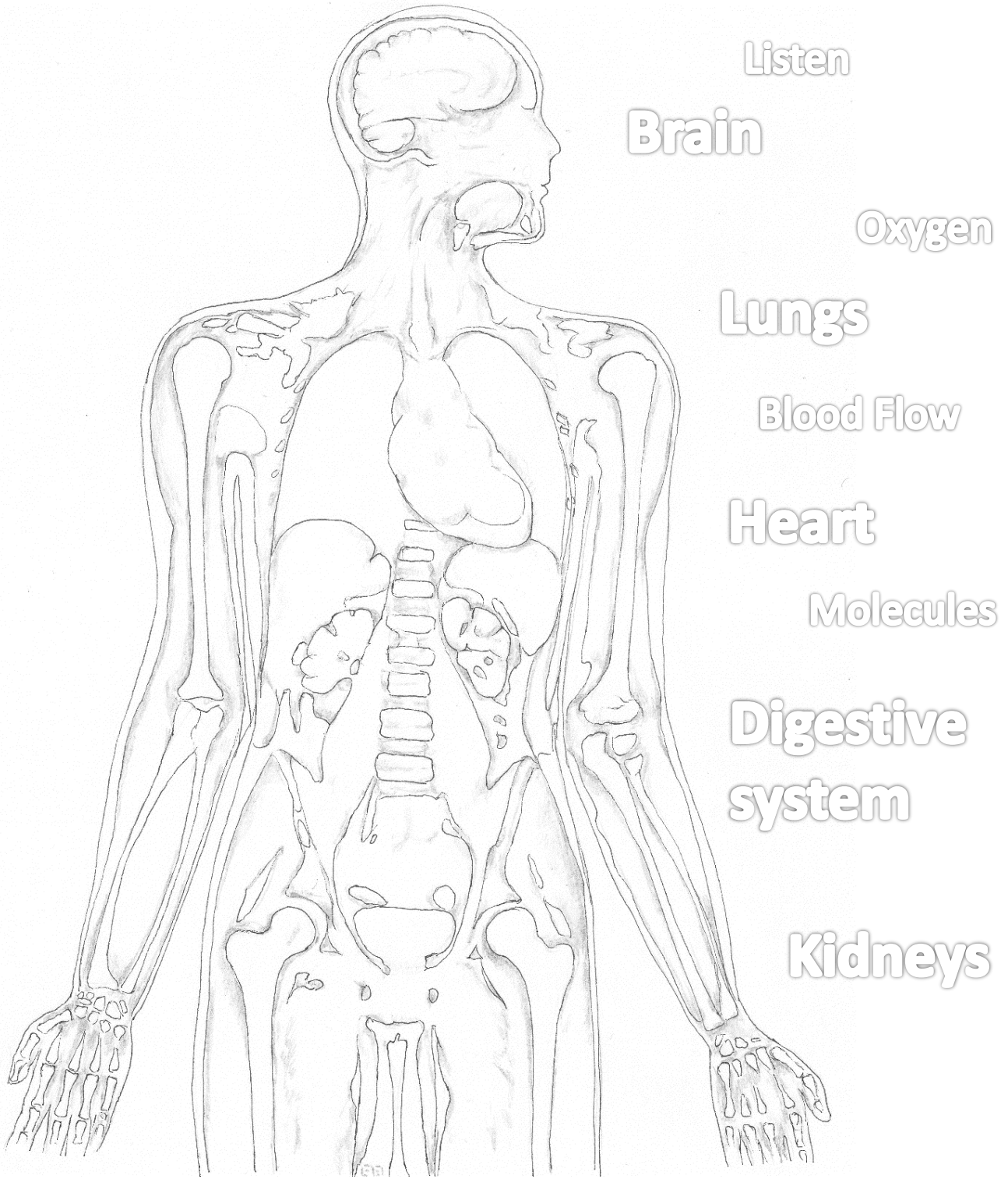
The Physiological Society

Amazing Body

A collection of drawings by Dr Lizzie Burns in collaboration with physiologists for adult colouring-in to learn about our remarkable human body

Physiology – *the way in which a living organism or bodily parts work*



Amazing Body

Your body is astonishing. Intricate, dynamic systems work within and between organs, cells and at a molecular scale, interacting to keep you alive and adapting to the world.

Just consider for a moment the wonder within your body. You breathe to bring air inside your lungs, where oxygen is picked up and carried by red blood cells throughout your body. Blood is pumped around your body by your heart depending on how active you are. Blood vessels themselves can sense and change blood pressure, and if oxygen was low your body would adapt. Your brain controls and co-ordinates a myriad of actions in your body through a network of neurons able to communicate through generating tiny electrical currents and chemical changes. Your brain regulates so much beyond your awareness including your heart, and senses. Listening or looking at the world is a complex process; converting light or sound into electrical signals between neurons to process to produce what we experience as the world. A basic need to fuel and build our body is finding and digesting food. Your brain encourages you to seek a diversity of food, to nourish and bring enjoyment through your senses. Your body also needs to get rid of your waste which may be less glamourous but an essential and extraordinary side of keeping your body well.

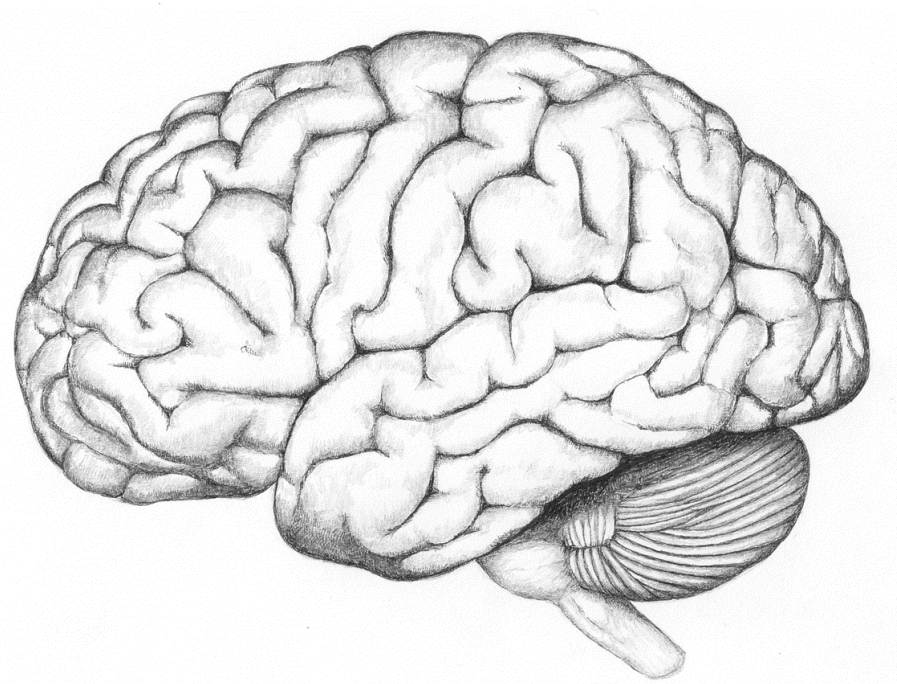
This collection of drawings is inspired by physiology which explores how our body works. Understanding illuminates changes with disease and brings hope for new medicines and treatments for the future. Physiologists often add dyes in their work to reveal structures inside the body. Colours can be bright and beautiful. This collection of drawings is aimed at encouraging you to add your own unique colours, to relax and get creative while learning about yourself. The collection also includes a couple of origami designs to bring flat paper into three dimensions.

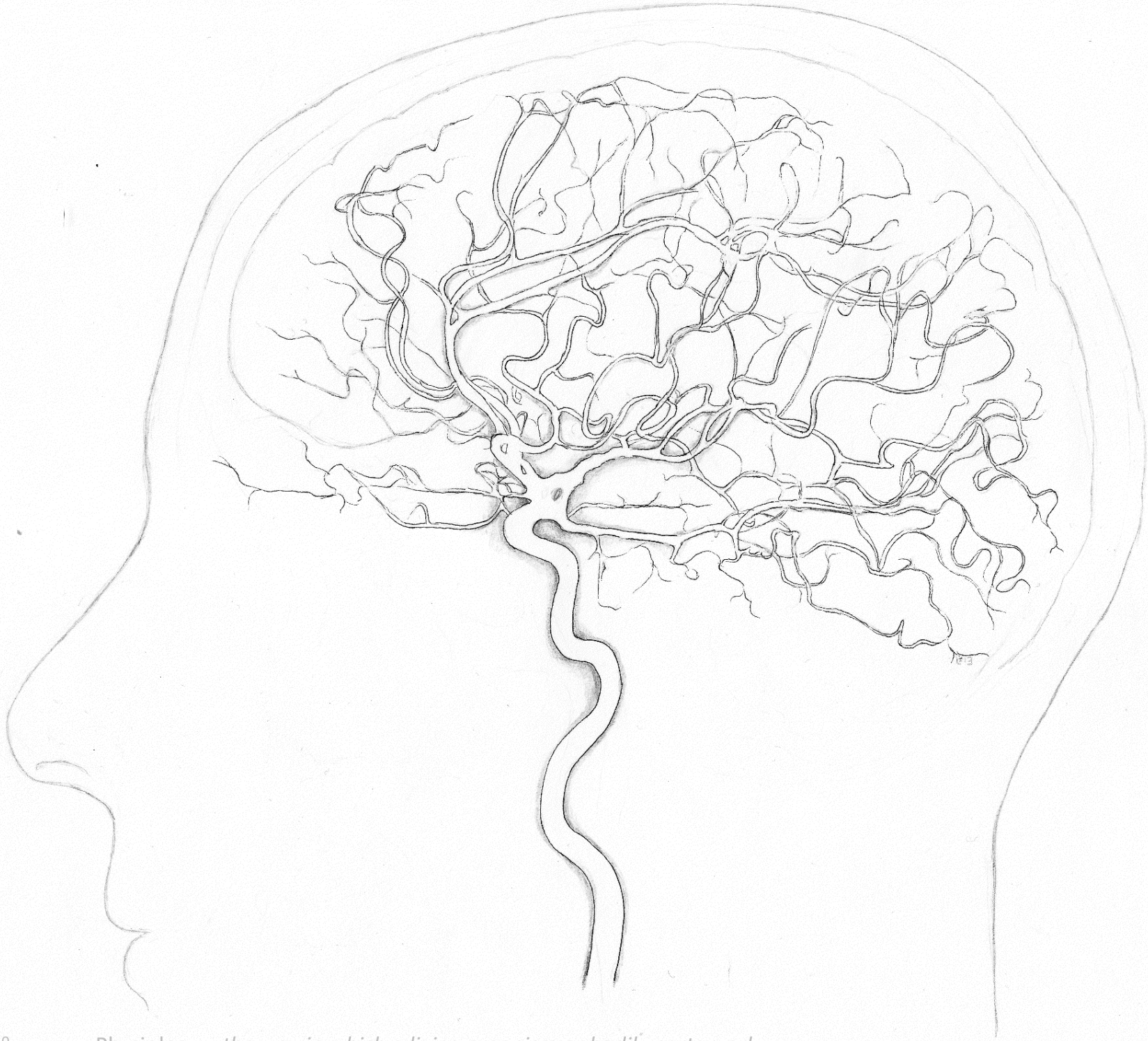
About Artist, Dr Lizzie Burns

Following a doctorate and postdoctoral research fellowship in cancer research from the University of Oxford, Dr Burns became a full-time science-based artist and communicator in 2002. Lizzie has worked for a wide range of organisations encouraging people of all ages to get inspired by the beauty and wonder science. Each drawing comes from a collaboration with members of The Physiological Society to visually convey the relevance and beauty of their work. Lizzie is also a member of the British Origami Society.

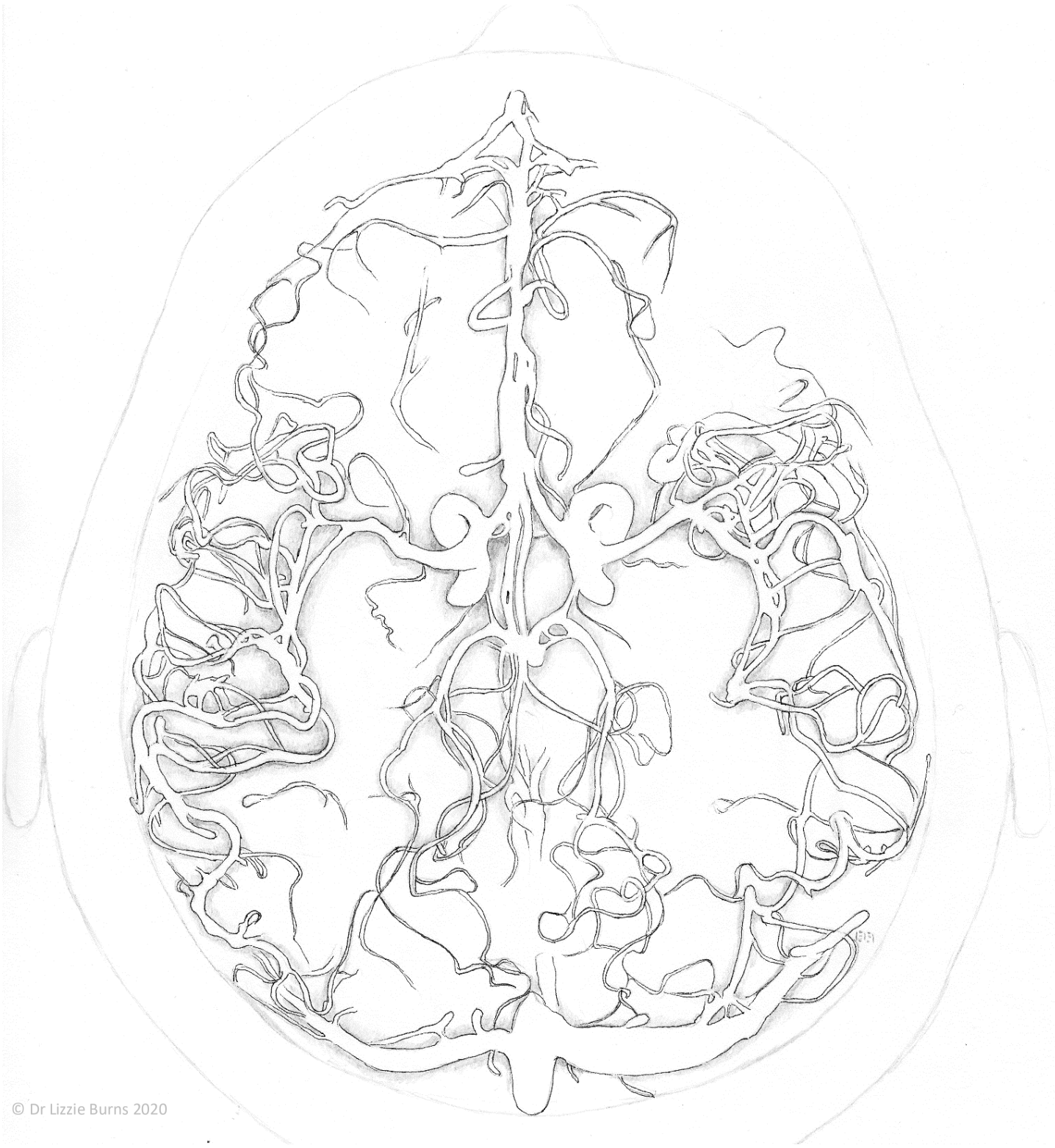
"*When I started this project in 2019 the world was different prior to COVID-19. I have been astonished how relevant these topics are to understand how the coronavirus can disrupt, and brings to light how interconnected systems are within our body. The virus can cause damage the lining of blood vessels leading to blood clots and damage across systems. Science brings hope and appreciation as to how astonishing our body is. This project also celebrates the creativity and curiosity of scientists. I hope this collection will bring you delight, joy and comfort in learning about yourself while unleashing your creativity.*"

Amazing Body: Brain





Physiology – *the way in which a living organism or bodily parts work*

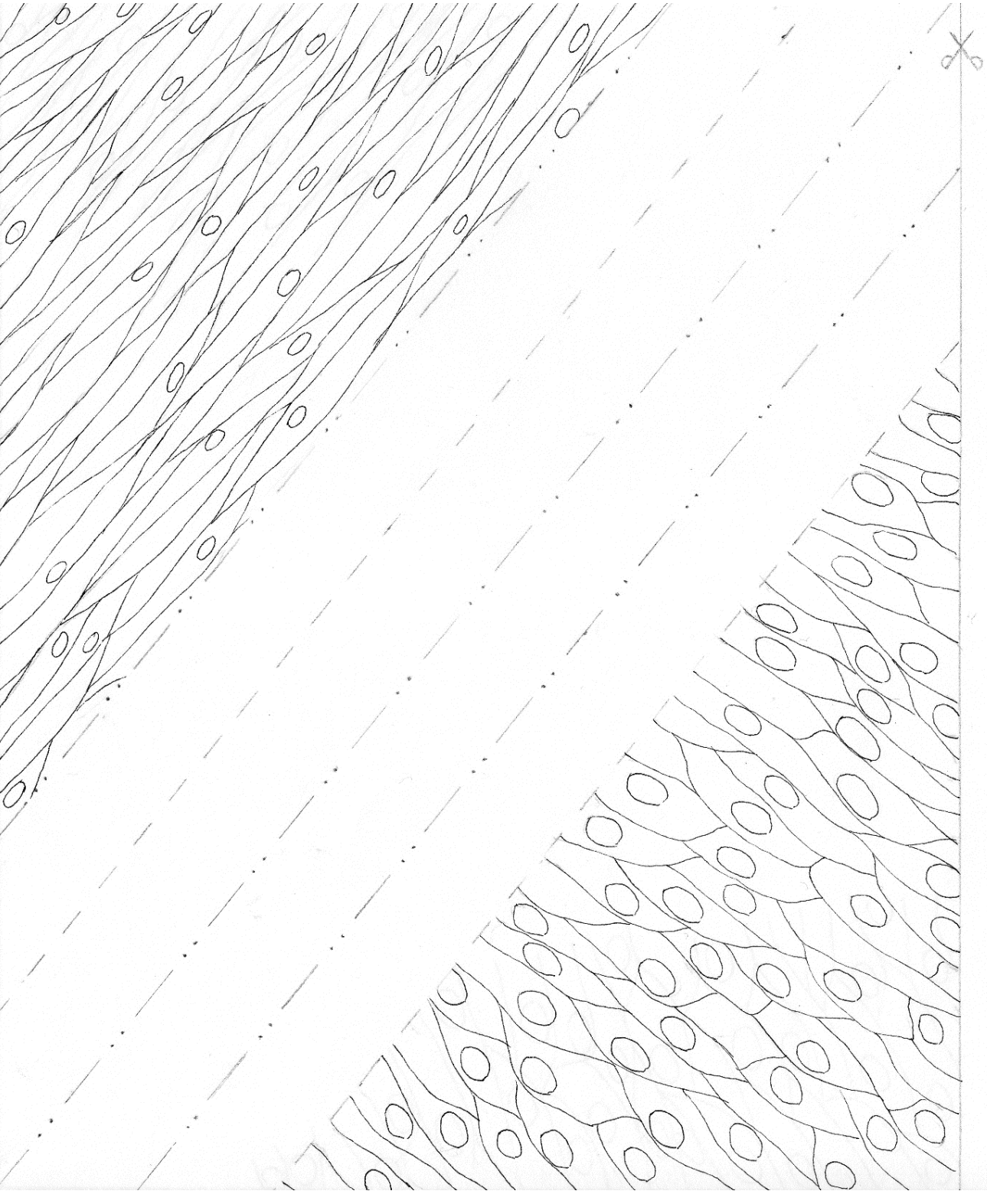


Amazing Body: Blood Flow

Your body is astonishing. Blood is pumped around your body by your heart to supply oxygen, food and all the chemicals of life needed to keep you alive. We have around 5 litres of blood constantly moving through arteries, veins and capillaries. Vessels that carry blood form beautiful tree-like structures across your body can sense and react to contract or relax to control flow and generate your blood pressure.

These two drawings are based on images of the remarkable blood vessels in our head. On the previous page a side view shows the branching tree-like structures supplying blood to the brain. On this page, the drawing shows arteries as seen looking down onto the head, giving another view of this complex and beautiful system. Here the 'Circle of Willis' can be glimpsed way down at the base of the brain as a circle of arteries, which supply your brain with blood. Add colour to celebrate these remarkable structures within your body which keep us healthy and well.

The Physiological Society

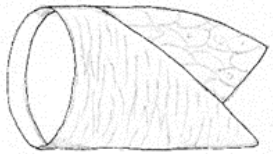


Amazing Body: Blood Flow

Your body is astonishing. At a microscopic scale your body is made of billions of cells. At this level, vessels that carry blood are seen as tiny tubes made of layers of different cells which help control the flow of blood. On the outside nerves control tiny smooth muscle cells that wrap around to form vessels that can relax or tense to change flow and blood pressure by changing the vessel diameter. When muscle cells pull or tense they shorten and constrict the vessel so increasing blood pressure, and when relaxed blood pressure drops. Beneath the muscle cell layer is a single layer of 'endothelial cells' which can sense the blood beneath and affect the muscle cells helping to regulate blood pressure through eeping vessels open.

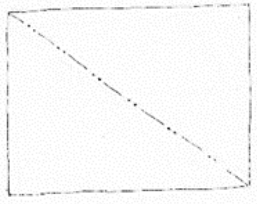
Cut out the rectangle and colour in the cells with nuclei to fold your own origami model of part of a blood vessel. Muscle cells are long and narrow, while endothelial cells are wider. Make cells colourful on both sides before then folding to make a circular structure. While paper is not suitable for liquids, this structure will glide through the air and can be seen as a video on The Physiological Society YouTube Channel.

Collaboration: Science-based artist, Dr Lizzie Burns with Professor Christopher Garland, University of Oxford. Time is an opportunity; find out more about the science of life: www.physoc.org



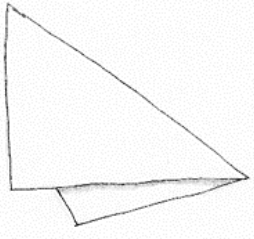
= valley fold

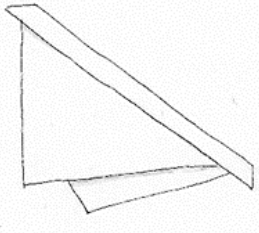
= mountain fold



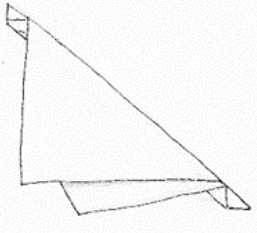
How to fold a model of a blood vessel

1. Cut out the rectangle
2. Fold along marked line so it resembles the next drawing

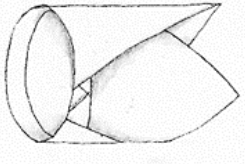




3. Fold along the first marked line to resemble this drawing

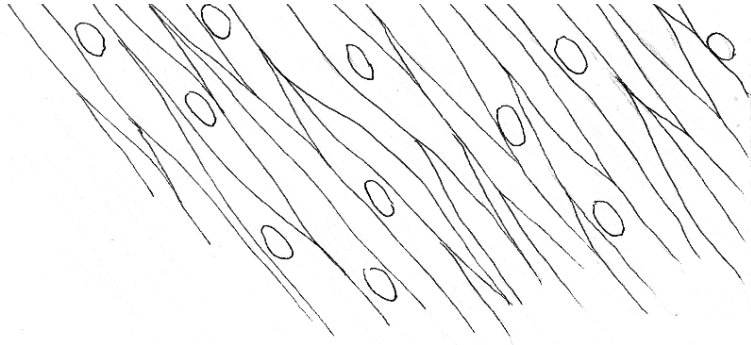


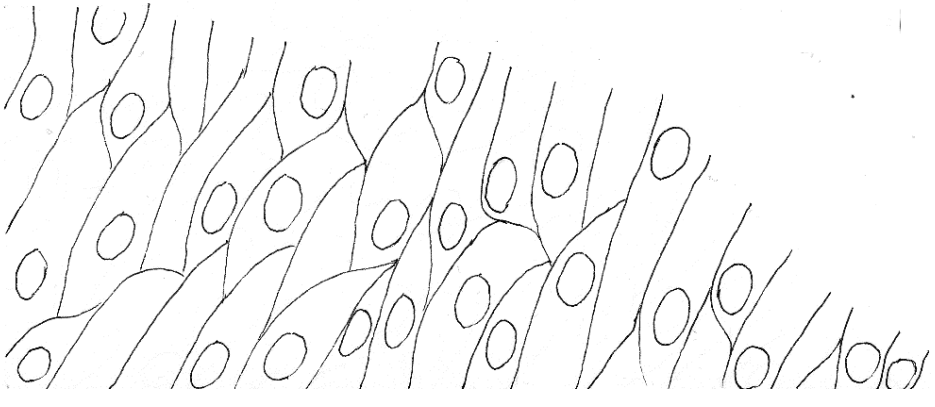
4. Fold back along the second marked line to resemble this drawing



5. Curve the paper so the outside is smooth and tuck one end into the other side to create a circular structure

For a demonstration as to how to make this go to: The Physiological Society YouTube



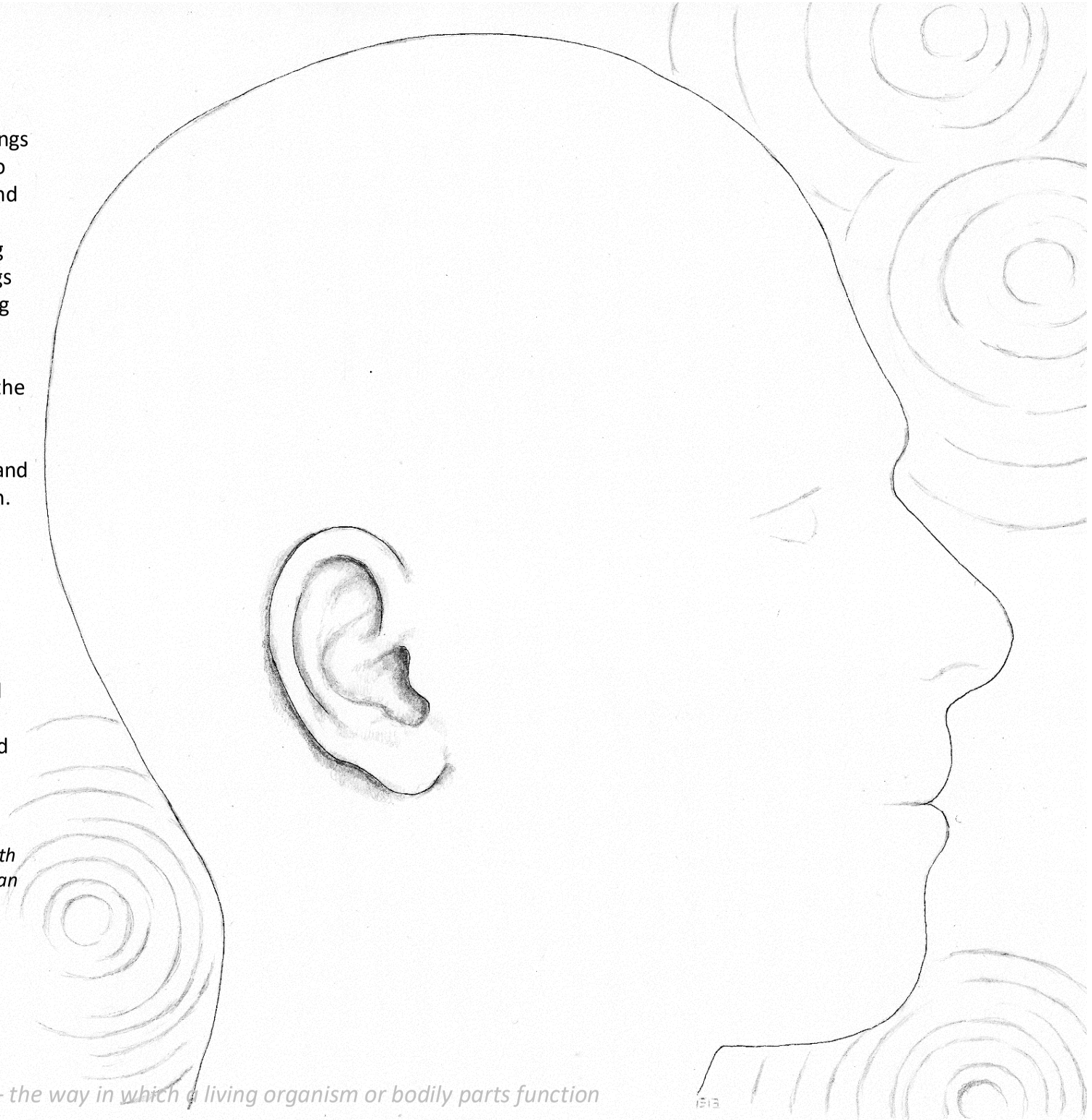


Amazing Body: Listen

Your body is a astonishing. For a moment just listen. We hear so much around us. These drawings show both sides of a head. We need both ears to help give our brain information as to where sound is coming from. We cannot see sound but here imagine sound as ripples, sound waves travelling through the air. On the second page are drawings to see the tiny structures inside our head starting with our ear drum which passes on vibrations in the air to the three smallest bones in our body (malleus, incus and stapes) which then push on the pea-sized cochlear (resembles a snail). Here vibrations are converted into electrical impulses passed on between neurons which make sense and create the experience of hearing inside our brain. Trace the journey of sound. On the third page a tiny brain shows where sound is initially 'heard' inside our brain from where activity patterns become more widespread as the content and meaning are processed.

Bring these drawings to life; add hair, colour and focus on the sounds you hear. Physiologists are working out how our brain makes sense of sound waves which could help those who may lose hearing.

Collaboration: Science-based artist, Dr Lizzie Burns with Professor Andrew King, University of Oxford. Time is an opportunity; find out more about the science of life: www.physoc.org *or* www.auditoryneuroscience.com *which includes a dancing cell inside an ear!*



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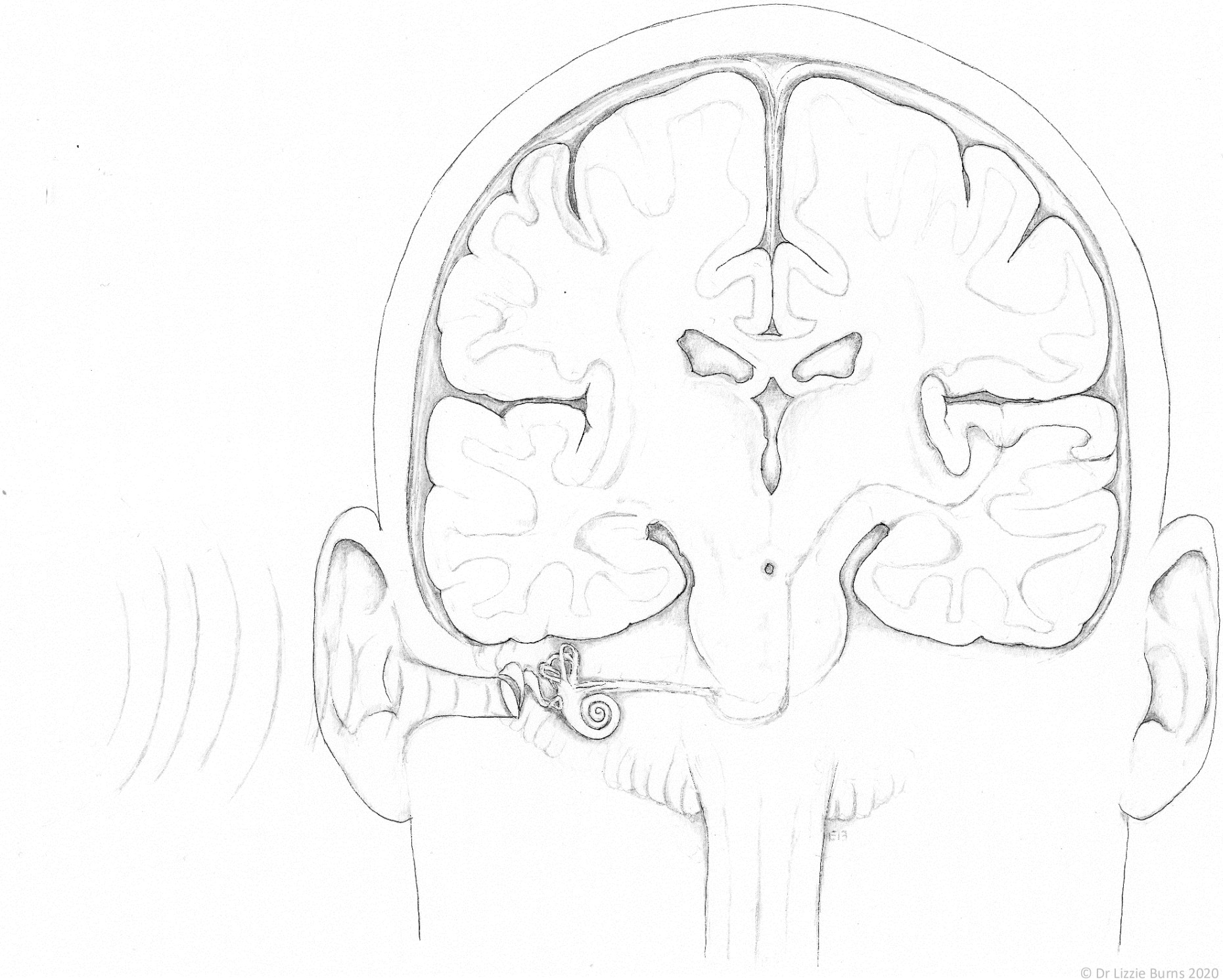
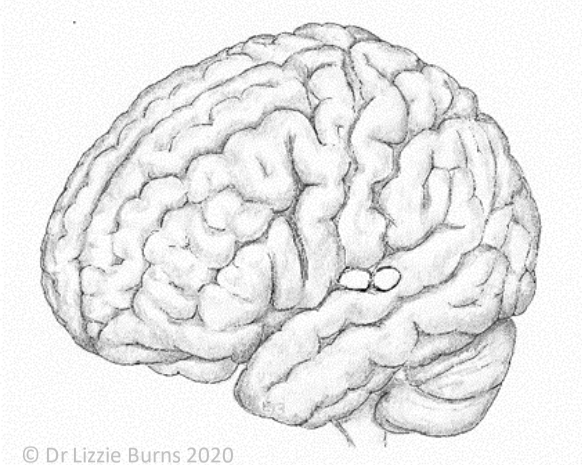
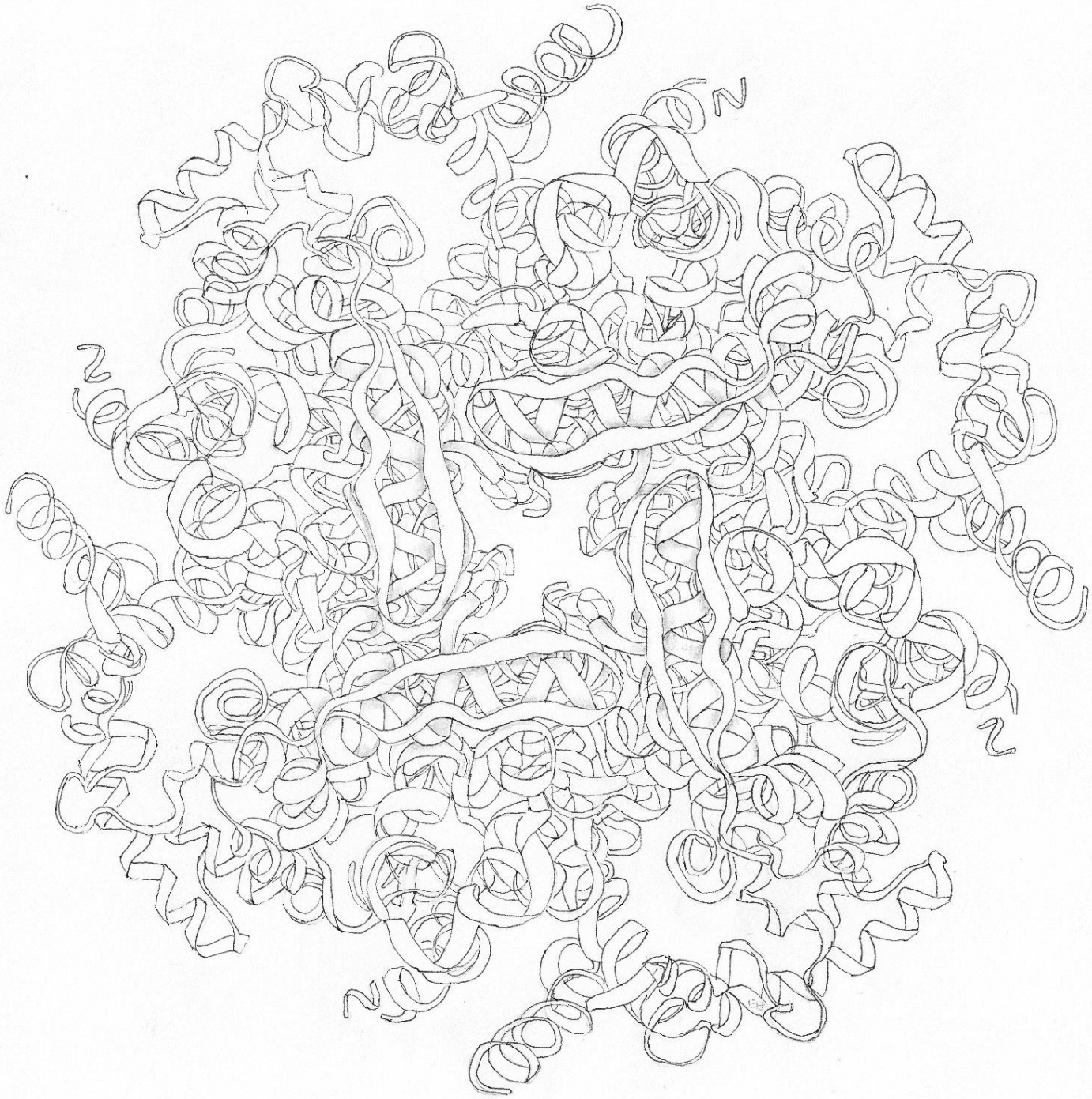


Amazing Body:
Listen

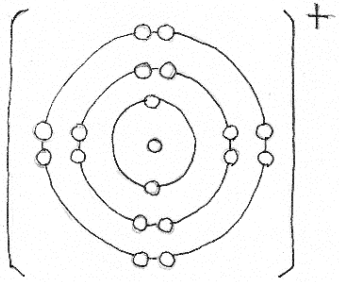


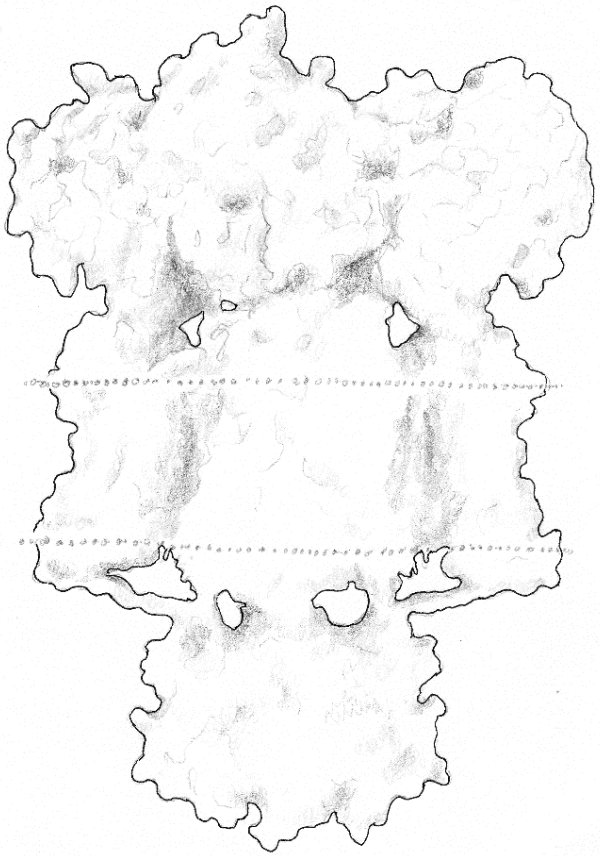
Drawing: from book 'The Brain as a Tool' by Ray Guillery, OUP

Amazing Body:
Listen



Amazing Body: Electricity in the Brain





We rely on electricity in our daily lives. The same is true, but more so for our body. Without electricity we would not be alive. Electricity is the flow of charge which can power machines. Our body generates electricity through movement of charged particles called ions. On the surface of our brain cells (neurons) are tiny proteins which allow charged ions in and out of the cells to create electric currents.

All we feel and think comes from neurons communicating with each other through electricity and chemicals which control our body's functions. As a neuron receives information proteins work together to pass on the message to the next cell. Physiologists explore how neurons work at a tiny molecular scale, and which ions are involved. It is possible to pick up electrical signals from the surface of our head to see which areas are busy which during sleep can be surprisingly active. Many brain diseases happen when our electrical signals are disrupted. Take a look below at brain waves from a person who was awake and relaxed.

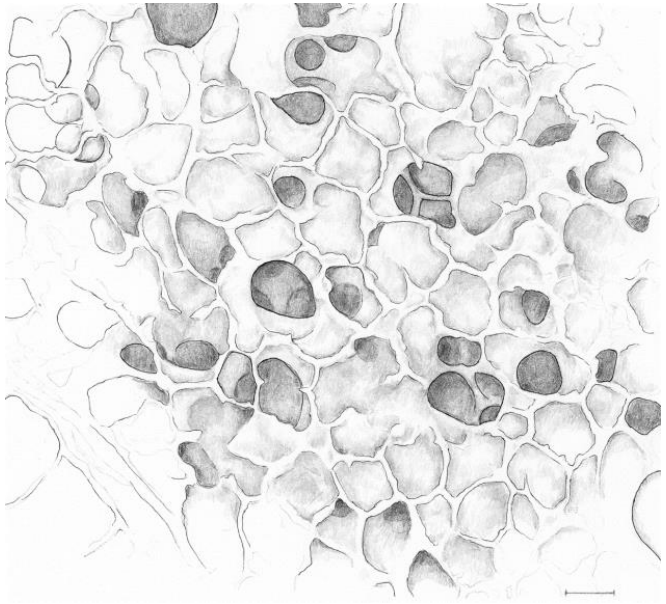
The drawing overleaf shows a view looking down the centre of a tiny pore where ions move in and out like a molecular game. To the right of this writing is a side view of the same molecular pore spanning a cell membrane. Above this drawing is a diagram of a potassium ion (K+) flowing through this particular pore. Add colour and bring these moving molecular electrical structures to life. They are being used all the time to allow you to think and move. Your body is amazing.

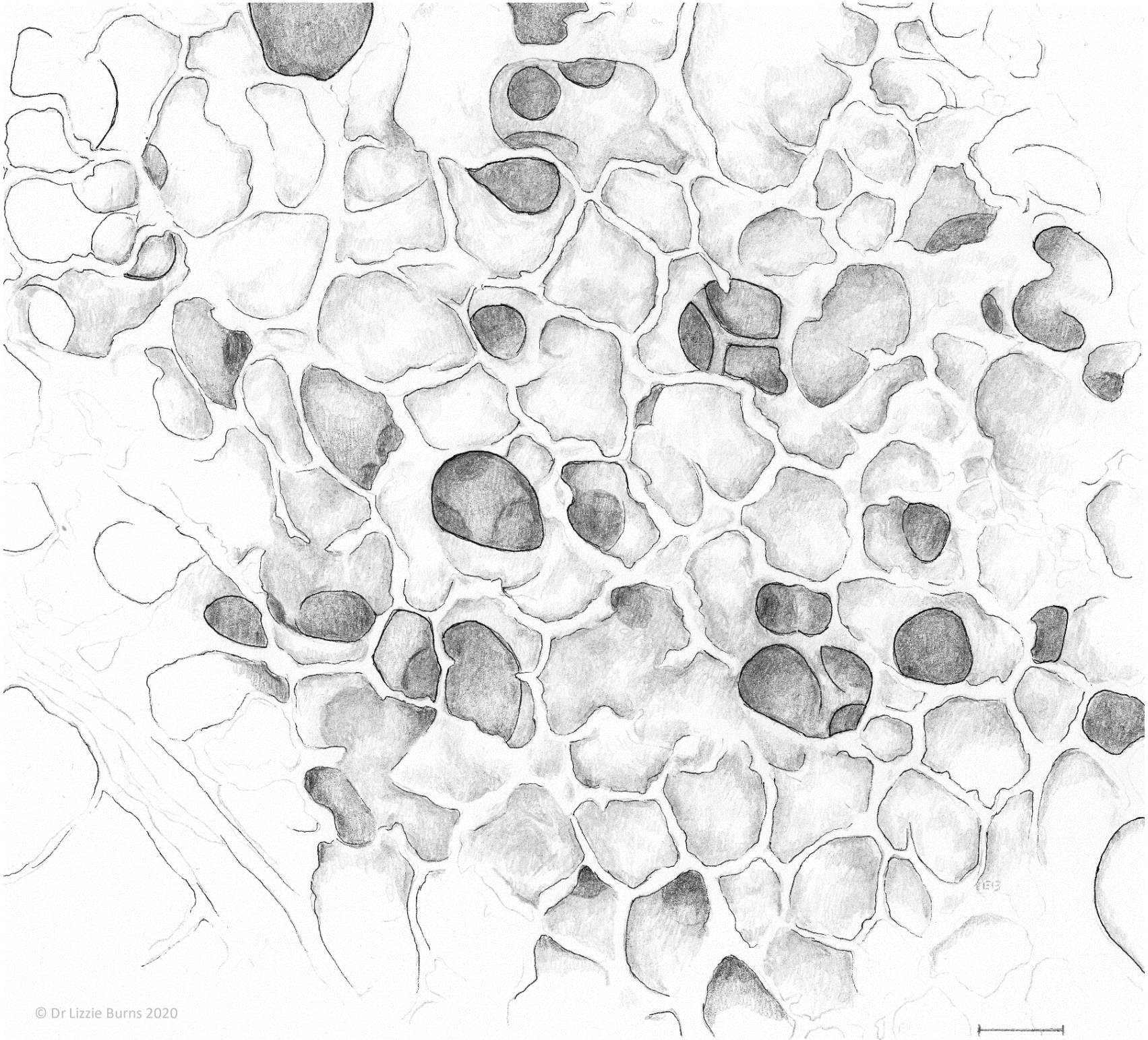
Collaboration: Science-based artist, Dr Lizzie Burns with Dr Mark Dallas, University of Reading. Time is an opportunity; find out more about the science of life: www.physoc.org

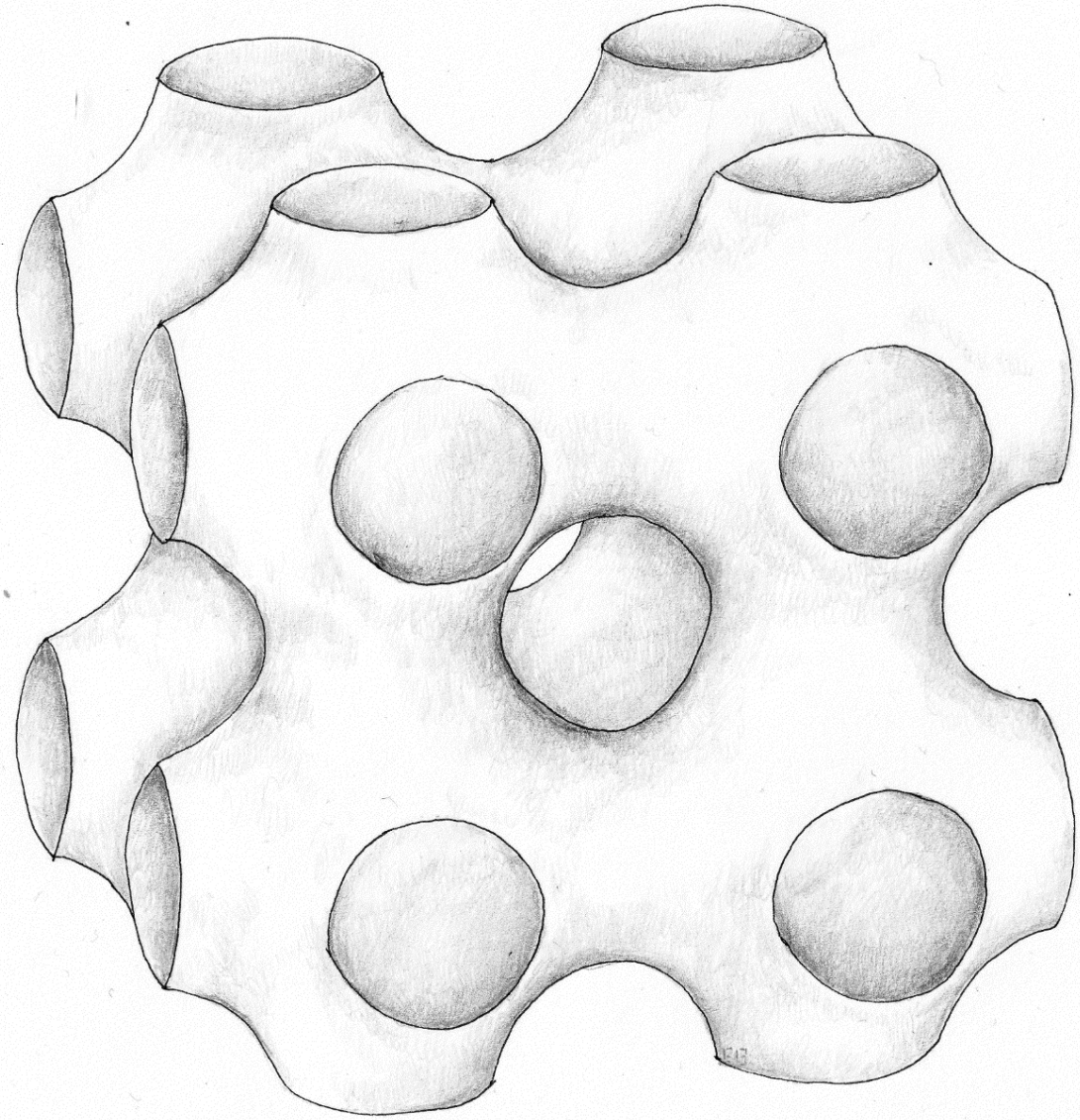
The Physiological Society

Physiology – *the way in which a living organism or bodily parts function*

Amazing Body: Lungs







Physiology – *the way in which a living organism or bodily parts work*

Amazing Body: Beautiful Lungs

Your body is astonishing. We take oxygen in from the air we breathe and excrete carbon dioxide. This exchange of gases takes place within lungs which resemble branched trees. On the previous page see the tiny beautiful honey-comb structures where red blood cells pick up oxygen to carry around our body. Marvel at a glimpse of the structures in our lungs which scientists are trying to understand how they work and move during breathing. Getting closer, our body is made of molecules, which form beautiful structures. The mathematical shape (Schwarz P structure) seen on the left may model how a liquid (surfactant) forms similar shapes which cannot collapse to ensure our lungs are open and flexible.

Add colour to the drawing on the previous page of the inside of our lungs at a microscopic scale. If you would like to inflate the drawing to become 3D take the bottom left corner and bring up to the top to cut a square. Use the diagram below to fold your square or look on The Physiological Society YouTube channel. Inflate using the breath from your lungs. The line on the drawing overleaf represents 50 micrometres which is around half the width of a human hair.

Collaboration: Science-based artist, Dr Lizzie Burns with Professor Peter Robbins & Professor Keith Dorrington, University of Oxford. Time is an opportunity; find out more about the science of life: www.physoc.org

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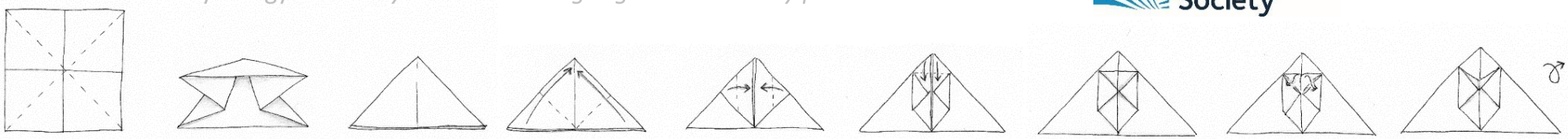
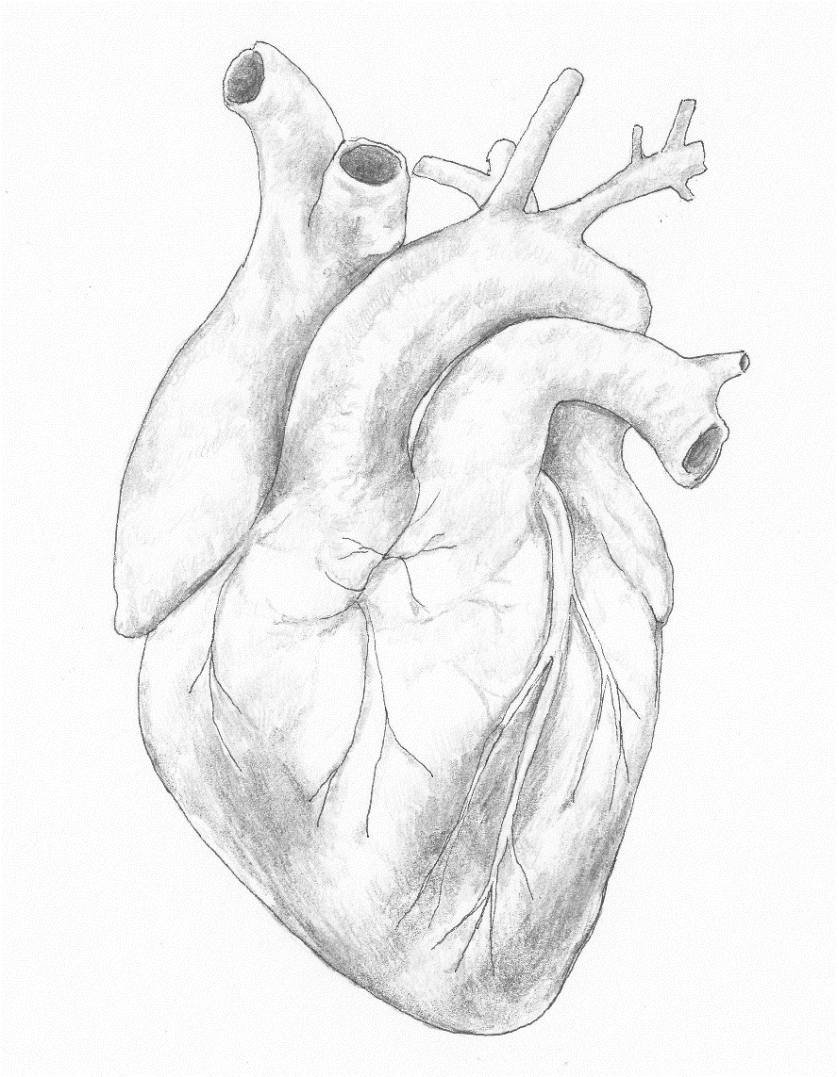
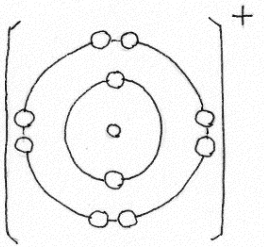
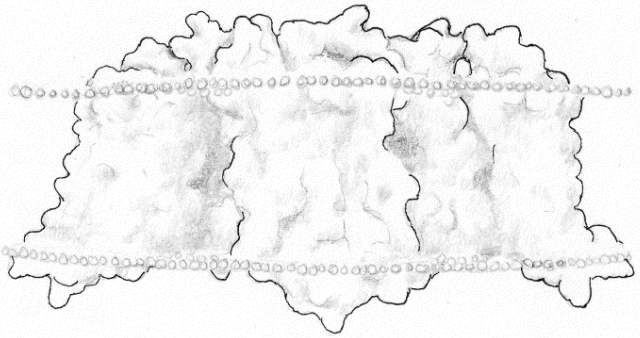


Amazing Body: Heart



Amazing Body: Electricity in the Heart



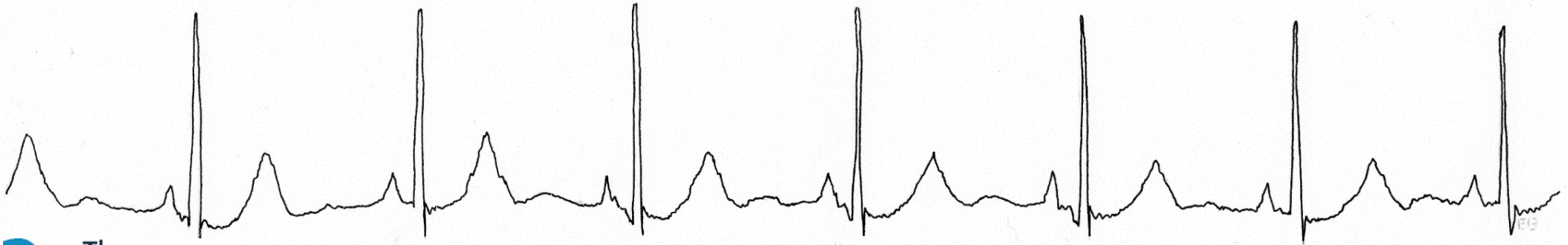


Without electricity we would not be alive. Our body generates tiny electric currents needed for us to work. Electricity is the flow of charge which can power machines. Our body generates electricity through movement of charged particles called ions allowing cells to communicate, and to control our body.

Our heart is a remarkable organ which pumps blood around our body. This constant flow of blood allows oxygen to be picked up from the air we breath in our lungs to keep us alive thanks to our heart beating around 3 billion times over a lifetime. The heart is made of muscles which naturally beat, but they need to be co-ordinated. Tiny molecular pores on the surface of muscle cells in the heart pump sodium ions out of the cell in exchange for potassium ions. When a muscle cell is triggered to contract by a neuron the pores stop working and sodium rushes into the cell. Molecular pores help keep muscle cells working and ready to contract. It is possible to pick up electrical signals from our heart and is a pattern you may recognise as showing those vital signs of life as seen below.

Take a moment to ponder how astonishing we are. Overleaf is a drawing based on a computer model of one of these tiny molecular pores with lets sodium ions in and out (Na+). This drawing shows a view looking down the centre of this tiny pump where ions move in and out like a molecular game. On this page electrical signals from a heart are seen below and to the right a side view of the same molecular pump spanning a cell membrane. Above this is a diagram of a sodium ion which will flow into the cell to keep your heart beating. Add colour and bring these moving molecular electrical structures to life. They are being used all the time to allow your heart to work. Your body is amazing.

Collaboration: Science-based artist, Dr Lizzie Burns, with Dr Mark Dallas, University of Reading. *Time is an opportunity; find out more about the science of life:* www.physoc.org



The Physiological Society

Physiology – *the way in which a living organism or bodily parts function*

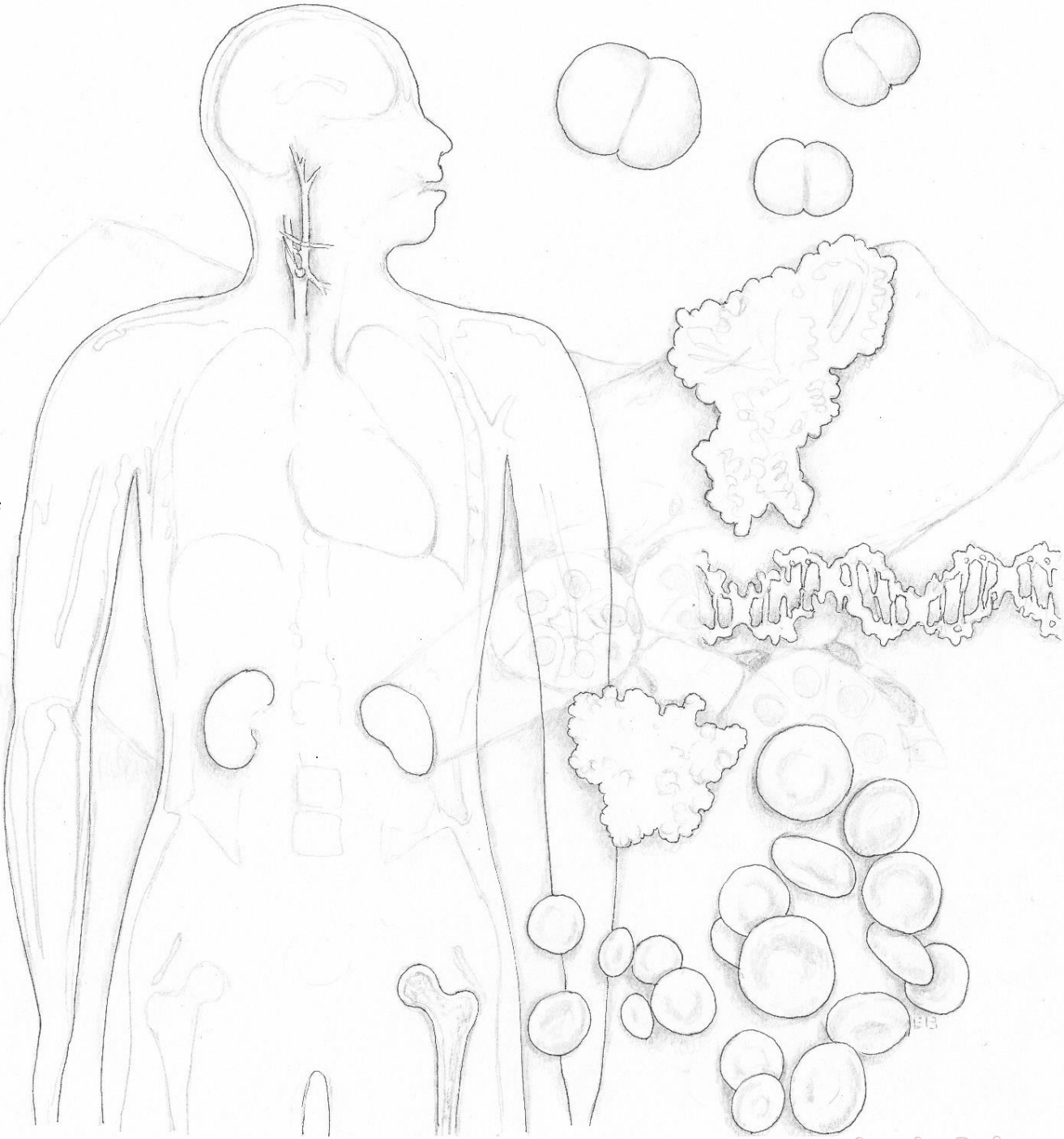
Amazing Body: Oxygen sensing

Your body is astonishing. We need oxygen to stay alive and well. Understanding how our body senses and adapts to low oxygen levels (hypoxia), with high altitude or with respiratory disease, reveals the intricate mechanisms spanning scales from the whole body, to organs, cells and molecules which work together to preserve life.

Drawings representing oxygen molecules (O_2) in the air we breathe are seen top right which enters our lungs. Within the lungs oxygen is picked up by red blood cells within blood vessels and pumped by the heart around the body. Low oxygen levels in blood are 'sensed' by kidneys to switch on gene expression to produce a hormone (erythropoietin) stimulating bone marrow to make more red blood cells*. As well as our kidneys, a tiny group of cells in our neck (carotid body; around the size of a peppercorn) can sense low oxygen levels in our blood stimulating our brain to start breathing more rapidly and deeper*.

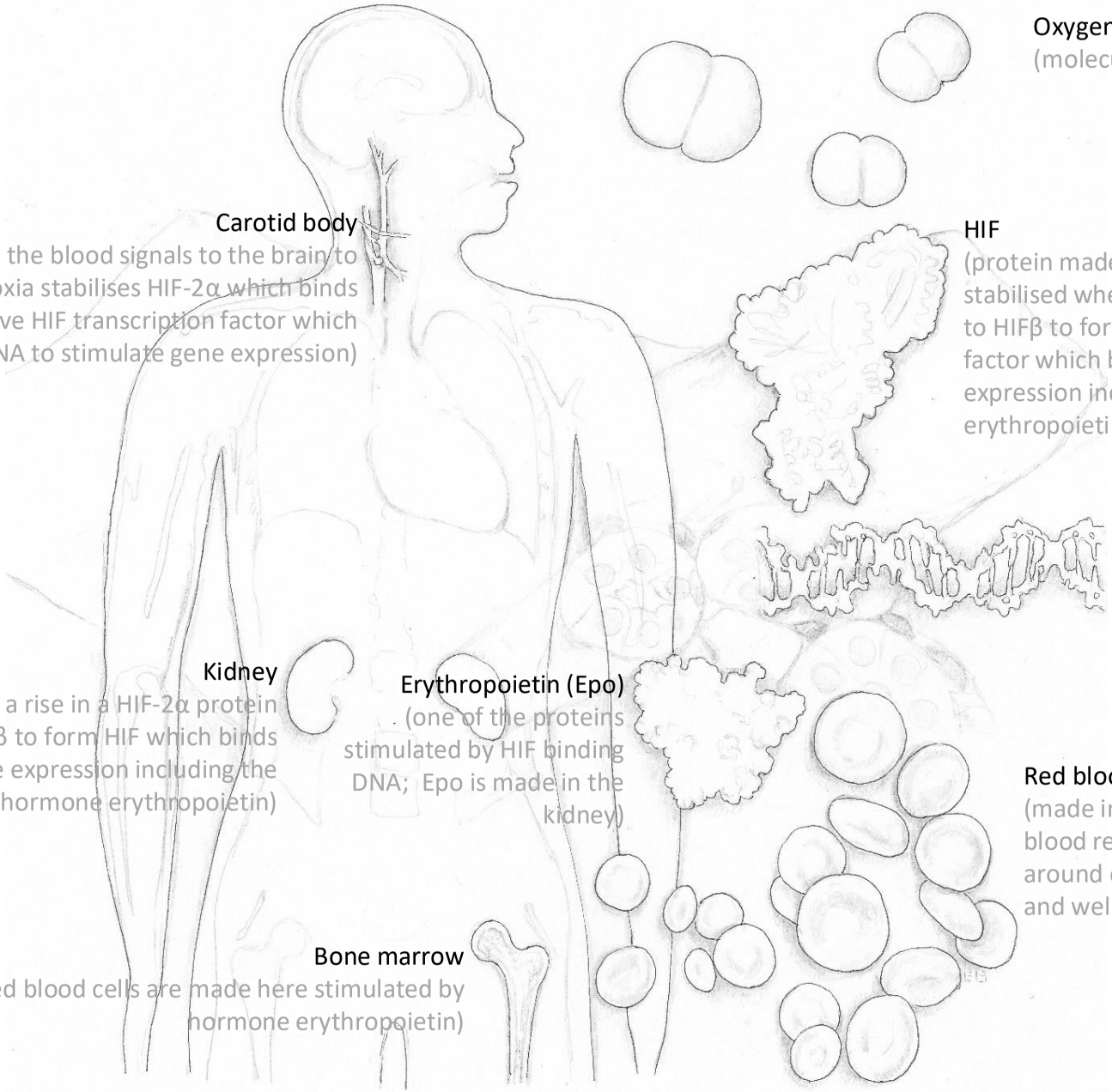
In essence our body senses low oxygen so we breathe deeply and make more red blood cells to carry oxygen. Red blood cells are responsible for making our blood red. In terms of scale, around 12 red blood cells would fit across the width of a human hair. Add colour to these drawings; your body really is remarkable.

Collaboration: Science-based artist, Dr Lizzie Burns with Sir Peter Ratcliffe and Dr Tammie Bishop, University of Oxford. Time is an opportunity; find out more about the science of life: www.physoc.org



* In more detail: In the kidney low oxygen levels leads to a stable HIF-2α protein to bind to its partner HIFβ to form an active transcription factor which binds to DNA to stimulate gene expression. In the carotid body a lack of oxygen in this clump of cells also stabilises HIF-2α protein to bind to HIFβ to drive gene expression.

Amazing Body: Oxygen sensing



Oxygen
(molecule in air essential for life)

Carotid body
(low oxygen – hypoxia - in the blood signals to the brain to increase breathing; hypoxia stabilises HIF-2α which binds to HIFβ to form an active HIF transcription factor which binds to DNA to stimulate gene expression)

HIF
(protein made of HIFα bound to HIFβ; HIFα is stabilised when oxygen levels are low, binds to HIFβ to form an active HIF transcription factor which binds DNA to stimulate gene expression including of hormone erythropoietin)

DNA
(molecule where genes are found which encode proteins; HIF binds to DNA to stimulate gene expression eg Epo)

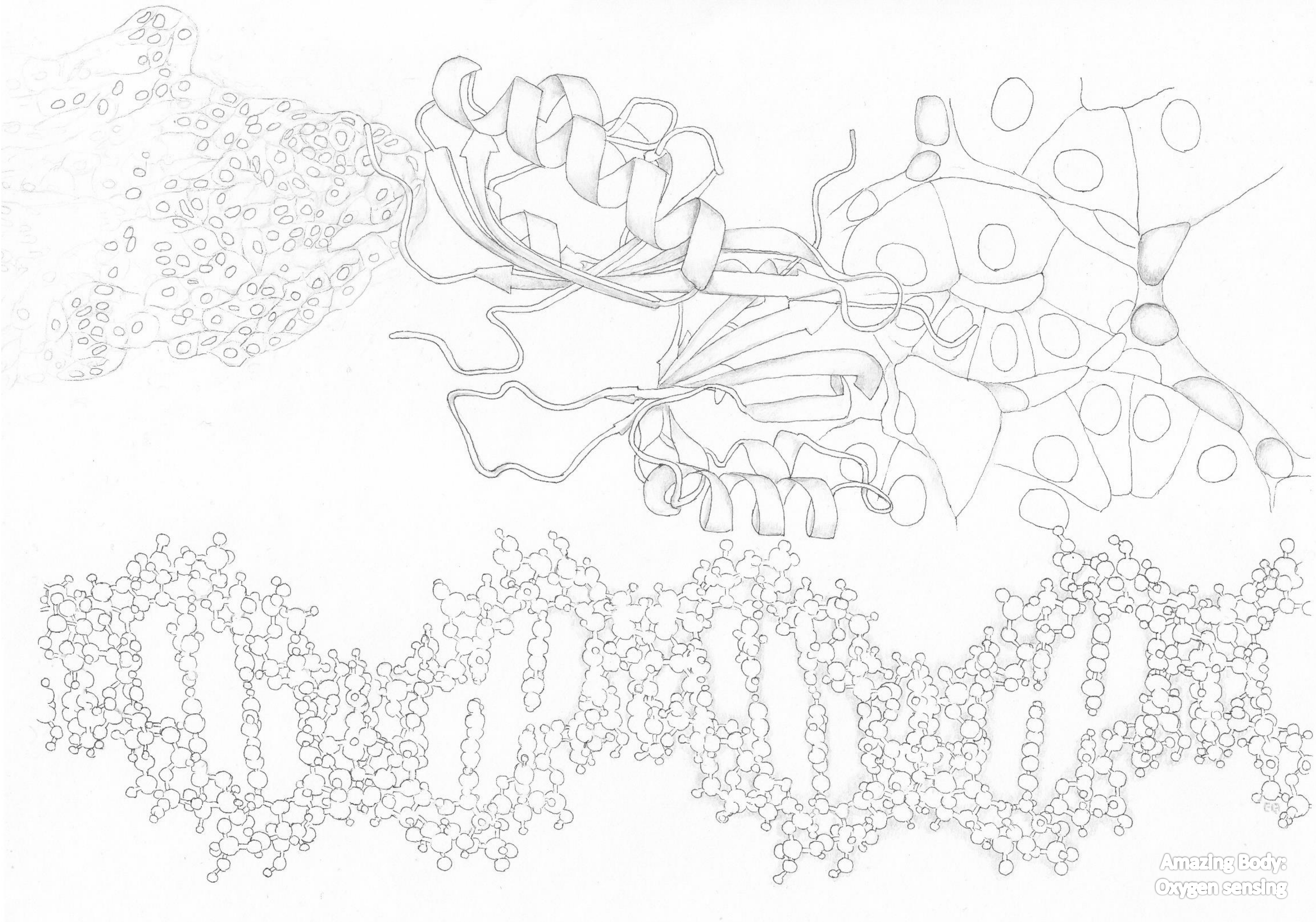
Kidney
(low oxygen brings a rise in a HIF-2α protein which binds to HIFβ to form HIF which binds DNA to stimulate gene expression including the hormone erythropoietin)

Erythropoietin (Epo)
(one of the proteins stimulated by HIF binding DNA; Epo is made in the kidney)

Red blood cells
(made in bone marrow; they make blood red cells which carry oxygen around our body to keep us healthy and well)

Bone marrow
(red blood cells are made here stimulated by hormone erythropoietin)

Colour in and celebrate the **Nobel Prize for Medicine** (2019) winning work of Sir Peter's team with William G Kaelin, Jr of Harvard University and Gregg L Semenza of Johns Hopkins University. The following drawing shows part of a protein (HIF) which bind to DNA when oxygen is lacking. In the background on the right are cells in the kidney and on the left cells in the carotid body which are found in our neck. There are also a couple of drawings showing two halves of the body which can be coloured in and put together. Understanding could help bring new ways to help tackle cancer, heart disease and effects of COVID-19. The final drawing shows the beautiful sculptural shapes of three proteins which sense a lack of oxygen to trigger gene expression (in order PHD2, HIF2α-ARNT-DNA and HIF1α VHL).



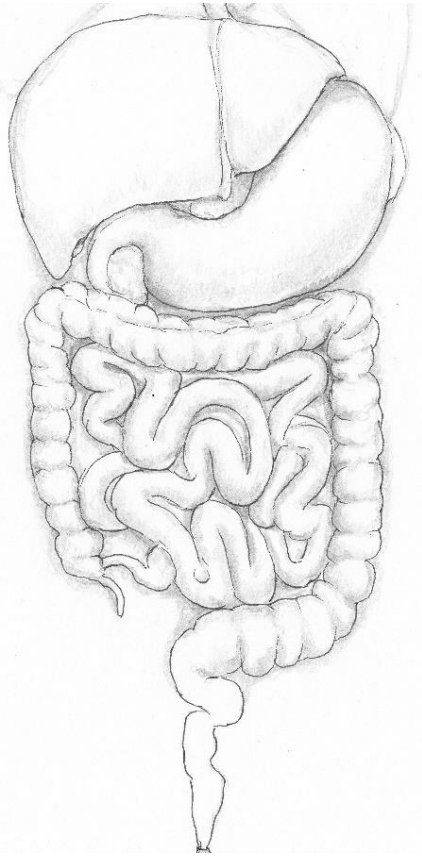
Amazing Body:
Oxygen sensing

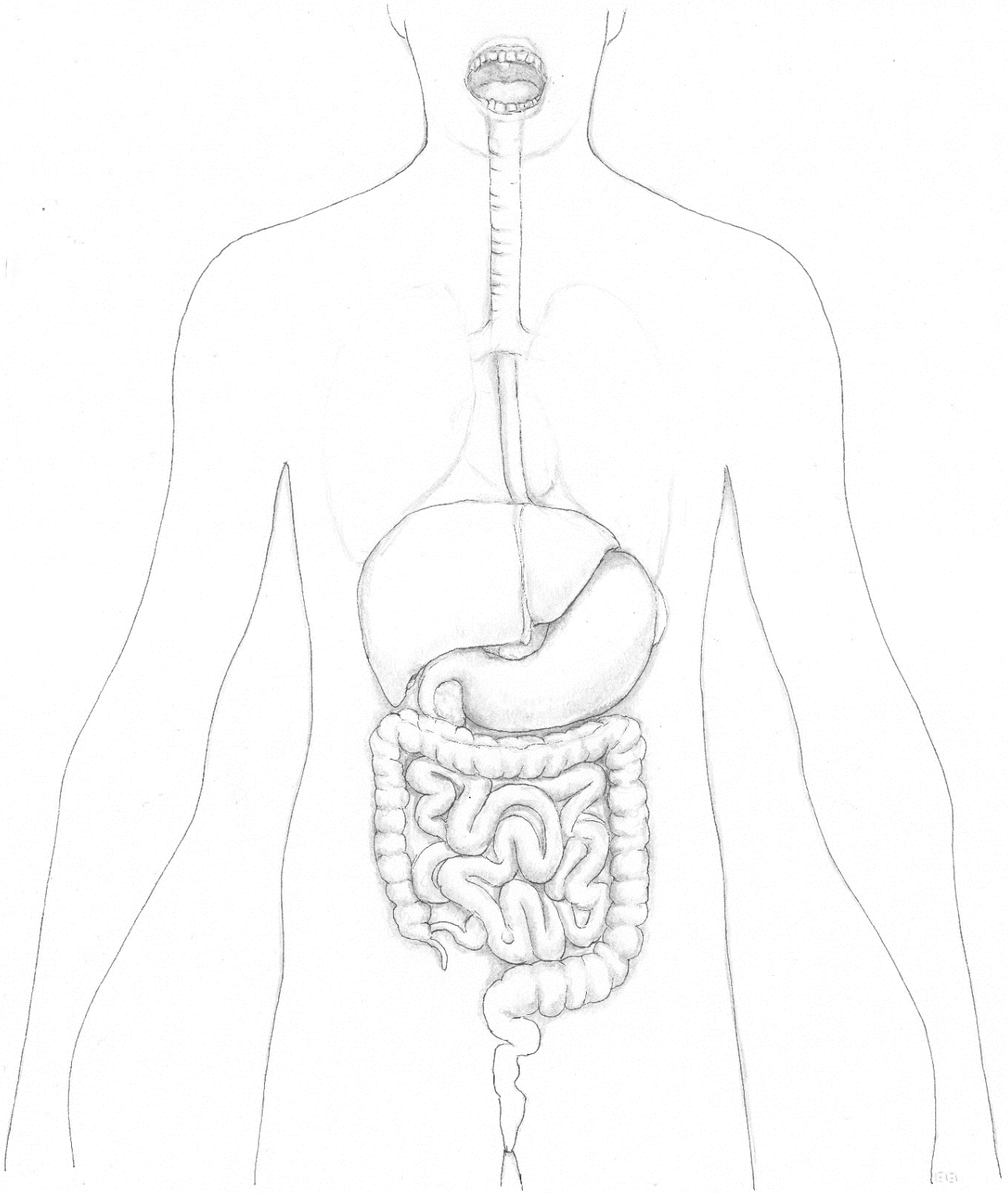
Amazing Body:
Oxygen sensing

Amazing Body:
Oxygen sensing

Amazing Body:
Oxygen sensing

Amazing Body: Digestive system





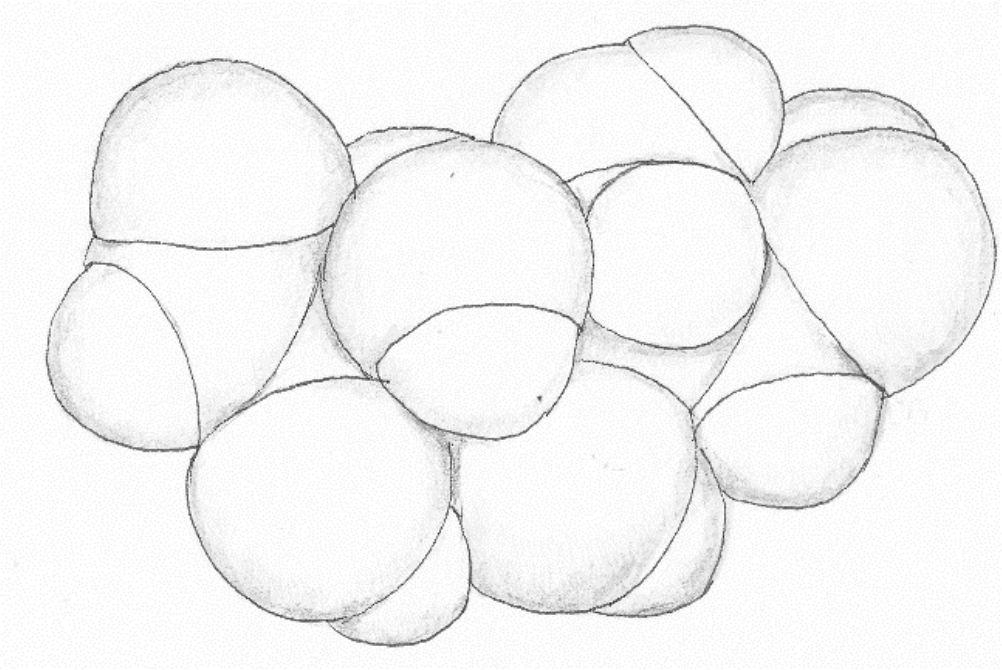
Amazing Body:
Digestive system

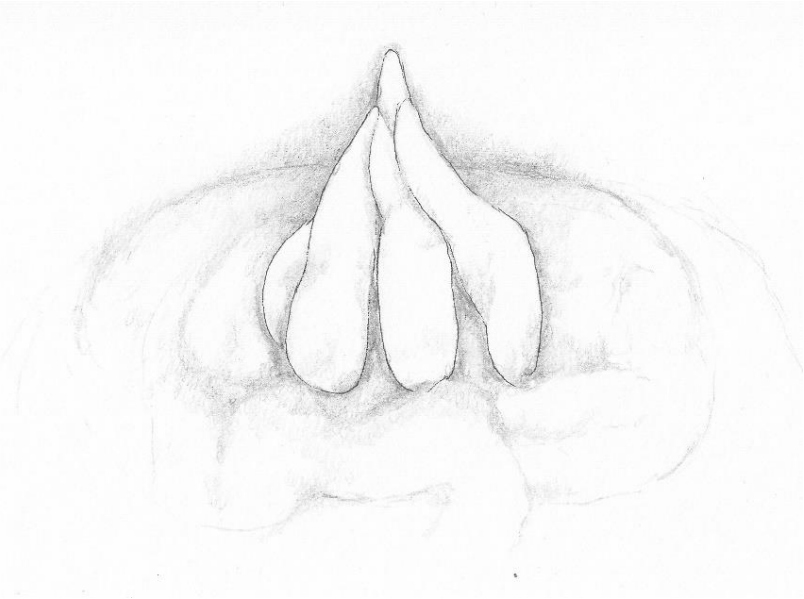
The Physiological Society

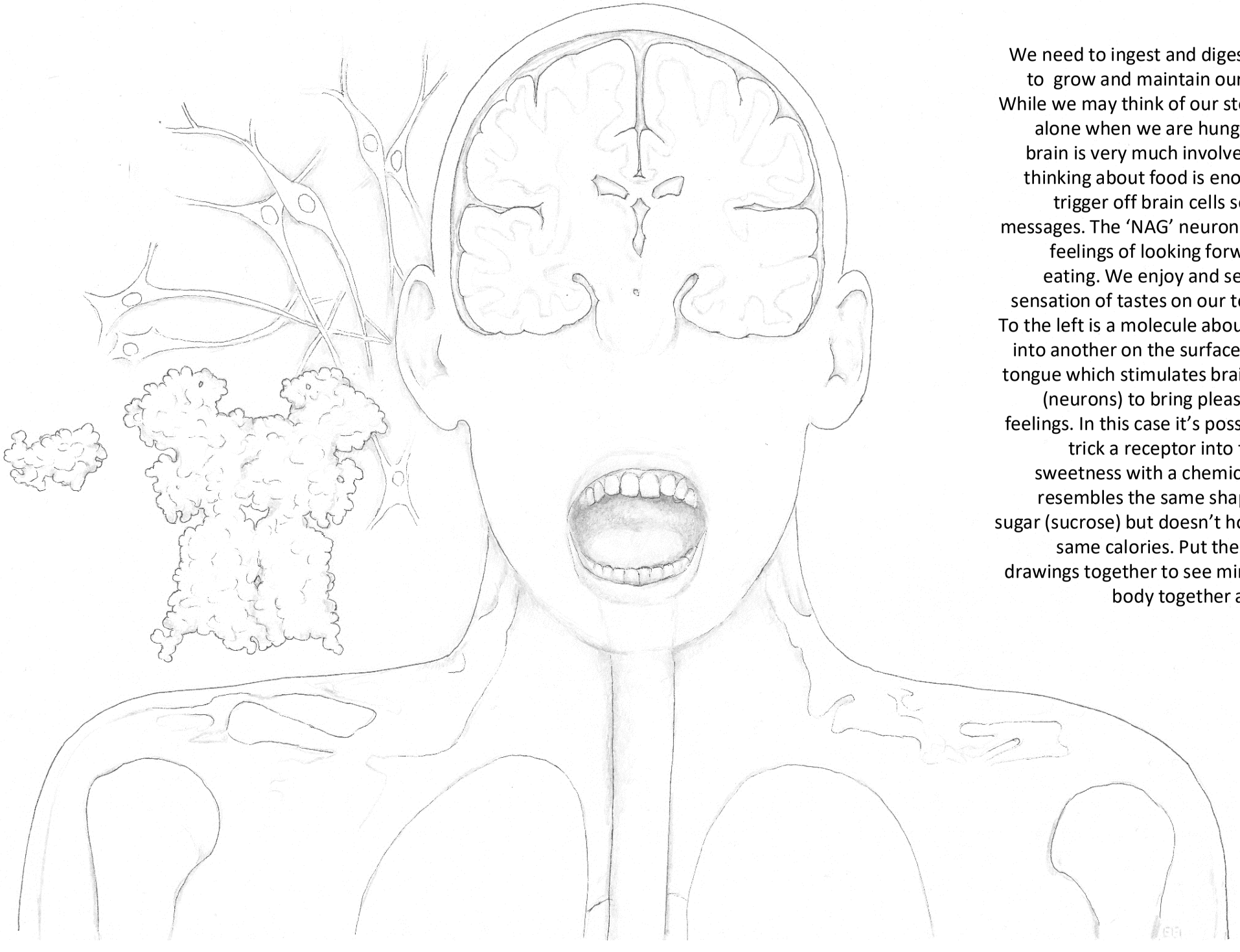
We need food to grow and maintain our busy active body. We interact with the world in a vital way through eating. Through eating a variety of food we ingest many molecules which are broken down (digested) through acids in the stomach. A hormone called ghrelin (seen over the stomach on the following pages) brings that hungry feeling which encourages us to find food. Once food is broken down in the stomach, molecules are absorbed along the length of our intestines. Molecules are brought into our blood stream and stimulate hormones and neurons to bring feelings of being full. Our pancreas which is tucked underneath our stomach helps neutralise acids from our stomach before digested food travels through our intestines. The pancreas also makes the hormone insulin which helps regulate glucose levels (molecule to the right at the top of this page). People with diabetes (Type I) suffer from the pancreas being unable to make insulin. Without insulin the body cannot regulate sugar levels which can be very harmful. Add colour to insulin seen on the second page of the body drawings, as a molecule on the left.

To the bottom right of this page is a drawing revealing the exquisite beauty of a taste bud resembling a plant bud or temple. Each 'petal' is a receptor cell and together they are surrounded by blood vessels within a single taste bud. These tiny structures allow us to taste and experience a depth of interest from food.

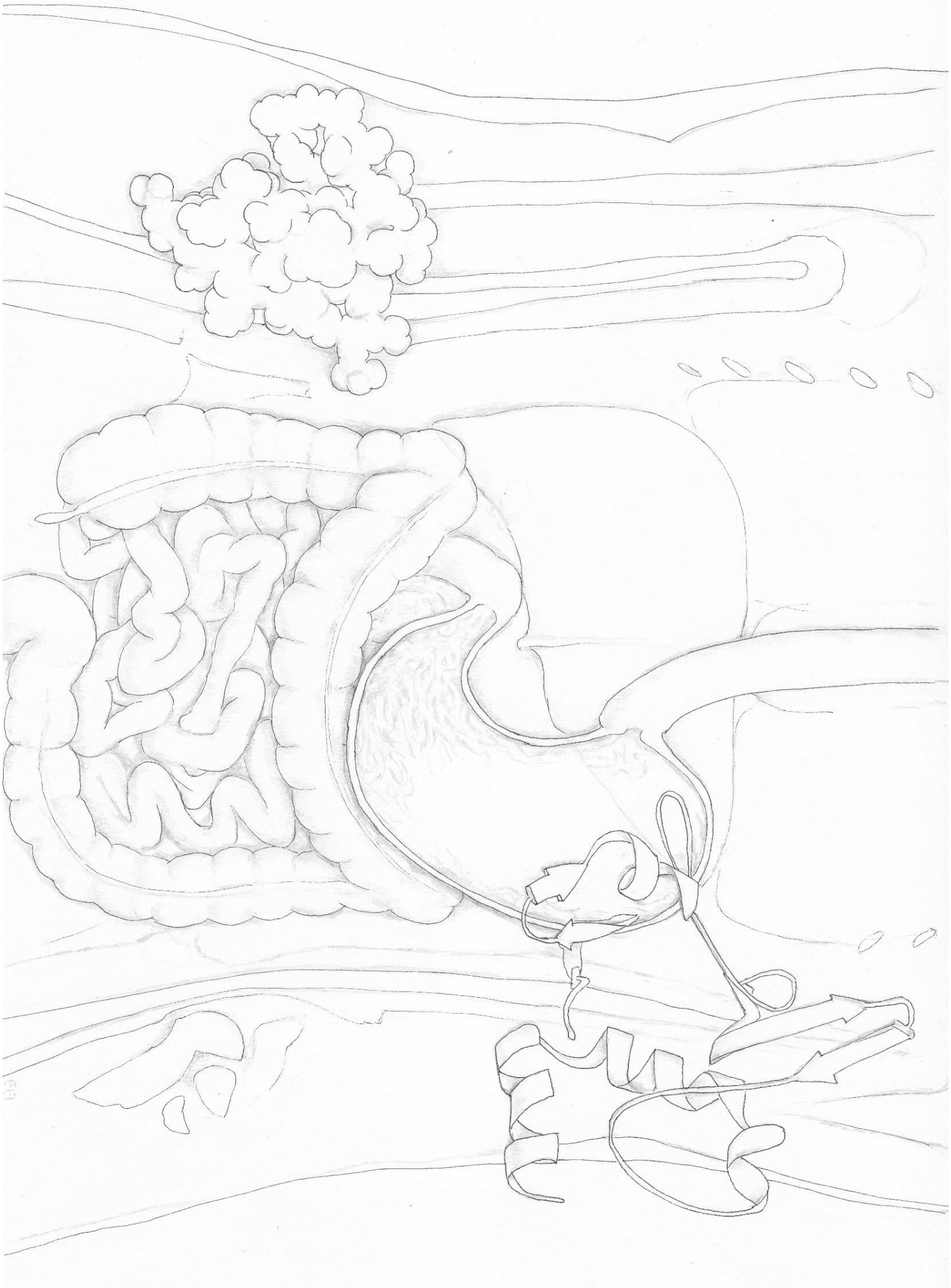
Collaboration: Science-based artist, Dr Lizzie Burns with Professor Heidi De Wet University of Oxford. Time is an opportunity; find out more about the science of life: www.physoc.org



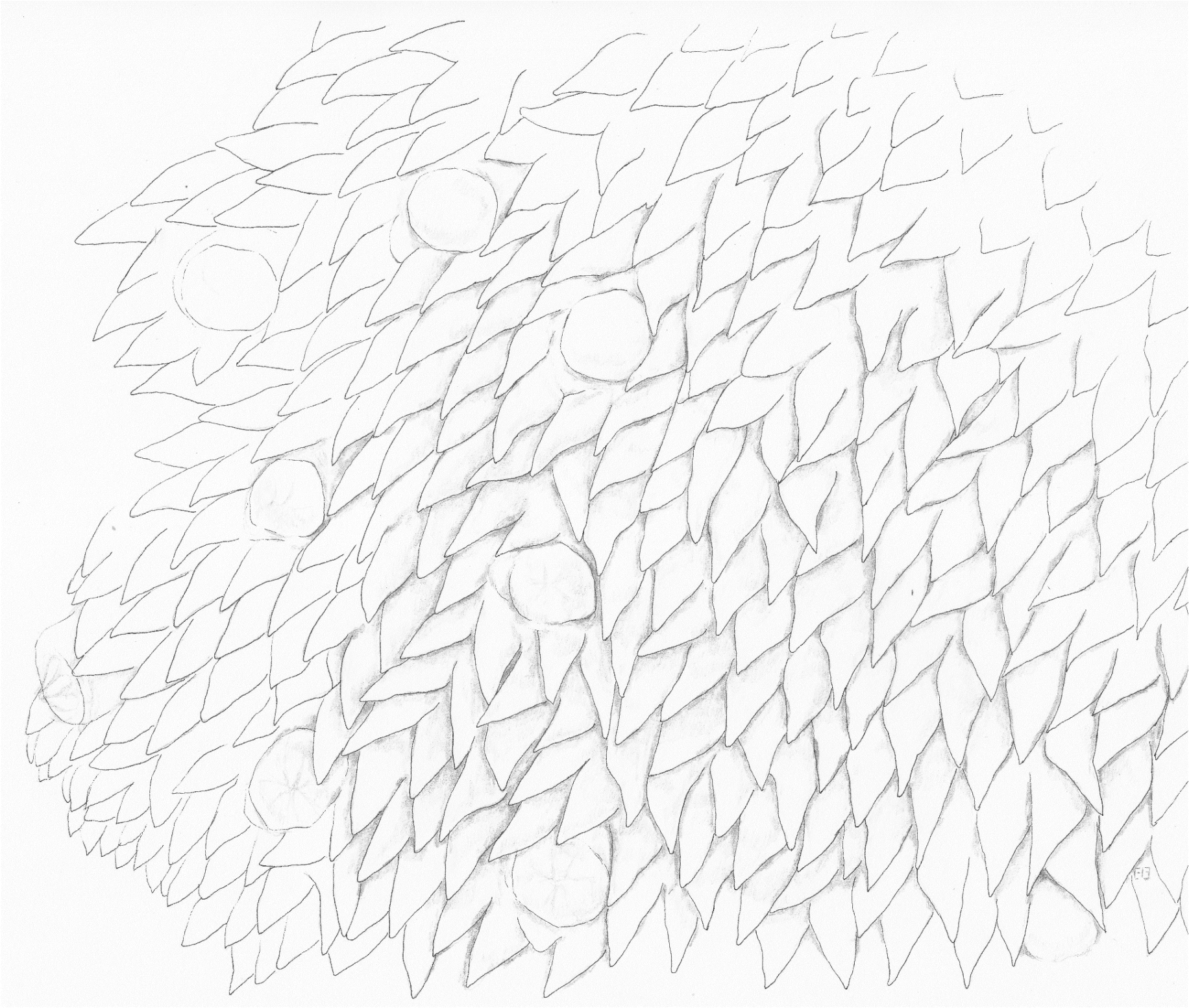




We need to ingest and digest food to grow and maintain our body. While we may think of our stomach alone when we are hungry, our brain is very much involved. Just thinking about food is enough to trigger off brain cells sending messages. The ‘NAG’ neurons bring feelings of looking forward to eating. We enjoy and seek the sensation of tastes on our tongue. To the left is a molecule about to fit into another on the surface of the tongue which stimulates brain cells (neurons) to bring pleasurable feelings. In this case it’s possible to trick a receptor into tasting sweetness with a chemical that resembles the same shape of a sugar (sucrose) but doesn’t hold the same calories. Put these two drawings together to see mind and body together as one.

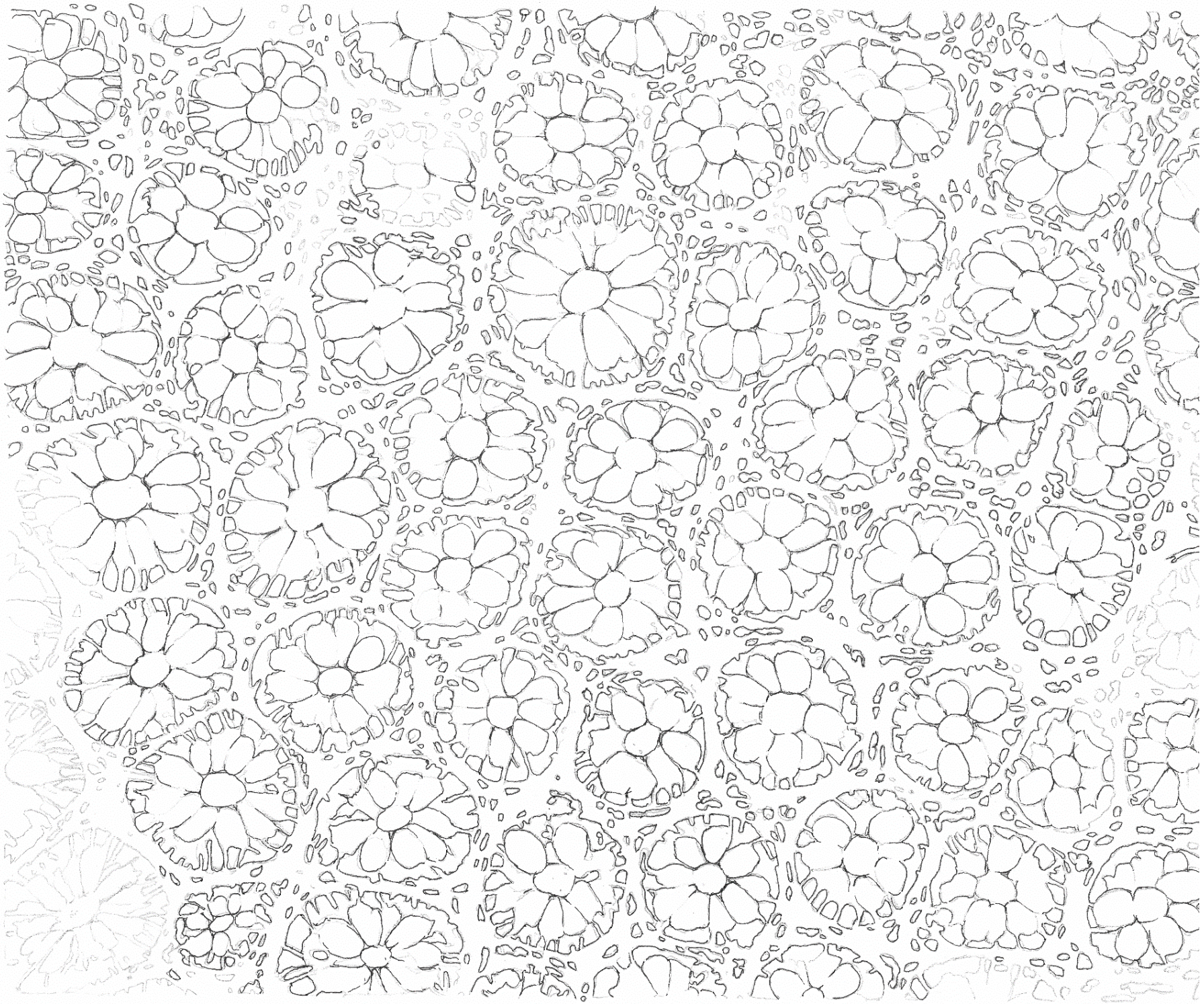


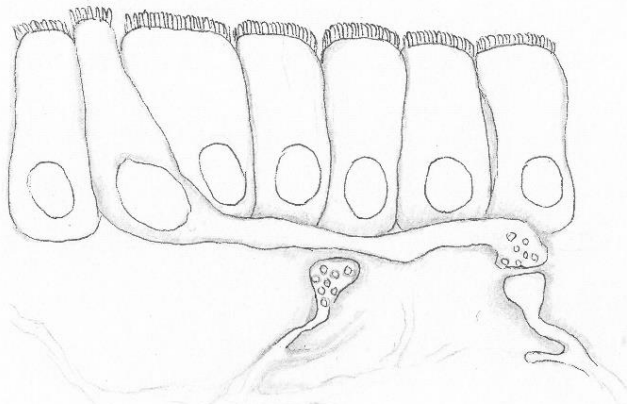
Your tongue is surprisingly beautiful at a microscopic scale. The tongue's surface is covered in 'papillae' where taste buds are seen as rounder structures. Each taste bud measures less than the width of a piece of your hair. Within taste buds proteins are waiting to be stimulated when a chemical binds to trigger neurons which allow us to experience flavour.



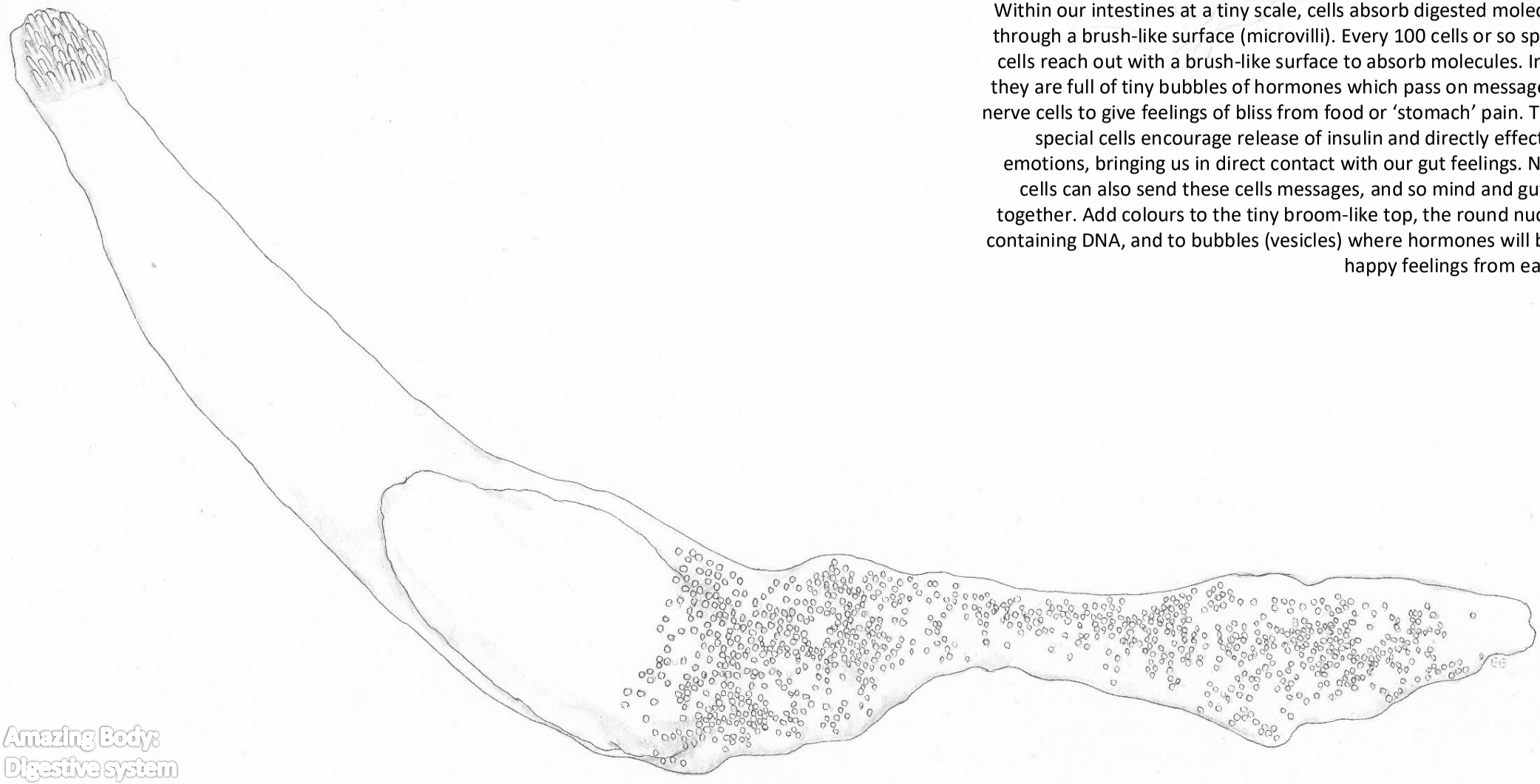
Amazing Body: Digestive system

Your intestine is surprisingly beautiful at a microscopic scale. In the small intestine tiny 'finger' like projections help to increase the area for your body to absorb digested molecules. Cells (epithelial) resemble petals to help absorb molecules while the centre of these flower-like shapes help bring absorbed molecules into the blood supply. These finger like 'villi' resemble daisies when viewed as a section cut horizontally which each measure the width of a human hair.



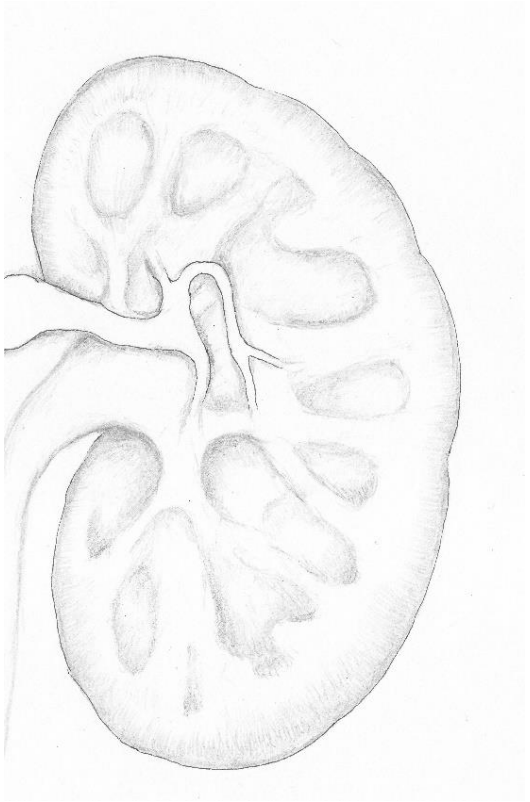


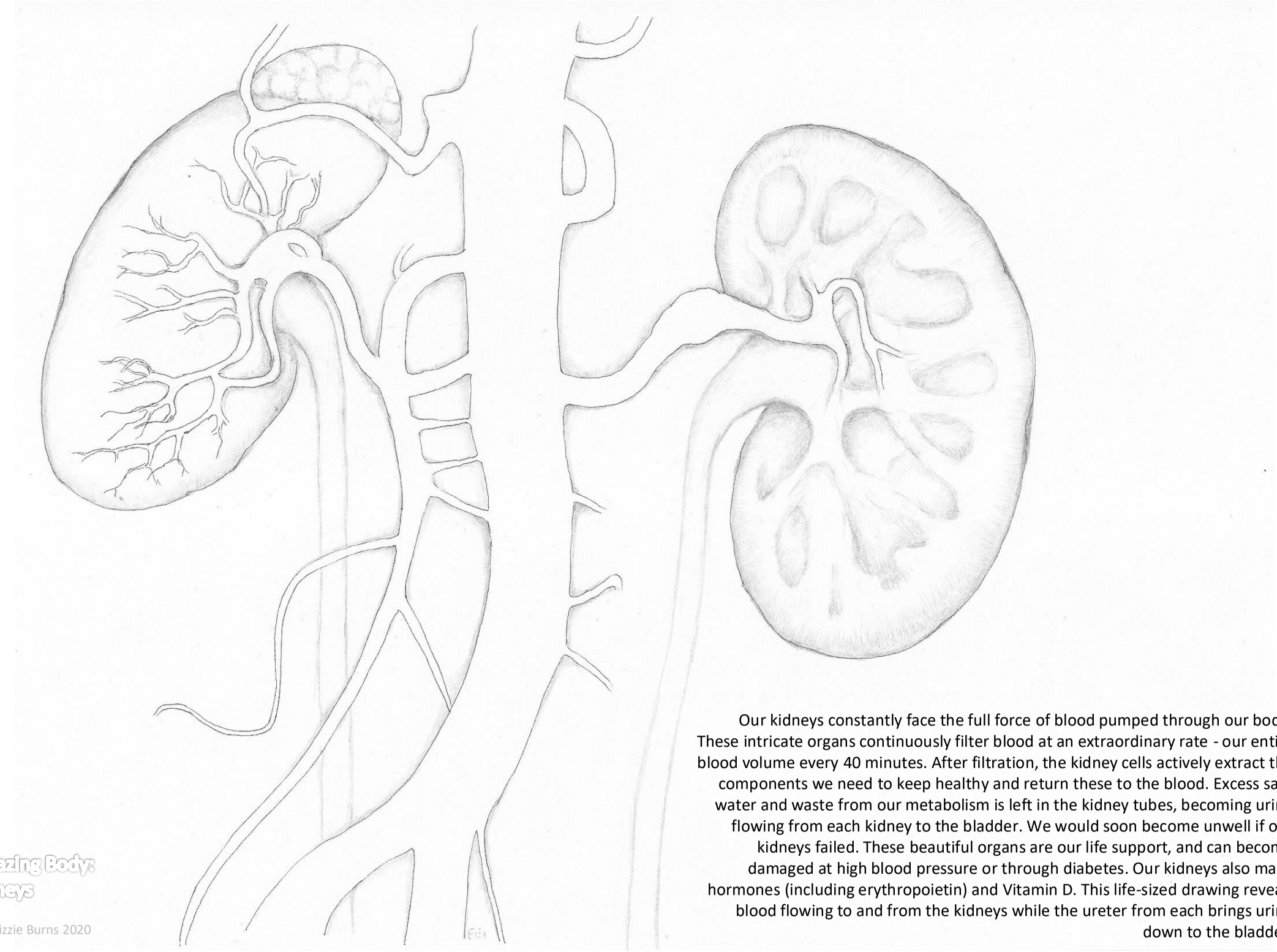
Within our intestines at a tiny scale, cells absorb digested molecules through a brush-like surface (microvilli). Every 100 cells or so special cells reach out with a brush-like surface to absorb molecules. Inside they are full of tiny bubbles of hormones which pass on messages to nerve cells to give feelings of bliss from food or 'stomach' pain. These special cells encourage release of insulin and directly effect our emotions, bringing us in direct contact with our gut feelings. Nerve cells can also send these cells messages, and so mind and gut are together. Add colours to the tiny broom-like top, the round nucleus containing DNA, and to bubbles (vesicles) where hormones will bring happy feelings from eating.



Amazing Body:
Digestive system

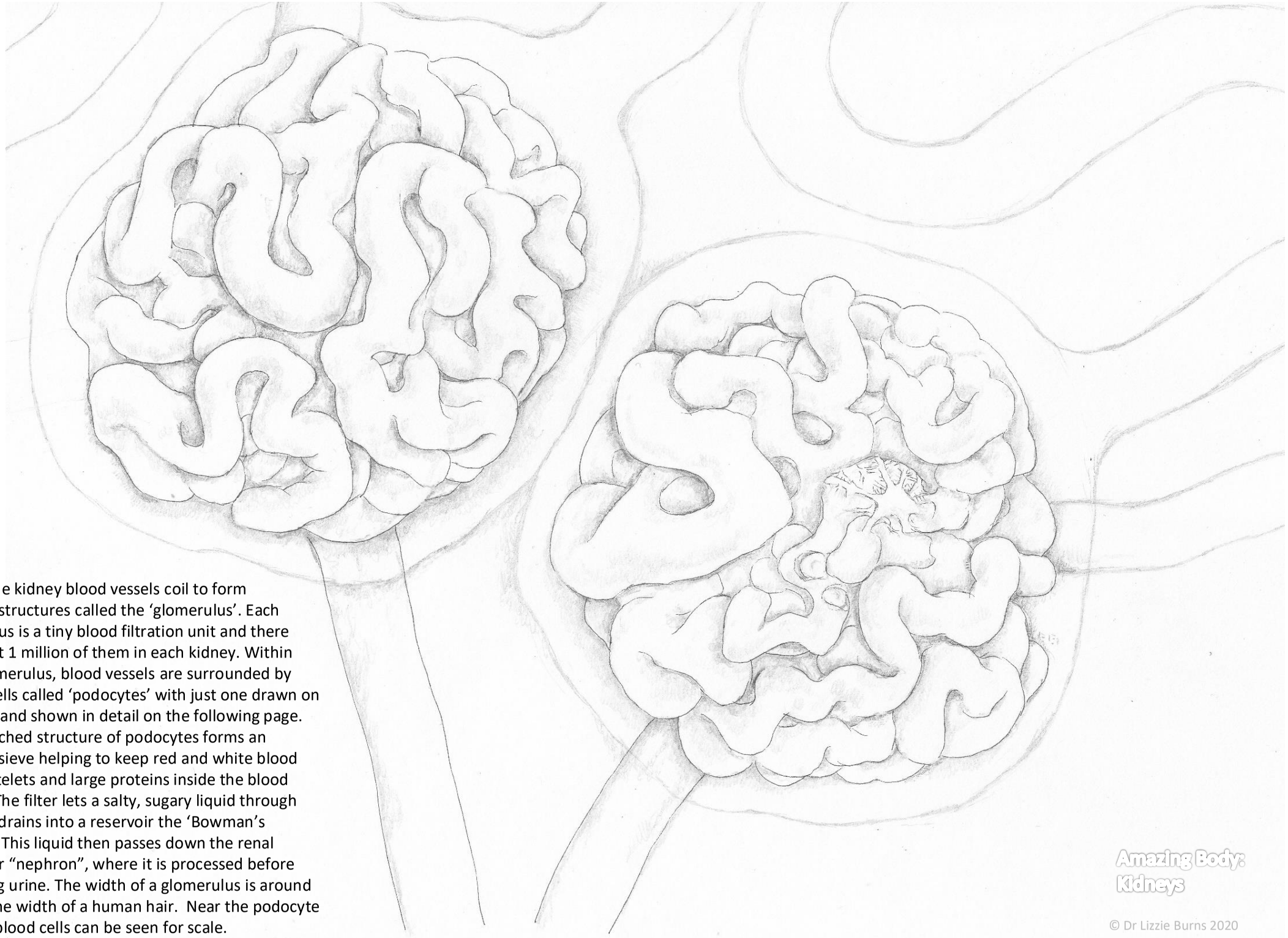
Amazing Body: Kidneys





Our kidneys constantly face the full force of blood pumped through our body. These intricate organs continuously filter blood at an extraordinary rate - our entire blood volume every 40 minutes. After filtration, the kidney cells actively extract the components we need to keep healthy and return these to the blood. Excess salt, water and waste from our metabolism is left in the kidney tubes, becoming urine flowing from each kidney to the bladder. We would soon become unwell if our kidneys failed. These beautiful organs are our life support, and can become damaged at high blood pressure or through diabetes. Our kidneys also make hormones (including erythropoietin) and Vitamin D. This life-sized drawing reveals blood flowing to and from the kidneys while the ureter from each brings urine down to the bladder.

Amazing Body: Kidneys



Within the kidney blood vessels coil to form intricate structures called the ‘glomerulus’. Each glomerulus is a tiny blood filtration unit and there are about 1 million of them in each kidney. Within each glomerulus, blood vessels are surrounded by special cells called ‘podocytes’ with just one drawn on the right and shown in detail on the following page. The branched structure of podocytes forms an intricate sieve helping to keep red and white blood cells, platelets and large proteins inside the blood stream. The filter lets a salty, sugary liquid through where it drains into a reservoir the ‘Bowman’s capsule’. This liquid then passes down the renal tubule, or “nephron”, where it is processed before becoming urine. The width of a glomerulus is around double the width of a human hair. Near the podocyte two red blood cells can be seen for scale.

Amazing Body: Kidneys

This drawing shows a podocyte cell with its intricate extensions that intertwine with projections from neighbouring cells to create the surface of the filtering blood vessel in the glomerulus. Our kidneys filter around 200 litres each day to keep your blood clean and life-sustaining.

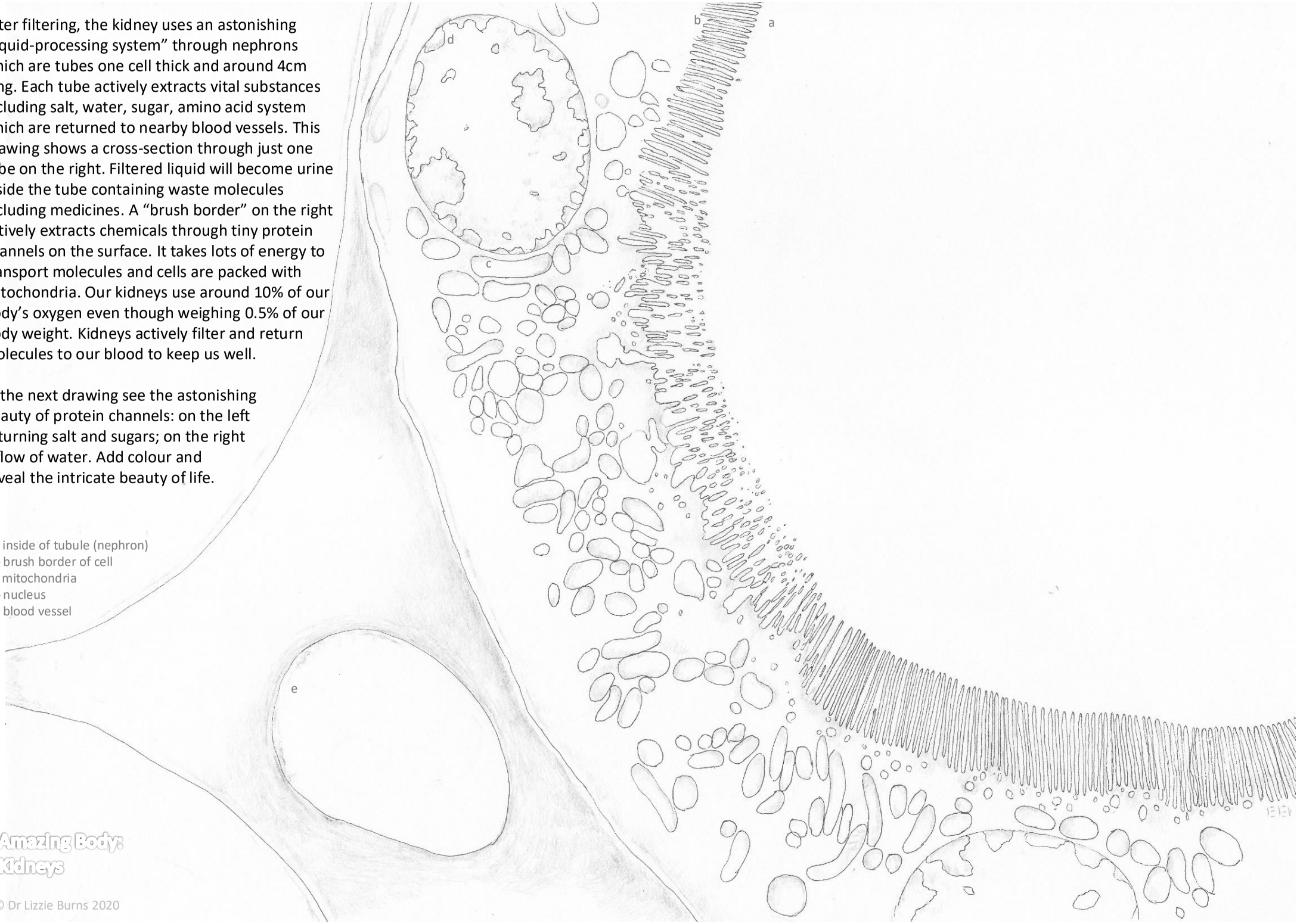
Collaboration: Science-based artist, Dr Lizzie Burns with Professor Matthew Bailey, University of Edinburgh. Time is an opportunity; find out more about the science of life: www.physoc.org

Amazing Body: Kidneys

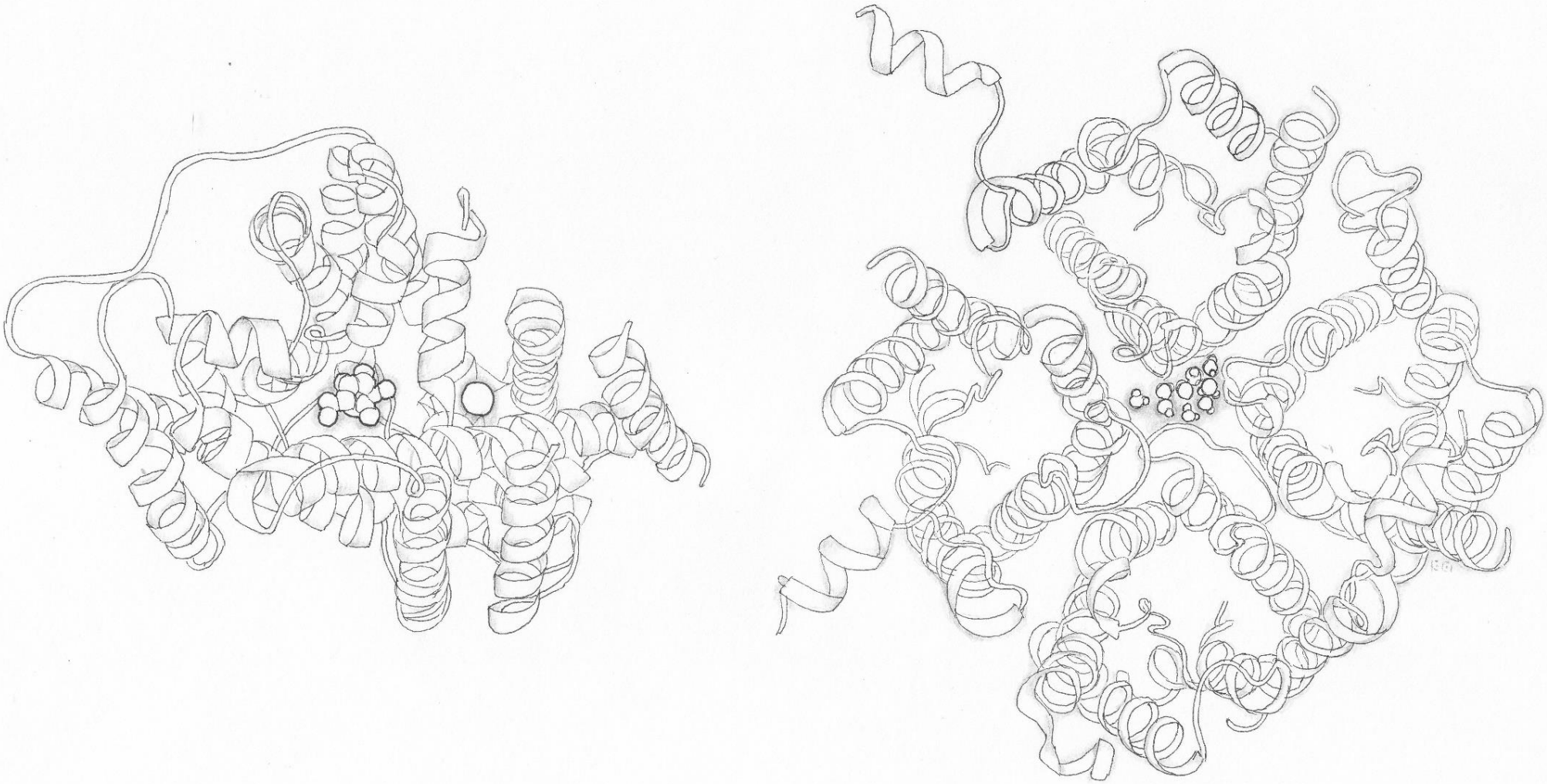
After filtering, the kidney uses an astonishing "liquid-processing system" through nephrons which are tubes one cell thick and around 4cm long. Each tube actively extracts vital substances including salt, water, sugar, amino acid system which are returned to nearby blood vessels. This drawing shows a cross-section through just one tube on the right. Filtered liquid will become urine inside the tube containing waste molecules including medicines. A "brush border" on the right actively extracts chemicals through tiny protein channels on the surface. It takes lots of energy to transport molecules and cells are packed with mitochondria. Our kidneys use around 10% of our body's oxygen even though weighing 0.5% of our body weight. Kidneys actively filter and return molecules to our blood to keep us well.

In the next drawing see the astonishing beauty of protein channels: on the left returning salt and sugars; on the right a flow of water. Add colour and reveal the intricate beauty of life.

a – inside of tubule (nephron)
b – brush border of cell
c – mitochondria
d – nucleus
e – blood vessel



Amazing Body: Kidneys



Amazing Body:
Kidneys