DYNAMIC ULTRASONIC MODEL OF LEFT VENTRICLE

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Two different tissue phantoms of the left ventricle to imitate a beating left ventricle were developed: first was prepared using a sponge material and second phantom was constructed using a polyvinyl alcohol material modeled into a homogeneous hollow cylinder: approximately 10 cm and 12 cm in length for the first and second phantom, respectively. Both phantoms were 5 cm in diameter, with a wall thickness of 1.0 cm. Additionally, a small part of the wall of the second phantom was processed to simulate the stiffness of myocardial infarction. The phantoms were connected at the end to an adjustable external pump. The pulse volume inside the cylinder was set between 12 to 50 ml at rates of 40, 60, 100, 120 beats/minute. The phantoms were immersed in water for ultrasound scanning with two different insonation angles (90 and 65 degrees). Strain and strain rate were measured with different combinations of angles and pulse rates. The main aim of this work was to develop the new method for validation of the human infarct wall strain calculation procedures using the speckles tracking.

INTRODUCTION

Improved endocardial border delineation with contrast also facilitates the detection of left ventricle (LV) motion abnormalities. The advent of contrast echocardiography has improved endocardial definition leading to better assessment of global and regional function after injection of intravenous contrast agents. However, despite the benefits of contrast agent imaging, the results may be affected by cardiac and respiratory motion, image attenuation, shadowing and the availability of suitable acoustic windows. Assessment of LV function remains difficult despite rapid technological echocardiographic developments. One of the major recent technical developments in ultrasound imaging is the ability to assess tissue deformation. Speckle-tracking echocardiography (2D-TMSA) has recently emerged as a quantitative ultrasound technique for accurately evaluating myocardial deformation by analyzing the motion of speckles identified on routine 2D sonograms. 2D-TMSA is potentially suitable for the measurement of angular LV motion because of its angle independence. 2D-TMSA modality provides new parameters to assess myocardial performance, and these parameters include strain and strain rate. Nevertheless, it has some limitations because the heart moves in three dimensions. The assessment by 2D-TMSA is based on the measurements of strain calculated on 2D projection only, ignoring the characteristics of threedimensional cardiac wall motion. The newly developed three-dimensional speckle tracking (3D-TMSA) has the potential to circumvent these limitations.

1. CURRENT STATE OF KNOWLEDGE

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

The new technological solutions and concepts of analyzing tissue structure images, which have been introduced over recent years this ultrasonography, allow more and more thorough quantitative description of wall movement and blood flow in the cardiac cavity. One of the most common applications of echocardiography in clinical practice is assessment of the left ventricle. Using current computational algorithms this task is, allows partly subjective and time-consuming. The cases in which it is difficult to expose endocardial boundaries constitute a huge challenge for the method. Despite tremendous technological progress for 10-20% of sick and especially obese people the optimal image cannot be obtained.

The other significant limitation in echocardiography is difficulty in proper assessment of segmental contractility. For this purpose quantitative assessment methods of contractility disorders are needed. During the last two decades it has been tried to implement a technique which would allow to analyze the work of the cardiac muscle during a loading test and at rest. Allows the subsequent introduced methods have fallen short of expectations.

One of the promising tools used during the last decade have been the techniques examining scattered echoes energy while using the unprocessed signal of the ultrasound beam (integrated backscatter) and Doppler assessment of tissue movement – the DTI (Doppler Tissue Imaging) [1], [2]. The first technique limitation is the lack of a uniform process of data processing and acquisition from the ultrasound beam. The limitation of the second technique is, as in all Doppler techniques, dependence of acquired values on the angle at which a Doppler beam reflects from moving tissue of the myocardium. Different parameters of DTI and deformation have been examined to give quantitative values to assess LV function. But these techniques have not caused remarkable progress.

From among different techniques used to examine elasticity of biological tissues, the tissue boundaries movement tracking by analyzing the movement of the so called speckle in ultrasound imaging – " speckle tracking "deserves special attention. Bohs and Trahey [3], who in 1991 worked out the two-dimensional method of soft tissue movement measurement using ultrasound, are regarded as forerunners of this technique. In 1993, Ryan, et al. [4] worked out the visualization method of intravascular elasticity of artery walls using rotating high frequency (42 MHz) ultrasound transducer and applying " speckle tracking ". However the analysis of artery wall movement was possible not in real time but only after completing the RF signals acquisition.

The authors applied the blood vessel phantom made of gelatine and subjected to intravascular change of pressure from 100 to 120 mmHg for examinations. The method of ultrasound RF signals correlation was applied to examine tissue elasticity apart from the "speckle tracking" method. Berrioz and Pedersen [5] in 1994, applied the correlation method to the ultrasound technique while examining diversified rigidity of model simulating vascular pathologies i.e. walls. atherosclerosis. Chen et al, [6-7] studied the dependence of errors of the '"speckle tracking" method on the influence of different factors connected with the type of tissue examined.

The worked out methods of examining elastic tissue properties were tested on specially prepared models in the form of elastic pipes made of different materials with similar to natural echogenicity ultrasound tissues. At first the mixture of agar and gelatine (in 1997 De Korte et al. [8] and Hall et al. [9]) or polyvinyl alcohol gel (in 2001 Brusseau et al. [10]) were used to build tissue phantoms. These phantoms were however not resistant to considerable pressure changes because they were torn when radial deformations exceeded 5%.

Langeland et al. [11] made the first attempt to apply this type of phantom to assess heart wall deformations in 2003 obtaining linear dependences between longitudinal and transverse strain and their determined estimators with the use of the ultrasound technique and RF signals correlation method.

For almost 7 years the " speckle tracking ' technique, which has been widely advertised by the majority of echocardiological equipment manufacturers without giving any details about the technique or even providing essential for diagnostics mathematical expressions, parameters notions and applied to describe elastic heart properties, has had a dominant position in cardiology. Lack of important definitions of measured parameters leads to impossibility of conducting comparative studies using ultrasound scanners of different manufacturers. This problem was noticed only by doctors carrying out examinations in big rich clinics already possessing several older as well as the newest devices.

The support of " speckle tracking " technique is even more inexplicable because it was proven in the work of Tournoux et al. in 2008 [12] that this method is two times worse than the method of tissue contours tracking of ultrasound image.

2. SPECKLE TRACKING

In our study we had applied the speckles tracking technique. The speckles, like tissue image is characteristic for all ultrasonic visualization. In a stationary targets the speckles are still, while in moving organs the speckles are displaced from one frame rate to another. It is assumed that tracking this displacement it can be estimate the strain and strain rate of the organ under investigation.

The percentage change in dimensions (length, thickness) of the examined object (in comparison to its previous dimensions) is called "Lagrangian strain" in medical diagnostics. “Strain” (S) and “Strain rate" (SR) imaging allows to measure the segmental myocardial strain for the assessment of its local and global functioning. Using “Strain" the relative strain (if the size of the left ventricle wall increases by one fourth the strain is 25%, but if it decreases to three fourth the strain is-75%) is measured. "Strain rate” is a measure of changes in strain in a unit of time. Both these parameters deliver complementary to each other information about heart function. “Strain” and SR values obtained in echocardiography were checked *in vitro* and *in vivo* by different methods. “Strain”' was assessed from the sternum projection on the short axis M-mode, calculated from the wall thickness during contraction.

3. METHOD

The repeatability of the parameters measured by using the ultrasound apparatus made by different producers is a major problem. In this work the new method for assessment of the quantitative speckles tracking method is proposed. Experiments were carried out using Artida Toshiba unit with 3.5MHz probe. The hydraulic model was based on the Super-Pump (Vivitro Systems Inc. Canada). The Left Ventricular (LF) phantom [13] was made from 10% solution of the POLY(VINYL ALCOHOL). The pathological change in the LV model wall (see Fig. 1b) was obtained by drying process. During cycle of the pump, the Strake Volume (SV) of water was pumped into the LV phantom and returned to the pump, resulting in changing the inner and outer diameters of the phantom. The SV was changed from 8 up to 24 ml. The number of hydraulic pump cycles (HR) was changed from 40 to 120 beats per minutes for each SV. The parameters examined were: Radial Strain and Circumferential Strain for two positions of LV phantom: 1) 0 deg and 2) 25 deg. The nonparametric U-test Mann-Whitney was used for confirmation that for 0 deg and 25 deg there was not exist any significant statistical difference between measured parameters. For all cases the level of the coefficient of significance was p=0.05.

a) b) c)

Fig.1. The LV models: a) – normal, b) with pathological change inside the wall, c) view of the cross-section of the LV model during examination.

4. RESULTS

The setup for elastic properties measurements of the LV is presented in Fig. 2. It consists of the LV model immersed in cylindrical tank filled with water, the hydraulic pump, the ultrasound scanner, the hydraulic pump controller, the pressure measurement system of water inside the LV model and the iMac workstation. Results of the statistical analysis of dependence of measured elastic parameters of the ultrasound model of the LV for two positions of the ultrasound probe are given in the Table 1.

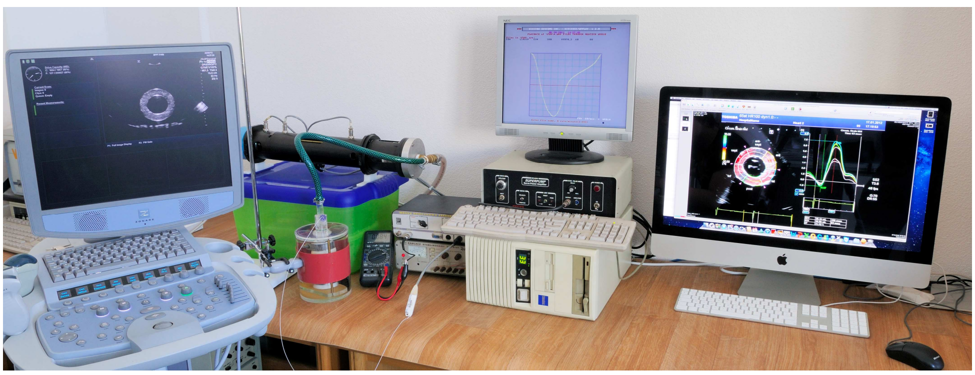

Fig.2. Setup for elastic properties measurements of the LV.

Tab. 1. Results of the statistical analysis of the examination of the difference between series of elastic parameters of the left ventricle.

SV=8 ml					
		Radial Strain	Rad. Str. Rate	C	Circ. Str. Rate
	HR 40	*p*<0.074	*p*<0.246	*p*<0.131	*p*<0.778
	HR 60	*p*<0.343	*p*<0.419	*p*<0.185	*p*<0.661
	HR 80	*p*<0.062	*p*<0.837	*p*<0.062	*p*<0.506
	HR100	*p*<0.447	*p*<0.765	*p*<0.209	*p*<0.719
	HR120	*p*<0.196	*p*<0.994	*p*<0.464	*p*<0.882
SV=16 ml					
		Radial Strain	Rad. Str. Rate	Circ. Str.	Circ. Str. Rate
	HR 40	*p*<0.112	*p*<0.266	*p*<0.085	*p*<0.999
	HR 60	*p*<0.838	*p*<0.927	*p*<0.941	*p*<0.958
	HR 80	*p*<0.4	*p*<0.72	*p*<0.110	*p*<0.506
	HR100	*p*<0.205	*p*<0.573	*p*<0.593	*p*<0.757
	HR120	*p*<0.204	*p*<0.859	*p*<0.412	*p*<0.941
SV=24 ml					
		Radial Strain	Rad. Str. Rate	Circ. Str.	Circ. Str. Rate
	HR 40	*p*<0.866	*p*<0.624	*p*<0.317	*p*<0.52
	HR 60	*p*<0.091	*p*<0.592	*p*<0.69	*p*<0.759
	HR 80	*p*<0.105	*p*<0.738	*p*<0.135	*p*<0.589
	HR100	*p*<0.870	*p*<0.693	*p*<0.434	*p*<0.946
	HR120	*p*<0.364	*p*<0.859	*p*<0.268	*p*<0.976

Where: SV – stroke volume of the input liquid into model, HR – number of the hydraulic cycles of the hydraulic pump during one minute, Rad. Str. – Radial Strain, Circ. Str. – Circumferential Strain.

5. DISCUSSION AND CONCLUSIONS

The experimental results indicate the usefulness of the implemented material for the construction of the left ventricle, which was proved by the model of heart infract, where walls' radial movement and comparable values of strains were achieved, regardless of the angle the ultrasonic beam was in. Over a parameter combination of radial and circumferentiall strain as well as radial and circumferential strain rate, speckle tracking was measured accurately. The angle of insonation did not affect 2D-TMSA. It was shown that second phantom is suitable for mimicking the left ventricle infarct. Presented ultrasonographic models may serve to analyze left ventricle strains in physiological as well as pathological conditions. The results of statistical analysis indicate that the change of the acquisition angle does not influence the measured parameters ($p>0.05$) for all cases. It may authenticate the applied ultrasonic speckles tracking method implemented in ultrasound.

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