Technical White Paper

Ultra Micro Angiography

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UMA: Microvascular Imaging Technology Focusing on Low-Velocity Flow

Preface

Color Doppler Flow Imaging (CDFI), as a non-invasive real-time flow imaging technique, displays the real-time vascular pattern in human blood vessels and provides clinicians with information on hemodynamics. Since its emergence in 1985[1], CDFI has been widely used and is currently the most important method to display the blood flow status and provide navigation for spectral Doppler sampling in clinical diagnosis.

Challenges to CDFI

However, the vascular diameter and blood flow velocity vary widely among the aorta, branches at all levels, and terminal microcirculation. For example, the flow velocity in the capillary is only 1/800 of that is in the aorta[2]. Compared with medium and large vessels, the blood flow in the microvessels has weaker scattering intensity and lower velocity, which is easily overwhelmed by tissue clutter. Limited by the real-time imaging requirements and the data processing capability of the ultrasound system, the traditional CDFI technology fails to display the microvascular structure and microcirculation vascular bed.

Contrast Enhanced Ultrasound (CEUS) has inherent advantages in detecting low-velocity blood flows. However, CEUS requires intravenous injection of contrast agents, and can only display microvascular perfusion in early arterial stages. Users cease to observe the microvascular network shortly after tissue background enhancement, and CEUS cannot guide spectral doppler to measure the blood flow velocity in real-time.

UMA: Focusing on Low-Velocity Microvascular Blood Flow

Ultra Micro Angiography (UMA) is a brand-new ultrasound microvascular real-time imaging technology established on the Mindray Resona R9 ultrasound imaging platform. Benefitting from the industry-leading beamforming computing power and powerful CPU/GPU processing performance of the Resona R9 platform, UMA acquires high-quality raw ultrasonic signals through the ultrasonic plane wave/divergent wave (hereinafter referred as plane wave) at high efficiency and utilizes an advanced tissue-rejection algorithm to intelligently remove tissue clutter from raw signals. These two core techniques allow UMA to break through the technical bottleneck of traditional CDFI, that greatly improves the sensitivity and spatial resolution of blood flow detection, and visualizes microvascular architecture undetectable by traditional CDFI.

Introduction to UMA

The high sensitivity and high spatial resolution of UMA come from two core technological innovations: high frame rate plane wave imaging technique and adaptive spatiotemporal tissue-rejection filtering technique.

High Frame Rate Plane Wave Imaging

Traditional ultrasound imaging generates images by multiple transmissions, with each insonifying only a small field of view. Whereas, a full-field-of-view image can be obtained by a single transmission with plane wave imaging technique, resulting a substantially increased frame rate.

However, the beamforming computation load of a single transmission in plane wave imaging is much higher than that of the traditional focused wave scanning, as shown in Figure 1 below. Thanks to the Resona R9 platform, UMA is able to construct the final ultrasonic image from a single transmission in time with a super-fast receive beamformer.

Coherence synthetic summation of ultrasonic images acquired with several tilted plane waves can effectively improve the image quality of plane wave imaging. Through coherent plane wave compounding, the optimal image quality (comparable to focused wave imaging in terms of signal-to-noise ratio, lateral resolution, and contrast resolution) can be achieved using a small number of plane wave transmissions while preserving high frame rates [3].

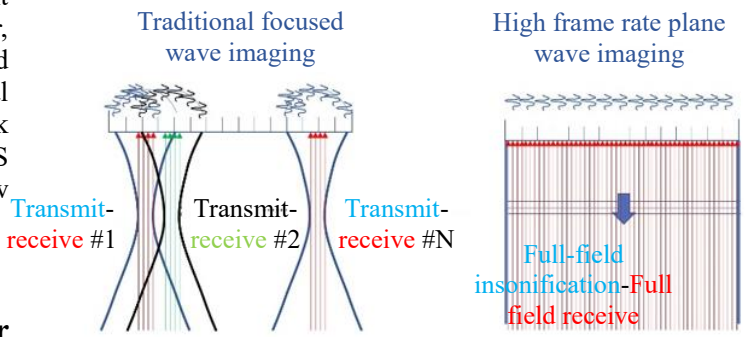


Figure 1 Comparison between focused wave imaging and plane wave imaging. Plane wave imaging obtains the whole image with much less transmissions compared with focused wave imaging. Since a single transmission insonifies a very large field of view, plane wave imaging requires super-fast receive beamformer.

In CDFI, flow velocity estimation relies on the N (commonly referred as the ensemble length) transmit pulses sent at a fixed pulse repetition interval (PRI) to estimate the Doppler frequency. A higher flow velocity requires a shorter PRI to avoid aliasing. Limited by the small insonified area of focused wave, a spatial interleaved scan strategy is applied in CDFI. The whole region of interest (ROI) is subdivided into several segments (three segments in this case) and the color scanning are done sequentially line-by-line for all segments as illustrated in the CDFI case of Figure 2. Whereas UMA uses ultra-broad beams of plane wave for Doppler signal acquisition. This technology obtains raw signals of the entire ROI with one single transmission, instead of the multiple transmissions sweeping along the scan line direction, which greatly increases the Doppler signal acquisition rate.

As shown in Figure 2, UMA reaches an ensemble length (N) 3-times longer than CDFI within the same acquisition time.

(The increase will be even higher when the lateral size of ROI increases.) A longer ensemble length results a higher blood flow sensitivity. Moreover, UMA adopts the coherent plane wave compounding technology, which further improves the signal-to-noise ratio and spatial resolution of raw ultrasonic signals. (The UMA case in Figure 2 shows coherent compounding with three tilted plane wave transmissions. A lower blood flow velocity indicates a longer PRI, which allows more coherence compounding.)

In addition, UMA obtains the two-dimensional spatial blood flow signals simultaneously rather than breaking the ROI into several segments and illuminating different segments alternatively in CDFI. As a result, UMA displays a smoother vascular pattern.

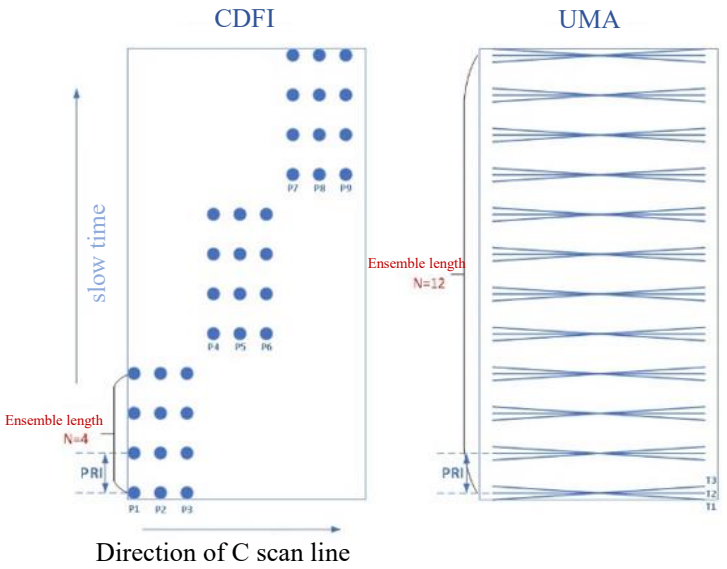


Figure 2 Comparison between CDFI and UMA. P1 to P9 represent different transmission positions in the direction of the C scan line. (In this case, focused wave of CDFI requires a total of nine different transmission positions to cover the entire ROI). T1 to T3 represent different tilted plane wave transmissions. (A single plane wave transmission can cover the entire ROI. In this case, three transmissions at different angles are combined to improve the signal-to-noise ratio and spatial resolution).

Adaptive Spatiotemporal Wall Filter Algorithm

Generally, Infinite Impulse Response (IIR) or Finite Impulse Response (FIR) high pass filter is used to suppress clutter signals originating from tissue motion in traditional Doppler flow imaging. This clutter filtering method is based on the underlying assumption that tissue signal and blood flow signal have completely different spectral characteristics: tissue motion is very slow whereas blood flow moves fast, meaning that demodulated tissue signal and blood signal have non-overlapping spectra centered on the zero frequency and the Doppler frequency respectively [4][5]. But it encounters difficulties in the case of slow blood flows or fast-moving tissue where both spectra overlap.

Compared with the above-mentioned traditional filtering method which operates only on the temporal dimension , UMA adopts an advanced tissue-rejection algorithm to effectively distinguish slow blood flow signals from tissue motion signals by the use of both temporal and spatial information of the signals (as shown in Figure 3). Combined high quality raw signals acquired by plane wave with the advanced spatiotemporal tissue-rejection algorithm, UMA significantly improves the sensitivity of low-velocity blood flow. This advanced filtering algorithm delivers satisfying results even when tissue moves faster than blood flow. The excellent performance of the advanced filter comes from a much greater computation load than traditional methods. The powerful CPU and GPU processing performance of the Resona R9 platform makes real-time imaging possible.

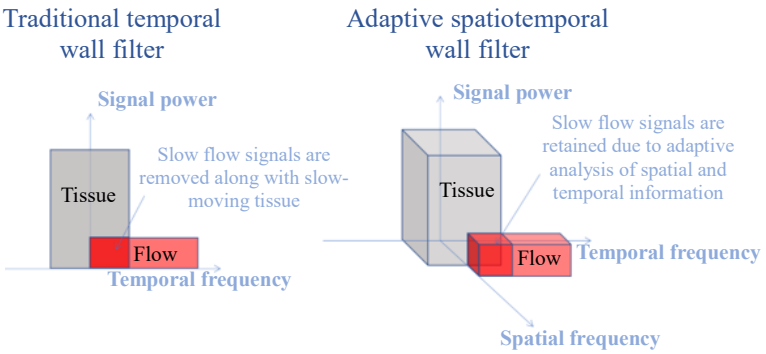


Figure 3 Comparison between traditional temporal wall filter and adaptive spatiotemporal wall filter

Technical Characteristics of UMA

Benefitting from the above-mentioned core technologies, UMA has significantly improved spatial resolution and sensitivity of Doppler imaging with a relatively low scale focused on slow flow detection , without compromising other imaging performances (as shown in Figure 4).

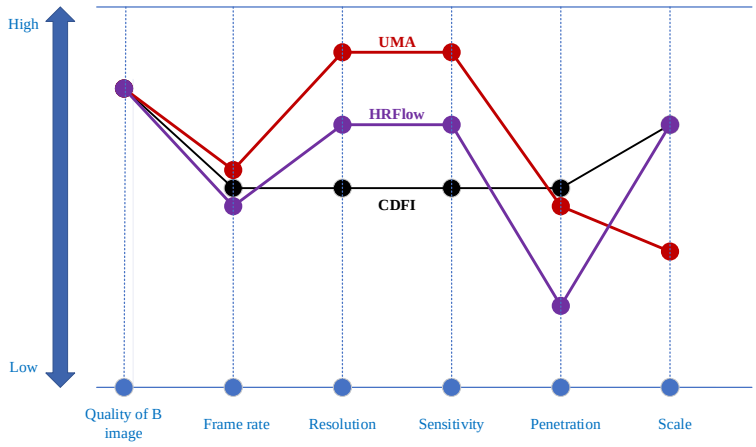


Figure 4 Performance of UMA and other traditional Doppler imaging modes.

The UMA technology implemented on the Resona R9 platform displays both tissue B image and blood flow image within the ROI in real time. The B imaging adopts both the coherent transmit synthesis strategy provided by the Zone Sonography Technology (ZST) platform and spatial compounding strategies to maintain the high quality of background tissue image. The blood flow imaging adopts the coherent plane wave compounding technology, which offers high acquisition rate without compromising the quality of blood flow signals. Also, its advanced adaptive spatiotemporal wall filter greatly improves the sensitivity of low-velocity blood flow. Despite the fact that the advanced wall filter processes raw ultrasonic data 10 times more than the traditional wall filter, the powerful performance of the Resona R9 platform enables UMA to achieve comparable frame rates

to conventional Doppler flow imaging.

UMA is available in three sub-modes (as shown in Figure 5): cUMA, pUMA, and sUMA.

- Color UMA (cUMA) demonstrates the velocity (including magnitude and direction information) of microvascular blood flow.
- Power UMA (pUMA) demonstrates the power intensity of microvascular blood flow, with option to simultaneously show the flow direction.
- Subtraction UMA (sUMA) demonstrates the power intensity of microvascular blood flow with higher sensitivity. With background signal subtraction (manually adjustable), users are able to observe microvascular blood flow in detail.

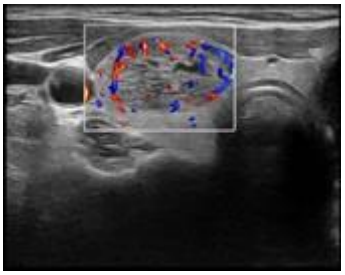


Figure 5(a)

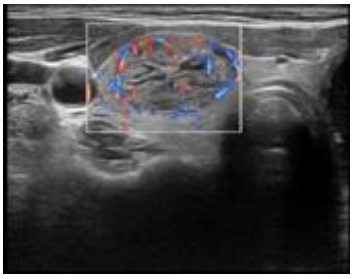


Figure 5(b)

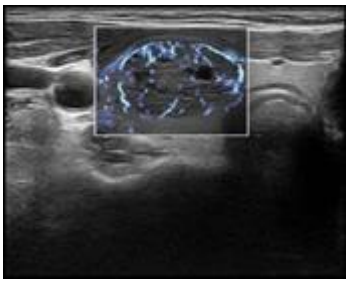


Figure 5(c)

Figure 5 UMA image of thyroid nodule. 5(a) is the cUMA image mode, which shows the velocity magnitude and direction of blood flow; 5(b) is the pUMA image mode, which shows both the power intensity and the direction of blood flow with a directional power map. 5(c) is the sUMA image mode, which shows the power of blood flow with higher sensitivity. As the intensity of the background tissue image is suppressed, sUMA displays more details of abundant microvascular blood flow.

Based on the diversified microvascular blood flow display mode, Resona R9 also provides a semi-quantitative measurement tool compatible with UMA: Color Pixel Percentage (CPP). This measurement tool allows users to customize the area of interest, automatically calculates the ratio of blood flow pixels to total pixels within the area of interest, and quantifies the detectability of micro blood flow.

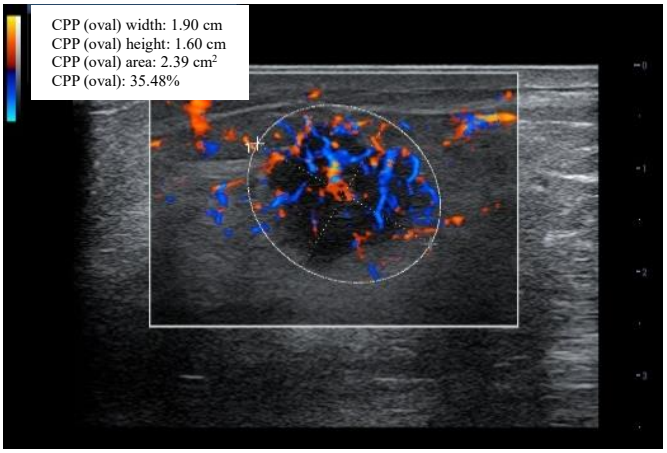


Figure 6(a)

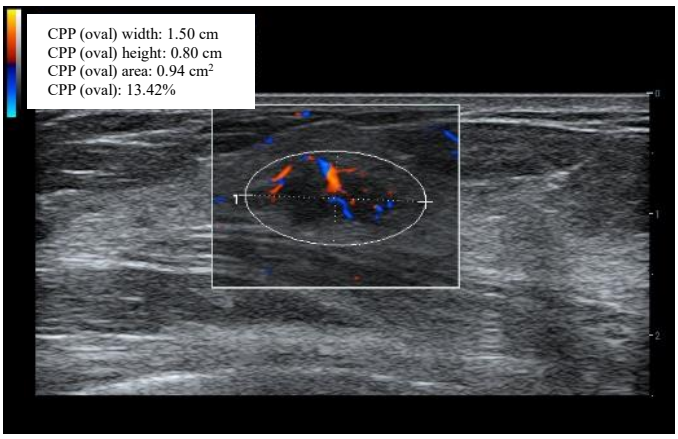


Figure 6(b)

Figure 6 CPP of blood flow of breast lesion. Figures 6(a) and 6(b) show the UMA images of two different breast lesions. CPP is activated on each blood flow image to draw an area of interest matching the lesion. The results show the ratio of the number of blood flow pixels to the total number of pixels in the area of interest. The visible blood flows in the lesion in Figure 6(a) are more abundant than those in Figure 6(b). Correspondingly, the CPP value (35.48%) in Figure 6(a) is larger than that is in Figure 6(b) (CPP value 13.42%).

Clinical Values of UMA

UMA breaks through the sensitivity bottleneck of CDFI, and displays a more detailed microvascular image. It provides clinicians with more comprehensive blood flow information for diagnosis in many fields.

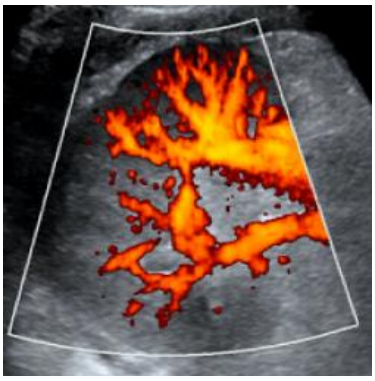
- When being applied to small organs (thyroid, breast, testis, submandibular gland and other glands, and superficial lymph node), UMA has great value in the identification and diagnosis of tumors. UMA provides important information for identification and diagnosis of benign and malignant tumors in superficial soft tissues [7]. As for the application of carotid plaque, UMA could also be employed in plaque vulnerability assessment by observing neovascularity of arterial plaques.
- As for the musculoskeletal disease, UMA helps doctors observe the blood supply to the tendon, ligament and soft tissue injuries, inflammation or other lesions more clearly. UMA displays a more comprehensive microvascular structure in keloids than CDFI, providing valuable information for assessment of keloids activity [6]. Preliminary clinical study shows that UMA displays better blood flow information in soft tissues such as the

joint synovial cells. The typical blood flow characteristics provided by UMA are likely to be associated with the severity of the rheumatoid arthritis [8], which is able to evaluate the treatment efficacy.

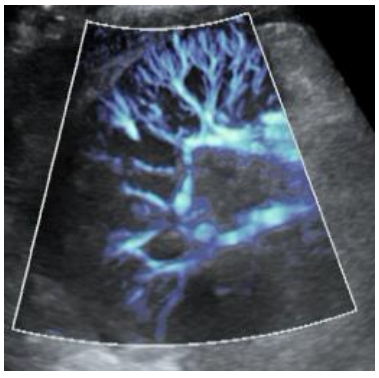
- When being applied to abdominal parenchyma and hollow organs, UMA visualizes the detailed microvascular structures such as arcuate arteries in kidney and interlobular arteries, providing valuable information for clinicians to evaluate the progression of acute and chronic kidney diseases or the risk of rejection after transplantation. In the case of liver, spleen, pancreas or other organs, the detection of micro blood flow may help to evaluate its functional status or treatment efficacy and diagnose inflammatory lesions and tumors. UMA shows great potential in identification/diagnosis/evaluation of gallbladder lesions, the Crohn's disease and gastric tumors.
- When being applied to pelvic organs, UMA is valuable in the evaluation of inflammation and identification/ diagnosis of tumors in prostate, and also the identification, diagnosis, and typing of low rectal tumors.

Cases of UMA

Case 1: Transplant kidney



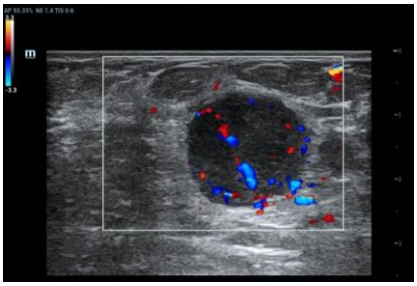
Traditional CDFI



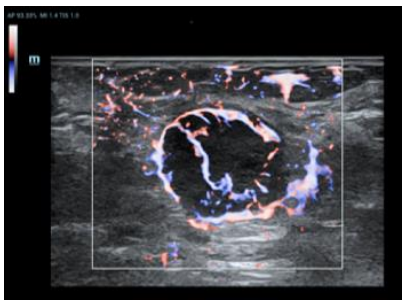
sUMA

Figure 7 Kidney blood flow in the case of transplanted kidney. UMA performs higher spatial resolution and blood flow sensitivity than traditional Doppler flow imaging. It can display not only relatively large vessels, such as renal arteries, sectional arteries, and apical arteries, but also smaller arcuate arteries and interlobular arteries, allowing clinicians to better observe the blood supply of peripheral vessels in the kidney.

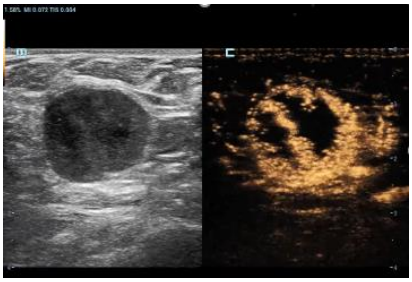
Case 2: Breast nodule



Traditional CDFI



sUMA

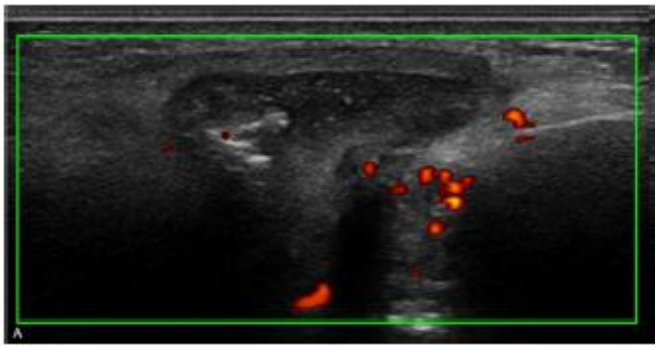


Contrast-enhanced image in the arterial phase

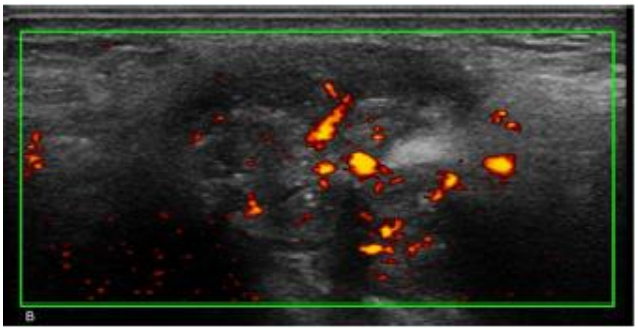
Figure 8 Blood flow and contrast-enhanced images of breast nodule. UMA shows the peripheral and internal vascularity of the lesion that are undetected by conventional flow imaging. The image generated by UMA is consistent with the Contrast-enhanced image in the arterial phase, as the same vascular pattern is observed.

Case 3: Rheumatoid arthritis

So far, relevant clinical researches have shown that Mindray's UMA technology has potential clinical value in evaluating rheumatoid arthritis [8]. This study applied ultrasound scan to a total of 364 joints (including metacarpophalangeal joints, proximal interphalangeal joints, metatarsophalangeal joints, and wrist joints) of 52 patients with rheumatoid arthritis. Data analysis has shown that UMA presents higher detection rate of synovial blood flow signals within the inflamed regions than CDFI. (The detection rate of CDFI is 18.68%, whereas the detection rate of UMA is 25.55%.) In addition, UMA can reveal the penetrating vessels on the surface of eroded bones, which was related to severe disease activity.



Traditional CDFI



pUMA

Figure 9 Blood flow imaging of the metatarsophalangeal joint in a case of rheumatoid arthritis. UMA shows more blood flow signals representing angiogenesis within the thickened synovium than traditional Doppler flow imaging, which helps clinicians in disease evaluation of rheumatoid arthritis.

Conclusion

Mindray's UMA technology is a real-time microvascular imaging technology focusing on the detection of low-velocity blood flow with vastly improved sensitivity and spatial resolution. Built on the Resona R9 platform with industry-leading beamforming capability and powerful GPU/CPU processing performance, UMA combines the abundant high-quality raw ultrasonic signals acquired by plane wave with the excellent tissue rejection performance provided by the adaptive spatiotemporal filtering algorithm , thus achieving better detection of low-velocity flow and depicting of microvascular morphologies.

Preliminary clinical validation demonstrates that UMA reveals the microvascular structure that is undetected by traditional Doppler flow imaging. It overcomes the disadvantage of traditional Doppler flow imaging in low-velocity blood flow detection and provides clinicians with more comprehensive blood flow information. In the future, more thorough clinical researches will further explore the diagnostic values of UMA in various fields. We hope that, by the introduction of this new technology, early and accurate visualization of abnormal blood flow in micro-vasculature will be feasible, which will be beneficial to the diagnosis and treatment of various diseases.

Acknowledgment

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References

[1] C. Kasai et al, Real-time two-dimensional blood flow imaging using an autocorrelation technique, IEEE Trans. Sonics and Ultrasonics, vol. SU-32, no. 3, May 1985

[2] Laurence E. Morehouse and Augustus T.Miller, Physiology of Exercise.

[3] Montaldo G, Tanter M, Bercoff J, et al. Coherent plane-wave compounding for very high frame rate ultrasonography and transient elastography. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 2009,56(3):489-506.

[4] J. C. Willemetz, A. Nowicki, J. J. Meister, F. De Palma, and G. Pante, Bias and variance in the estimate of the Doppler frequency induced by a wall motion filter, Ultrason. Imag., vol. 11, no. 3, pp. 215–225, Jul. 1989.

[5] C. Tysoe and D. H. Evans, Bias in mean frequency estimation of Doppler signals due to wall clutter filters, Ultrasound Med. Biol., vol. 21, no. 5, pp. 671–677, 1995.

[6] Cheng Chen, Sirui Liu, Chengyang Zhao, et al. Activity of keloids evaluated by multimodal photoacoustic/ultrasonic imaging system, Photoacoustics 24(2021) 100302

[7] 陈涛, 超微血流成像技术（UMA）在肌骨疾病中应用探讨, 中华医学会全国会议大会报告，Aug. 2019

[8] Chenyang Zhao, Qian wang, Ming Wang, et al. Ultra-microangiography in evaluating the disease activity of rheumatoid arthritis and enhancing the efficacy of ultrasonography: A preliminary study, European Journal of Radiology 137(2021) 109567

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