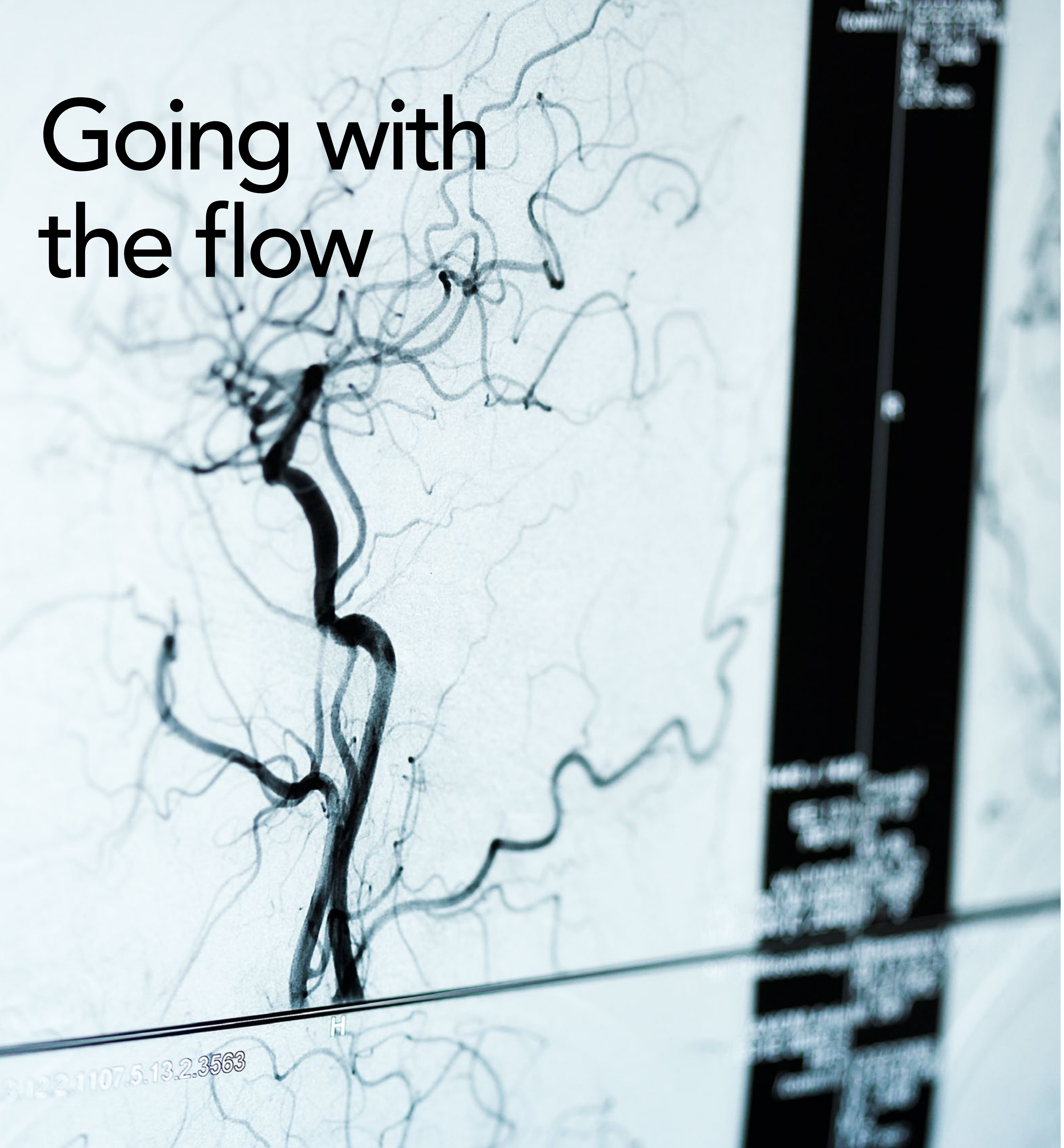


Going with the flow

Measuring blood flow in vessels throughout the body can be crucial for the correct diagnosis and treatment of disease, but it is no easy task. A research group led by **Dr Stefanie Demirci** at the Technical University of Munich has taken on this challenge, creating novel algorithms to quantify blood flow and minimise risky surgical interventions.

The flow of blood around the body is essential for the transport of nutrients, hormones and – crucially – oxygen to all tissues. Any interruption or alteration to blood flow can therefore have significant deleterious effects, and these changes can provide valuable markers of disease.

For instance, the rate of blood flow to and through the heart can be an important indicator of its condition. Tumours, such as liver tumours, can be identified based on an increased blood flow, due to proliferation of blood vessels in their vicinity. Conversely, decreased blood flow in the extremities can indicate cardiovascular problems. In the brain, measurements of blood flow can help to pinpoint the site of a stroke and identify tissues at risk of further damage. Thus, obtaining an accurate assessment of the flow of blood within veins and arteries throughout the body can be a first step to diagnosing and treating a range of diseases.

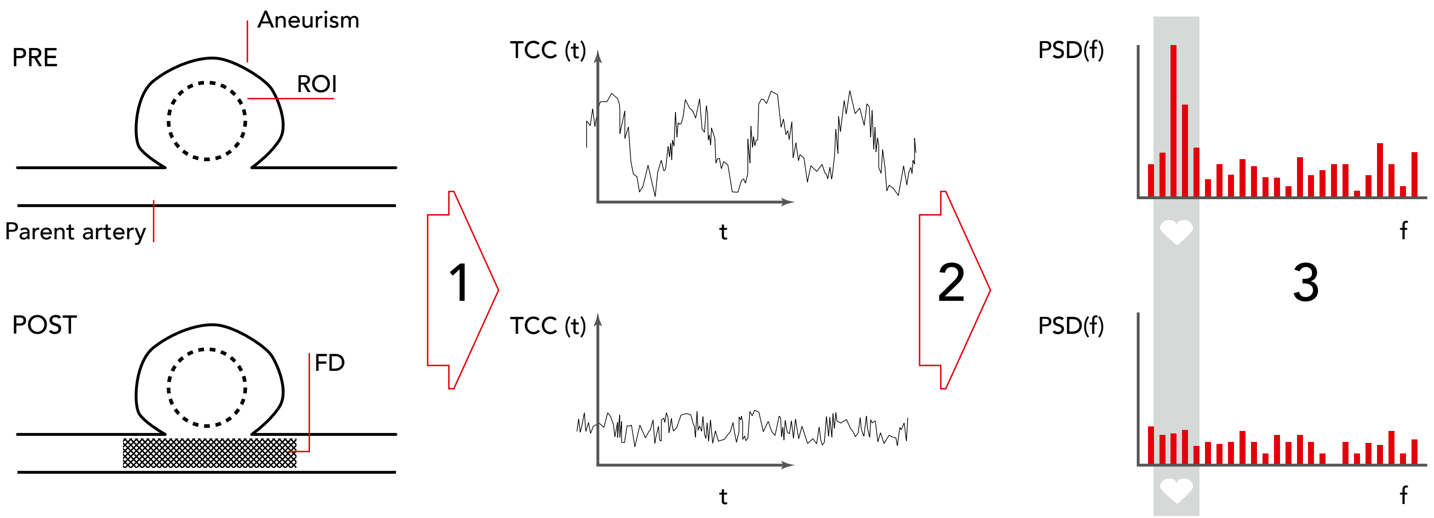
MINIMALLY INVASIVE IMAGING

As with any medical procedure, reducing surgical invasion is key to patient health in terms of reducing recovery time and the likelihood of complications. For many vascular diseases such as stroke, time is a crucial factor. Dr Demirci and her collaborators' research focuses on fast and minimally invasive methods for monitoring blood flow throughout the body, using interventional X-ray images interpreted through computer algorithms. Having published many papers on blood flow in the brain, in a new three-year project funded by the German Science Foundation (Deutsche Forschungsgemeinschaft), and supported by Siemens Healthineers, the team is now turning to the cardiovascular system itself.

Non-invasive techniques such as ultrasound can provide a qualitative view of blood flow, but X-ray is still the gold standard due to the large field of view. To quantify blood flow accurately, and provide the most appropriate patient care, a high-contrast dye is added to the blood stream, via a carefully-positioned catheter. The blood vessel in question is then visualised using an aptly-named 'C-arm scanner' – a C-shaped device in which one end of the C contains an X-ray source and the other, an X-ray detector. The patient is positioned inside the 'C', before a series of X-ray images (known as angiographs) are taken in quick succession. A computer then uses these to generate a graph of contrast through time. From this, parameters relating to the flow of blood in the vessel, such as speed and volume, are calculated.

The team around Dr Demirci has developed an algorithm using models from computational fluid dynamics, to make these calculations for cerebral blood vessels. At the same time, her system identifies the optimum timing for capturing blood flow data, based on pinpointing the arrival of the contrast dye at the point of measurement. So far, results suggest that the method can calculate blood flow with less than 12% error rates. The system can be used in 'computer-assisted endovascular procedures' which minimise the time spent in surgery by predicting and simulating information that could otherwise only be obtained under the surgeon's knife.

Accurate assessment of the flow of blood within the body using interventional imaging only, could speed up diagnosis and treatment of a range of urgent vascular diseases



The injection of contrast medium into blood vessels allows the visibility of blood in X-ray imaging and its characterisation by time-contrast curve (TCC) and corresponding power spectral density (PSD) in Fourier space. The figure shows results pre and post flow diverter treatment and clearly support the clinical hypothesis that flow diversion leads to a reduction of pulsatility of intra-aneurysmal haemodynamics

MOVING UP A DIMENSION

Calculating blood flow from two-dimensional angiographs of a three-dimensional vessel, as described above, is a difficult task requiring a good understanding of the nature of each patient's blood vasculature. Despite this, 2D imaging is popular with clinicians due to its relatively quick and easy application. Alternative 3D techniques, which Dr Demirci and her collaborators are also developing, may be more accurate but can require patients to undergo multiple injections of contrast dye and multiple X-rays, and involve lengthy computerised interpretations of the images to calculate blood flow statistics.

Before it will be adopted in practice therefore, the increase in accuracy gained with 3D imaging must outweigh the complexity, time taken, and risks to the patient, in terms of higher doses of X-rays and contrast dyes. Together with her collaborators from industry and academia, Dr Demirci is working to develop increasingly efficient algorithms to speed up the computer interpretation of multiple 3D X-ray images, using a method known as tomographic image reconstruction.

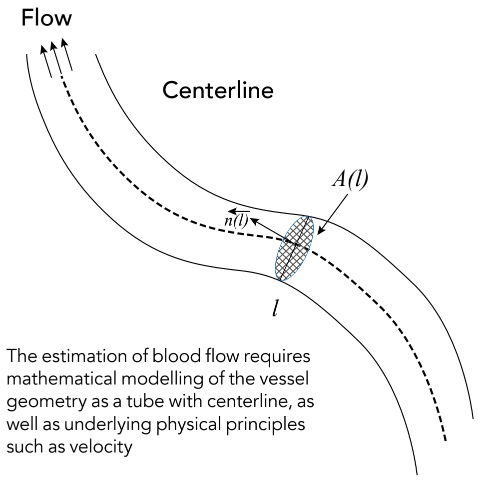
NOT JUST A DIAGNOSIS

The systems, processes and algorithms of 2D and 3D blood flow visualisation are not only useful for diagnosis, but are also increasingly being integrated into treatment. For instance, 'flow diversion' is a treatment for cerebral aneurysms (swellings in the wall of a blood vessel in the brain), in which a prosthetic blood vessel is inserted to divert blood flow away from the area weakened by the aneurysm. Dr Demirci and colleagues have developed a metric for quantifying blood flow before, during and after surgery, which reduces interference caused by the patient's own heart rate, thereby providing accurate information about the success of the flow diversion treatment and aiding clinical decision-making.

Even more excitingly, computer algorithms may in future be used to produce virtual assessments of blood flow around the flow diverter, providing a prediction of the results prior to surgery, and enabling doctors to test alternative placements of the device to optimise clinical outcomes, without going through a risky 'trial and error' process within the patient.

TO THE HEART OF THE MATTER

While Dr Demirci's progress in monitoring blood flow in the brain is impressive, the brain is, in fact, one of the easiest parts of the body to work with, since it is subject to



The estimation of blood flow requires mathematical modelling of the vessel geometry as a tube with centerline, as well as underlying physical principles such as velocity

minimal movement apart from the flow of blood. Elsewhere in the body, interference from breathing, the heartbeat, and muscle contractions make visualising blood flow even trickier. Not to be deterred, Dr Demirci and her project partners are now working to assess blood flow in other systems, including the heart and liver. One example within this includes monitoring the success of methods that divert blood away from a tumour, by inserting a small artificial blockage, in a procedure known as 'embolisation'.

In the cardiovascular domain, Dr Demirci is working on algorithms to improve the accuracy of 'image registration'. This process involves merging multiple images taken at different time points to build a comprehensive picture of a structure, such as a blood vessel or heart valve – and to support accurate tracking of devices such as cardiac stents during surgery. Her advances in software and algorithms should have dramatic impacts in practical surgery, speeding up operations, improving patient recovery times, and in some cases even avoiding the necessity for open heart surgery.

Dr Demirci's advances should have dramatic impacts in practical surgery, speeding up operations, and drastically improving patient recovery times

Q&A

How are computers being used in medicine today?

In recent years, computers have become more and more important inside clinics, beyond hospital administration. With increasing performance and decreasing size, nowadays, computers play an important role in the diagnosis and treatment of various diseases. Supporting medical expertise, computers are able to combine various specific pieces of information about a single patient or a group of patients and give specific hints to physicians for diagnosis. During surgery, computers can again combine this data with planning sketches in order to allow for a disease- and treatment-specific visualisation of the patient's anatomy and physiology.

What kinds of conditions can your research help to treat?

In our research, we are aiming at solutions to aid and support doctors, physicians and surgeons so that they can fully concentrate on their job. Besides great opportunities, the appearance of computers inside medical workflows has also introduced many challenges for medical staff. We try to develop smart machines that provide necessary information at the right time without requiring too much interaction. In this specific research topic quantifying blood flow, we are focusing on cardiovascular diseases such as stroke, arteriovenous malformation (AVM) and coronary artery disease.

What is the difference in approach between 2D and 3D imaging of blood flow, and what are the advantages of the latter?

In conventional clinical practice, blood flow is measured using diagnostic X-ray imaging methods such as Computed Tomography. In urgent cases (such as stroke), time is crucial and physicians would like to eliminate the necessity for a diagnostic scan. Instead, they would like to be able to use interventional X-ray imaging for measuring the true volumetric blood flow. Our research is a first step in this direction. The biggest challenge here is to move from volumetric scans showing a 3D anatomy of the body, to projection X-ray images that are acquired by interventional machines. We have proposed novel solutions that calculate an estimated volumetric blood flow from 2D projection images only. Interventional 3D imaging is possible, but not performed as standard due to its increased radiation dose. If applied, however, our method for calculating the true volumetric blood flow is more accurate.

What are some of the additional challenges to measuring blood flow elsewhere in the body compared to in the brain?

The cerebrovascular region is hardly affected by any sort of motion. Breathing as well as organ specific motion is not present in this anatomical area and patient motion such as moving of the head can easily be detected by imaging systems. The cardiovascular region, however, is subject to various motion types such as breathing motion, heartbeat, and motion by the gastrointestinal tract. These motion types are very specific and may divert from their known pattern due to disease and patient stress. Algorithms that have been invented for the cerebrovascular region are not easily transferable to other anatomical regions of the human body without further research to solve the above-mentioned challenges.

How do you envisage computer-assisted methods moving forward over the next five to ten years?

Over the upcoming decade, computers in clinics will transform from bulky machines towards smart, invisible systems that are embedded within each single clinic device ranging from a simple patient bed to a single lamp within the OR unit. Clinics will be equipped with such smart devices allowing for disease- and treatment-specific assistance portfolios depending on the application scenario they are placed within.

Detail

RESEARCH OBJECTIVES

Dr Demirci's work aims to provide quantitative methods of measuring personalised blood flow from interventional images. Her current research focuses largely on biomedical imaging and image processing.

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BIO

Dr Stefanie Demirci received her PhD from the Technical University of Munich in 2011 for her work on novel approaches to computer assisted endovascular procedures. She is currently co-managing the Computer Aided Medical Procedures (CAMP) lab focusing on biomedical imaging, image processing and biomedical gamification.

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