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Taking the **plunge**

Dr Ingrid Eftedal leads controlled laboratory experiments examining the dangers associated with underwater diving

Could you describe the nature of your current research and what sparked your interest in this area in particular?

We are essentially studying the nature of physiological balances in the circulatory system. Such balances are complexly orchestrated processes, and in order to understand how they work you need to perturb them in a controlled fashion and then observe the reactions this provokes.

For me, the biggest attraction of environmental physiology lies in the opportunities it provides to study interaction between our genes and the environment; how the human body reacts and responds in order to regain its balances. I find that an extremely fascinating field of research.

To what extent does an individual's health history and genetic factors determine the impacts of diving on a person's body?

Our bodies have evolved to function optimally in what we perceive as a normal environment, with one atmosphere ambient air pressure, a gravity of 1 g and exposure to daylight on a 24-hour rhythm. Under these conditions, most humans are able to maintain the physiological balances that are necessary to stay healthy. Altering our surroundings will challenge this ability, but whether this triggers negative effects is likely to depend on individual traits – inherent or acquired – that may not be discernible under normal conditions.

Diving is not recommended for those with known reduced function of airways or lungs, but individual vulnerabilities may also be unknown prior to diving. We hope to contribute to the identification of factors that modulate how the human body responds through the project Fitness to Dive.

What are the effects of hyperbaric exposure on the central nervous system?

We still know very little about this. What we do know is that some veteran divers report symptoms that may indicate functional changes in the central nervous system. In previous studies we have seen signs of temporary changes in the blood-brain-barrier in rats exposed to simulated diving conditions in pressurised air. One of the aims of the Fitness to Dive project is to determine whether exposing rats to high pressure alters the function of their central nervous system, and also whether particulate pollutants are more likely to pass over the blood-brain barrier under conditions of high pressure.

Why have you chosen to use rat models for this project? Could you expand on how they are being used to better understand the impacts of diving on the central nervous and circulatory systems in humans?

The central nervous and circulatory systems of rats and humans have largely similar structure and function. Ethical and technical barriers will often prevent us from studying extreme physiological exposures of humans – for instance obtaining fresh brain tissue and blood vessels from human divers is clearly not feasible – whereas rats can be used to directly target the organs and tissues we want to study. Also, with rats we can control environmental and genetic factors better than we can with humans. This makes it easier to design experiments that specifically target the exposures and effects we are interested in.

How is this research of relevance to the offshore Norwegian oil industry in particular?

Despite technological advances, there is still no good substitute for humans when it comes to high precision tasks such as welding of pipes underwater. Better understanding of hyperbaric effects related to individual variation could aid in establishing criteria for the assessment of fitness when preparing divers for underwater work.

Studying acute and long-term health effects of exposure to air borne components in the hyperbaric work environment is important in establishing safe hyperbaric exposure limits. While this project is targeted at issues relevant to the offshore oil industry, its results may also benefit those who use diving to perform other tasks such as underwater rescue.

Uncovering **underwater** effects

Divers play a pivotal role in some of the world's essential underwater work but exposure to rapid pressure changes and potentially toxic gas levels may place this group at risk of acute or even long-term injury. Crucially, new research from the **Norwegian University of Science and Technology** may help bring much-needed protection to divers

SOME OF THE WORLD'S most diverse and beautiful diving can be found in Europe. Norway in particular is considered to be one of the world's more extreme places to dive. Lake Lygnstøylsvatnet is visited by divers the world over, keen to explore the country's kelp forests, whilst Saltströmmen boasts the strongest current in the world.

However, although a popular adventure sport and crucial occupation for Norway's offshore oil and gas industry, diving is not without its dangers. Divers are exposed to rapid pressure changes, increased ambient pressure and potentially toxic levels of breathing gas components, all of which can result in the risk of injury. According to the Diver's Alert Network, pre-existing diseases or pathology in the diver is the biggest cause of death, followed by poor buoyancy control and rapid ascent/violent water movement.

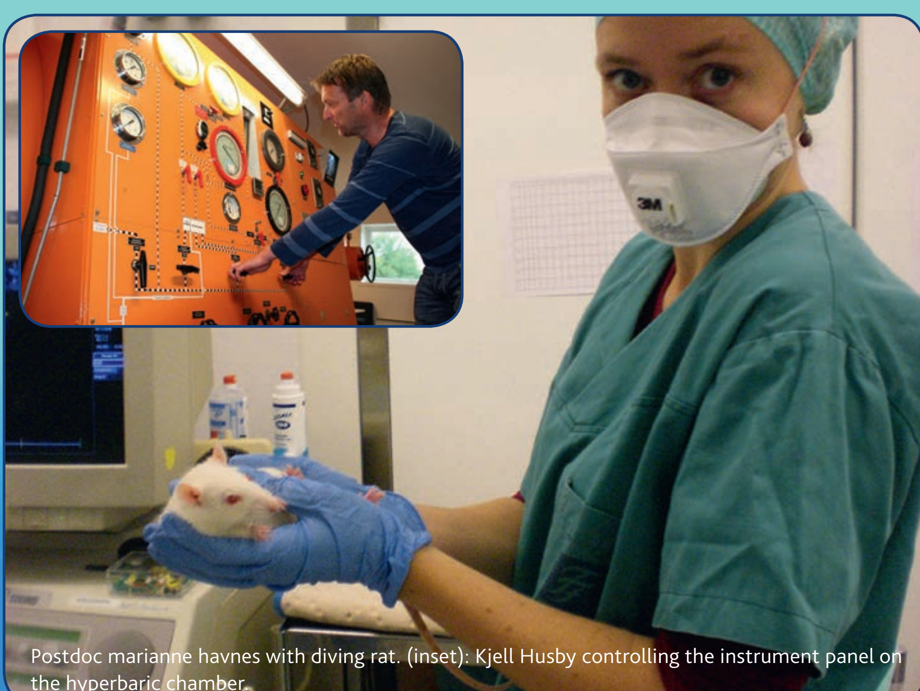
Research into diving's risk potential has so far uncovered inflammatory reactions in the body's circulatory system. This occurs when the body experiences physical stress from external factors such as an increased pressure of oxygen and decompression-induced gas bubbles. Better understanding of individual-specific factors, such as a diver's respiratory capacity, vascular health and nutrition, is considered to help diver's risk injury, but research has been limited. Causing more concern in the diving industry is the potential long-term effects associated with the occupation, about which even less conclusive evidence exists.

NORWEGIAN DIVING MEDICINE

Norwegian studies into the medicine and physiology of diving began over 25 years ago, led by Professor Alf Brubakk. Combining his personal passion for SCUBA diving with his professional interest in ultrasound imaging, Brubakk and his research group established methods for gas bubble detection in blood vessels and demonstrated the link between high levels of circulating bubbles and the risk of decompression sickness. An industry highly dependent on diving, Norway's oil and gas sector took great interest in his research, in the hope that his findings would better protect those working on the development and maintenance of offshore installations.

However, concern reached a peak when reports began circulating of a reduction in health-related parameters among experienced divers from the region's continental shelf, and raised concerns about the possible long-term effects of diving. Dr Ingrid Eftedal and her colleagues at the Department of Circulation and Medical Imaging at the Norwegian University of Science and Technology (NTNU) are exploring how better physiological knowledge may protect divers from acute and long-term injury.

Named Fitness to Dive, the project seeks to understand how and why inflammation arises, and at what threshold natural responses stop maintaining physiological balances and start progressing towards disease. Understanding this shift could help both scientists and the diving community to further their understanding: "While as researchers we focus on understanding how extreme environmental exposures affect the human body, the diving operators can apply this knowledge to prepare and protect their divers from injury; this is the context from which our project arose," Eftedal reveals.



Postdoc marianne havnes with diving rat. (inset): Kjell Husby controlling the instrument panel on the hyperbaric chamber.

RAT SIMULATION MODELS

To address this objective the team use rats, which are known to have central nervous and circulatory system similar to humans, to examine how the circulatory system reacts and adapts to hyperbaric exposure. The project also set out to assess whether hyperbaric exposure with or without particulate pollution, generated after welding at elevated pressure, has any effect on the rat's central nervous system. Finally, Fitness to Dive seeks to understand how individual-specific factors, including aerobic capacity, vascular health and nutritional status in the rat, affect circulatory reactions to hyperbaric exposure.

Officially started in October last year, the project's early stages focused on establishing laboratory conditions that simulate those in human saturation diving. The experiment exposed the rats to high pressure in a closed chamber, filled with a concoction of oxygen and helium to assess how extreme environmental exposures affect the body.

The NTNU research group collaborates with a number of other researchers in the US, Croatia and Sweden to examine the impact of vascular bubbles and hyperbaric oxygen. The project also leverages experience from other disciplines and draws on the knowledge of colleagues at the NTNU Medical faculty for research relating to circulatory function and fitness, structure and function of the central nervous system, immunology, statistics and biomedical instrumentation.

RESEARCH CHALLENGES

Paradoxically, whilst playing a critical part in the research, the use of rats also presents one of the biggest challenges when it comes to translating the results from animals in a controlled laboratory setting into human reality. Rats and humans possess many similarities, but the blaringly obvious differences between the two species make it complicated to design studies whose results are applicable to real-life situations.

Additionally, although providing a huge amount of benefit to Norway's oil and gas industry, Eftedal also finds it challenging to communicate with industry collaborators, having never before led projects that aimed to produce directly applicable results: "Basic research can be quite introverted, with the risk of producing work that is not very relevant for practical uses," she notes. Moreover, any research results that may uncover differences based on genetic variation must be taken into careful consideration when applied. Individual divers may benefit from risk predictions of adverse health effects but genetic information carries a potential for misuse and unanticipated disclosures.

MAKING A SPLASH

Following the project's completion, the research results are intended to be published and made widely available in referee-based journals, and will also be presented at both national and international scientific meetings. Not forgetting the primary goal of protecting divers from acute and long-term injury, the group also plans to disperse the findings across the industry to reach a wider audience, which they intend to achieve in part via presentations at the biannual Norwegian Diving Seminar and at the Norwegian Baromedical Society.

In the long term, the researchers hope the project will bring fundamental benefits to Norway's knowledge regarding diving medicine, as well as help the country's offshore oil industry. Eftedal is enthusiastic about the future of the project: "I anticipate the results of this study to be of benefit to saturation divers as part of the knowledge basis that may be applied to promote health and safety. Research into extreme physiology will also provide knowledge that is of wider interest".

DIVING DANGERS

DECOMPRESSION SICKNESS

CAUSE: bubble formation due to super saturation of inert gas in the body's tissues
EFFECT: aching joints, skin rash, paralysis or, in severe cases, death

NITROGEN NARCOSIS

CAUSE: excess nitrogen in the body
EFFECT: impaired judgement and sensory perception

OXYGEN TOXICITY

CAUSE: excess oxygen absorption
EFFECT: altered lung function, tunnel vision, nausea, twitching and loss of consciousness

PULMONARY EMBOLISM

CAUSE: a rapid ascent can cause gas in the lungs to expand too quickly
EFFECT: swelling and risk of rupture of alveoli and blood vessels in the lungs

DYSBARIC OSTEONECROSIS

CAUSE: long-term exposure to high pressure
EFFECT: aseptic death of bone tissue

HIGH PRESSURE NERVOUS SYNDROME

CAUSE: compression of tissues in deep dives; breathing helium-based gas
EFFECT: neurological changes

INTELLIGENCE

FITNESS TO DIVE

OBJECTIVES

The primary objective of this project is to provide physiological knowledge that may be applied in preparing and protecting divers from acute and long-term injury. The objective is addressed through translational studies of the circulatory and central nervous system of laboratory animals and human divers.

COLLABORATORS

Marianne Havnes, Norwegian University of Science and Technology, Norway

Astrid Hjelde, Norwegian University of Science and Technology, Norway

Andreas Møllerløkken, Norwegian University of Science and Technology, Norway

Zeljko Dujic, University of Split, Croatia

Mikael Gennser, KTH Royal Institute of Technology, Sweden

Stephen Thom, University of Pennsylvania, USA

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CONTACT

Dr Ingrid Eftedal
Research Scientist

NTNU Medical Faculty
Department of Circulation and Medical Imaging
PO Box 8905
7491 Trondheim
Norway

T +47 7257 3265
E ingrid.eftedal@ntnu.no

DR INGRID EFTEDAL holds a Master's in biophysics and medical technology and a PhD in molecular genetics. After postgraduate work in Strasbourg and Copenhagen, she was Head of the Medical Genetics Section at St Olav University Hospital in Trondheim before returning to NTNU in 2009 to conduct research in barophysiology.

NTNU
Faculty of Medicine
Department of Circulation and Medical Imaging