PROFESSOR ØRJAN G MARTINSEN INFORMS **PEN** OF THE HISTORY OF THE OSLO BIOIMPEDANCE GROUP AND HOW WORK IN THIS FIELD IS HELPING TO INFORM VARIOUS FACETS OF MODERN MEDICINE

Bioimpedance

The Oslo Bioimpedance Group is composed of researchers in the Oslo region with a special interest for electrical bioimpedance (bioimpedance being the electrical impedance of biological materials). Their affiliation is mainly with the Department of Physics at the University of Oslo and the Department of Clinical and Biomedical Engineering at Oslo University Hospital, with both students and co-workers.

The activity was started around 1980 by Sverre Grimnes who, at that time, was the founder and head of the clinical engineering department of Oslo University Hospital. He received reports from surgeons who claimed that they could feel an 'electrical sensation' around the eyes when looking into the ocular lens of their microscopes. Measurements revealed that an electrical current of a few microamps was flowing between the eyepiece and the skin of the operator, but this was far less than the established limit of perception of about one milliamp.

Electrovibration

Grimnes pursued this question, and his work led to the discovery of a new mechanism for perceiving small electrical currents, which he named 'electrovibration'. This is the sensation felt when moving a dry finger over the metal surface of a non-grounded appliance connected to the mains. The 50-60Hz voltage of the mains supply will be capacitively coupled to the metal surface and will generate a small current through the skin. This current cannot be perceived if the finger is kept still on the surface, but as soon as the finger is moved, the electrical field will modulate the friction between the metal and skin, and this can be felt all the way down to around one microamp.

Grimnes received a PhD a few years later based on a thesis of the electrical properties of human skin. In addition to his position at the hospital, he was also appointed adjunct professor at the Department of Physics at the University of Oslo. In 1990 he formed the Oslo Bioimpedance Group with me as his colleague and PhD student. Grimnes remains active in research as a professor emeritus, and I am now a professor of electronics, both at the university's physics department.

Impedance

It was Luigi Galvani who, in 1780, showed that the living body utilises electricity to control muscle movement; that nerves act as electrical wires. The term 'impedance' was coined by Heaviside much later (around 1880). About the same time, measurement of electrical conductance in human skin began and became the precursor of the lie detector.

Around 1905, the electric galvanometers were sensitive and rapid enough to non-invasively pick up the very small potential difference generated by heart activity (ECG), and, by 1910, Höber used bioimpedance methods to prove the existence of cell membranes and calculated how extremely thin they are (less than 0.01 micrometer).

Professor Ørjan G Martinsen, head of Electronics Research Group at the University of Oslo's Department of Physics

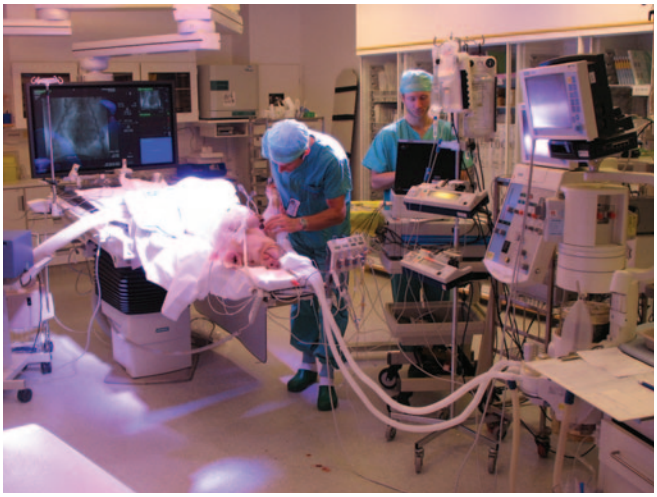
By sending a very weak AC current through the thorax, the bioimpedance electrodes could pick up the respiration signal, and this method rapidly spread during the 1950s. From then on, many clinical applications based upon bioimpedance have been developed, including measuring cardiac minute volume non-invasively, measuring lung respiration activity, and taking electronic biopsies for diagnosis of skin cancer.

A common platform

For many years, the international bioimpedance field lacked a common platform. Researchers came from diverse professional backgrounds (including physics, engineering, chemistry, medicine, biology, pharmacy, and so on), and they all brought their theories and terminologies into the field. In an effort to build a common arena, the first International Conference on Electrical Bioimpedance was held in New York in 1969 and has since been organised every three years. The Oslo group held the 11th conference in 2001 and the 15th conference was held in Heilbad Heiligenstadt, Germany, in April this year.

To further establish a common basis for bioimpedance research, Grimnes and I have authored the first textbook in this area, *Bioimpedance and Bioelectricity Basics*. The second edition of this book appeared in 2008.

Professor Sverre Grimnes, co-founder of the Oslo Bioimpedance Group



Members of the Oslo Bioimpedance Group doing impedance measurements on a pig model. Dr Håvard Kalvøy and Dr Christian Tronstad have a background in physics and biomedical engineering, and are both researchers at the Department of Clinical and Biomedical Engineering, Oslo University Hospital

In 2010 we also established the first scientific, peer-reviewed journal dedicated to bioimpedance research, *Journal of Electrical Bioimpedance* (www.bioimpedance.net). This open access journal is entirely based on voluntary work and thus no publication fee is claimed.

Projects

The Oslo Bioimpedance Group has initiated a large number of research projects within which bioimpedance methods were developed to characterise tissue within a wide range of applications – cosmetics, food industry, sports and medicine. In recent years, the focus of these projects has been narrowed, however, and they now mainly pursue medical areas.

One example of this is the needle positioning system. Imagine a nurse or physician giving an injection of some kind to a patient. In some cases, it is very important to know the exact anatomical location or in what sort of tissue the injection is to be administered, such as the epidural analgesia given during childbirth or surgery. In this instance, the position of the needle tip must be in the so called epidural space, but without penetrating the *dura mater,* and the clinician often has no other tools than their experience and finger feeling to get it right, meaning that the result is not always a success.

The Oslo group therefore decided to send a small, electrical sensing current through the needle and measure the impedance. The main contribution to this measured impedance will be the volume where the current density is greatest, i.e. where the current has to pass a very small cross section. Because of the sharp needle tip, the measurement will thus be effectively focused on the tissue surrounding it.

With a combination of impedance spectroscopy and multivariate statistical methods, this method can be used to recognise the type of tissue surrounding the needle tip in real-time. Hence, when the clinician pushes the needle into the tissue, the instrument can continuously detect the transitions e.g. from skin to fat to muscle to blood.

Skin conductivity

Another example is from the Oslo group's long history of research on the electrical properties of human skin. The skin, and in particular the outer epidermis with the uppermost layer of dead cells called the *'stratum corneum',* is a very poor conductor of electricity. When moistened with saline or water it becomes somewhat more conductive and when the body is perspiring, the filled sweat ducts make numerous small shunt paths for the current, thus further increasing the conductance.

The team has developed a small instrument for the measurement of sweat activity. It is based on electrical impedance measurements, but the technology makes it possible to focus on the filling and emptying of the sweat ducts. Similar methods have been used for many years in applications such as lie detection, but the Oslo group has taken the technology a step further by introducing an alternating current (AC) instead of the present dominant use of direct current (DC), as well as new measured parameters, and by using advanced signal processing. The result is a small, portable, wireless and extremely sensitive instrument with a wide range of potential application areas.

Measuring sweat activity is interesting because sweating is not only a way of getting rid of excess body heat (thermal sweating), but is also a measure of the activity in a person's autonomous nervous system. Particularly in the palms of the hands and the soles of the feet, sweating is mainly psychologically controlled rather than being a function of temperature.

The term electrodermal response (EDR) is often used for this phenomenon, as are galvanic skin response (GSR – from the older DC based instruments), psychogalvanic reflex (PGR) or electrodermal activity (EDA).

Diabetes

The Oslo group is currently involved in many projects where this method is utilised, and has recently been awarded funding for a large project on the use of sweat activity measurements, together with other bioimpedance methods, to provide an early warning of severe hypoglycemia for persons suffering from diabetes.

It is well known that low blood sugar is associated with increased sweat activity, and by combining several bioimpedance based and other techniques in a multi-sensor system, the group hopes to develop a new, non-invasive device which can improve the quality of life for patients with impaired awareness of hypoglycemia.

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