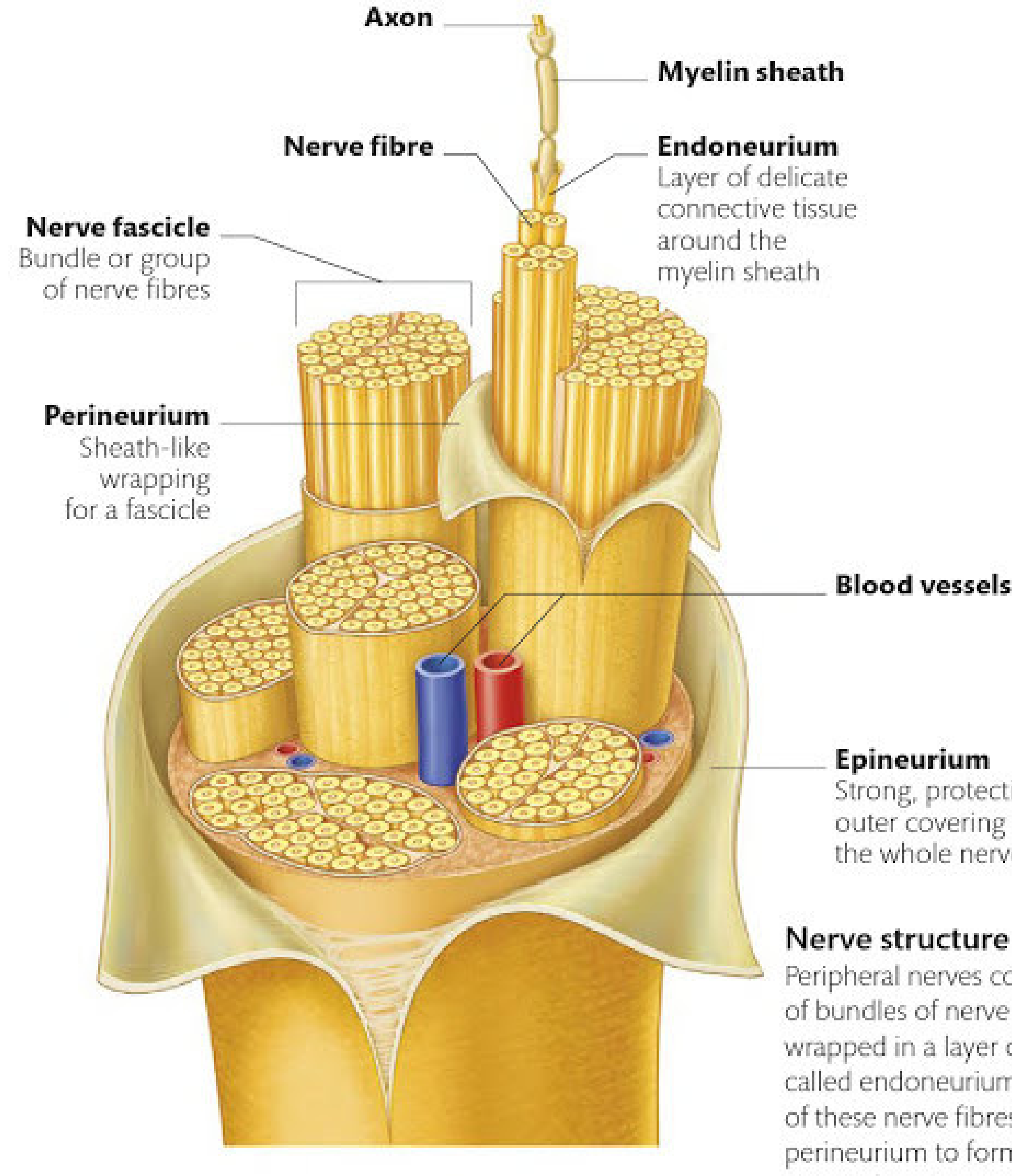
Head and neck
This coloured MRI scan reveals the structures of the brain and upper spinal cord (orange-red). The brainstem emerges from the base of the brain to continue as the spinal cord. The branched cerebellum is visible at the lower back of the brain.





TYPES OF NEURON

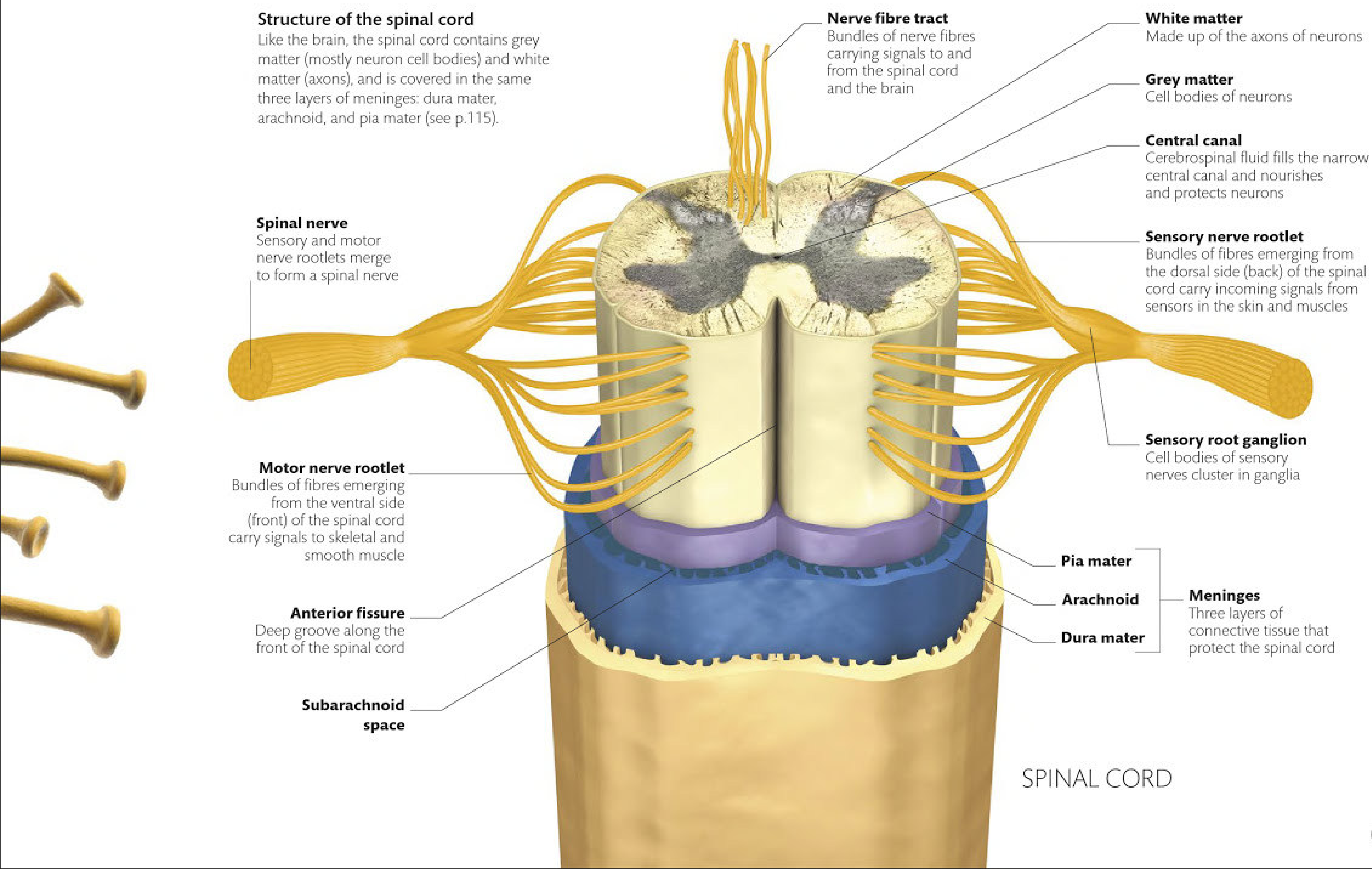
Types of neuron
Neurons can be classified according to how many projections (dendrites and axons) extend from the cell body. The most common is multipolar, with three or more projections. Unipolar neurons lie mainly in the sensory nerves of the peripheral nervous system. Bipolar neurons are found in only a few locations, such as the eye's retina.



PERIPHERAL NERVE

Nerve structure
Peripheral nerves comprise bundles of bundles of nerve fibres. Axons are wrapped in a layer of packing tissue called endoneurium. Small bundles of these nerve fibres are packaged in perineurium to form fascicles, and several fascicles are bundled within epineurium to form the nerve.

Structure of the spinal cord
Like the brain, the spinal cord contains grey matter (mostly neuron cell bodies) and white matter (axons), and is covered in the same three layers of meninges: dura mater, arachnoid, and pia mater (see p.115).



SPINAL CORD