JASA REFLECTIONS

The *Reflections* series takes a look back on historical articles from *The Journal of the Acoustical Society of America* that have had a significant impact on the science and practice of acoustics.

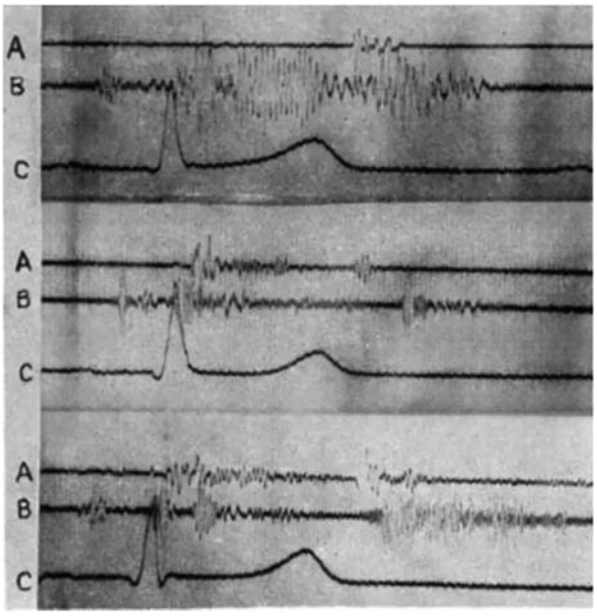
# Heart heard in motion

**Article:** Ultrasonic Doppler method for the inspection of cardiac functions
**Author:** Shigeo Satomura
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## ARTICLE OVERVIEW

In 1957, Shigeo Satomura from Osaka University published a pioneering study in the *Journal of the Acoustical Society of America* introducing continuous-wave (CW) Doppler ultrasound for transthoracic cardiac assessment.[1] This work followed the early pulse-echo investigations of cardiac motion performed in the mid-1950s by Inge Edler and Carl Hellmuth Hertz at Lund University,[2] which laid the foundations of M-mode echocardiography. While the Lund group quantified myocardial displacements by measuring the time-of-flight of reflected pulses, Satomura focused instead on the kinematic dimension by applying the Doppler principle to ultrasound. He insonified the heart with a continuous 3-MHz beam and electronically derived the frequency shifts of waves reflected by moving cardiac structures. These Doppler shifts provided direct measurements of the axial velocity components of reflecting targets, whether originating from heart walls or cardiac valves.

Satomura's experimental device used a bespoke transducer design consisting of a central 3-MHz transmitting element surrounded by a concentric ring-shaped receiver. The reflected signal was mixed with the original oscillator signal to produce a beat (Doppler) frequency proportional to the axial velocity of the target. This demodulated signal was subsequently amplified and selectively filtered. Because CW Doppler lacks range (depth) gating, it recorded superposed motion from all structures in the beam. Satomura, therefore, interpreted the Doppler components on the basis of their frequency content to distinguish likely anatomical sources. He isolated low-frequency shifts (below 500 Hz) produced by the relatively slow motion of ventricular and atrial walls and distinguished them from the higher-frequency components (around 1000 Hz) associated with the rapid opening and closure of cardiac valves.




Three time-aligned oscillogram panels. In each panel the traces are: (A) phonocardiogram (heart sound); (B) Doppler trace; (C) electrocardiogram (ECG). For the three panels, the Doppler trace (B) shows, respectively, a low-frequency Doppler component (predominantly myocardial wall motion), a high-frequency Doppler component (valvular motion), and a "Doppler heart noise" (high-frequency vibratory signal). Reprinted with permission from S. Satomura, J. Acoust. Soc. Am. 29, 1181–1185 (1957). © 1957 Acoustical Society of America.

Satomura first identified Doppler signals by listening to them through earphones, then presented his results as oscillograph tracings where these signals were aligned with standard clinical markers. By synchronizing these signals with electrocardiograms (ECG) and phonocardiograms, Satomura timed valvular events, such as mitral valve opening and closure, with a temporal resolution sufficient to document mechanical delays and disease-related alterations in timing relative to the ECG. He described distinct Doppler signatures corresponding to ventricular wall motion, atrial contraction, and valve movements and reported characteristic alterations in heart disease.[3] He also identified so-called "Doppler heart noises," which he attributed to small-amplitude high-frequency vibrations in diseased cardiac walls, undetectable by standard ECG.

## IMPACT OF THE ARTICLE

Satomura's 1957 paper provided one of the earliest and most influential demonstrations of medical application of the Doppler frequency shift, seeding two major diagnostic pathways. Its most immediate impact was the birth of noninvasive hemodynamic assessment. While the JASA paper focused on tissue and valvular motion, Satomura and his collaborators soon extended Doppler to the

study of blood flow. By 1959, he had published on peripheral arterial flow patterns,[4] and together with Ziro Kaneko, developed a transcutaneous Doppler flowmeter,[5,6] termed "ultrasonic blood rheography," capable of qualitatively assessing vascular flow from the skin's surface. These developments occurred in parallel with work in the United States by the Seattle group led by Robert Rushmer and Donald Baker,[7] collectively establishing Doppler ultrasound as a central tool in vascular diagnostics.

The 1957 paper also provided the conceptual groundwork for tissue Doppler imaging. Satomura's core idea of using Doppler frequency shift to measure tissue velocity anticipated later pulsed-wave investigations of myocardial motion.[8,9] Over subsequent decades, these principles were refined through advances in range-gated Doppler, digital signal processing, and imaging technology, culminating in modern color-coded myocardial velocity mapping techniques.[10,11]

The enduring legacy of Satomura's work is particularly evident in the continued clinical relevance of continuous-wave Doppler. Because CW Doppler is not limited by pulse-repetition frequency, it is not subject to the Nyquist aliasing that constrains pulsed-wave Doppler systems. As a result, CW Doppler can accurately measure high axial blood velocities, albeit at the cost of depth localization. Since the 1980s, CW Doppler has, therefore, remained the clinical standard for quantifying high-velocity jets in aortic stenosis and other valvular pathologies.[12] By applying the simplified Bernoulli equation or other fluid-dynamics formulations to CW-derived velocities, clinicians can estimate transvalvular pressure differences and guide therapeutic decision-making.[12,13] In this sense, Satomura's 1957 article bridged anatomical echographic imaging with functional, velocity-based cardiovascular assessment, opening a window onto cardiac and vascular dynamics that continues to define modern cardiology and medical ultrasonics.

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