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EDITORIAL COMMENT

The Shifting Tides of Coronary Blood Flow and Medical Imaging Economics*

Timothy F. Christian, MD, MPA
Cambridge, Massachusetts

There is a tide in the affairs of men.
Which, taken at the flood, leads on to fortune;
Omitted, all the voyage of their life
Is bound in shallows and in miseries.
On such a full sea are we now afloat,
And we must take the current when it serves,
Or lose our ventures.

—William Shakespeare (1)

The well-done paper by Chiribiri et al. (2) in this issue of *iJACC* has 2 signal points of interest: one as it pertains to coronary physiology and the other as it pertains to the changing face of health care. Let us be scientists for the moment and explore the first point first.

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Cardiac magnetic resonance (CMR) imaging has high spatial resolution. Consequently, much in the heart that was beyond scope is now visible. The present study introduces a semiquantitative myocardial perfusion method to aid in the interpretation of stress CMR results by taking advantage of the physiological differences in myocardial blood flow (MBF) between the endocardium and epicardium during hyperemic stress and the spatial resolution of contrast CMR to capture these differences. The measured flow gradient across the ventricular wall correlated moderately well with an independent measure of coronary flow reserve assessed using a pressure-sensor wire within the coronary artery. Importantly, the gradient can be displayed graphically in a user-friendly format, providing some of the first semiquantitative reader aids for this technique (along with another recent article in *iJACC*) (3). The exclusion of patients with congestive heart failure, coronary artery bypass grafting, or prior myocardial infarction are certainly populations where performance of noninvasive testing is crucial. These and the length for processing studies with this algorithm are areas that need to be addressed in the future.

The original theory of coronary flow reserve states that during pharmacologic hyperemia, MBF increases from 1.0 ml/min/g in tissue to 4.0 to 5.0 ml/min/g in territories with normal arteries, and less (1.0 to 3.0 ml/min/g) in zones supplied by obstructed vessels. This concept was largely based on an early O-15 positron emission tomography (PET) study when transmural resolution was less discriminating (4). Perfusion defects generated from pharmacological vasodilation were termed "flow reserve abnormalities," not ischemia, as there was no mismatch of MBF to oxygen demand. Defect MBF was thought to be above resting levels but less than maximal. But there is mounting evidence that this concept should be revised. The results of this CMR study and others (3) suggests that MBF in the subendocardium falls below resting levels in the setting of single-vessel disease during hyperemia, whereas MBF in the subepicardium increases, much like the redistribution of seawater at low tide. This produces the visual transmural gradient reported by Chiribiri et al. (2). Such a scenario is still consistent with the original PET data that spawned the coronary flow reserve concept. For example, if we divide a myocardial

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From the Mossaver-Rahmani Center for Business and Government, Harvard Kennedy School of Government, Harvard University, Cambridge, Massachusetts. Dr. Christian has reported that he has no relationships relevant to the contents of this paper to disclose.

segment into endocardial and epicardial zones at rest and during hyperemia, the following scenario is possible:

$$\begin{aligned}
&\text{MBF at rest:}\\
&\text{endocardial} = 1.0\ \text{ml/min/g}\\
&\text{epicardial} = 1.0\ \text{ml/min/g}\\
&\therefore\ \text{transmural MBF} = 1.0\ \text{ml/min/g}
\end{aligned}$$

$$\begin{aligned}
&\text{MBF at hyperemia:}\\
&\text{endocardial} = 0.7\ \text{ml/min/g}\\
&\text{epicardial} = 2.5\ \text{ml/min/g}\\
&\therefore\ \text{transmural MBF} = 1.6\ \text{ml/min/g}
\end{aligned}$$

Using a technique that can only assess transmural flow, such as single-photon emission computed tomography or early PET, would conclude that MBF increased, whereas the regionality of the process is uncovered with higher-resolution imaging. Dipyridamole echo wall motion abnormalities in single-vessel disease and other fractional flow reserve studies support the concept of true ischemia being produced during hyperemia from a redistribution gradient of flow across the ventricular wall. Defining the mechanism, in the absence of an increase in oxygen demand, opens an intriguing line of possible research.

Despite its inherent superiority in resolution and detail, CMR remains outside the mainstream of imaging for coronary artery disease. In contrast to its dazzling cardiac function and viability sequences, the perfusion sequence is a first-pass affair, low in signal and prone to artifact. The technique takes technical experience to perform and interpret. These problems are reminiscent of nuclear imaging in the era of thallium-201. One approach that worked for nuclear cardiology, in addition to developing new perfusion agents, was the establishment of semiquantitative algorithms that gave a "second read" to the subjective interpretation. These were based on a comparison of the image counts to a normal sex-specific dataset of images, and displayed agreement and discrepancies graphically. These programs grew in sophistication and accuracy, and became standard analysis software packages on most nuclear systems. Such aids allowed for more definitive and standardized reports, and wider acceptance of the modality within clinical medicine. The present study (2) is a significant step toward bringing CMR into mainstream imaging through this approach.

In trying to make CMR more user friendly, one wonders about the fate of high-tech, high-cost imaging. The case of another imaging technology—plasma television—is illustrative. Disruptive innovation in a market is the introduction of a product that performs with a mild loss of quality but with a major drop in marginal cost (5). Flat panel liquid crystal display televisions were such an example, as quality was almost as good as plasma television, but at a fraction of the cost. It is hard to find a plasma screen television these days.

Which brings out the second point: the tide in healthcare reimbursement is about to turn. Imaging will go from a revenue-generating center to a cost center with the introduction of bundled payments and accountable care organizations. Consequently, the system will be looking hard at potential disruptive innovations that can do the job almost as well but at considerably lower cost. Plasma screen producers beware.

Medicine has been a market failure in the classic economic sense, partly due to the highly asymmetric information that has existed between providers and consumers (patients) in terms of evaluating medical tests. By changing to a fixed sum to spend per patient, the role of the consumer will shift from the insured patient to the ordering physician, who has a stake in the final cost. This creates something more akin to a functioning market where the consumer is informed to make choices about the diagnostic product. For coronary artery disease, it seems likely that the pressure will be toward use of coronary angiography as both a diagnostic and therapeutic modality for all but the very low-risk patients in order to minimize cost uncertainty. Although this may not be optimal care, we do not live in optimal times. The challenge for imaging is to stay in the game by being simpler and cost effective in relation to coronary angiography. CMR is in the complicated and expensive category. But by taking advantage of its superior imaging characteristics and comprehensive information, a concerted effort by vendors and investigators to make acquisition and reading more automated, and reducing the cost to competitive levels, it can be that disruptive innovator. For on such a full sea are we now afloat, and we must take the current when it serves, or lose our ventures.

Reprint requests and correspondence: Dr. Timothy F. Christian, Mossaver-Rahmani Center for Business and Government, Harvard Kennedy School of Government, Harvard University, 79 JFK Street, 5 Belfer, Cambridge, Massachusetts 02138. *E-mail: Timothy_christian@hks.harvard.edu.*

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