Ground control to Major Tim

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By now, at the time of writing, Major Tim Peake is on day 105 of his mission on the International Space Station (ISS). The main reason for his expedition is to perform a number of scientific experiments under the effect of weightlessness, as well as collecting samples from his own body for studies here on earth. He's blown into lung–function kits, collected blood, stool and urine samples, measured properties of his skin, given himself ultrasounds, conducted eye examinations and completed numerous health questionnaires, just to name a few!

His body has now been feeling the effects of microgravity for over three months, but what kind of consequences do we already know zero gravity is having on his biochemistry? We can all imagine some of the physiological effects he might be experiencing, but what are some of the molecular changes behind these alterations? And how could the experiments he's performing better aid biochemical research here on earth as well as in space?

"Take your protein pills and put your helmet on"

It’s well known that astronauts lose weight in space, in fact, loss is estimated at around 2.4% per 100 days in space. This decrease in weight is due mainly to muscle and bone changes. Our muscles are made up of proteins and the balance between synthesis and breakdown is directly related to the amount of food we eat and the amount of energy we expend. In space, as there is no gravity, the amount of stress on muscles is decreased, which means that less protein is made and more protein is degraded. The likely protein breakdown mechanism involves a protein called ubiquitin and a protein complex called the proteasome. Ubiquitin attaches onto the muscle protein which is then taken to the proteasome for destruction. The proteasome is like a big machine, made up of lots of enzymes which attack the protein and cut it up into its smaller components, amino acids. This then results in loss of muscle mass.

Major Tim’s bone structure will also be affected by the microgravity environment; during the whole mission, he could end up losing up to 20% of his total bone mass! Our bones are made by groups of cells called osteoblasts and are broken down by osteoclasts. Osteoblasts make collagen, a type of dense protein which is the main component of bone, along with skin and hair. Osteoclasts in turn break down and destroy bone by secreting acids and enzymes, reducing it to its molecular components: calcium, magnesium and phosphate; a process known as bone resorption. As Major Tim’s bones do not need to support him in order to stand up and walk around, less collagen is made by osteoblasts and more bone is broken down by osteoclasts, resulting in an overall decrease in bone density.

"I’m floating in a most peculiar way"

We take knowing that we are upright and where our arms and legs are for granted; but in space, Major Tim cannot rely on his internal sense of up and down. Our brains consolidate information from passages in our inner ears, our vision and from receptor proteins in our muscles and tendons, to make sense of our motion and orientation. Movement of liquid found in the ear labyrinth stimulates hair cells lining these channels to activate receptors. Similarly, tissue receptors are activated by the stretching of tendons and muscles. On activation, they cause an electrical change involving movement of positive sodium and potassium ions across nerve cell membranes. The change in charge triggers the release of a neurotransmitter, a molecular messenger that allows the electrical signal to pass between nerves to the brain, carrying information about the type of movement made. Of course, these systems are effectively calibrated to upright movement.
against gravity on earth. So in zero gravity space, where there isn’t really “up” or “down”, they are thrown off. These systems can actually adapt to microgravity, but it could mean that Major Tim experiences some space motion sickness, or sometimes feels that he is the wrong way round. Problems can also arise with body coordination when performing simple tasks, as fewer forces acting on the body means less stimulation of muscle and tendon receptors. Consciously moving arms and legs can require some re-training of the brain.  

“The stars look very different today”

The operators of Major Tim’s mission will be monitoring his health during this flight, in particular his eyes, as up to 20% of astronauts report persistent vision changes. We know that in low gravity situations, body fluids shift upwards causing increased pressure in the head and possibly the nerve which relays information from the eye to the brain. This could be part of the physical explanation, but why does it only affect 20% of astronauts? Previous astronauts’ blood tests revealed that those who experienced vision deterioration had different levels of some molecules compared to those who didn’t. The molecules involved suggested a process called the one-carbon pathway, which can be thought of as an assembly line for making DNA. Genetic differences between people can sometimes mean that they respond to environmental changes in different ways. For example, people exposed to the same amount of sun can burn, tan or experience very little skin change at all. Similarly, in space the common stress of microgravity affects the one-carbon pathway differently in various individuals. Some astronauts might experience a slowing of this assembly line and consequently a deterioration in eyesight, while others have no adverse effects at all. The way in which this pathway is related to vision is still uncertain, and the experiments that Major Tim is undertaking will provide important insight into making these connections.

“Press your space face close to mine”

It might be obvious from pictures of Major Tim that an astronaut looks rather different in space; and not just because they’re floating. Due to the shift in fluid from the lower body, the face and neck can look full

European Space Agency (ESA) astronaut Timothy Peake prepares to install a space acceleration measurement system sensor inside the European Columbus module aboard the International Space Station. The device is used in an ongoing study of the small forces (vibrations and accelerations) on the International Space Station resulting from the operation of hardware, crew activities, dockings and maneuvering. Results generalize the types of vibrations affecting vibration-sensitive experiments. Photo credit: NASA/Tim Peake
and puffy; indeed, some have even been remarked to regain a youthful appearance during space flight! But this fluid shift can also cause changes to the lungs and cardiovascular system. The increase in pressure around the lungs can temporarily affect their function, and an increase in blood volume in some heart chambers means that the body needs to quickly adapt before the heart is overloaded. It does this by excreting more urine and maintaining a body fluid level 10% lower than on earth. Amount of fluid excretion is controlled by anti-diuretic hormone released from the brain.

The baroreceptor reflex is also affected by microgravity; it is the system responsible for cardiovascular control. It involves receptors, or sensors found in blood vessels which detect changes in blood pressure. At upright gravitational resting blood pressure, the baroreceptors send electrical impulses to the brain carried via the movement of sodium and potassium ions across nerve membranes, at the same rate as the heartbeat. Pressure increases cause receptors to send an increasing rate of electrical impulses. This leads to a decrease in heart output and changes to muscles in the walls of blood vessels, resulting in an overall lowering of blood pressure. However, in space, as the body is no longer in a gravitational upright position, and fewer forces are acting on it, the baroreceptors are not able to sense normal changes in pressure and send moment-to-moment electrical stimuli. This means the baroreceptor reflex needs to adapt and find a new balance appropriate to the microgravity conditions. Indeed, as time goes on during the space flight, blood pressure and heart output seem to return to levels seen on earth.

“Changes”

So now we know some of the changes that Major Tim’s biochemistry might be undergoing during his mission on the ISS, but his research will without doubt elucidate details of the pathways and mechanisms involved. They will also certainly aid our understanding of diseases affecting people here on earth. For example, experiments on his own bones will help inform research into osteoporosis, a major cause of bone loss in the elderly. His muscle research could elucidate the biochemical mechanisms causing bed-bound patients to lose muscle mass and tone, and how to prevent this. His experience of orientation and spatial awareness could help researchers better understand how damage to the inner ear can affect balance and how electrical signals to the brain can be altered in some disorders. His eye tests could aid research into the causes of migraine and strokes, and investigation into his own heart performance and blood pressure has a clear benefit to people suffering from cardiovascular diseases. Lastly, thinking to the future, his work will also be invaluable as mankind considers longer journeys into space. Even though Major Tim’s physiology and biochemistry has been affected in the short term, the long term benefit of his research could shape the future of biomolecular research and treatments on earth as well as that of space travel itself.

References

Tim Peake of the European Space Agency is carried to a medical tent after he and Tim Kopra of NASA and Yuri Malenchenko of Roscosmos landed in their Soyuz TMA-19M spacecraft in a remote area near the town of Zhezkazgan, Kazakhstan on Saturday, June 18, 2016. Kopra, Peake, and Malenchvenko are returning after six months in space where they served as members of the Expedition 46 and 47 crews onboard the International Space Station. Photo Credit: NASA/Bill Ingalls