Evaluation of segmental myocardial work in the left ventricle

Eigil Samset, PhD
[1]GE Healthcare, [2]University of Oslo

Introduction

Left ventricular (LV) function can be quantified with echocardiography by measuring the strain experienced by individual segments during the heart cycle. The resulting strain traces reveal information about global function, dyssynchrony and poorly contracting segments.

Automated Functional Imaging (AFI) employs speckle tracking to allow quantification of LV strain. The tool provides the user with capabilities to track “natural acoustic markers” in the myocardial tissue in any direction within the tracking plane throughout the heart cycle.

GE Healthcare has, through a series of breakthroughs, continued to lead the development of quantitative ultrasound based technologies. Recently a new index to evaluate myocardial work was introduced.

Myocardial Work augments AFI by taking dynamic LV pressure into account. This adds an important dimension to the assessment of LV function and facilitates interpretation of strain traces in relation to LV pressure dynamics.

Stroke work

As the heart is pumping blood into the circulatory system it is performing work on the blood for every beat. This work is often denoted the stroke work. The stroke work can be explained as the area of the pressure-volume loop (Figure 1). The systolic stroke work is the pattern filled area in the figure, which does not include the work performed by the blood on the ventricle during diastole (negative work).

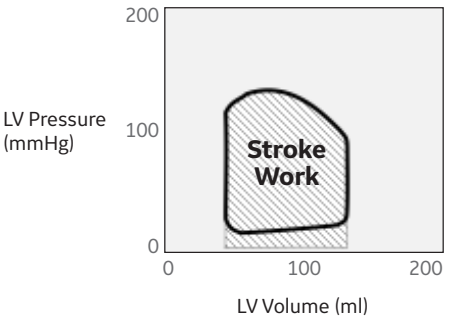

Figure 1. Stroke work, the area of the LV pressure-volume loop. The figure also indicates the systolic stroke work (larger than stroke work as negative work during diastole is not included)

Estimation of LV pressure

Russel et.al.[1] described a simple method that can estimate LV pressure non-invasively based on measurement of cuff pressure and the timing of valvular events. The method was validated in a variety of pathologies (not including severe stenosis and regurgitation). A normalized pressure curve was obtained by pooling invasive pressure measurements from a number of patients with different pathologies, normalized to equal durations of isovolumetric contraction, ejection and isovolumetric relaxation as well as peak pressure. To individualize this normal pressure curve, it is scaled in amplitude with measured systolic cuff pressure and warped in time by aligning valvular event times.

Segmental work

Stroke work, as defined by the pressure-volume area, should be equal to the work performed by the myocardium (when neglecting energy losses), which for each segment can be expressed as the segmental strain – LV pressure area (Figure 2). This simplification provides a surrogate for the work performed by each segment, as LV pressure does not fully explain the force developed by each segment.

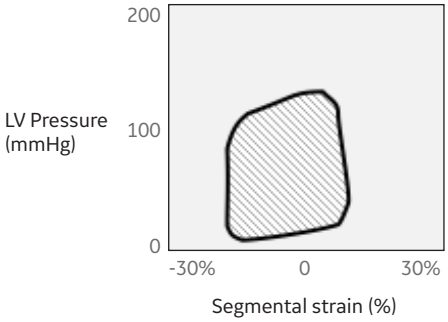

Figure 2. Regional contractile work represented by the area of the strain – pressure loop

Myocardial Work

The Myocardial Work module in AFI asks the user to provide blood pressure and valvular event times as input to the myocardial work estimation. Only the systolic cuff pressure measurement is used in the calculation as an estimate of peak LV pressure. A bull's eye (Figure 3) with the segmental myocardial work values and global values are provided. Work is evaluated from Mitral Valve Closure (MVC) to Mitral Valve Opening (MVO), in other words: mechanical systole including isovolumetric relaxation (IVR).

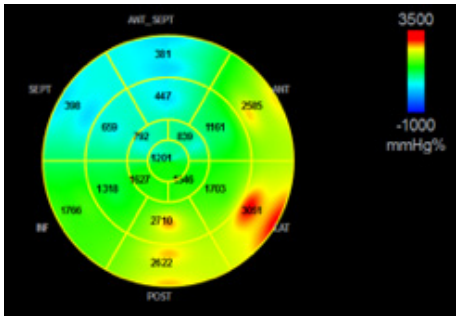

Figure 3. The Myocardial Work bull's eye shows areas of negative work as blue, green indicates normal values while red shows areas of high work.

The global values are calculated as the average of all segmental values.

Along with segmental and global values for myocardial work, a set of additional indices are also provided:

- **Constructive work:** work performed by a segment during shortening in systole adding negative work during lengthening in IVR
- **Wasted work:** negative work performed by a segment during lengthening in systole adding work performed during shortening in IVR
- **Myocardial work efficiency:** constructive work divided by the sum of constructive and wasted work (0-100%) (Figure 4)

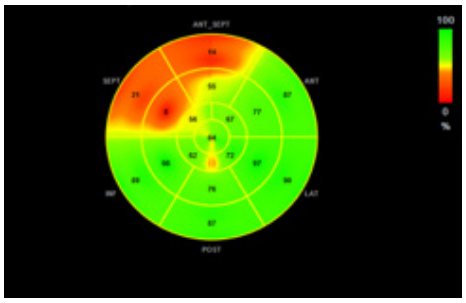

Figure 4. Myocardial Work Efficiency. These values will not be affected by peak LV pressure. 0 Wasted Work will give 100% Myocardial Work efficiency, equal amounts of Wasted and Constructive Work will give 50% Cardiac work efficiency, while 0 Constructive Work will give 0% efficiency.

Myocardial Work values

Assuming normal systolic pressure (120 mmHg) and normal global longitudinal strain (-20%) Myocardial Work will be approximately 2400 mmHg%. With all segments contracting during systole the Myocardial Work Efficiency will be 100%.

An increase in afterload may lead to reduced strain (Boe et al.[2]) while the myocardial work may be preserved or even increased. Myocardial Work can be seen as a less load dependent measure of LV function than mere strain.

In patient follow-up (such as during oncology treatment), the Global myocardial Work Index allows for quantification of global function controlled for systolic blood pressure at the time of each examination. This may be of importance in patients with variable blood pressure from exam to exam.

In dyssynchrony, such as left bundle branch block (LBBB), the septum contracts early (against a low LV pressure) and lengthens as the lateral wall contracts late. This will result in elevated wasted work values in the septum and reduced Myocardial Work Efficiency (possibly below 50% if Wasted work > Constructive work) while the lateral wall will provide a larger contribution to constructive work. This may result in a (partial) clock-wise rotation pattern of the strain-pressure loop, which can be visualized on a per segment basis while comparing to the global loop (Figure 5).

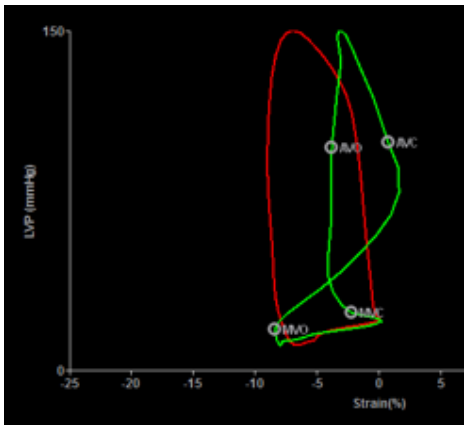

Figure 5. Segmental work, approximated as the area of the strain-pressure loop. The red curve is the global curve for the LV, while the green curve shows the septum contracting early and performing mostly wasted work.

The hallmarks of myocardial infarction, when reading strain traces, are: early systolic lengthening, reduced peak systolic strain, and post-systolic shortening. These hallmarks will all contribute to reduced Myocardial Work Efficiency and reduced Constructive work.

Literature

Early literature on cardiac physiology introduced the concept of pressure-volume loops and stroke work. Regional work, looking at fiber stress, has been studied in-vitro and in-vivo (Delhaas et.al.[3]).

Boe et.al.[2] showed increased sensitivity and specificity in identifying acute coronary occlusion in patients with non-ST-segment elevation using regional cardiac work index.

J. Vecera et.al.[4] showed a marked decrease in wasted work in the septum after CRT for responders while no significant change for non-responders to CRT.

Russel et. al.[1] used a qualitative assessment of wasted work ratio (corresponding to Cardiac Work Efficiency) distribution over the LV to discern dyssynchrony from re-synchronized LV function.

Note: Myocardial Work is covered by patent 2013-535297 (Japan), 201180059482.2 (China) and patent pending 11793651.8 (PCT)

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2. Boe E, Russel K, Eek C, Eriksen E, Remme EW, Smiseth OA, Skulstad H: «Non-invasive myocardial work index identifies acute coronary occlusion in patients with non-ST-segment elevation-acute coronary syndrome." European Heart Journal – Cardiovascular Imaging (2015) 16, 1247-1255
3. Delhaas T, Arts T, Prinzen FW, Reneman RS: "Regional fibre stress-fibre strain area as an estimate of regional blood flow and oxygen demand in canine heart." Journal of Physiology (1994), 447.3, pp.481-496
4. Vecera J, Penicka M, Eriksen M, Russell K, Bartunek J, Vanderheyden M, Smiseth OA: "Wasted septal work in left ventricular dyssynchrony: a novel principle to predict response to cardiac resynchronization therapy"; European Heart Journal – Cardiovascular Imaging (2016) 17(6): 624-632

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Imagination at work