Appendix 2

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Into the abyss

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How deep can a diver go on one lungful of air?
Helen Phillips explores the fine line between a record-breaking dive and suicide

IT'S DEATHLY dark, wet, and you're chilled right through. You haven't drawn a breath for a couple of minutes now, and your heart is barely beating. Your lungs have been crushed until they take up little more space than a Coke can, and although your spleen has splurged out a mass of extra blood cells, your veins have collapsed and the blood forced out of your limbs into the space where your lungs should be. What little oxygen you have left is devoted only to keeping your heart and brain ticking over, and there's an intolerable pain as your eardrums feel about to burst.

This is what your body would be going through 150 metres below the surface of the sea. It sounds like a living hell. Yet, believe it or not, people do this for sport. Last June, Frenchman Loïc Leferme became the world record holder for 'no limits' freediving when he took a deep breath and was dragged 152 metres down on a weighted sled without any breathing apparatus. He went down further than the doomed Kursk submarine. But whereas the Norwegian rescue divers who cut into the sub spent the next five days recovering in a decompression chamber, Leferme was talking to the press just moments after he broke the surface.

Competitive freediving pushes the body to the absolute limits of endurance. And for as long as divers have been willing to test the body's limits, scientists have come along for the ride. Researchers are studying some of the world's most talented freedivers, scanning their brains, monitoring their hearts and lungs, even simulating deep dives in the lab. They're busy trying to figure out how the body copes with such unnatural challenges, and trying to hazard a guess at just how much further you can push the human body and live.

From the very first moment cold water hits the face, your body starts behaving differently. There is a huge shift in the pattern of blood circulation. Blood vessels in the muscles, skin and internal organs contract, channelling pretty much all of the available oxygen to our two most vital organs – the heart and brain. "The other tissues can make do for a while," says Claes Lundgren, Director of the Center for Research and Education in Special Environments at the State University of New York at Buffalo.

At the same time, the heart slows right down. "When you shut off a big part of the circulation, you can survive with a much lower heart rate," says Erika Schagatay, a physiologist at Mid Sweden University in Harnosand. And by reducing the heart rate, you also reduce the amount of oxygen your big, energetic heart muscle needs.

These effects are known as the physiological diving response. "It is something that we share with all other vertebrates, even the fish," says Lundgren, although in fish, the oxygen-preserving reflex kicks in when they're out of the water. The human diving response is so efficient that the world record for breath-holding is a phenomenal 7 minutes 35 seconds.

To survive a deep dive you need this efficient diving response, and as big a lungful of air as you can manage. Some divers have even learned to swallow air into their already full lungs. It's not just to keep up the oxygen supply, but also to cope with the increasing pressure. For every 10 metres you descend, the pressure rises by 1 atmosphere, and the air in the lungs is compressed to match. When the chest cavity has compressed as much as it can and the pressure is still rising, the space has to be filled up somehow, so blood is sucked into the blood vessels around the collapsing airways and alveoli.

Tanya Streeter, who holds the women's record for 'constant ballast' freediving, explains that she feels this as a real crushing sensation in her chest down to about 60 metres. Deeper down, the chest pain eases and another problem takes over. As the pressure on the outside of her eardrums mounts, the biggest thing on her mind is finding enough air left to force into the

Eustachian tubes between the throat and middle ear to equalise the pressure. “The limits are about finding one more equalisation,” she says.

Getting back to the surface can be just as gruelling. Paradoxically, the problems increase as divers near the surface. When the lungs expand again, the oxygen pressure drops, most dramatically in the final 10 metres where the lungs double in volume. Now, with less oxygen passing into the blood, there’s a big risk of fainting – what’s commonly known as shallow water blackout.

Pushing the limits

With all these hazards and discomfort, as well as such major physiological changes going on, what is it that makes a record-breaking diver? Can the body adapt to the pressure and lack of air through sheer hard work and training, or are the best divers born rather than made?

To try to find out, Schagatay measured the strength of people’s diving response, using the drop in heart rate as an index. When trained divers from the Swedish national freediving team submerged their faces and held their breath, their heart rates dropped by half – a diving response comparable to otters and beavers. And the colder the water, the stronger the response. In a sample group who had never been diving, the drop was less impressive, more like 20 or 30 per cent.

Schagatay and her colleagues also compared the breath-holding ability of the Swedish freedivers to populations with a long history of diving. She studied Ama divers from Japan – a population that has been using breath-holding techniques to harvest shellfish and seaweed for more than 2000 years. And she also tested members of a tribe called the Suku laut, or the ‘Sea People’, who live a semi-aquatic existence in the Indonesian archipelago. The Sea People spend up to 10 hours every day in the water, they give birth in the water, the children dive before they walk and the people harvest all their food from the sea.

Despite the long history of diving in these two populations, Schagatay and her colleagues found no obvious differences between them and the freediving team in their breath-holding skills and diving responses. In another study, Swedish non-divers practised breath-holding for two weeks, and both their breath-hold times and diving response increased. This suggests that skilled divers don’t have specialised genes, she believes. “Practice can bring out these effects in anyone,” says Schagatay. “The diving response is clearly trainable.”

She also found that divers could improve breath-hold times by half as much again after just five successive attempts in a single day. Most divers turn this to their advantage by performing a series of breath-holds and shallow warm-up dives in the run-up to a record attempt. Schagatay’s latest work shows how the spleen, an organ that rarely gets a mention, might be the key to this successive improvement. In a study published in next month’s issue of the *Journal of Applied Physiology*, she describes how breath-holding seems to cause the spleen to release a store of oxygen-carrying red blood cells.

Animals such as racehorses and seals were known to do this, but “it is quite new that this mechanism is important in humans in any situation,” says Schagatay. Diving or breath-hold training might help this reservoir get bigger or, more likely, empty more efficiently, she adds.

The body seems to cope with unusually long breath-holds in other ways, too. Paul Gabbott and his colleagues from the University of Oxford have some preliminary evidence that the blood flow in divers’ brains rises substantially while they are holding their breath. The researchers used a technique called transcranial Doppler ultrasonography on freediving instructor Marie-Teresa Solomons. The technique used changes in reflected sound waves from moving red blood cells to measure the speed of blood flow in a major blood vessel, the middle cerebral artery.

The velocity of blood flow was normal until Solomons held her breath. Then the flow began to increase dramatically. “There seemed to be a 100 per cent increase in the flow of blood through the middle cerebral artery after 4 minutes of apnoea,” says Gabbott. He is planning to follow up this study with functional brain imaging. He’s particularly interested in how conscious control and the divers’ psychological state blend with the physiological processes to help them cope during a dive.

Fighting the urge to breathe is just one of the psychological challenges. Streeter admits that a deep dive can be a frightening experience. It’s completely dark, you’re all alone, intensely cold as the blood drains from your limbs, and you have to brake the sled to keep from plummeting quicker and quicker. “You need balls of steel,” she says.

And she’s right to take the risks seriously. Several divers have died during training. “There are frequent deaths in snorkellers, swimmers and breath-hold divers that can’t be explained,” says Lundgren. He speculates that abnormal heart rhythms triggered by the diving response could be to blame in some cases. He found that even fit, trained divers experience abnormal heart rhythms during simulated dives in a pressure chamber.

Indeed, Lundgren thinks an inappropriate diving response, perhaps sparked by an icy blast of wind to the face, might explain some mysterious wintertime deaths out of the water. An overactive diving response might even be behind some cases of sudden infant death syndrome. When a warm baby turns their face into a cold draft, the diving response could slow the heart dangerously, says Schagatay.

But it's not just abnormal heart rhythms at fault. Not everyone could survive the pressure at the depths they're now reaching in competitions. Most researchers are reluctant to put a figure on how much pressure the human body can survive – partly because they keep being proved wrong. Just 40 years ago, the medical world thought the lungs would never cope with the pressure 50 metres down, yet that's just a warm-up by today's standards. But Lundgren is willing to stick his neck out. "I think we are now at the limit," he says. Schagatay agrees. "We were not meant to be deep divers," she says.

Indeed, something strange seems to be happening to the blood during dives deeper than 30 metres, according to experiments done at the Wirral Hyperbaric Centre at the Murrayfield Hospital on Merseyside. The researchers took arterial blood samples from two divers immediately after a simulated deep dive, and within 30 seconds of taking the sample, the blood had coagulated. "The blood was definitely sticky," says Dave Alcock, Director of Operations at the unit. The red blood cells also looked abnormal under the microscope. They are planning more tests to find out what's really going on.

Even if this effect proves to be harmless, as the pressure increases further and more and more blood is sucked into the chest space, the tiny blood vessels become ever more distended. Their strength and the point at which they would rupture is a very individual thing. Already, some divers cough blood after a dive – and that can only mean they have sustained some sort of damage. "If they really knew what they were putting their bodies though, I don't think they would dive," says Lundgren.

The quest for greater depths is sure to continue – Francisco 'Pipin' Ferreras has already claimed an unofficial record of 162 metres. But each body and each day is different. If someone has a greater tendency to bleed, or if the water is just that bit warmer, the depth could be too great. "Breath-hold diving is a wonderful thing," says Lundgren. "But no researcher would say it's safe to go so far or so deep. It's a very, very fine line they are treading at those depths."