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Review

Two-dimensional strain imaging: A new echocardiographic advance with research and clinical applications

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Abstract

Over the past two decades the quest for quantitative evaluation of left ventricular function and regional wall motion has escalated, allowing several aspects of myocardial contractile patterns to be quantified, both during stress echocardiography and in the assessment of dyssynchrony. Most of the literature to date has used Tissue Doppler Imaging (TDI) techniques to assess essentially long-axis function due to the angle dependency of Doppler based techniques. This brief review introduces the early development, validation and potential clinical applications of a new technique of quantifying two-dimensional (radial and circumferential) strains and strain rates through tracking myocardial "speckles". *In-vivo* and *in-vitro* validation of this 2D-strain imaging technique has been undertaken and reached a point where it is considered ready for more widespread investigations into clinical utility. One important advantage over TDI techniques is that it is not limited by dependency on the angle of insonation. Several recent studies looking at ventricular function in specific groups of patients have reported practical ability to distinguish the abnormally from the normally contracting regions of ventricular walls. It provides new and complementary quantitative information about ventricular dyssynchrony and regional wall motion abnormalities. More research studies are needed to determine the sensitivity and specificity of the measurements obtained using this technique and define its strengths and limitations. In particular, whether the measured values correlate well with clinical outcomes will need to be established in longitudinal interventional studies. The clinical utilities of this technique over the coming years are likely to expand rapidly.

Keywords: Echocardiography; Speckle tracking; 2D-strain imaging; Myocardial strain rate; Ventricular wall motion; Contractile dyssynchrony; Tissue Doppler Imaging

1. Introduction

Cardiologists have an ever-increasing array of investigations and imaging modalities available to them and the clinical utilities of these techniques within echocardiography are rapidly expanding. Echocardiography is an attractive imaging modality for several reasons. Images are displayed in real time allowing prompt diagnosis, echocardiography is freely available, relatively inexpensive to perform and does not involve ionising radiation. One of the most common reasons for echocardiographic examination is in the assessment of left ventricular (LV) function but this is time-consuming and often rather subjective, especially when the endocardium cannot be clearly visualised [1,2]. Another major limitation of echocardiography has been the difficulty in accurate quantitative assessment of regional myocardial function. The need for formal quantitative assessment of regional myocardial function is increasing and there are emerging techniques enabling this to happen. The most widely used and validated technique so far is Tissue Doppler Imaging (TDI). Various Doppler-derived velocity and strain analyses have been suggested as measures of regional left ventricular function [3–7] but newer techniques may offer additional advantages [8].

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2. The concept of strain and strain rate

Strain is a measure of deformation, in other words, lengthening or shortening. Strain and strain rate imaging allow the measurement of regional myocardial deformation to assess specific local and global function. Strain measures deformation whilst strain rate is the rate of change of the deformation [9]. Both of these measures have been shown to provide complementary information about the clinical assessment of cardiac function [10–12]. Strain and strain rate can be estimated from echocardiographic images by several methods. In the simplest form strain can be derived from a parasternal short-axis M-Mode view, calculated by assessment of wall thickening during systole. This however only gives estimates of anteroseptal and posterior wall thickening. To allow the assessment of other regions of the left ventricle, TDI techniques can be employed. TDI, rather than assessing the rapid velocity blood pool as with conventional Doppler, uses filters to remove these signals to concentrate solely on the lower velocity myocardial motion. Velocities in the myocardial wall are much lower than that of the blood pool and are typically less than 15 cm s^{-1}. From these velocity vectors it is possible to calculate strain as the change in unit length relative to the initial length. Strain (S) is represented as:

$$S = \frac{l - l_0}{l_0} = \frac{\Delta l}{l_0},$$

where l is the instantaneous length, l_0 is the initial length and Δl is the change in length (epsilon (ε) can also be used to denote strain). The strain rate can then be represented as $\dot{S} = \frac{\Delta S}{\Delta t}$, where S is the strain and t the time. The unit of strain rate is s^{-1}.

The quantification of strain measurements derived from TDI has been extensively validated [4,10,13,14]. Tissue Doppler-derived strain has over the last ten years been utilised in a great many clinical situations including the assessment of ischaemia and stress echocardiography [15–20], in the evaluation of dyssynchrony [21–25] and the assessment of function in relation to valve abnormalities [26].

3. Limitations of Tissue Doppler-derived strain

TDI, like all Doppler-derived measurements, is dependent upon the angle of insonation [27]. TDI is only able to estimate strain along the ultrasound beam and thus cannot reliably measure strain in the azimuth or perpendicular plane. If the tissue under investigation is not moving perfectly in line with the ultrasound beam then the measurement obtained will be subject to inaccuracy (dependent on Cos θ of the angle of insonation). This limits the use of TDI-derived-strain measurements primarily to longitudinal fibres with the inability to quantify deformation in the radial plane. Furthermore in patients with left ventricular dilatation, the full extent of the myocardial wall cannot be aligned within the ultrasound beam making the resultant strain values potentially misleading. To be able to overcome these limitations it is necessary to estimate the in-plane velocity vectors. A technique known as 2D-strain has been developed and validated and it is the purpose of this review to discuss the development and possible utilisation of this technique [28–30].

4. Speckle tracking or two-dimensional strain imaging

In standard grey scale images, interference from back-scattered ultrasound waves from neighbouring structures creates a speckled pattern. It can be shown with M-Mode imaging that the myocardial speckle patterns remain relatively constant during the cardiac cycle. With this in mind, a small area of the myocardium with its unique speckle pattern can be defined and referred to as a “kernel”. This kernel of myocardium can be tracked by a commercially available computer software throughout the cardiac cycle using radio-frequency (RF) tracking [31] from which 2D-strain imaging has evolved. Multidimensional strain was estimated by using radiofrequency (RF) tracking to show that it was possible to overcome the problem of unidirectional strain data whilst maintaining both tracking and accuracy.

Since the kernel can be tracked in any direction then it is possible to measure its movement in both the axial and azimuth planes allowing estimation of radial and circumferential strains (see Fig. 1). This removes the previous constraint of being able to measure strain only along the beam of ultrasound. This new technique therefore provides additional information to further our understanding and to advance potential clinical utilisation of strain imaging. Other methods are available using computer vision techniques [32], 3D deformation techniques [33] and Vector Velocity Imaging (Sequoia, Siemens Medical Solutions) which have been shown in clinical trials to have utility in assessment for Cardiac Resynchronisation Therapy (CRT) but these are outside the scope of this review [34,35].

5. Experimental studies

Speckle tracking has been widely used in blood velocity measurements [36], in non-invasive ultrasonic imaging of

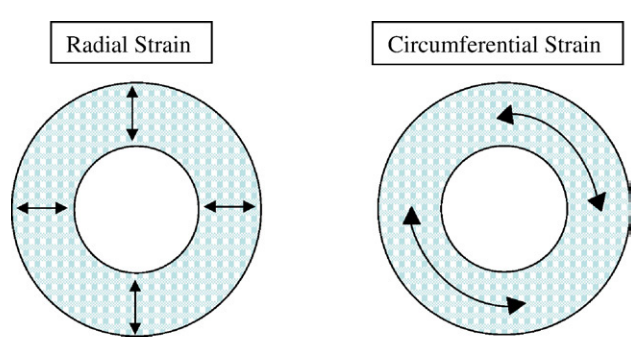

Fig. 1. Diagram to demonstrate radial and circumferential strain vectors.