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the first to show that RIPC under opioid/isoflurane anesthesia provides prognostic benefit for up to 9 years of follow-up in patients undergoing CABG surgery. In fact, a survival benefit persisted for so long after the procedure that the all-cause mortality rate in our control group was comparable to that in a contemporary CABG cohort (5). The survival curves diverged immediately, and this effect persisted, supporting the notion that RIPC attenuates the acute injury.

Our study has limitations. It was a retrospective analysis of a single-center trial that was powered only for the primary endpoint of the area under the curve of troponin I as a surrogate marker for cardioprotection. Due to the retrospective nature of our analysis and the long time between the procedure and follow-up, there were no reliable data on the causes of death, and we therefore report only all-cause mortality.

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REFERENCES

1. Thielmann M, Kottenberg E, Kleinbongard P, et al. Cardioprotective and prognostic effects of remote ischaemic preconditioning in patients undergoing coronary artery bypass surgery: a single-centre randomised, double-blind, controlled trial. Lancet 2013;382:597–604.

2. Heusch G, Rassaf T. Time to give up on cardioprotection? A critical appraisal of clinical studies on ischemic pre-, post-, and remote conditioning. Circ Res 2016;119:676–95.

3. Kottenberg E, Thielmann M, Bergmann L, et al. Protection by remote ischemic preconditioning during coronary artery bypass graft surgery with isoflurane but not propofol—a clinical trial. Acta Anaesthesiol Scand 2012;56:30–8.

4. Zangrillo A, Musu M, Greco T, et al. Additive effect on survival of anaesthetic cardiac protection and remote ischemic preconditioning in cardiac surgery: a Bayesian network meta-analysis of randomized trials. PLoS One 2015;10:e0134264.

5. Adelborg K, Horvath-Puho E, Schmidt M, et al. Thirty-year mortality after coronary artery bypass graft surgery: a Danish nationwide population-based cohort study. Circ Cardiovasc Qual Outcomes 2017;10:e002708.

Functional Contribution of Circumferential Versus Longitudinal Strain

Different Concepts Suggest Conflicting Results

The study by Stokke et al. (1) notes that circumferential strain contributes more than twice as much as longitudinal strain to left ventricular ejection fraction, but previous research has shown that 60% of stroke volume is generated by left ventricular longitudinal function (2). The different interpretations stem from alternative physiological conceptual frameworks and methods. Although at first glance these differences seem to be in conflict, they are both valid and compatible.

Alternative perspectives of cardiac pumping include the ventricular perspective or the reciprocating, integrated atrioventricular (AV) volume perspective. Stokke et al. (1) uses strain as a local, directional, wall-motion measure. Because fiber angle varies continuously from the epicardium to the endocardium (longitudinal to circumferential to longitudinal), a convenient simplification is to express global function in longitudinal or circumferential components. Radial strain and fractional shortening are due to conservation of myocardial mass and longitudinal shortening influenced by wall thickness. Longitudinal and circumferential function must be coupled. Consider a thought experiment of a left ventricle having only longitudinally arranged fibers. Longitudinal contraction (with zero or minimal epicardial inward displacement) alone must generate concentric wall thickening (radial strain). A midwall circumferential line should, due to concentric wall thickening (3), shorten in systole. Thus, there ought to be finite circumferential strain despite the exclusively longitudinally oriented fibers. Hence, circumferential systolic strain cannot be ascribed to a separate "circumferential fiber function" but instead is generated by all fibers having varying orientation, including longitudinally oriented fibers.

The results of Stokke et al. (1) are not in conflict with the higher values attributed to longitudinal function obtained in studies using the reciprocating, integrated AV volume perspective. In this perspective, motion and AV reciprocating volume pumping is viewed from the outside. It does not involve fiber orientation or strain. Longitudinal shortening is described and measured in terms of apically directed AV plane (piston-like) displacement with concomitant atrial filling (2,4,5). The outer (pericardial, all 4 chambers) total heart volume has only a small systolic decrease, corresponding to the radial decrease in epicardial ventricular size; is much smaller than left or right ventricular ejection fraction; and is 8% in humans (5). Longitudinal and radial contribution to stroke volume have been quantitated by measurements of all inflow and outflow to the heart (2,5) and showed a strong correlation between the absolute longitudinal function and the difference of inflow and outflow ($r = 0.92$).

In summary, the seeming difference in the degree of "longitudinal" versus "radial" contribution to left ventricular pumping is resolved by noting the differences between the physiological conceptual frameworks used. When focusing on the contribution of myocardial tissue displacement to pumping, using a geometrical model as in Stokke et al. (1), short-axis function must be dominant (due to Poisson ratio, limited epicardial displacement, and conservation of tissue volume). This approach, however, does not account for the degree by which longitudinal shortening per se through wall thickening contributes to circumferential shortening. When using an integrated whole-heart or AV reciprocating volume approach, longitudinal shortening of the entire ventricle and descent of the AV valve plane causes predominantly systolic atrial filling and concomitantly is the dominant contributor to stroke volume.

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REFERENCES

1. Stokke TM, Hasselberg NE, Smedsrud MK, et al. Geometry as a confounder when assessing ventricular systolic function: comparison between ejection fraction and strain. J Am Coll Cardiol 2017;70:942–54.

2. Carlsson M, Ugander M, Heiberg E, Arheden H. The quantitative relationship between longitudinal and radial function in left, right, and total heart pumping in humans. Am J Physiol Heart Circ Physiol 2007;293:H636–44.

3. Stoylen A. Basic concepts in myocardial strain and strain rate. Available at: http://folk.ntnu.no/stoylen/strainrate/Myocardial_strain#circumferential_strain. Accessed September 20, 2017.

4. Smiseth OA, Thompson CR, Lohavanichbutr K, et al. The pulmonary venous systolic flow pulse—its origin and relationship to left atrial pressure. J Am Coll Cardiol 1999;34:802–9.

5. Carlsson M, Cain P, Holmqvist C, Stahlberg F, Lundback S, Arheden H. Total heart volume variation throughout the cardiac cycle in humans. Am J Physiol Heart Circ Physiol 2004;287:H243–50.

Myocardial Contraction Fraction

A Volumetric Measure of Myocardial Shortening Analogous to Strain

Stokke et al. (1) showed that despite reduced longitudinal and circumferential strain, ejection fraction is maintained by geometric factors, which prompted the editorialists to note, "although strain is emerging as the more optimal marker for LV systolic function, there seems to be no way to replace LVEF at this time, no matter how inaccurate it may be" (2). We would suggest that the myocardial contraction fraction (MCF) (3) fulfills the editorialists' suggestion for indexing left ventricular function to geometric parameters.

MCF, the ratio of stroke volume to myocardial volume, is a volumetric measure of myocardial shortening that is independent of chamber size and geometry, can distinguish physiological from pathological hypertrophy (3), is highly correlated with global longitudinal strain (4), and has shown prognostic significance in a variety of studies with various imaging techniques. As a measure of myocardial shortening, stroke volume is most appropriately assessed relative to the myocardial volume, because it is the myocardium that shortens. MCF is a measure of the amount by which the myocardium contracts during systole relative to total myocardial volume, although the myocardium itself has not undergone a reduction in volume. As with left ventricular ejection fraction, MCF is a unitless ratiometric with normal values similar to ejection fraction, thereby facilitating its clinical adoption.

In a cohort of patients with varying cardiac pathology, MCF, measured with freehand 3-dimensional echocardiography (3), had a very similar relationship to what was reported by Stokke et al. (1) (**Figure 1**), further supporting its potential clinical utility. We respectfully submit that MCF should be explored further to advance our understanding of this seemingly powerful, yet simple, metric.