Source: istockphoto.com

INFORMATION, COMMUNICATION & COMPUTING

Fields of Expertise TU Graz

Kay Uwe Römer, Information, Communication & Computing
Source: Lunghammer – TU Graz

After more than one and a half years of online and hybrid conferences (often with very limited in-person attendance) I just returned from my first presence-only conference just like they used to be in good old pre-COVID times. Many senior persons and close colleagues attended and were actually around in the lecture hall most of the time – as if they had missed the possibility to mingle. During the joint lunch I learned informally about the latest research topics they are currently investigating. We exchanged experience about online teaching during the coffee breaks. We went out in the evening for a glass of wine over which we shared the latest rumors about who had accepted a faculty position at which university. They told me during the social event – in a beautiful collegiate church with an organ whose low notes could literally be felt in the belly – how their families are doing. The welcome reception was held in a smart factory, so we could see and touch the latest equipment they have installed there. During the demo session there were many good hands-on demonstrators where one could touch and play with the prototypes. All this never happened during the online conferences and only to a very limited degree during hybrid conferences, because the "interesting" colleagues joined only online. This reminded me that all these informal side activities during an in-presence conference are at least as important as the paper presentations. Fortunately, there are things in life that cannot be digitalized.

In this edition of TU Graz research, Alice Reinbacher-Köstinger, assistant professor at the Institute of Fundamentals and Theory in Electrical Engineering, gives us some insights into her research. Enjoy reading!

Alice Reinbacher-Köstinger

Identification and Monitoring of Aortic Diseases by Electrical Impedance Measurements

Aortic diseases such as aortic aneurysm or dissection can be life-threatening and are not always detected in time. Therefore, an easy-to-use, non-invasive method to detect such a disease would be of great benefit. A suitable method that is already in clinical use but for a different purpose, is impedance cardiography. With numerical simulations of an adapted measurement system, including patient-specific geometries, the feasibility of such a method to be able to identify and monitor pathologies of the aorta is being investigated.

Electrical bio-impedance measurements are performed by placing adhesive electrodes on the body surface and injecting a low-amplitude alternating current. As shown in Fig. 1, additional sensor electrodes measure the voltage drop in the region of interest, which is proportional to the impedance and varies during a cardiac pulse wave. Since blood has a higher electrical conductivity compared to the surrounding tissue types, the impedance changes are mainly due to the pulsatile blood flow in the aorta. The blood pulsation causes volumetric changes of the aorta and also flow-induced conductivity changes.

>

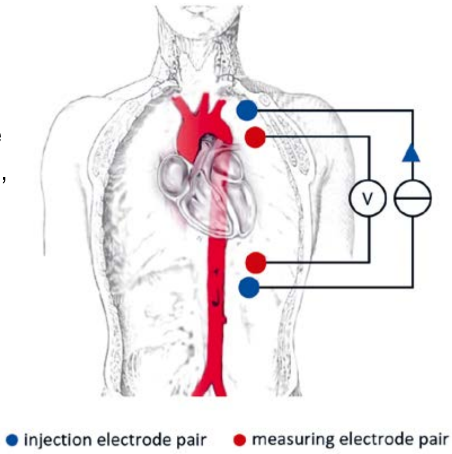

Figure 1: Principle of thoracic bio-impedance measurements.
Source: J. Heuser, Wikimedia, with modifications

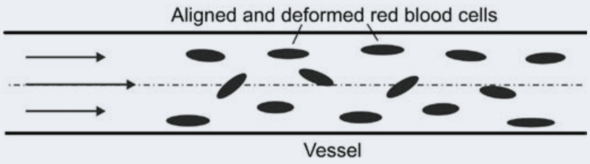

Figure 2:
Sketch of the alignment and deformation of red blood cells in a vessel.
Source: Alice Reinbacher-Köstinger

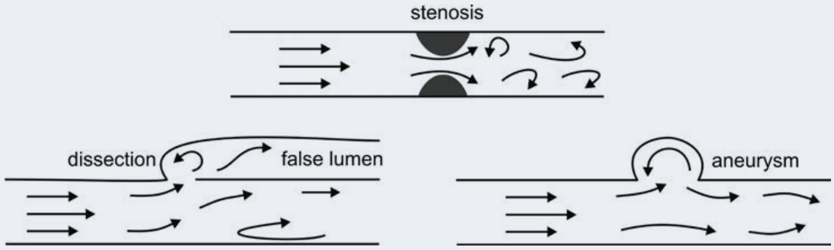

Figure 3:
Sketch of flow disturbances for different aortic pathologies.
Source: Alice Reinbacher-Köstinger

Both are altered in case of an aortic pathology and these changes should provide the opportunity to identify the disease.

A numerical model of the thorax is used to simulate the electrical behavior of the measurement setup mentioned above. By simulating and assessing many different models the most influential factors can be identified. While the geometry of the different tissue types and also the temporal volumetric changes of the blood-filled aorta can be extracted from imaging data, the material parameters have to be taken from the literature and are subject to a very high uncertainty. Special attention must be paid to the flow-induced and therefore time-dependent behavior of the conductivity of blood.

Blood is a physically highly complex fluid that consists of cells (red and white blood cells and platelets) suspended in blood plasma. From experiments over the last 100 years, it turned out that the electrical conductivity and the viscosity are mainly determined by the properties of the red blood cells (RBCs) and the surrounding plasma. Furthermore, it has been observed that the alignment and deformation of the electrically isolating RBCs suspended in the well-conducting blood plasma causes the blood conductivity to become anisotropic in the case of flowing blood, i.e. it is higher in the direction of flow and lower in orthogonal direction. Furthermore, it is spatially distributed since the shear stresses are higher close to the vessel wall, as can be seen in Fig. 2. This anisotropic, flow-dependent conductivity is calculated based on CFD simulation results performed by our partners within the TU Graz lead project "Mechanics, modeling and simulation of aortic dissection", the groups of Thomas Hochrainer, head of the Institute of Strength of Materials and Günter Brenn, head of the Institute of Fluid Mechanics and Heat Transfer. In order to model the non-Newtonian behavior of blood used in the CFD simulations, rheological data is needed. Ursula Windberger, head of the rheology lab of the Center for Biomedical Research (Medical University of Vienna), conducts research in the field of material characterization of suspensions and, in particular, of human and animal blood and measured the viscosity of various blood samples at different shear rates. With the resulting flow field quantities, the spatial, anisotropic electrical conductivity is calculated using a sophisticated conductivity model for suspensions of ellipsoidal particles.

While the numerically obtained conductivity changes in laminar flow in a rigid vessel have already been validated by measurements, there are no data available for the case of flow disturbances in the vessel,

Alice Reinbacher-Köstinger has been an assistant professor at the Institute of Fundamentals and Theory in Electrical Engineering since 2020. Her work is focused on the numerical optimization of technical systems and on inverse problems, especially in electro-biomedical applications.

Source: Privat

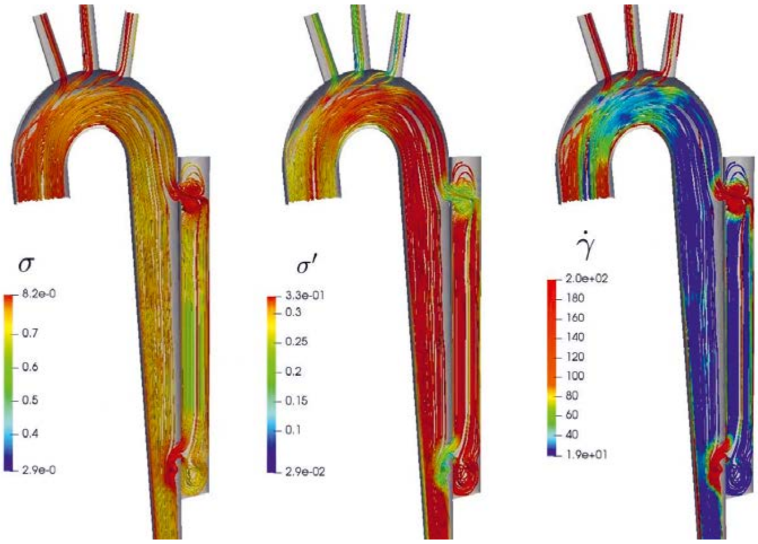

Figure 4: Shear rate ($\dot{\gamma}$) and el. conductivity in flow direction (σ) and orthogonal to the flow (σ') in case of an aortic dissection.

Source: Alireza Jafarinia

as is the case with aortic diseases. Therefore, experimental investigations for different types of disturbances (see Fig. 3). are performed in our laboratory. Before using human blood for the experiments, a suspension made of fibers in the μm range, which have been provided by the Institute of Chemistry and Technology of Biobased Systems, is used. Due to the shape of the fibers (non-spherical isolators in a well conducting liquid) a similar behavior of the alignment at higher flow rates is observable.

For the case of an aortic dissection, where the innermost layer of the aorta ruptures and blood starts to flow between the intima and the media layer, the blood conductivity has been computed using openFoam and the result is shown in Fig. 4. As a result of the dissection, a new, so called false lumen develops besides the original aorta. The local hemodynamic conditions such as flow disturbances and recirculations may cause thrombus formation and growth there and the status of this thrombosis is of great importance in the medical management of respective patients. By 3D FEM electric field simulations using openCFS, as shown in Fig. 5, significant impedance changes due to physiological changes during a thrombosis are determined, confirming that the modified impedance cardiography can be a valuable method in the medical management of aortic dissections.

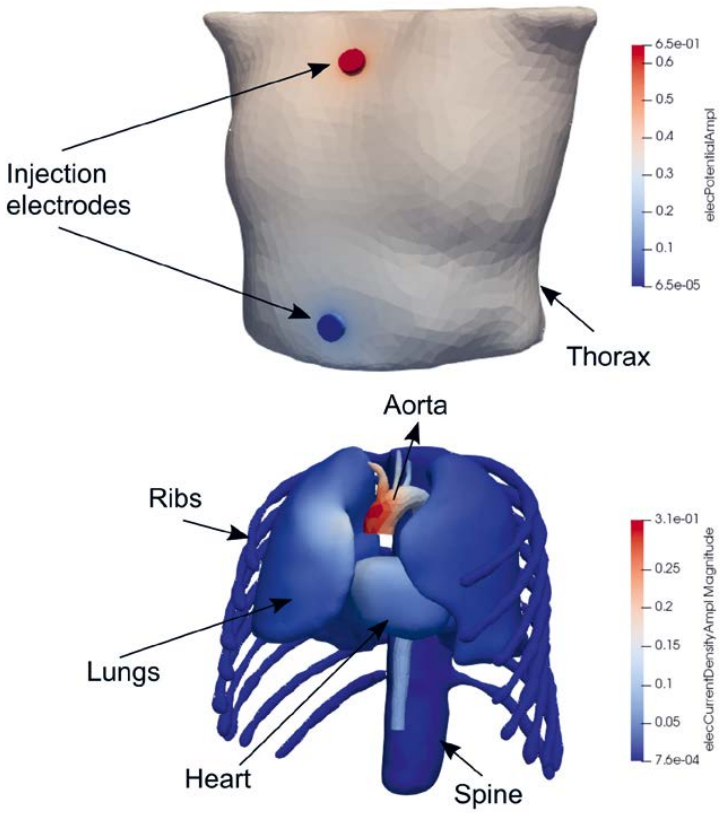

Figure 5: Patient-specific 3D FEM model.

Source: Vahid Badeli

ACKNOWLEDGEMENTS

This work is part of the TU Graz lead project "Mechanics, modeling and simulation of aortic dissection". The main contributors to this subproject are Vahid Badeli from the Institute of Fundamentals and Theory in Electrical Engineering, Alireza Jafarinia from the Institute of Strength of Materials and Gian Marco Melito from the Institute of Mechanics.