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New approach based on the combination of phase and orientation vector for the detection of wall motion abnormalities

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Abstract

Objective The aim of this study is to propose a new approach based on the combination of local phase and orientation vector for the regional detection of cardiac wall motion.

Materials and Methods Cine-MRI images obtained in 20 patients were used to compute the proposed image. Two expert radiologists reviewed the cine-MRI images to define regional wall motion areas for each patient.

Results According to the results. The accuracy of the detection of wall motion abnormalities improved by adding the proposed images (from 79.5% to 86.4%) together with sensitivity (from 79.4 % to 87.3%) and specificity (from 74.3 % to 86.4%).

Conclusion The use of the proposed image based on local phase and orientation vector proved to be a promising technique for the detection of left ventricular wall motion abnormalities.

Keywords Cardiac contraction. Phase. Vector. Magnetic Resonance. Dyskinesia

1. Introduction

Cardiovascular diseases (CVDs) are among the major causes of morbidity and mortality [1]. Consequently, advances in cardiovascular research are needed to improve early diagnosis of cardiac diseases. In this context, cardiac magnetic resonance imaging (CMRI) is considered as the reference technique for the diagnosis of patients with cardiovascular diseases thanks to its ability to evaluate cardiac function, anatomy, and perfusion in a single examination [2]. In the last years, CMRI has also proven its accuracy in the evaluation of myocardial function and several studies have shown the clinical impact of CMRI in making the therapeutic decision (reperfusion strategies) [3,4].

The evaluation of cardiac function is based on cine-MRI images that are synchronized with the ECG. However, identification and localization of contraction abnormalities, such as hypokinesia or dyskinesia, is based on visual interpretation of these images by radiologists or cardiologists, and thus suffers from intrinsic intra- and inter-operator variability.

Although several commercial packages are available to perform semi-automatic quantification of the cine-MRI sequences, the analysis is mostly limited to global indexes of left ventricular (LV) performance such as cardiac output, end systolic volume (ESV), end diastolic volume (EDV), stroke volume (SV), myocardial mass, and ejection fraction (EF). These parameters indicate the overall functional state of the LV chamber but do not allow an accurate localization of the extent of cardiac contraction abnormalities.

The development of an efficient method for the identification of regional contraction abnormalities has been the topic of our study due to its importance in the definition of areas of risk able to recover their function after revascularization.

The aim of this study is to develop new approaches based on the combination of phase and orientation vector features for the regional identification of cardiac wall motion abnormalities.

2. Materials and methods

2.1 Materials

Twenty patients were retrospectively included in the study (age 51 ± 13): 15 presenting an aneurysm and 5 control subjects with normal wall motion.

For each patient, two standard views (short axis view and 2 chamber) were acquired using 3 Tesla Siemens Avanto MRI scanner and a segmented True FISP sequence. The used parameters are the following: TR = 3.4; TE = 1.49 ms; matrix size = 134 * 208; Field of view = 276* 340; Flip angle = 60°.

Late Gadolinium Enhancement (LGE) images for the same patients were also acquired (10 min post-contrast injection of 0.2 mmol/kg of gadolinium-based contrast agent) using Phase sensitive Inversion recovery (PSIR) sequence.

2.2 Methods

In magnetic resonance imaging (MRI), the intensity variations come from inhomogeneities of the magnetic field and intensity artifacts associated to the MRI devices and image acquisition process. In tagged MRI, the tags fade exponentially as a function of the relaxation time T1. Obviously, the same problems arise when contrast agents are used, such as in perfusion MRI or when recording images of different modalities, such as computed tomography (CT) and positrons emission tomography (PET), is required.

These considerations explain the growing interest in monogenic signal analysis applied to medical imaging problems in recent years. For example, the monogenic signal was successfully applied for the analysis of edge detection [5], segmentation [6], multimodal recording [7,8], pattern recognition[9] and wavelet filtering [10]. This tool was introduced as an extension of the concept of the multidimensional analytical signal and it is able to provide the local characteristics of the processed signal: amplitude, phase and information on the local orientation.

The monogenic signal is composed of three orthogonal components which represent independent information. These components are the local amplitude, the local phase and the local orientation which make it possible to provide information respectively on the intensity or the variations of energy on a large scale (envelope), the transition of the gray level values (structural information such than edges) and the direction of the highest signal variance. In this study, we aim to combine two local parameters which are phase and orientation vector to detect regional wall motion abnormalities associated to different cardiovascular diseases.

The principle of this method consists in the combination of two physical features able to identify and to assess the severity of cardiac dysfunction through a series of images that represent the different phases of the cardiac cycle. The extracted features are used to compute a mapping image where the location of regional wall motion abnormalities can be identified using a color display reflecting the degree of local contraction, thus allowing a direct localization of cardiac wall motion dysfunctions, such as dyskinesia, akinesia or hypokinesia, without the need of detecting the myocardial contours. The main advantage of this approach lies to the fact that they are less sensitive to noise and they are well suited for both stationary and non-stationary signals, unlike the classical methods that require the periodicity of the data.

3. Monogenic signal computation

The monogenic signal is defined as follow [11]:

$$S_M = w + i*q_1 + j*q_2: \quad (1)$$

Where w is the real component computed from the real image convolved with an even rotationally invariant bandpass filter H .

q_1 and q_2 are the two imaginary components which are the results of the convolution of the real component by two odd quadrature filters h_1 and h_2 , respectively [12]:

$$W = I(x) * H \quad (2)$$

$$q_1 = w * h_1 \quad \text{and} \quad q_2 = w * h_2 \quad (3)$$

With h_1, h_2 representing the odd filter responses. In the frequency domain, they are defined as follows [13]:

$$H1 = \frac{\mu_1}{\sqrt{\mu_1^2 + \mu_2^2}} \quad (4)$$

$$H2 = \frac{\mu_2}{\sqrt{\mu_1^2 + \mu_2^2}} \quad (5)$$

The computation of the phase parameter from the monogenic signal is based on the Riesz transform which represents the 2D extension of the Hilbert transform. This tool is well suited to image processing and it is directly applied to cine-MRI images without the need to extract 1D signals. The simplicity of this method could facilitate its use not only in MRI images but also in other imaging modalities, without the need for geometric hypotheses.

To compute the phase feature, each pixel of the initial cine-MRI image was convolved with a filter called ‘‘Difference of Poisson’’ (DOP) denoted H. from this convolution, it possible to obtain respectively the real components W of the monogenic signal as shown in equation (2). The orientation vector θ and the phase value φ are computed from the equation (1) as follows:

$$\theta = \tan^{-1}\left(\frac{q_2}{q_1}\right) \quad (6)$$

$$\varphi = \text{atan2}(W + i(q_1 \cos \theta_1 + q_2 \sin \theta_2)) \quad (7)$$

From (6) et (7) phase and orientation can be combined using the following equation:

$$r(x) = \varphi(x) * [\cos \theta(x), \sin \theta(x)]^T \quad (8)$$

Were r is the orientation-phase vector.

The phase parameter is able to detect the relative contraction while the orientation vector gives additional information on the direction and therefore, it is possible to detect some cardiovascular diseases and wall motion abnormalities related to some paradoxical movement during heart contraction such as the aneurysm and Tetralogy of Fallot. By combining these two parameters, it is possible to differentiate different types of cardiac wall motion abnormalities and to identify left ventricular dysfunction such as dyskinesia which cannot be detected using the amplitude image.

4. Results

Two radiologists with over 10 years and 9 years CMRI experience participated in the evaluation of the proposed method. They established a qualitative evaluation by means of a visual inspection of the

images obtained by our algorithm, always referring to the results of the diagnosis established by the clinical protocol. In addition, a quantitative evaluation was carried out by the comparison of the contraction value of the different left ventricular myocardial areas. The clinical characteristics of the study population are summarized in the following table:

Table 1. Main characteristics of the studied population using MRI.

Parameters	Patients (n = 20)
Age (years)	51 ± 13
Gender	F* = 13, M* = 7
EDV (ml)	192 ± 18
ESV (ml)	115 ± 0
LVEF* (%)	43 ± 16

LVEF: Left Ventricular Ejection Fraction.

F= Female

M= Male

Figure 1 shows an example of the proposed image associated to a control subject. The result shows that there is a homogeneity of color intensity at the level of the myocardium. In addition, the myocardium does not reveal any variation in color intensity, which confirm the absence contraction dysfunction.

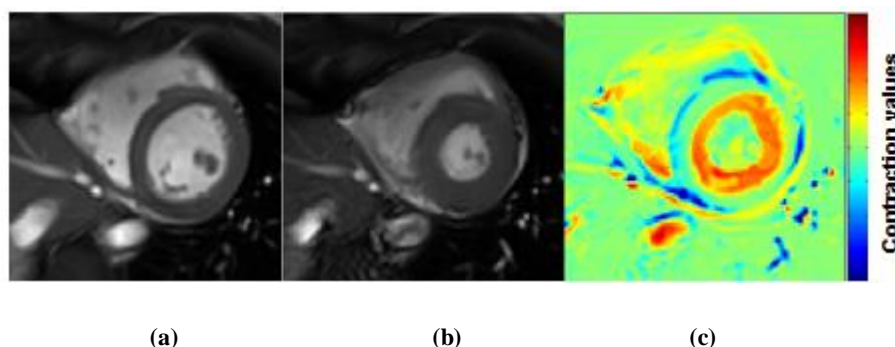


Fig.1 End diastole (a) and end systole images (b) with the corresponding proposed image (c) related to a control subject.

Figure 2 presents an example of two cine-MRI images (end diastole and end systole images) related to a patient with an infero-lateral infarction of the basal endocardial wall at the level of the medio-basal section, responsible for dyskinesia with normal LVEF. By examining these images, we can notice that they do not allow a regional localization of hypokinesia at the level of the infero-lateral sector. In addition, the overall visual inspection of these images appears normal. In clinical routine, the identification of such dysfunction requires the acquisition of several cine-MRI image sequences on the different sections and sometimes a late enhancement sequence is required. The radiologist observes each sequence in the form of 25 cine-MRI images in order to identify the area with abnormal motion. This task is tedious and time consuming.

The proposed image based on the monogenic signal for the same patient shows an homogeneous color at the level of the myocardium except at the level of the lateral sector which presents a reduce color intensity indicating the presence of dyskinesia. The result demonstrates that our method is likely to provide more precise information on the location and the extent of the contraction abnormalities.

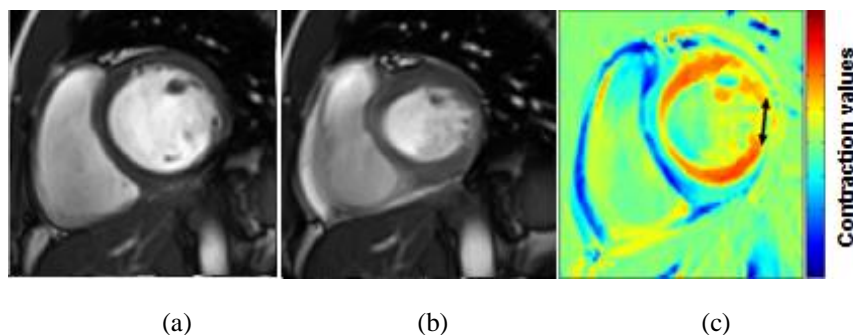


Fig.2 Two cine-MRI images (a,b) with the corresponding proposed image (c) related to a patient with a lateral infarction.

In order to reduce the inter and intra-observer variability, the segmentation of the Left Ventricle into six sectors (Anterior (A), Antero-Lateral (AL), Infero-Lateal (IL), Inferior (I), Infero-Septal (IS) and Antero-Septal (AS)) was established according to the standards established by American Heart Association (AHA). This segmentation provides a reproducible and standardized assessment of left ventricular function. Figure 3 shows an example of the myocardium divided into six sectors on the proposed image.

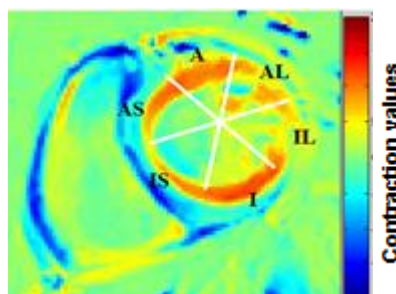


Fig. 3 Division of the myocardium into six sectors (Anterior (A), Antero-Lateral (AL), Infero-Lateal (IL), Inferior (I), Infero-Septal (IS) and Antero-Septal (AS)) was established according to the standards established by American Heart Association (AHA).

The segmentation into six regions of the myocardium according to the standards confirms that the decrease in contraction is located in the lateral sector. The sectoral analysis proved the usefulness of the proposed images in the regional evaluation of cardiac function.

To evaluate the role of the proposed image on the assessment of wall motion abnormalities, cine MRI images only and the same cine MRI in conjunction with their corresponding phase images were analyzed independently by two expert radiologists. The results of the sensitivity, specificity, and accuracy are summarized in table 2:

Table.2 Results of comparison between the qualitative analysis and the proposed image interpretation.

	Sensitivity (%)	Specificity (%)	Accuracy (%)
Detection of wall motion abnormalities by radiologists	79.4	74.3	79.5
Detection of wall motion abnormalities by the proposed image	87.3	82.0	86.4

According to the results, an improvement in the accuracy was observed by using the proposed image for the detection of wall motion abnormalities. In addition, an enhancement of sensitivity and the sensitivity was noticed.

Table 3 shows the running time of our proposed algorithm with those of other two methods dedicated to dyskinesia detection. The three algorithms have been implemented in Matlab (R2013b, the math-works, Natick, MA) using Intel (R) Core TM i7 5500 CPU @ 2.4 GHz and 8 GB of RAM.

Table.3 Execution time comparison.

Image Dimension	Execution Time (s)		
	Our approach	Approach based on variational data assimilation [14]	Approach based on parametric images [15]
512*512	0.81	1.74	2.11

The result shows that the proposed algorithm based on the combination of local phase and orientation vector achieves minimum execution time in comparison with the other algorithms.

In order for further validation, the correlation between the contraction values and LVEF indices was measured for the 20 patients. Fig.4 shows the correlation between the contraction values obtained by the proposed approach and the LVEF values.

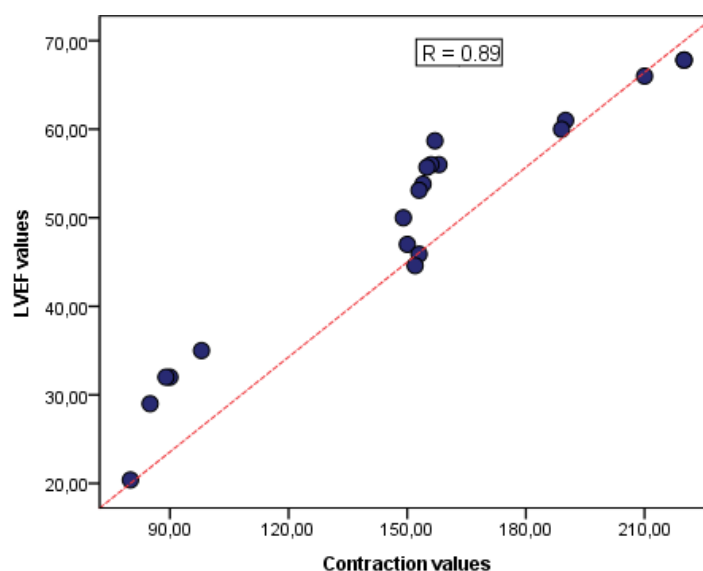


Fig. 4 Correlation between contraction values obtained by the new approach and LVEF indices.

The results show that the contraction values obtained by our algorithm are well correlated ($r=0.89$, $p < 0.01$) with LVEF indices measured in clinical routine. The outcomes of this study demonstrate that, the proposed image was able to provide information potentially useful for the detection of wall motion abnormalities in conjunction with LVEF values.

Conclusion

The proposed approach plays an important role in the evaluation of cardiovascular dysfunction and in the prediction of functional recovery. The results show that the use of this new technique in MRI clinical routine is likely to represent a promising technique for the improvement of the detection of cardiac dysfunction.

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