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Original article

Deformability of the pulsating left ventricular wall: A new aspect elucidated by high resolution ultrasonic methods

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ABSTRACT

Background: Although the deformability of the left ventricular (LV) wall appears to be important in maintaining effective cardiac performance, this has not been debated by anyone, probably owing to the difficulties of the investigation.
Objectives: This study applies a new technology to demonstrate how the LV wall deforms so as to adjust for optimum cardiac performance.
Subjects and methods: Ten healthy volunteers were the subjects. Using echo-dynamography, an analysis at the “microscopic” (muscle fiber) level was done by measuring the myocardial axial strain rate (aSR), while the “macroscopic” (muscle layer) level contraction-relaxation/extension (C-R/E) properties of the LV wall were analyzed using high frame rate 2D echocardiography.
Results: Deformability of the LV was classified into three types depending on the non-uniformity of both the C-R/E properties and the aSR distribution.

“Basic” deformation (macroscopic): The apical posterior wall (PW) thickness change was concentric and monophasic, whereas it was eccentric and biphasic in the basal part. This deformation was large in the PW, but small in the interventricular septum (IVS). The elongation of the mitral ring diameter and the downward movement of its posterior part were shown to be concomitant with the anterior extrusion of the PW.

“Combined” deformation (macroscopic and microscopic): This was observed when the basic deformation was coupled with the spatial aSR distribution. Three patterns were observed: (a) peristaltic; (b) bellows-like; and (c) pouch-like.

“Integrated” deformation: This was the time serial aSR distribution coupled with the combined deformation, illustrating the rotary pump-like function.

The deformability of the LV assigned to the apical part the control of pressure and to the basal part, flow volume. The IVS and the PW exhibited independent behavior.
Conclusions: The non-uniformity of both the aSR distribution and the macroscopic C-R/E property were the basic determinants of LV deformation. The apical and basal deformability was shared in LV mechanical function.

Introduction

The deformability of the left ventricular (LV) wall may be an indispensable determinant of smooth and effective LV mechanical performance [1,2]. However, this concept was not noticed by previous researchers. Although it might have been speculated, it would have been difficult to investigate because of the poor spatial

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resolution of past investigative methods [3–11], such as X-ray, magnetic resonance imaging (MRI), and conventional 2D echocardiography, including the speckle tracking method. Also, the experimental studies [12–16] and artificial cardiac models [17,18] are not physiological, and cannot observe the phenomena of the living heart moving under "negative pressure" in the thorax [19–24]. The present study attempts to challenge this difficult problem by using the high-resolution non-invasive methodology (echo-dynamography) to confirm the significance of the deformability for LV performance.

Objectives

We attempted to disclose LV wall deformability *in situ* using echo-dynamography which has been heretofore repeatedly described. The "microscopic" method (to the muscle fiber level) measured the axial strain rate (aSR) using the phase difference tracking method [25–29]. The "macroscopic" method (to the muscle layer level) observed the morphology using high frame rate 2D echocardiography. In addition, the spatial and time serial behaviors [7,8,30,31] were observed.

Subjects and methods

Ten presumably healthy volunteers aged 30–50 years (39.6 ± 10.4 years) who had given informed consent were the subjects. They are working in our laboratory, and volunteers with past and present history of adult disease were not included in this study.

Acquisition of the information

The information of the wall dynamics was obtained using the specially designed ultrasonic machine (Aloka 6500 model, Hitachi Aloka Medical, Tokyo, Japan). While the examinee was in the supine or left lateral decubitus position, a transthoracic parasternal 90° sector scan was passed through three points (center of both the aortic and the mitral orifices and the LV apex) so as to include the center of the LV, the left atrium (LA), and both axis lines of the inflow and outflow. This plane was named "longitudinal section plane [32]" and the LV structure was symmetrical with this plane (Fig. 1). The rectangular plane perpendicular to this was named "short-axis plane" throughout which 3D measurement of the LV was done from the apex to base precisely. Then, we measured the intra-ventricular blood flow [30,31] and the LV mechanical phenomena with minimum acoustical measurement error [8,33,34].

Measurement of the macroscopic (muscle layer level) dynamics of the LV wall

A high speed of 66 frame/s with 3.5 MHz in frequency and 4.5 KHz in repetition rate was used for 2D echocardiography [7,8,32]. A 90° scan from the base to the apex was performed.

During one cardiac cycle, the images of continuous 30 frames of every 30 ms were analyzed at each of the 3 points, that is, the apical (A: just above the papillary muscle level), basal (B: ca 10 mm apart from the mitral valve ring), and central (C: in the middle of A and B) (Fig. 1).

The thicknesses of the posterior wall (PW) and the interventricular septum (IVS), and the internal diameter of the LV were measured, respectively. Mitral valve ring *diameter* (MRD) and the mitral ring *movement* (MRM) were also measured.

Selected heart rate was about 70/min and the time course of the cardiac cycle of each case was corrected by R–R interval after Bazett's equation to stabilize the data among the subjects.

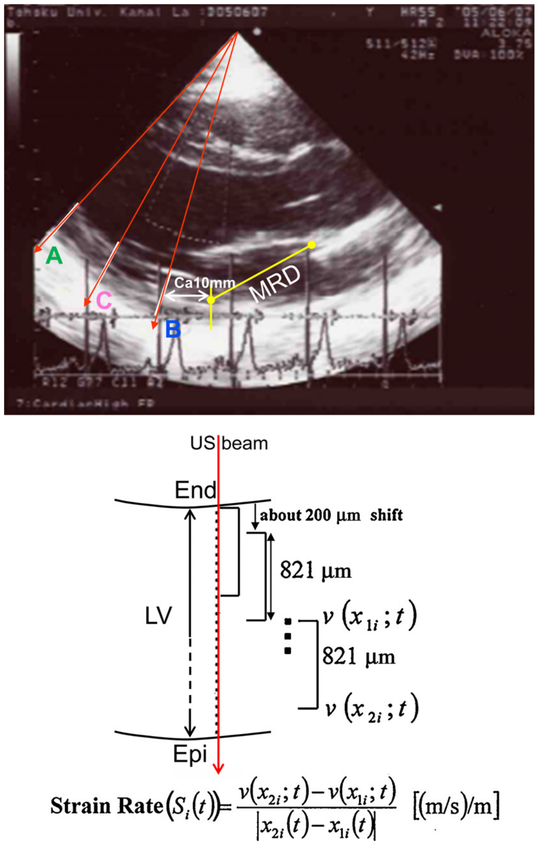

Fig. 1. Measurement methods of the structure change of the LV wall by high frame rate 2D echocardiography and of the high-resolution axial strain rate (aSR) by phase difference tracking method. Cardiac structures confirmed by 2D echocardiogram. The 1–3 beam directions to parts A (apical), C (central), and B (basal) were decided on the long-axis section plane. In the aSR method, the beam direction was decided on the systolic maximum image. The received echo signals from the wall for about 6 s were stocked in the digital memory and processed off-line by using our own developed software. The aSR at the point area on the beam was calculated by the bottom equation (strain rate). Details were shown in the previous papers [35,37]. MRD, mitral ring diameter; US beam, ultrasonic beam; LV, left ventricle; End, endo-cardium; Epi, epicardium; $v(x_{1i}; t)$, velocity at the point of x_1; $v(x_{2i}; t)$, velocity at the point x_2.

Measurement of the microscopic (muscle fiber level) dynamics of the LV wall by the aSR

For methodological reasons, we measured the myocardial fiber "thickness" change instead of the change in the fiber "length". This is because the change in the pulsating myocardial fiber length is in inverse proportion to the thickness [21–23], which is easily and accurately measured by the present methodology.

The ultrasound used was 3.75 MHz in frequency and 133 μs in the pulse repetition interval. The limited angle of each 30° out of 90° was scanned at a high speed of 630 frame/s from the base to the apex (sparse scan) (Fig. 1A–C). The B point was decided from the maximum systolic image. The thickness (821 μm) was measured at the microscopic level with a high spatial resolution of 200 μm by using the phase difference tracking method of ultrasound [26,27]. Furthermore, the non-uniformity of the contraction and extension in the local myocardium was estimated from the result of the spatial aSR distribution [25–29,32,35].

The calculated aSR was displayed on the M-mode images. The cold color indicates the increment of the aSR [contraction: aSR(+)] and the warm color, the decrement [extension: aSR(−)]. In this regard, the relaxation (B1) (no active movement) is indicated by black color, where there is nearly no contraction nor extension (the muscle is completely relaxed either in systole or in diastole).

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