A Review on Recent Echocardiographic Software

Advancing the Field through the Emerging Science

Mersedeh Karvandi
Saeed Ranjbar

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Mersedeh Karvandi
Taleghani Hospital
Shahid Beheshti University of Medical Sciences
Tehran, Iran

Saeed Ranjbar
Institute of Cardiovascular Research
Shahid Beheshti University of Medical Sciences
Tehran, Iran

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Preface

Recent technological developments have introduced new diagnostic devices to doctors, who can use the devices to diagnose diseases faster and more precisely. In addition, doctors can suggest better treatments using the new devices. However, since these developments merge basic sciences such as mathematics and physics with bioscience, understanding the basic and functional principles of these new devices is not easy. When the users—who are mostly doctors—understand all the functional aspects of the new devices, they can gain the best results from them, find new functions for them, and even promote them.

Echocardiography devices have a range of modern and sophisticated hardware components that have been manufactured based on mathematics, physics, and cardiovascular physiology; therefore, to get optimal usage from these devices and maximize their capabilities for diagnosis, all doctors should have a basic knowledge of how they function. That is why we decided to compile this manual, which introduces the details of sophisticated systems to doctors in a simple manner.

This manual is also useful for researchers who want to enter interdisciplinary fields such as physics, mathematics, medicines, and computer science. Finally, users of echocardiography devices such as applicable fellowships will benefit from studying this manual.

Tehran, Iran

Mersedeh Karvandi
Saeed Ranjbar

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1

Echocardiography of Left Ventricular Myocardium Deformation

As we know, evaluating the deformation of the myocardial muscle in the cardiac patient is important. Evaluating the myocardial motion includes evaluating the velocity and its displacement size, and evaluating the deformation includes evaluating the strain and strain rate.

The strain is the same as the muscular deformation compared to its primary shape, and the strain rate is the velocity of this muscular deformation. The measured type of deformation by echocardiography machines is based on Lagrangian deformation; however, the various systems of these machines can identify the deformation indexes (strain and strain rate) differently.

Assigning the deformation at the various segments of the left ventricular myocardial muscle should be performed by experts, but assigning systems in echocardiography devices have been designed that can automatically measure the deformation indexes.

The "strain" parameter can be measured via different mathematical techniques, such as tissue Doppler imaging (TDI) combined with velocity gradient (VG), speckle tracking (ST), speckle tracking with seven endpoints, speckle tracking combined with TDI, 2D base strain (which means speckle tracking combined with velocity vector imaging [VVI]), and left ventricular (LV) modeling, as a polygon shape combined with speckle tracking and even simple M-mode is able to measure a special kind of strain. Therefore, the value of strain depends on how one measures the strain and what kind of strain is meant (longitudinal, radial, circumferential strain, etc.). The following review provides a general overview of the currently available imaging techniques that enable strain measurements based on the available literature and ongoing works [1–3].

The main goals in this chapter are to review the measurement methods of the velocity and deformation indexes (left ventricular myocardium) in the different echocardiography machines and to cover the methods of their mathematical software.

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These methods are as follows:

TDI can indicate the velocity in any segment of the myocardium and calculate the displacement size and the applicable segment's deformation size (strain and strain rate). The main question is, how can the velocity at the applicable cardiac muscular tissue be calculated by the tissue Doppler ultrasound method?

If we calculate any segment at the left ventricle, such as the septal base, the reversal waves from this segment in the time, T_0, would be a frequency of f_0 (Fig. 1.1).

Despite being dynamic, all reflected waves in time T_1 are a wave with the frequency f_1. The applicable segment in a cardiac cycle from T_0 to T_n could have different frequencies from f_0 to f_n (Figs. 1.2 and 1.3).

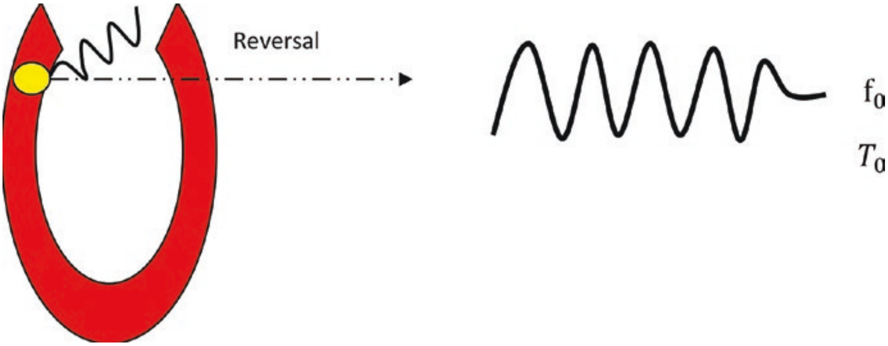


Fig. 1.1 Reversal wave of cardiac segment

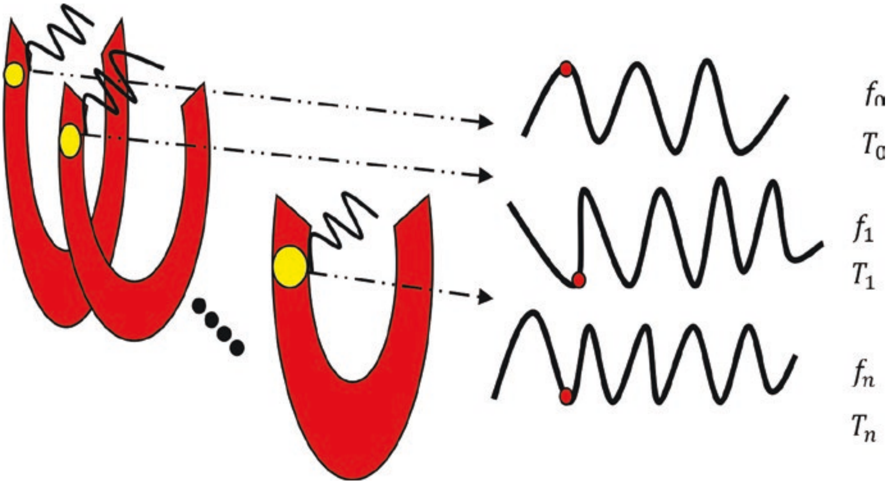


Fig. 1.2 Reversal waves from the basal septal segment in a cardiac cycle; all reversal waves are disrupted by each other at different points

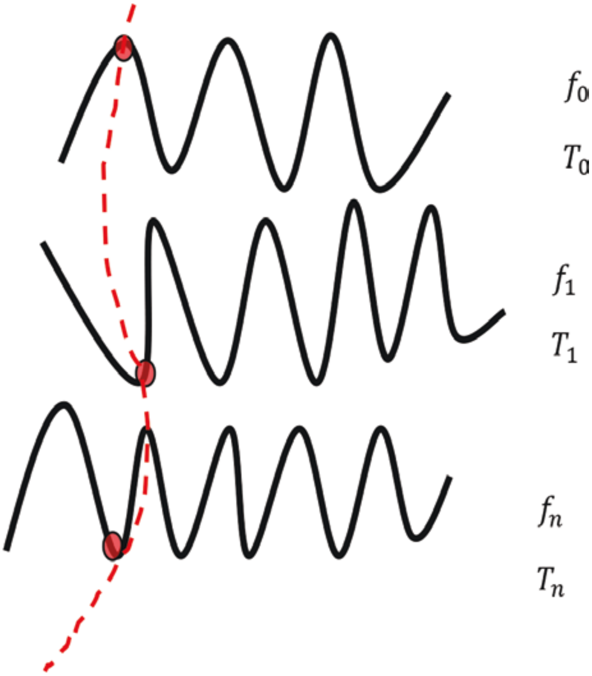


Fig. 1.3 Waves' disruption at different points

If we connect these points to each other, we will have a curve that indicates the waves' disruption; this curve is called the *wave equation of d'Alembert* (Fig. 1.4).

This equation can be used to get the velocity curve via a Fourier transform [4, 5] (Fig. 1.5a, b).

From the velocity curve of each segment in the left ventricle, we can assign the strain and strain rate. For instance, if the septal base in T_1 has velocity v_1 and in T_2 has v_2, and from T_1 to T_2 has a displacement of size L, then the strain rate would be calculated as follows:

$$\varepsilon'\left(L_1,t\right)=\frac{V_2\left(t\right)-V_1}{L\left(t\right)}$$

From the integral of the strain rate, we could get the strain as follows (Figs. 1.6 and 1.7):

$$\varepsilon\left(L_1,t\right)=\int_0^t \varepsilon'\left(L_1,u\right)\mathrm{d}u$$

Fig. 1.4 Wave curve of d'Alembert

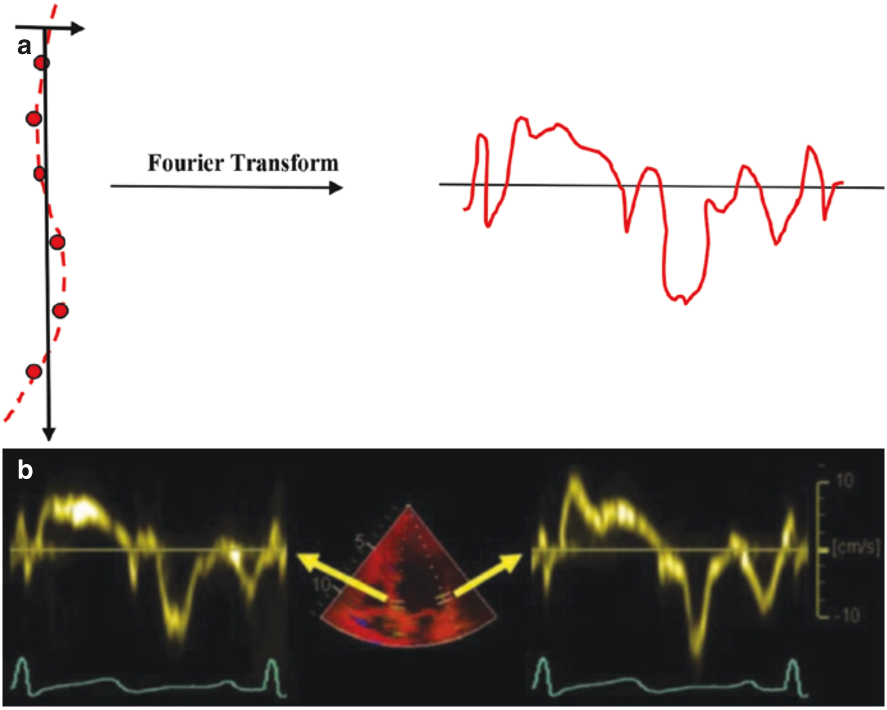
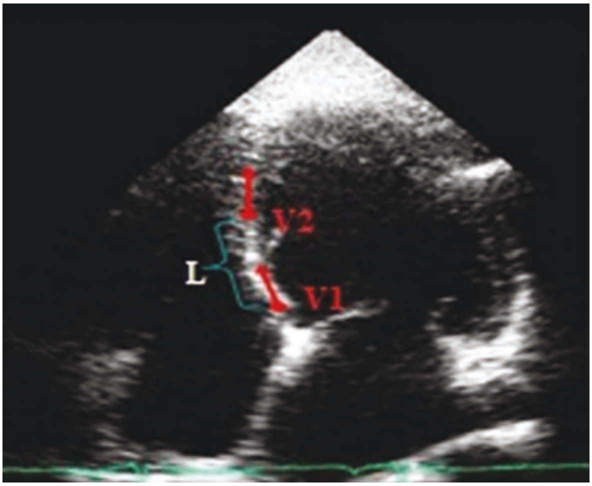


Fig. 1.5 (**a**) Velocity curve in cardiac muscle, (**b**) velocity of myocardium based on the TDI method

Fig. 1.6 The TDI-VG method to obtain the strain by the time integrating the strain rate curve. V_1 is the velocity at the region of interest 1, and V_2 is the velocity at search region 2. *L* is the distance between the 1 and 2 regions



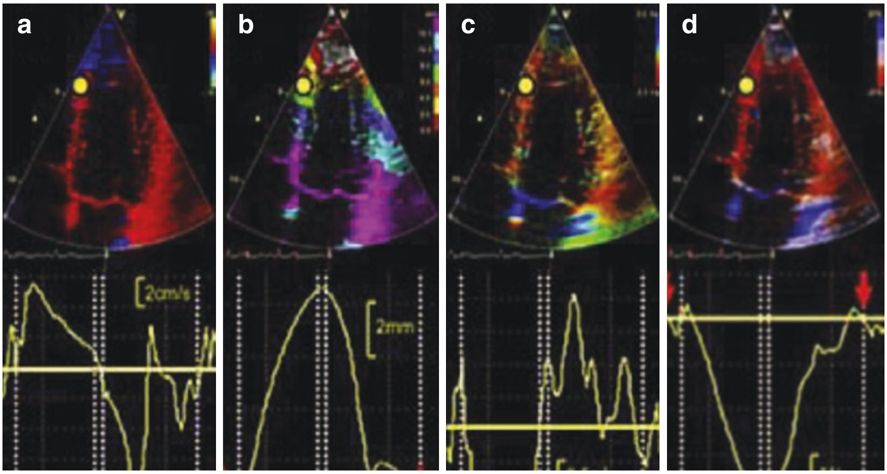


Fig. 1.7 (**a**–**d**) Velocity and displacement of myocardium and deformation indexes (strain and strain rate) based on TDI method

Speckle Tracking Method

In the echocardiography machines with the speckle tracking system, the velocity and tissue moving would not be assigned by the tissue Doppler ultrasound imaging method. In this system, there is a new software in the field of image processing that can assign the velocity and deformation of the cardiac muscle. This software can track the applicable segment and can identify its place on the coordinate screen.

In this system, the strain would be calculated first, and then the strain rate would be calculated. For instance, the basal septal segment would be tracked in time T_0 at point A with the clear coordinate (X, Y, Z), in time T_1 at point B, and in time T_n at point N (Fig. 1.8).

Points A, B, … , N would be connected by vectors (Fig. 1.9).

The aggregated number of these vectors' length as the applicable segment reaches from A to N could calculate the strain as well.

$$\varepsilon\left(i,t_n\right)=\sum_{k=1}^{n-1}\frac{\left(L_{k+1,t_{k+1},}-L_{k,t_k}\right)}{L_{k,t_k}}$$

From the differentiation of the strain, we could calculate the strain rate, and from the differentiation of displacement, we could calculate the velocity (Fig. 1.10a–c).

So, in the TDI method, the velocity, displacement, strain rate, and strain would be respectively calculated, and this trend in the speckle tracking would be performed as follows: displacement, strain, strain rate, and velocity.