Advanced Techniques for Studying Blood Flow

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Editorial

Impaired vascular function is known to play a role in both cardiovascular and non-vascular diseases (e.g., Alzheimer's disease). Therefore, methods for assessing vascular function are becoming increasingly important in many diseases for the diagnosis, monitoring, and prevention of further complications. However, it is evident that visualizing the presence of vessels alone is not sufficient; instead, vascular imaging must provide information on vascular function (i.e., blood flow). Detecting blood flow, however, can be difficult, depending on the specific organ, tissue, or area of interest. The detection of blood flow often requires the signal to first penetrate through more superficial tissues, such as bone in the case of the cerebral vasculature. The imaging also needs to be performed at a resolution suitable for the specific task. For example, low-resolution techniques can provide global perfusion values, but higher resolution is needed for monitoring specific vessels or understanding perfusion changes in relation to the vascular structure. Numerous technologies have been developed that overcome these difficulties to successfully measure vascular function. The articles in this methods collection each present a unique and innovative vascular imaging technique that evaluates blood flow and/or the delivery of oxygen to specific organs, tissues, or regions of interest.

In the first article, Tang and Kim[1] use laser Doppler imaging, a common clinical technique, to evaluate global perfusion within the mouse footpad in a model of hindlimb ischemia. While the technique does not enable the visualization of the underlying vascular structure, their study elegantly demonstrates that high-resolution imaging is not always practical or necessary to acquire valuable functional information. The main limitation of laser Doppler imaging is the relatively shallow scan depth, but the technique enables the tracking of peripheral perfusion within the limbs or digits. It can also be adapted for use in more focal regions (e.g., to examine wound healing or determine burn severity).

Hage et al.[2] demonstrate that an alternative to functional MRI, functional transcranial Doppler ultrasound, can measure brain function in real time. They illustrate how to locate and image the middle cerebral artery by positioning the ultrasound probe both manually and with a fixation device. By limiting the imaging to only this single vessel, they acquire high-resolution temporal blood velocity measurements rather than a spatial image of the vessel. Since the middle cerebral artery supplies the majority of the cerebral hemisphere, the time course of the blood flow can be used to estimate neural activation. The technique has widespread applications for monitoring brain function during a variety of conditions (e.g., during breath holds or surgery) or other activities (e.g., exercise).

Baranger et al.[3] introduce ultrafast Doppler imaging. This technique represents an advancement in ultrasound imaging technology that increases the image frame rate (up to 10,000 Hz) and spatial resolution (down to 50 µm). This technique enables the creation of a Doppler-based flow map of the entire field of view, thus providing information on both the blood flow velocity and vascular structure in a single image. The technique can also be adapted for imaging at depths of 15–20 cm, although this requires downscaling the spatial resolution to 1 mm. Ultrafast Doppler imaging obtains single frames quickly enough to image the blood flow within moving organs, such as the heart. The principal drawback of this technique is that most ultrafast ultrasound scanners only provide 2D images.

Granja et al.[4] introduce another new technology—multispectral optoacoustic tomography. Optoacoustics combines optical imaging with ultrasound; the tissues are excited with visible to near-infrared laser pulses, which generate thermoelastic expansions that are detected as acoustic signals by an ultrasound transducer. Different wavelengths invoke different responses from different tissues; by tuning to specific wavelengths, this technique detects and differentiates signals from both oxygenated and deoxygenated hemoglobin and builds a map of the vascular structure. While this modality does not provide any information on blood flow, it enables a unique, and arguably more direct, readout of vascular function—the oxygenation status of the blood as it flows through a tissue. While the technique is limited to surface scans (up to a depth of 15 mm) and small volumes (15 mm^3), it has great potential for monitoring ischemia.

Phase-contrast MRI is commonly used to quantify blood flow in adults, but Goolaub et al.[5] demonstrate how this technique can be adapted to obtain fetal blood flow measurements. Specifically, they combine motion correction, accelerated imaging, and an alternative method of cardiac gating to enable the imaging of the major fetal vessels (i.e., the aorta, ductus arteriosus, main pulmonary artery, and superior vena cava). Through these advancements, they obtain both vascular anatomy and blood flow information in fetuses within the third trimester. This imaging provides critical monitoring of fetal health and can detect changes in fetal blood flow that indicate serious fetal pathologies, such as congenital heart defects and fetal growth restriction.

Together, the methods included in this methods collection represent a diverse array of imaging technologies that all enable the quantification of vascular function. These techniques encompass varying organs and tissues of interest, and each can be extended to numerous disease applications, including in both clinical and pre-clinical settings. Imaging technologies are constantly improving, being modified for new uses, and being adapted for specific needs. We anticipate that this methods collection will help vascular and imaging specialists alike to understand the fast-paced advancements in the monitoring of vascular function.

Disclosures

The authors have no conflicts to disclose.

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