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Scar tissue evaluation in the left ventricular endocardial wall using Pixel-based concept

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Abstract. Scar tissue is an identified cause for the development of malignant ventricular arrhythmias in patients of myocardial infarction, which ultimately leads to cardiac death, a fatal outcome. The scar formation is an irreversible process of the formation of dead muscle cells that is related to the blockage of a coronary artery. Here, we present a framework to find the possible scar tissue location on the left ventricular (LV) endocardium wall using computed tomography (CT) with delayed-enhancement images by implementing a pixel-based concept. We performed automated LV segmentation to find the LV endocardial wall, extracted the pixel value of the endocardial wall for each image in the sequence, performed morphological operations and marked the particular regions where is the more possible region of the scar tissue on the endocardial wall of LV. This proposed methodology will help in a better understanding of scar tissue remodeling and ways to improve LV function.

Keywords: Scar Tissue, LV endocardial wall, Morphological operations, Myocardial infarction, Cardiac remodeling.

1 Introduction

The scar tissue development in patients who suffered from Myocardial Infarction can lead to fatal outcomes due to the development of ventricular arrhythmia. According to the WHO (World Health Organization) report, over a million people suffer from cardiovascular disease (CVD) each year and it is predicted that the number of CVD patients in the United States will increase by 2.5 times by the end of 2050 and other developed countries [1]. During the myocardial infarction, scar tissue formation on the myocardium wall leads to the rupture of the myocardium. The size and the location of the scar are very critical factors to determine the outcome of the patients who are suffered from the initial myocardial infarction as the left ventricular (LV) pump function also depends on infarct size. It is important to understand the process of the development of LV remodeling [2]. The number of infarcts cannot survive the mechanical loads and they get rupture shortly because of catastrophic and fatal complication issues. The few infarcts develop a thin myocardial wall, to increase the myocardial wall stresses. Though, it has been verified remarkably difficult to design therapies that can improve heart function or remodeling. There are numerous exciting new therapies that are still under development to assess the scar tissue because it needs a deep understanding of infarct scar formation, properties and how the scar structure affects not only cardiac mechanics as well as electrical conduction and reflex hemodynamic compensations in the clinical aspects [3]. Here, we represent an overview of published research articles before in the field of scar detection and quantification algorithms. We have shown all reports on how they were evaluated (Table1).

Publications	Subjects	*n*	Modality	LV/LA	Algorithm	Assessment
Kolipaka et al[4] (2005)	Human	23	CMR	LV	SD	Percentage scar
Positano et al[5] (2005)	Human	15	CMR	LV	Clustering	Percentage scar
Yan et al[6] (2006)	Human	144	CMR	LV	SD	Percentage scar
Schmidt et al[7] (2007)	Human	47	CMR	LV	SD	Infarct size
Hennemuth et al[8] (2008)	Human	21	CMR	LV	EM fitting	Percentage scar
Oakes et al[9] (2009)	Human	81	CMR	LA	SD	Percentage scar
Detsky et al[10] (2009)	Human	15	CMR	LV	Clustering	Infarct size
Tao et al[11] (2010)	Human	20	CMR	LV	Otsu thresholding	Dice
Knowles et al[12] (2010)	Human	7	CMR	LA	MIP	Percentage scar
Lu et al[13] (2012)	Human	10	CMR	LV	Graph-cuts	Infarct size
Rajchl et al[14] (2014)	Human	50	CMR	LV	SD, FWHM	Percentage scar

Table.1 A brief summary of previously published scar detection articles (LV = Left ventricular, LA= Left atrium, n = Number of datasets, SD = Standard deviation, FWHM = Full-width-at-half-maximum, MIP = Maximum intensity projection, EM = Expectation-maximisation fitting.

Whenever we focus to the computational field, a lot of studies has been done using CMR modalities for scar detection on myocardium wall but not using CT modalities and in the case of algorithm implementation, they have used only standard deviation and average of the intensity value method which is very common for scar detection till now. Our motive is to use the CT modalities because CT scan works by acquiring several X-rays at many angles, these modalities are very quick, faster and widely available which is a very challenging task. Here, we designed an automated method for the detection of myocardium scar tissue using computed tomography (CT) with delayed-enhancement images by implementing a pixel-based concept.

2 Materials and Method

Data Acquisition

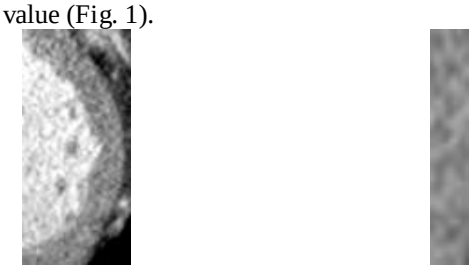
We acquired the cardiac CT images datasets of five Inpatients which are captured 10 sets of timing frames at the same position with different contrast mediums, including a complete cardiac cycle by the Philips computerized tomography instrument. Every data set has 409 images with 512×512 dimensions. We used the Delayed enhancement cardiac CT images dataset. Dataset was in the DICOM (Digital Imaging and Communications in Medicine) format. We used the RadiAnt DICOM Viewer program to see the dataset. We extracted the desired dataset that exhibits the LV part (149 CT images) and few layers were avoided due to its insignificance. Data is provided by the National Institute of Hospital of Yang-Ming University. The informed consent procedure and the study was conducted as per the Institutional Review Board of National Yang-Ming University Hospital.

Automatic segmentation of LV

We have used Segment CT software for automatic LV segmentation. It is applied on short-axis stacks, by the entering points in the reconstruction process and found LV. This software is optimized for automated description of chambers from CT images, helps in the finding of endocardium and epicardium. We considered only the desired dataset for the study that shows the LV part, performed automatic LV segmentation, found LV epicardial and endocardial wall.

Mathematical calculation of pixel value

This step is involved with the selection of the LV myocardium wall and extracted the pixel value of the selected myocardium wall region. We performed SD & average of the pixel value for finding the possibilities of scar area in the desired dataset. This idea was taken from the literature which is if three SD values are more than the average intensity value of a healthy myocardium region that shows the possibilities of scar tissue (4, 7, 15). We have focused to find out the pixel value of the LV myocardium wall region because every pixel present on the surface as HU provides the clues to precede this research work. From the literature, we get the idea HU allows a simple method to characterize certain tissue. In the CT scan image, HU is directly proportional to the degree of x-ray attenuation to every pixel to exhibit the image, represents the density of the tissue [16, 17]. Here in this step, we performed the automated localization and subsequent cropping of the selected myocardium wall that infers to LV of heart and calculated SD and the average value (Fig. 1).



(A) (B)

Fig.1 (A) LV myocardium wall (B) Selected myocardium wall region

Implementation of region growing algorithm

This part has performed on MATLAB, R2018a platform. The seeded region growing algorithm for image segmentation, proposed by Adams and Bischof [18], is very easy to execute method. This method is very efficient, easy to apply on grayscale images, and can be extended to color images as well. The algorithm begins with a set of seed points in an individual region. The seed points compare to their neighbors on the basis of a similarity criterion and then the neighbor's pixel is computed by 4-connectivity where the pixels are connected horizontally and vertically. This is the simplest similarity criteria to calculate the difference between the intensity value of the image pixel and the corresponding region mean. In this way, we performed SD and average calculation of the region growing area which is LV myocardium (Fig.2).

(A) (B)

Fig.2 (A) Original image (B) Region growing

Implementation of morphological operations

In this step, we tried to implement basic morphological operators which are erosion, dilation, opening and closing that helps to get some clues. Firstly, we performed erosion function which means “shrink” or “thin” of an image in a binary image. After erosion, we moved to the Dilation function which means “grow” or “thicken” an image in a binary image. Further, we performed Opening and closing functions which make breaks narrow isthmuses, eliminates thin protrusions, fuses narrow breaks, long thin gulfs, and eliminates small holes [19]. In the next step, we performed masking of the original image with a close image and we found the bold boundary color. Here, we set the criteria if two STD and one average value are higher than the pixel value that will be considered as a contrast area in the particular dataset. Finally, we were able to get a clear view of the contrast area.

3 RESULTS

In this study, we investigated the method for the automatic prediction of scar tissue on the LV myocardium wall. According to literature, the presence of the scar tissue on the endocardium of the LV plays a significant role in determining function and remodeling. Here, we calculated the Standard Deviation (SD) and an average of selected myocardium wall pixel values of every slice, calculated average 58.7777 and SD 20.7579 of the whole dataset. This was the very initial step. After this, we performed region growing algorithm on the original dataset and calculated the average, SD and number of pixels present in the particular growing area of the dataset which is the myocardium wall of LV, performed standard deviation for the whole population which is found 59.89 and 21.2014. Here, our result is getting a match with the previous studies; it means we have performed the analysis in the right direction. In the further step, we performed the morphological algorithm of image processing such as erosion, dilation, closing, and opening. After region growing, we did erosion where the image shrinks (Fig .3) and after that performed dilation where the images become thicker (Fig.4) but the images were small holes in the dilated part, performed closing algorithm which removes the small holes (Fig.5).

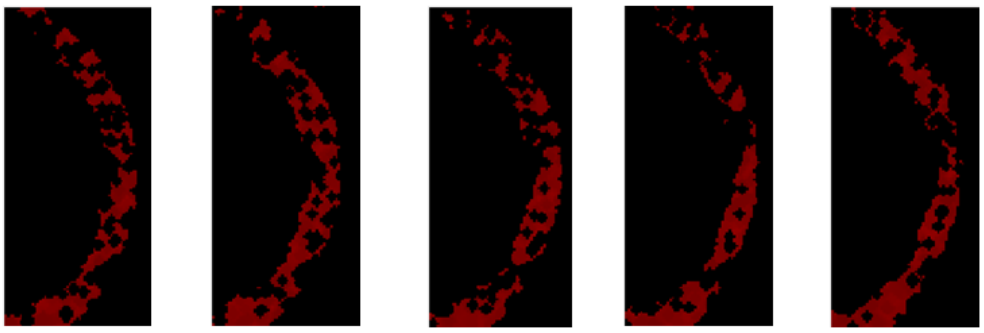


Fig.3 Erosion of images

Fig.4 Dilation of the images

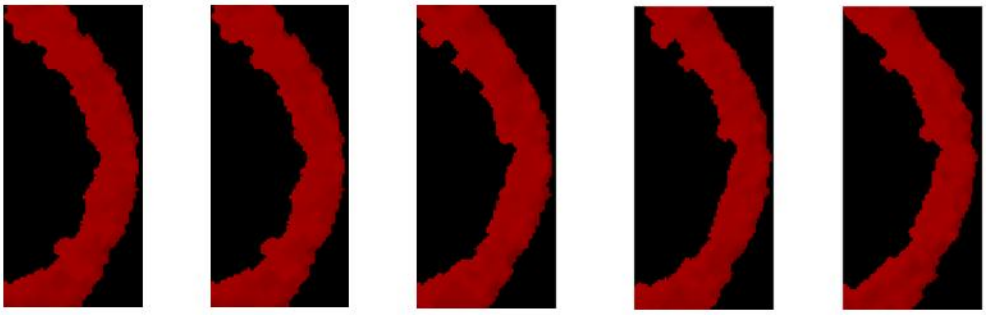


Fig.5 Closing of the images

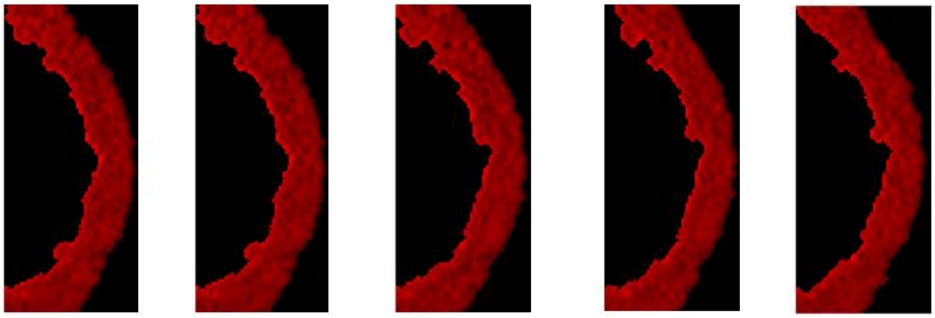


Fig.6 Masking of the original images

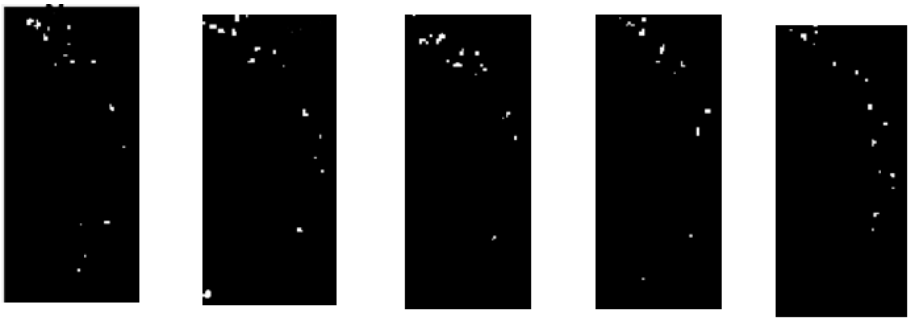


Fig.7 Clear view of Contrast area

After this step, we did masking of the image with the original to closed image; provide the masked image where the area becomes a bit bold color (Fig.6). Here we considered the threshold value of the mean of intensity which converts the image into binary form, we found black and white spots, and white spots represent the high intensity means more high contrast area (Fig.7). Finally, we marked the point where is the more pixel value that shows the possible area of scar tissues. Various studies have exhibited a linear relationship between HU and the pixel value in CT images and suggested that pixel value can be used for estimation of tissues. Here, in this study, we have shown the connection of the pixel value to tissue recognition.

4 DISCUSSION

Numerous clinical studies have exhibited that myocardial scars are very significant in the evaluation of the recovery of function after revascularization [20]. In the literature, CMR is the only imaging modality allowing for the identification of scar tissue till now. Scar appears whiter in comparison to normal myocardium because of high spatial resolution. CMR modality has become the most popular method for assessing the presence of myocardial scars [4, 5, 6, 7, 8, 9, and 10]. In this research, we have delineated a novel automated method to find the scar on the endocardium wall from cardiac CT cardiac images using the pixel-based concept, to our knowledge, this is the first description of LV myocardial scar tissue identification from cardiac CT images. However, this work is a bit challenging due to the large variability of cardiac structures across patients. Various research groups have validated the potential of imaging data to provide meaningful insights into scar structure for the intention of modeling ventricular arrhythmia. The aim of this research is to provide a standardized methodology for evaluating scar tissue which will help to provide a better understanding of the structure and possible location of the scar.

CONCLUSION

Pixel-based concept defiantly plays a major role in the quantifying scar tissue on the LV endocardial wall. As we know, Computed tomography (CT) with delayed-enhancement images is a very challenging imaging technique for tissue detection. This study helps to give a new direction and this proposed framework gives some standing and acceptability for future algorithms of scar detection techniques.

LIMITATIONS

This study included a very limited number of patients who had myocardial infarctions and the methodology of the present study requires future validation on a large scale study.

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