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Original Research Article

Strain examinations of the left ventricle phantom by ultrasound and multislices computed tomography imaging

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ABSTRACT

The main aim of this study was to verify the suitability of the hydrogel sonographic model of the left ventricle (LV) in the computed tomography (CT) environment and echocardiography and compare the radial strain calculations obtained by two different techniques: the speckle tracking ultrasonography and the multislices computed tomography (MSCT). The measurement setup consists of the LV model immersed in a cylindrical tank filled with water, hydraulic pump, the ultrasound scanner, hydraulic pump controller, pressure measurement system of water inside the LV model, and iMac workstation. The phantom was scanned using a 3.5 MHz Artida Toshiba ultrasound scanner unit at two angle positions: 0° and 25°. In this work a new method of assessment of RF speckles' tracking. LV phantom was also examined using the CT 750 HD 64-slice MSCT machine (GE Healthcare). The results showed that the radial strain (RS) was independent on the insonifying angle or the pump rate. The results showed a very good agreement, at the level of 0.9%, in the radial strain assessment between the ultrasound M-mode technique and multislice CT examination. The study indicates the usefulness of the ultrasonographic LV model in the CT technique. The presented ultrasonographic LV phantom may be used to analyze left ventricle wall strains in physiological as well as pathological conditions. CT, ultrasound M-mode techniques, and author's speckle tracking algorithm, can be used as reference methods in conducting comparative studies using ultrasound scanners of various manufacturers.

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Abbreviations: LV, left ventricular; CT, computed tomography; MSCT, multislices computed tomography; RF, radio frequency; DTI, Doppler tissue imaging; US, ultrasound; PVA, polyvinyl alcohol; PR, pump rate; SV, stroke volume; S, strain; SR, strain rate; RS, radial strain; RSR, radial strain rate; ECG, electrocardiograph.

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1. Introduction

During the nearly four last decades, echocardiography has become the most widely applied clinical local and global method of the left ventricle functioning assessment by measuring the changes of the interior heart dimensions as well as of the heart walls contractility. At first, isolated measurements of the distance between two selected points on the echographic image were examined and then the systems registering images and processing radiofrequency (RF) signals were applied. There were high expectations regarding the Doppler tissue imaging (DTI) technique but this method has not been wider adopted for heart wall elasticity assessment, as yet.

One of the most common applications of echocardiography in the clinical practice is assessment of the left ventricle (LV) function. During the last two decades attempts have been made to implement a technique that would allow to analyze the work of the cardiac muscle during a loading test and at rest and to assess types of contractility disorders. The two promising tools used during the last decade have been the techniques acquiring scattered echoes energy from the unprocessed (RF) signals and Doppler assessment of tissue movement using the DTI [1,2]. However, the first technique suffers from the lack of a uniform algorithm of data acquisition and processing. The limitation of the second technique is, as in all Doppler techniques, the dependence of acquired data on the angle at which an ultrasonic beam reflects from the moving tissue of the myocardium. Different parameters of DTI and deformation have been examined in order to assess the LV function. However, neither of these techniques have brought any remarkable progress. From among different techniques used to examine elasticity of tissues, the so-called *speckle tracking* modality deserves special attention. In 1991 Bohs and Trahey [3] have developed the two-dimensional method of soft tissue movement measurement using ultrasound, regarding as forerunners of this technique.

In 1993 Ryan et al. [4] have developed the visualization method of intravascular elasticity of artery walls using a rotating high frequency (42 MHz) ultrasound transducer and applying the *speckle tracking* technique. However, the analysis of artery wall movement was not possible in real time but only after completing the RF signals' acquisition. The authors applied the blood vessel phantom made of gelatin and subjected it to an intravascular change of pressure from 100 to 120 mmHg, next, the RF echoes were correlated between successive frames. In 1994 Berrioz and Pedersen [5] applied the correlation method to study the diversified rigidity of model simulating vessel wall atherosclerosis. In 1995 Chen et al. [6] studied the dependence of errors of the *speckle tracking* method on the influence of different factors related to different types of examined tissue.

Properties of elastic soft ''tissue'' were measured using specially fabricated models in the form of elastic pipes made of different materials with echogenicity similar to that of the human tissue. At first the mixture of agar and gelatin was used to produce tissue phantoms. However, phantoms were not resistant to applied pressure changes – they were ruptured when radial deformations exceeded 5% [7,8]. Next, polyvinyl alcohol gel was used to produce tissue phantoms [9]. In 2004 Langeland et al. [10] made the first attempt to apply this type of phantom to assess heart wall deformations obtaining linear dependences between longitudinal and transverse strain – they used the RF echoes' correlation method.

The dual-chamber ventricular phantom was used for ultrasonic examination of the left ventricle strains during an *in vitro* experiment [11]. The authors focused on testing of the physiological LV strains by imitating more ellipsoidal shape of the ventricle and on the dependence of left ventricle functions and its ''interconnection'' with the right ventricle.

The three dimension tensor analysis of cardiac wall strains on the base of the univentricular polyvinyl alcohol cardiac phantom was recently published in 2012 by Heyde et al. [12]. However, using the radial strain, the authors were not able to detect the region affected by the pathological process under a relatively small stroke volume.

During the last decade the *speckle tracking* modality has been widely advertised by the majority of echocardiological equipment manufacturers, however, without a thorough discussion of the applied algorithms and mathematical expressions. The lack of important definitions of the measured parameters makes conducting comparative studies using ultrasound (US) scanners from different manufacturers impossible. This problem was noticed by echocardiographers carrying out examinations in clinics already possessing different US scanners. Despite the fast development of new scanning machines and new algorithms, the objective method of verification of the results (especially obtained using different scanners) is missing.

The main purpose of our work was to develop the mathematical/numerical model and construct a simple phantom of the LV deformation with the acoustic properties similar to those measured in the real echography. The LV phantom can serve as a reference physical model of the left ventricle for different imaging modalities having realistic deformation parameters which are stable over time and can be used as a calibration tool for commercial imaging systems.

There is a commercially available product that can be used as both an US and CT phantom Model: PVAH-01 (Shelley Medical Imaging Technologie, London-Ontario, Canada) however, there is no strain and strain rate mathematical modeling related to it.

The basis of the concept of speckle tracking algorithm is a relationship between displacement of the tissue scatterers and displacement of the resulting speckles in the US image. The support of the *speckle tracking* technique is even more inexplicable because it was proved in 2008 by Tournoux et al. [13] that this method is less reliable than the method of tracking ultrasound image tissue contours. However, the speckle tracking technique is used in most of the commercial echo units. Recent studies have shown that the Multislices Computed Tomography MSCT [14,15] are effective in quantitative analysis of LV strain. The novelty of this article is the introduction of the quantitative comparison of the radial strain (RS) results from the dynamically moving LV phantom obtained by means of three different modalities; MSCT, ultrasonic speckle tracking and numerical modeling.