USING CINE MR IMAGES TO EVALUATE MYOCARDIAL INFARCT TRANSMURALITY ON DELAYED ENHANCEMENT IMAGES

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ABSTRACT

Evaluating myocardial viability is an important prognostic factor in the follow-up of infarctions. Delayed Enhancement (DE) perfusion images in MRI have been shown to be very valuable in the evaluation of myocardial viability [1]. Visual interpretation is the most commonly used method. This study aims to segment the (DE) images prior to the estimation of the extent of infarcted tissue. Segmenting the myocardium using cine contraction images presents a high contrast between cavity and myocardium. After the segmentation, the fuzzy c-mean clustering algorithm was applied to estimate segmental transmurality using a conventional five point scale, which was then compared to the visual classification provided by the experts. Results on 14 patients (224 segments) showed an absolute agreement of 81% and a relative agreement (with one point difference) of 93%.

1. INTRODUCTION

Over the last 20 years, it has been proven that left ventricular dysfunction after myocardial infarction in patients with acute or chronic coronary artery disease (CAD) is not necessarily an irreversible process. It appears that if the dysfunctional segments of the myocardium show some viability, both the regional and the global performance of the left ventricle can be restored partially or even totally, either naturally or following revascularization.

Noninvasive assessment of myocardial infarct size is important in the follow-up of patients with CAD because of its known prognostic value [2]. Clinically, the distinction between reversible and irreversible injury within the risk region is important in order to select the appropriate course of action following an ischemic event.

CT, Nuclear Medicine, Ultrasound and MRI are the most common cardiac imaging techniques. The main advantage of MRI compared to other techniques is its ability to study in only one examination the contraction and the viability through first-pass perfusion and delayed enhancement. MRI combines an excellent spatial resolution of the contraction data, and an increasing time resolution thanks to faster sequences.

Some studies [3, 4, 5] show that the MR delayed enhancement (DE) image acquired 15 to 20 minutes after injection of a contrast agent such as chelate of gadolinium, allows the clinician to detect and localize the nonviable areas, which are characterized by a hyper-enhanced signal [3]. It was noticed that DE images illustrate with high accuracy even small infarcts [6]. Thanks to its resolution, this new method has proven its superiority over nuclear methods particularly in the detection of sub endocardial necrosis [7]. These studies also show that an infarct limited to the sub endocardium is a sign of viability, which is not the case of a transmural infarct. Therefore it is important to measure the extent of the infarcted myocardium.

In clinical routine, DE images are interpreted visually [9]. This interpretation is subjective and induces inter- and intra- observer variability.

Moreover differentiating between the left ventricle cavity and the infarcted area in a DE image involves a major difficulty, owing to the fact that blood and infarcted zone have almost the same grey level intensity. So in the majority of studies, endocardial and epicardial contours were outlined manually followed by the use of different algorithms for quantifying infarcted zones [3, 9, 10, 11, 12]. But the manual segmentation of all the left ventricular slices is time consuming.

To reduce the subjectivity of visual assessment, and to decrease the interpretation time, we suggest a method to segment the myocardium using the contraction images because of their high contrast between cavity and myocardium. A temporal search window over the cardiac cycle was defined in order to find the image of contraction best corresponding to the DE image. A superposition criterion was introduced to validate and readjust the optimal

image of contraction overlaying the DE one. Once the myocardium delineation was achieved, the unsupervised clustering algorithm fuzzy c-means was applied to quantify myocardial infarct extent and to provide segmental transmurality scores.

2. METHOD

2.1. Image acquisition

Fourteen subjects were prospectively studied; 11 after myocardial infarction and 3 without myocardial infarction. MR acquisitions were acquired at the European Hospital Georges Pompidou. All studies were performed with the same 1.5-T MRI system (Signa LX, General Electric Medical Systems, Waukesha, WI, USA) using ECG gating with fiberoptic leads and a thoracic phased-array surface coil for radiofrequency signal detection. This protocol of acquisition includes:

- a dynamic study of the contraction,
- a dynamic study of the perfusion at the first pass,
- a static study of the DE.

It was done as follows: after the injection of a first amount of the contrast agent (Gd-DTPA) using 1.5 times the conventional dose, the first pass perfusion was acquired. Five minutes later 0.5 times the dose was injected. While waiting to acquire delayed enhancement (15-20 min), the cine images were acquired using steady-state technique (FIESTA).

Segmental infarct transmurality was visually assessed by an expert on a 5-point scale:

1: No infarction,
2: Transmurality ≤ 25%,
3: Transmurality from 26% to 50%,
4: Transmurality from 51% to 75%,
5: Transmurality from 76% to 100%.

2.2. Slice selection and preprocessing

For each patient, three short axis slice levels were selected from the DE study and their corresponding anatomical levels on cine study. Then a corrective factor estimated from variable spatial resolutions was applied for each pair of DE image and contraction data set.

Thereafter two points were manually positioned on each image of the DE study: the first point p_0 as the centre of the left ventricle and the second point p_1, as the upper intersection between the two ventricles. These two points allowed us to define a rectangular region of interest including the two ventricles. The following procedures were restricted to this region.

The two points p_0 and p_1 were also used to divide the myocardium automatically into 16 segments, according to the standard model [13].

The synchronization with the ECG of the two studies allowed us to define the zone Z of the cardiac cycle where the appropriate cine image can be found. From this image, myocardial contours are extracted (Figure 1).

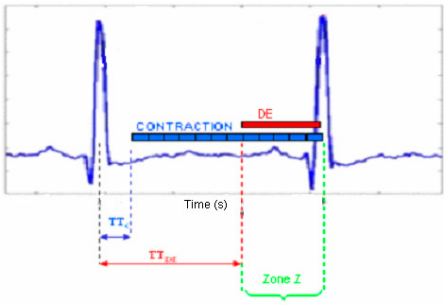

Figure 1 Temporal search zone Z using the synchronization of the two studies with the ECG.

2.3. Image processing

2.3.1. Contour detection

To estimate contours on both DE and cine image the Deriche operator [14] was chosen, since it provides both good detection and localization of contours. This operation provided the gradient of both the DE and the cine image. The gradient local maxima of the DE image is called G_{DE}, and those of all the selected cine images: $G_{c/c\in Z}$.

2.3.2. Superposition criterion

A superposition index *I* was defined as follows:

$$I = \frac{N_1}{\sum_{p\in S1} d(p)} + \frac{1}{4}\frac{N_2}{\sum_{p\in S_2} d(p)} + \frac{1}{8}\frac{N_3}{\sum_{p\in S_3} d(p)},$$

where S_1 is the set of the N_1 pixels which superpose exactly between both G_{DE} and G_C image, S_2 the set of the N_2 pixels which superpose according to a four connectivity criterion (i.e. superposition with one of the four neighbors of the contour points), and S_3 the set of pixels, which superpose according to an eight connectivity criterion. The distance map $d(p)$ defining the distance to p_0, was computed to give a more significant weight to pixels located around the two ventricles.

A registration based on a shift window in both the vertical and horizontal directions was applied to each pair matching G_{DE} image and $G_{c/c\in Z}$ image. The G_C shifted image which provides the maximum superposition index was retained and called G_{C_OPT}.

2.3.3. Endocardial and epicardial extraction

On the G_{C_OPT} image, pixels belonging to the same connected component were labeled (Figure 2). Then the

endocardial contour was extracted by selecting one point of its contour.

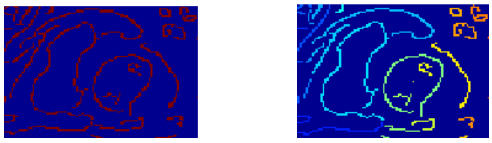

Figure 2: Binary image of G_{C_OPT} (left), same connected components labeling of G_{C_OPT}.

Then the epicardial contour was extracted by applying successive expansions to the endocardial contour. This operation is carried out under visual monitoring, and the process can be stopped as soon as the contour reaches the right ventricle. If necessary, a manual intervention by moving control points is then required to adjust the shape of the contours. Finally these contours were transferred to the DE image.

2.4. Infarct size

A membership probability to the DE class was calculated for each pixel in the region containing the cavity and the myocardium defined by the extracted contours. An index of DE extension was computed as the mean membership probability for each of the 12 sub regions (3 radial sub sectors divided into 4 layers) [15], defined inside each segment. The infarct transmurality scores were assessed for each sub sector as follows:

Let Ii, be the index of extension in the i^{th} layer, (i =1,2,3,4),
if I1< S, then score = 1;
else if I2 < S, then score = 2;
else if I3 < S, then score = 3;
else if I4 < S, then score = 4;
else score = 5;

S being a threshold which was chosen equal to 0.4 by observation. A final segmental score was obtained for each of the 16 segments, by combining the three sub sector scores and privileging the most serious ones.

3. RESULTS

The proposed method was applied to the fourteen subjects. Five cases have necessitated an important manual intervention.

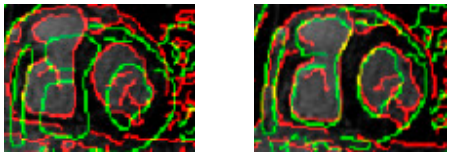

Figure 3: Superposition of G_{DE} (red) and G_{C_OPT} (green) before registration (left), and after registration (right).

Figure 3 shows the repositioning of the G_{C_OPT} image on the G_{DE} one, by using the registration process.

The endocardial contour was extracted from the G_{C_OPT} image (Figure 2). Sometimes (especially for mid ventricular slices), the endocardial contour is not exactly circular because of the papillary muscles, so a manual intervention was required to adjust its shape.

Figure 4 shows the successive steps used for the extraction of the epicardial contour.

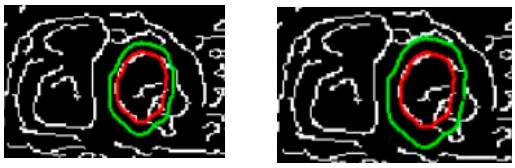

Figure 4: Extraction of the epicardial contour by successive expansions.

Finally a head-to-head comparison was performed between the visual classification, made by an expert and the proposed method on the 224 segments of the database.

	1	2	3	4	5	Total
1	162	2	2	1		167
2	8	1	1		1	11
3	4	1	4	6		15
4		1		5	4	10
5	1	2	4	5	9	21
Total	175	7	11	17	14	224

Table 1: Contingency table between visual assessment (horizontal) and the proposed method (vertical).

An absolute agreement (segments were categorized similarly by visual and quantitative analyses) of 81% was computed, and a relative agreement (a difference of one between the quantitative scores and the expert scores was accepted) of 93% was obtained.

4. DISCUSSION AND CONCLUSION

In this paper a semi-automatic method for segmenting the myocardium to quantify the infarct extent on DE images is proposed. It shows the relevance of using the contraction data for endocardial and epicardial contour tracing and the fuzzy c-mean algorithm to quantify the infarcted tissues.

This approach has some limits: first of all, it should be noted that the acquisitions of contraction images in this study were taken after the first injection of the contrast agent. This protocol decreases the total time of examination but it also reduces the contrast between the myocardium and the cavity. So it does not favor our processing which uses this contrast to achieve a good segmentation of the endocardium. Consequently, on the gradient of the contraction images acquired after the injection, part of the

infarction can be confused with the cavity due to the weak contrast existing between these two areas, which produces an under-estimation of the infarction.

As new imaging techniques more and more minimize acquisition times, it is possible to carry out the acquisition of contraction before the injection of the contrast agent "before-Gadolinium". This acquisition was tested on some patients, while using the proposed method to extract contours.

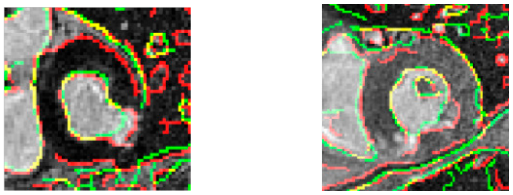

Figure 6: Superposition of both DE and Contraction images on a "post-Gadolinium" (left), and "before-Gadolinium" (right).

Figure 6 shows that a "before-Gadolinium" contraction acquisition is more adequate in extracting the endocardial contour than the "post-Gadolinium" acquisition.

Our approach was also limited by another problem. The mapping between the contraction slices and those of DE was not possible in some cases. This problem was illustrated by one case in Table 1 (where experts gave a score of 1 and our method attributed a score of 5). The over-estimation of the infarction was due to the fact that the left ventricular size on the contraction image was smaller than that on the DE image, so a part of the cavity was considered as a transmural infarction.

This type of problem related to acquisition could be solved by taking into account an increased number of slices of both acquisitions, so that it would be possible to acquire almost the same slice levels for the two studies.

Finally five cases have necessitated an important manual intervention especially in median slices, where papillary muscles appear and can distort the endocardial contour.

In spite of the problems inherent to the acquisition, the proposed method provides very encouraging results. However, the evaluation must be extended to a larger number of patients, to show its value versus a strictly visual approach. When the concept is proved, more sophisticated algorithms could be tested to improve the segmentation phase of the endocardial and epicardial borders on the cine images.

In this study, the aim was to segment the myocardium then to estimate the transmural extent of the infarction on 2D images. The developed method can also provide infarct size. Its application to 3D data would allow estimating infarct volume which is a strong prognostic factor for the patient and a valuable tool in patient medical management.

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