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MICROVASCULAR IMAGING - AN ADVANCED DOPPLER TECHNOLOGY

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Abstract

Microvascular imaging (MVI) is an advanced Doppler ultrasound technique that enhances the visualization of micro vessels without contrast agents. Unlike traditional Doppler methods that may struggle with slow or complex flows in small vessels, MVI employs intelligent algorithms to separate low-flow signals from tissue motion artifacts, preserving data and providing high-resolution images. This technology has broad clinical applications, including the characterization of liver lesions. By allowing clinicians to see minute vessels and low-velocity flows at high frame rates, MVI improves diagnostic accuracy and treatment monitoring. Its non-invasive nature and detailed vascular insights make it a valuable tool in modern medicine, showcasing the ongoing innovation in medical imaging and the potential to enhance patient outcomes through better diagnostic capabilities.

Introduction

Ultrasound is a widely used and effective diagnostic imaging modality for various conditions, including soft tissues and vascular structures and flow [1]. It has a great safety profile, making it highly significant [2]. Doppler ultrasound has been the cornerstone of non-invasive vascular diagnostic imaging for years, enabling the detection and evaluation of blood flow within the body's vessels [3]. However, conventional Doppler methods, including colour and power Doppler, have their restrictions, specifically in detecting slow and complex flows in microvessels [4]. This is where Microvascular Imaging technology represents a significant leap in diagnostic abilities [5].

Basics of Ultrasound and Doppler

Ultrasound waves are longitudinal sound waves with a frequency higher than 20 kHz, which is beyond what a human ear can hear [6]. Ultrasound for diagnostic purposes comprises complex physical principles and sophisticated instrumentation [7]. Ultrasound has several characteristics that contribute to its diagnostic effectiveness. The ultrasound waves can be directed as a beam and focused. Passing through a medium, it obeys the laws of reflection and refraction. Finally, targets of comparatively smaller size reflect ultrasound and are therefore detected and visualized [8]. The Doppler Effect is a change in the perceived frequency of sound emitted by a moving source [9]. This phenomenon was described by Christian Doppler in 1843. The Doppler Effect can be used to study the flow of blood and provides the operator with three sets of information:

- Presence/absence of flow
- Direction of blood flow
- Velocity of blood flow

The transducer serves as both a sender and receiver in Doppler ultrasound. When studying blood flow, the transducer detects returning echoes, which are then processed by the machine to identify frequency shifts by comparing them to the transmitted signals [10]. The frequency shift observed depends on the magnitude and direction of blood flow [11]. Colour Doppler technology is designed to generate real-time images of flow throughout an entire area, enabling the visualization of blood vessels and their characteristics [12]. A colour map indicating movement is overlaid on the Pulse Echo image. This technology finds numerous applications, particularly in visualizing blood flow and cardiac muscle to a

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significant extent. Clinical uses of colour Doppler include assessing carotid arteries, cardiac arteries, peripheral arteries and veins, investigating deep vessels in the abdomen and pelvis, and examining blood flow in the foetus.

Power Doppler revolutionized radiology by enhancing the capabilities of colour Doppler, incorporating strength or power alongside velocity and direction [6]. Developed in 1993 by Rubin and Adler, Power Doppler encodes the intensity or power of signals along with changes over time in specific areas of interest. Unlike colour Doppler, which sacrifices certain aspects of Spectral Doppler to generate a 2D map of signals within a region, Power Doppler provides real-time information on signal intensity and temporal changes [7].

Contrast-enhanced ultrasound (CEUS) plays a crucial role in visualizing microvessels within tumors, aiding in perfusion assessment for improved diagnostic accuracy [8]. However, its utilization may be limited due to invasiveness and cost constraints [9]. The development of Microvascular Imaging technology stemmed from challenges in accurately assessing blood flow, particularly low-velocity flow, using conventional Doppler ultrasound techniques [10]. Colour Doppler and Power Doppler are commonly used but may struggle to differentiate motion artifacts from actual blood flow [11]. While Contrast-Enhanced Ultrasound can identify microvessels with reduced flow, its use may be restricted due to invasiveness, lack of contrast media availability in emergencies, and higher costs [12]. Additionally, these techniques may encounter limitations such as poor signal-to-noise ratio, angle and depth dependency, among others.

Microvascular Imaging

Microvascular Imaging Technology can detect slow flow in microvessels without using contrast media [5]. It utilizes a new adaptive algorithm to analyze motion-related artifacts, separate signals from multiple flows, and achieve higher frame rates, improved resolution, and sensitivity with reduced motion artifacts compared to conventional Doppler techniques [6]. This technology facilitates the diagnosis of minute vessels when evaluating lesions, cysts, inflammatory diseases, and tumors [7].

Principle: Colour and Power Doppler remove clutter by suppressing low-velocity components [8]. Because of this suppression, there is a loss of data followed by a loss of visibility in smaller vessels. Microvascular Imaging Technology has a powerful and smart algorithm [9]. This algorithm, instead of suppressing low flow signals, separates these flow signals from superimposing tissue motion artefacts, thereby preserving low-flow components and providing good detail [10]. They analyze clutter motion with the help of an adaptive algorithm to categorize and eliminate tissue motion artefacts, thus providing images of good quality [11]. The images produced are of very high resolution where minute vessels can be demonstrated, showing low-velocity flow. The whole process is done at high frame rates, which is not feasible in any other Doppler Technology [12].
Modes

- **Monochrome Mode**: By removing background information, monochrome mode enhances the vascular system's sensitivity and produces a grayscale image as the end product.
- **Colour Coded Mode**: It simultaneously demonstrates the flow and grayscale data with high temporal resolution and spatial resolution.
- **3D Mode**: The vascular structure and branching of vessels can be visualized.

Structure

The vascular index, a quantitative metric that represents the proportion of coloured pixels relative to all pixels in a region of interest, can be computed thanks to Microvascular Imaging Technology [5]. By designating a region of interest, it can be computed using a specific ultrasound device application. Microvascular Imaging Technology has been developed by different vendors and integrated into ultrasound equipment for clinical use, as shown in Table 1.

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Table 1: Commercial Names of Microvascular Imaging Technology by Different Vendors

Technology	**Vendor**
Microflow Imaging	Philips Healthcare
Microvascular Imaging	GE Healthcare
Microvascular Flow Imaging	Samsung Medison Co
Superb Microvascular Imaging	Canon Medical System

Clinical Applications

- **Obstetrics**: Microvascular Imaging can show the filling of ventricles and the ventricular outflow tracts in early pregnancy, aiding in fetal heart assessment in the first trimester with precise visualization of the interventricular septum, aorta, and pulmonary arteries [6].
- **MSK**: Helps detect low-grade inflammation where minimal flow is undetectable by power Doppler [7].
- **Sports Imaging**: Helps in staging the progression of tendinosis [8].
- **Cardiovascular Imaging**: Detects neovascularization inside chronic or calcified carotid plaques, which may cause plaque hemorrhage and rupture [9].
- **Liver**: Highly sensitive in differentiating focal liver lesions by detecting small vessels and slow blood flow [10].
- **Breast Imaging**: Provides detailed microvascular information, surpassing Colour Doppler Flow Imaging in sensitivity [11].
- **Kidney**: Helps in the differential diagnosis of renal lesions, acute pyelonephritis, and evaluation of renal function by showing cortical flow and vascular index correlated with Chronic Kidney Disease [12].
- **Gynaecological**: Improves vascularization assessment in ovarian pre-treatment and uterine fibroids [6].
- **Staging of Malignancies**: Identifies microvessels involved in tumor development, aiding in diagnosing and staging malignant tumors [7].

Conclusion

Microvascular Imaging Technology is an innovative ultrasound technology that offers enhanced vascular visualization, surpassing the capabilities of Power or Colour Doppler. This non-contrast method is highly sensitive in detecting micro blood vessels and holds considerable clinical potential, potentially reducing reliance on Contrast-Enhanced Ultrasound. Recent advancements have significantly impacted diagnostic approaches related to thyroid, breast, liver, and kidney conditions. However, further research is essential to fully harness this technology's potential and optimize its utilization in clinical settings.

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