

The Role of Adrenaline

By Colin Begg

Squeezed as I am between her cot and the wall, I can still see Rayah's small heart beating as it keeks beneath the wound in her sternum, its edges the colour of stale corned beef. Beating is too forceful a word for its mothy flicker. It tap-taps irregularly, making tiny undulations in the slow tide of bloody fluid that will rise around it over the course of the next twenty seconds, until Stephanie notices and gently siphons it away.

Now she is poking the heart again, gently with her gloved finger and thumb, like a vet reanimating a stillborn kitten — if a kitten were the size of a large walnut. At her touch, the heart's irregularity regularises. I look down at the numbers on the piece of paper just handed to me, Rayah's most recent results. My feet clench slightly in my shoes. I have been standing here for almost two hours. It was a slow start. I stretch over the machine nearest me and make some adjustments to another machine beyond it. I could tell you exactly what those adjustments were, but I fear there is scant poetry in this patient's physiology. Maybe I am wrong in that. But there is certainly a better tale in hope.

There are twelve people gathered around this heart in a loose circle of masks and hats: Stephanie, her assistant Bashir, their scrub nurse Kirsty, two circulating nurses Ross and Erica, whose names I learnt for the first time this morning, Jen the perfusionist, nurse specialists Angela and Katja, a puffy-eyed-and-obviously-hungover medical student observer (whose name we also just learnt but are too embarrassed to ask for again), me, my bored trainee Stuart — who is drinking a coffee while pretending to edit some notes on the computer — and a blood bank courier newly arrived with a fresh pack of the good stuff. Twenty-four eyes, and considerably more machines.

First and foremost, there is the ECLS Pump at Rayah's feet: which is really more an assemblage of pumps, drivers, sensors, and gas and heat exchangers. These have been keeping Rayah with us for the past 72 hours since her Big Operation. Today we hope to get rid of The Pump. Out of the corner of my eye, a temporary pacemaker blinks in time to those tidal undulations and the bigger waves of the monitor above me. Beside me is the ventilator, a Life Support Machine to you, which Stu and I hope will be sufficient to keep her still-soggy lungs in business once The Pump is away. On the opposite side, a rack of syringe drivers the height of a small Christmas tree blink and whirl about nine important drugs into a big tube in

Rayah's tiny jugular vein. These are what I twiddle with next, balancing the uppers and the downers like a slow-motion physiological rally driver, my foot on both accelerator and brake. All eyes stare at the heart and wait. My mind flicks to Rayah's Mum and Dad, who must content themselves with staring at the tastefully-decorated walls of the family room along the corridor.

Stephanie stretches and twists her neck, the miner's lamp on her head temporarily blinding Katja and me. She puts down her tools and stands back a little, still watching the flickering heart before her. I watch too. Slowly, inexorably, that flicker is becoming less tentative. It's the good stuff I just gave her: red cells, each new gram of their haemoglobin lugging an extra 1.39 millilitres of oxygen per minute around her bloodstream. That, and the adrenaline infusion I have just tweaked to make her heart's myocytes twitch a little stronger and faster.

My toes relax a bit. I rock back on my heels against the wall and sip the coffee Stu brought us earlier. It's cold now, but I convince myself I can feel the caffeine creeping into my veins. This place runs on goodwill and caffeine. Caffeine, like adrenaline, is sympathomimetic, an upper. It enhances the second messenger of my adrenaline receptors and, like adrenaline, increases calcium flow in my heart cells, allowing actin to bind to myosin, making the muscle fibres pull faster, stronger.

Stephanie clamped Rayah's tubes from The Pump about three minutes ago. Jen watches over The Pump as its fluid circulates via a small bypass tube called The Bridge. Stu has lumbered from his screen to turn up the ventilator, and I can now see the velvet purple edges of Rayah's lungs swing up and down inside her ribcage. We will sit like this for another ten minutes or so, run a couple of tests and then make The Call — whether or not we remove the big tubes from her atrium and aorta, the umbilical that was keeping her three-week-old circulatory system going, allowing it to rest and recover from The Big Operation.

There is a glitch. For the past two and a bit hours we have been so accustomed to the beep-beep of the heart monitor that we have tuned it out. Now the tone changes, its note lowering to a boop-boop: Rayah's oxygen saturation levels are sliding. Stu and I run our standard check of the ventilator and its connections but find nothing. We turn up the oxygen concentration and ventilator pressure. The boop-boop deepens. Looking inside her ribcage, we notice Rayah's lungs are moving less. There is probably only one cause. I dip my head and duck beneath the blue surgical drapes, into the rats' nest of tubes, lines and wires that surround Rayah's tiny head. The breathing tube to her lungs was kinked a little by Bashir's forearm as he moved a clamp. I straighten it and the boops swiftly turn back to beeps. Lungs

move well. No harm. Easy done when two pairs of surgeons' hands are operating in a field the size a laptop trackpad.

Five minutes pass to ten. Sal the Cardiologist and Euan the Cardiac Physiologist arrive. Two more brains. Four more eyes. Euan scrubs hands, gowns up and places an ultrasound probe gently on the beating surface of Rayah's heart. They look at its function and the result of the Big Operation. Encouraging, says Sal. Stephanie nods.

We have to make a call soon or else there is a chance that Rayah's blood will thicken, risking a clot or worse, a stroke. Angela has pulled a blood sample from a cannula in Rayah's radial artery, a half-millimetre tube in a wrist barely wider than my thumb. She takes another from her jugular vein and carries them to the side room lab at the end of the intensive care unit. Time slows again. Lungs rise and fall, hearts move blood, those usually invisible lungs and hearts: organs you might never give second thought to until they falter.

Stephanie is getting impatient in that way that surgeons do. Her hands move back to Rayah's sternum, she leans into the wound, gently poking its edges with the suction catheter, looking for small escapes of blood, zapping errant capillaries with her diathermy probe. She glances at Rayah's monitor, then at me, her headlight beam on my forehead like a sniper's dot. Well? I pause for a second, look down at the flicking heart. Looks encouraging, I say. Wait on the gases.

Angela returns from the lab, passes me the blood gas results with a flourish. They are printed on the same thin thermal paper used for till receipts. I scan the numbers. I have read this data so many times, it is pattern recognition. It looks adequate. Not great but adequate. Clinical medicine is an imperfect science, a risk assessment. I look again at the monitor. Little has changed in the numbers and waveforms since my last mental snapshot ten minutes ago. Stephanie turns to me, I read her the numbers aloud. I think we should go for it, I say. She taps her finger gently on Rayah's skin. I agree. Okay everyone, heads up, we are coming off.

Stu runs a checklist with Katja, Jen and Angela. I won't bore you with the details. It is to make sure we don't forget anything. Based on past omissions we don't wish to repeat. Everything is ready. Stephanie reaches forward into Rayah's chest. Bashir controls a running suture as Stephanie gently delivers a tube from the wall of the right atrium. There is a small dribble of blood. Bashir makes good the hole and they leave some small orange slings in place in case they need to go back. Then they turn to the root of the aorta and repeat the process. She hands the tubes to Jen, who wraps them up and wheels away The Pump. Bashir and Stephanie wash out the chest cavity a final time with warm saline, place some new drains

through the front of the rib cage, and construct a cat's cradle of thick sutures to pull the raw edges of Rayah's sternum to opposition.

A final hitch. As Stephanie draws the sutures up, the two halves of the divided sternum close down like tiny double doors. But Rayah's lungs are too stiff to go back in their bony cage: the ventilator protests with a high pressure alarm. The surgeons refashion their sutures and settle for closing the skin with a little white patch of Goretex. This will keep moisture in and bugs out until they try again on Thursday. Kirsty and her colleagues count their swabs and kit. Nothing left inside. The surgeons step back. Stuart tweaks our pumps and ventilators, more blood samples are sent. Katja calls for a chest X-ray. Instruments rattle in their trays. There is much tidying and removing of drapes and gowns and gloves. We have filled two orange bin bags with surgical rubbish.

The Pump sits silently at the edge of the room, its screens dark. Jen and Angela remove its parts and place the used bloody tubes in a huge yellow box. I stretch and step out from my corner. I check my pulse, drain the last of my cold coffee from its cup. I look at the monitor, then the adrenaline infusion. I turn it down a fraction. After this I will hover here a while, wait for more blood gases, and we'll call her parents in. I can no longer see inside Rayah's chest, but I hope her heart ticks on.

Scientific Statement

This story is a fictionalised exploration of NHS professionals' lived experience of a technique that we use to support some cardiac patients: a technology called Extra-Corporeal (outside of the body) Life Support, or ECLS for short. It uses a modified heart-lung bypass machine to support a patient's own heart and lungs — in this case until they recover from major heart surgery. The machine is often connected by tubes that pass directly through the opened front of the patient's chest. This means that the patient's beating heart can be seen directly under the surgical dressings, as described in the story. Patients can remain on ECLS in the ICU for periods ranging from several days to a few weeks until they recover or need further treatment such as re-operation, a longer-term temporary device or a heart transplant. While using ECLS is "routine" for us, to our patients, their families and lay people it is most certainly not.

The ECLS machine consists of a magnetic impeller pump (assisting the heart) and a hollow-fibre polymer gas exchanger (assisting the lungs). The story I have written describes the end of the ECLS support period, where we "decannulate" the patient, i.e. surgeons remove the large bore tubes connecting the patient's main artery and veins to the machine. This is a big

step, and while we always strive to judge it right, success is not guaranteed. The process involves a large team of professionals from several disciplines, with the patient at the centre. This spirit of collaboration is at the heart of the story.

After the ELCS machine is taken away, the patient is not yet “on their own” as we must continue to support them using conventional organ support methods like mechanical lung ventilators and targeted medicines to aid the function of the heart until they have further recovered.

The adrenaline referred to in the story title is both a natural hormone of the catecholamine family, and a drug that we give to some ICU patients as a continuous infusion to provide additional inotropy (strength of contraction) to the heart muscle cells (myocytes.) In the human body, adrenaline is part of the sympathetic nervous system, which in lay terms can be thought of as the “accelerator” of the autonomic (involuntary) nervous system. Among other things, it controls our “fight or flight” stress response, a response which is also experienced by me and my colleagues as we carry out this difficult work... So the story title is a double allusion. Many other drugs act on this system, including common substances like caffeine — and coffee is a beverage which oils the wheels of the NHS. Scientifically, substances which upregulate the sympathetic nervous system are termed sympathomimetics.

Finally, some physiological concepts for readers who want to know more about the basic science. My care of the type of patient described in this story is underpinned by these three physiological formulae:

$$CO = HR \times SV$$

$$CaO_2 = (1.39 \times [Hb] \times SaO_2) + (0.003 \times P_aO_2)$$

$$DO_2 = CO \times CaO_2 \times 10$$

CO (cardiac output in Litres per minute) is the amount of blood pumped by the heart in a minute. It is the product of HR (heart rate in beats per minute) multiplied by SV (stroke volume; the amount of blood pumped by each heartbeat in mL ÷ 1000). We use the same concept when talking about the amount of blood pumped by an ECLS pump, except we substitute the RPM of the pump for Heart Rate.

CaO₂ describes the arterial blood oxygen content in mL of oxygen per 100mL of blood, including both the oxygen that is bound to haemoglobin (Hb) in red blood cells (most of it) and the oxygen dissolved in the plasma (a less significant amount), where:

[Hb] is the blood haemoglobin concentration in grams per decilitre (g/dL).

SaO₂ is the arterial blood oxygen saturation, expressed as a percentage (of the potential oxygen binding sites on haemoglobin that can be saturated with oxygen). Because haemoglobin is a pigment which becomes redder with oxygenation, its saturation can be measured using colorimetric techniques. This is how the pulse oximeter light you may have seen in hospitals or on your smartwatch works.

PaO₂ is the partial pressure of oxygen in arterial blood, in kilopascals.

The constant 1.39 represents the oxygen-carrying capacity of human Haemoglobin A (in millilitres of O₂ per gram of haemoglobin).

The value 0.003 is the solubility coefficient for oxygen in human plasma.

DO₂ (oxygen delivery in mL per minute) is the product of cardiac (or ECLS pump) output (CO) and arterial oxygen content (CaO₂) in mL per dL. This is how much oxygen the circulatory system delivers to the body's organs and tissues each minute.

Bibliography

Pappano, A. J., & Wier, W. G. (2019). *Cardiovascular physiology* (11th ed.). Elsevier.