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Two-Dimensional Strain Imaging: Basic principles and Technical Consideration

İki Boyutlu Strain Görüntüleme: Temel Esaslar ve Teknik Özellikler

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Abstract

Tissue Doppler Imaging (TDI) and TDI-derived strain provide considerably accurate information in the non-invasive assessment of local myocardial functions. Given its high temporal and spatial resolution, TDI allows assessment of local myocardial functions in each phase of cardiac cycle. However, the most important limitation of this method is its angle dependence. New techniques to measure myocardial deformation, such as speckle tracking echocardiography, overcome the angle-dependence limitation of TDI-derived strain. Moreover, these techniques provide more unique information about myocardial fiber orientation. This review examines the architectural structure and function of the myocardium and includes technical revisions of this information that will provide a basis for STE.

Key Words: Left ventricle, speckle tracking, strain, deformation

Özet

Doku Doppler görüntüleme (TDI) ve TDI kaynaklı strain bölgesel miyokardial fonksiyonların non-invasiv değerlendirmesinde oldukça doğru bilgiler vermektedir. Yüksek temporal ve spatial çözünürlüğü nedeniyle, kardiyak siklusun her fazında bölgesel miyokardiyal fonksiyonların değerlendirmesine imkan tanır. Ancak, bu metodun en önemli kısıtlılığı açı bağımlı olmasıdır. Speckle tracking echocardiography gibi miyokardiyal deformasyonu ölçen yeni teknikler, TDI kaynaklı strainin açı bağımlılığı limitasyonunun üstesinden gelebilmektedir. Üstelik miyokardial fiber orientasyonunu ile ilgili daha değerli bilgiler vermektedir. Bu derleme miyokardiyal mimari ve fonksiyonları ve STE için temel oluşturacak bu bilgilerin teknik olarak gözden geçirilmesini içermektedir.

Anahtar Kelimeler: Sol ventrikül, speckle tracking, strain, deformasyon

Introduction

In the assessment of cardiac function and loss of function, it is essential to understand the helical architecture of myocardial fibers and concordantly examine the fibers in terms of shortening, thickening and torsion movements around its own axis during systole and diastole [In addition to the closing of two opposite walls, basal segment movement towards the apex and their rotary motion in opposite directions result in the formation of vortex flows (vertical flows), wherein energy is considerably more preserved compared with linear flow mechanics. This principle, which is applicable for ejection during systole, is vitally important given that it provides effective absorption power throughout diastole [1].

Myocardial Fiber Mechanics

The left ventricle (LV) performs longitudinal shortening-lengthening movements around the long axis as well as thickening and thinning movements around transverse axis, whereas both thickening-thinning (in the radial axis) and lengthening-shortening (in the circumferential axis) movements occur in the short axis throughout the cardiac cycle [2] (Figures 1 and 2). As the heart contracts due to its incompressible nature, myocardial fibers shorten longitudinally and thicken transversely. While the cardiac apex is relatively fixed, the basal left ventricle approaches the apex throughout systole and reverts back in two stages during diastole. As a tissue that moves and displaces in time, the left ventricle likely fulfill this function via shape changes (*deformation*) by moving in different segments and at various velocities [3]. The specific velocity and displacement of each segment naturally results in different intersegmental velocity from which strain rate and thereby strain values, which are frequently used in deformation imaging, can be calculated [4]. The frequently used deformation parameters include *strain,* an expression of the ability of shortening/thickening in comparison with the baseline length proportionally, and *strain rate,* which reflects that this proportional change is made within a specified time frame. When evaluated within the cardiac cycle and time frames, it is practically impossible to calculate the baseline

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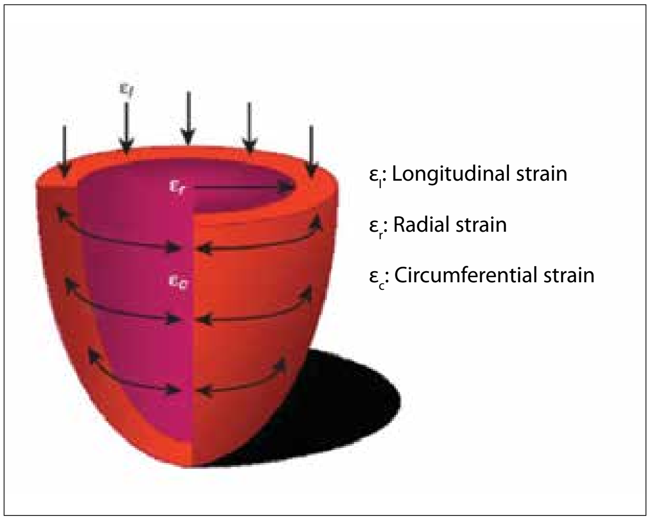

Figure 1. *Left ventricular longitudinal deformation.*

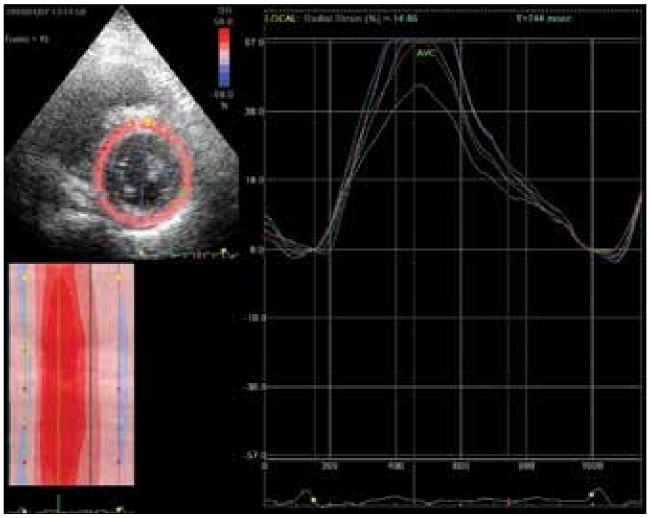

Figure 2. *Left ventricular radial and circumferential deformation.*

length of the myocardial fiber. Therefore, in contrast to the *Euler's* equation, which reflects more accurate results, the *Lagrange's* formula, which reflects this proportion indirectly, is more practical. When immediate changes are taken into consideration, the Eulerian formula more clearly reflects the immediate change, which occurs in the length of the fiber from t_0 to any t time.

The left ventricle performs the lengthening-shortening/thickening-thinning movement in a linear fashion, whereas it performs rotation mechanics in an angular fashion due to the specific electrical stimulation that fiber sequences experience from endocardium to epicardium/base to the apex [5, 6]. When the LV is examined from the apex, basal segments rotate clockwise, whereas apical segments rotate counterclockwise throughout systole [7]. If this movement, which is defined as the rotation movement, is considered globally, two segments rotating in opposite direction will create an angular gradient across the long axis of the heart [8]. The total angle value of two segments rotating in opposite directions is called twist, and torsion parameters can be calculated based on the distance between these two segments. In addition to the temporal changes limiting the use of the Eulerian equation, it is almost impossible to evaluate the angular movement individually for basal and apical segments on a three-dimensional plane. Therefore, although an inward-to-outward/apex-to-base angular gradient occurring on the LV reflects the actual torsion and angular shear stress in an angular fashion, its precise calculation requires the measurement of three-dimensional movement by observing the time frames in a linear and angular fashion [9-11].

Deformation Imaging

In the 1970s, while the anatomists investigated the fiber architecture of the myocardium, McDonald [12] and Ingels [13] used cine-angio and cine-radiography through radio-opaque crystals placed on the epicardium to demonstrate that the basal segment not only approached the apex throughout systole but also rotated clockwise across the long axis of the heart during cardiac surgery. In the 1990s, studies performed by a different type of magnetic resonance imaging (MRI), tagged MRI, [14-16] allowed for visualization of the movements of the heart on different axes by non-invasive methods [14, 17-22]. Although the temporal resolution of MRI is low, it was used in pilot studies to describe the rotation mechanics and has an important place in the validation of tissue Doppler-based (23, 24) or speckle tracking-based echocardiography studies [20-22, 25] bCurrently, tagged MRI is generally used for research purposes, and in particular, speckle tracking-based echocardiography techniques make it possible to perform practical and reproducible measurements for current research in a cost effective manner [26, 27].

How to Calculate Deformation?

Physically, the movement of an object with a velocity and its displacement in time is an inevitable result according to the rules of physics. However, every object with a velocity is not necessarily subject to deformation. Therefore, if velocity, displacement and deformation ability are evaluated within the concept of time, it is certain that they will reflect different results. On the other hand, as two objects displaced at the same level do not possess the same velocity, they may exhibit different deformation amounts. In that case, deformation may be measured indirectly over velocity or directly over displacement using the same time frame. Velocity can be measured with the aid of Doppler, and displacement can be

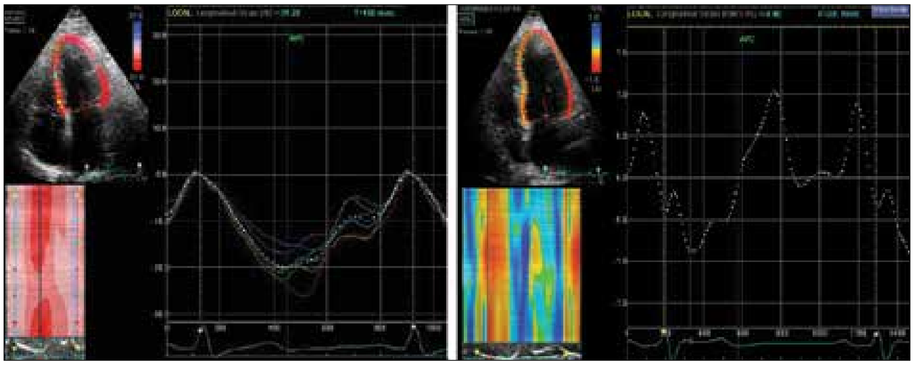

Figure 3. *Deformation imaging speckle-tracking-based techniques.*

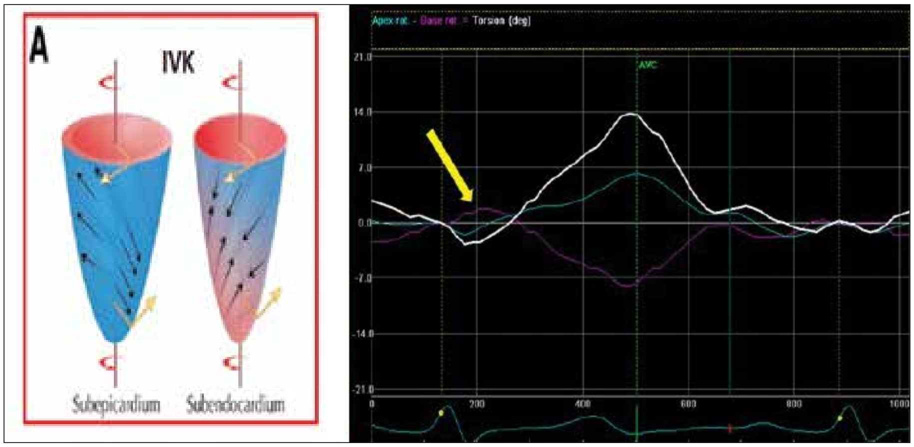

Figure 4. *Apical and basal rotation.*

measured by means of tracking the speckles detected on 2D grayscale. Consequently, deformation measurements may be performed by parametrical tissue Doppler-based and grayscale speckle tracking-based techniques (Figure 3). Given the angular-dependence disadvantage of Doppler echocardiography, it is possible that relatively less angular-dependent speckle tracking gives more more accurate results, and the technique is more comfortable for patients [28-31].

Basic Principles of Rotation Mechanics

Due to different muscular arrangement and electrical activity [6, 32], rotation mechanics are more complex than movements performed on other planes. Discussing and investigating the rotation mechanics that occur within the cardiac cycle will provide more accurate results for systemic aspects and in terms of analyzing the variances in the healthy and unhealthy conditions. Throughout isovolumetric contraction, the shortening of subendocardial fibers and tension of the fibers in the subepicardial region result in a short-term clockwise rotation in the apex; the basal segment moves in the opposite direction during this period (Figure 4). In the beginning of the rotation movement, the apex and base pass in opposite directions, and afterwards their deflections represent the different electrical activities from the apex to the base and endocardium to epicardium [7].

During ejection, subendocardial and subepicardial fibers shorten simultaneously. The tension in the apex is greater than that of the base, and the potential energy required for diastole is stored in the subendocardium at the end of systole (subendocardial fibers are more dominant in the apex). Torsion is observed counterclockwise in the apex and clockwise in the base. In the isovolumetric relaxation phase, subepicardial fibers elongate from the base to the apex, whereas the fibers in the subendocardial region elongate from the apex to the base. The isovolumetric relaxation phase is important given that untwisting is initiated before mitral valve opening and that the intraventricular pressure gradient is produced in the period leading to the valve opening [33-35]. On the other hand, although conventional methods do not provide information regarding this phase of diastole, untwisting onset, velocity and place within the cardiac cycle are of great clinical importance [36]. In early diastole, immediately following mitral valve opening, the fibers in the subendocardial and subepicardial layers continue to relax; it is noteworthy that minimal untwisting occurs during this period [33, 34] .

In conclusion, speckle tracking echocardiography is a rapidly growing technique that has been an important component of routine clinical practice in the recent years. Speckle tracking echocardiography has been demonstrated to be superior to tissue Doppler imaging based on various aspects of its deformation imaging. Moreover, speckle tracking echocardiography is an easy-to-use method that provides more objective data on myocardial mechanics and reflects the regional and global ventricular functions in a superior way in terms of diagnosis and prognosis.

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