Quantitative Assessment of the Infarct Transmurality Using Delayed Contrast Enhanced Magnetic Resonance Images: Description and Validation

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Abstract

The extent and degree of myocardial injury after an ischemic event are strong predictors of patient's outcome. After acute infarction, delayed contrast enhancement magnetic resonance imaging allows clinicians to distinguish between viable and non-viable myocardium and can delineate with high precision the infarcted tissue. The aim of this study is to provide a quantitative method based on the fuzzy c-means clustering algorithm to assess the location and the extent of the infarcted area. Segmental infarct trasmurality was visually assessed on a 5-point scale for the 288 segments. The agreement between visual and quantitative analyses was good: 84% of the segments were categorized similarly by quantitative and visual analyses.

1. Introduction

Noninvasive assessment of myocardial infarct size is important in the follow-up of patients with coronary artery disease because of its known prognostic value (1). After myocardial infarction it allows the evaluation of myocardial viability, which has an important impact in patient management. One of the main challenges remains to differentiate reversible from nonreversible myocardial injury.

Several methods have been developed for the measurement of infarct size, such as contrast echocardiography (2) which, however, is not able to delineate specifically nonreversible injury. Another method validated and accepted in clinical routine is based on nuclear imaging techniques; it provides semi quantification of the infarct size (3).

Several studies show the relevance of magnetic resonance imaging in the assessment of myocardial viability which can be assessed using contraction MR studies under pharmacological stress (4) or more directly thanks to delayed enhancement images which illustrate with high accuracy even small infarcts (5). Thanks to its precision, this new method has proven its superiority over nuclear methods particularly in the detection of sub endocardial necrosis (6). The delayed enhancement image is acquired 10 to 20 minutes after the injection of the contrast agent. At this steady-state, non viable regions are characterized by hyper-enhanced signal (7). Myocardial functional recovery after an acute coronary event is inversely correlated with the extent of non viable myocardium (8). Therefore, it is crucial to measure precisely and with high reproducibility infarct transmurality.

In clinical routine, delayed enhancement images are interpreted visually (9). To reduce the subjectivity of visual assessment, a number of quantitative approaches have been developed. The first methods use thresholds which are based on statistical criteria such as the mean gray level and its standard deviation in the myocardium. However, the threshold value depends on the study and can vary from 1 to 6*SD (7, 10, 11). The second semiautomatic approach defines a threshold value as a mean value of two regions, the first one being delineated in the remote myocardium and the second in the infracted tissue. This threshold combined with the gray level on the centerline chords provides the infarct transmurality. Finally a method based on full-width at half maximum (FWHM) criteria was developed, the user clicks in the hyperenhanced region, and a multi pass growing algorithm is used to delineate the infarcted area (12). For all these methods, in addition to the delineation of myocardial borders, the operator has to delineate a region within a remote and or infarcted tissue which increases variability (13).

In this paper, a semi-automatic method based on the unsupervised algorithm of the fuzzy c-means clustering was developed to quantify myocardial infarct extent and to provide segmental delayed enhancement scores.

2. Methods

2.1. Image acquisition and preprocessing step

MR acquisition for 15 patients having myocardial infarction and 3 normal subjects were acquired at European Hospital Georges Pompidou (HEGP) according to a standard clinical protocol. Images were acquired using a clinical GEMS Signa CV/i [TM] 1.5 T magnet. For each patient, three short axis slices were selected (apical, mid-ventricular and basal). Myocardial borders were outlined manually by an expert. Then myocardial segments were defined using two manually placed points (the centre of the left ventricle and the superior intersection between the two ventricles) according to the recommended multimodality 17-segments model (14). Segmental infarct size was visually assessed by an expert on a 5-point scale:

0: No infarction,
1: Transmurality $\leq 25\%$,
2: Transmurality 26% to 50%,
3: Transmurality 51% to 75%,
4: Transmurality 76% to 100%.

2.2. Image processing

Inside the region delimited by the epicardial contour, including the myocardium and the cavity, the fuzzy k-means algorithm (number of clusters= 2, parameter of fuzziness =2) was applied. Two classes were estimated: the first class referred to us (E) contains enhanced pixels; it is represented by both the cavity and the infarcted tissue. The second class contains none enhanced pixels (NE). For each pixel p, the membership probability to the class E $u(p,E)$ is stored.

These probabilities are restricted to the myocardium. Each segment is then divided into 4 layers using successively the centerline method (Figure 1). These layers are called L_1, L_2, L_3, L_4 from the endocardial border to the epicardial border.
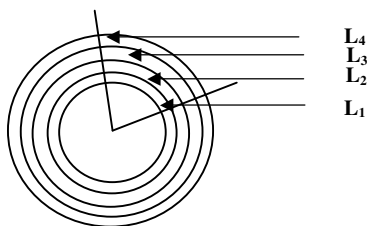

Figure 1: Four myocardial layers

Thereafter, each segment is subdivided in three sub segments, resulting in 48 sub segments per patient (12 sub segments for the apical slice and 18 for both mid-ventricular and basal slices).

For each sub segment S_j (j=1:48) and for each layer L_k (k=1:4) a mean membership probability U(j, k) is

computed and called enhancement index :

$$U(j,k) = \underset{p \in (S_j \cap L_k)}{mean}(u(p,E))$$

2.3. Segmental scoring

For each patient enhancement indexes U(j,k) (j=1 to 48, k=1 to 4) are stored and then a threshold value (TH) is used to give for each sub segment a transmurality extent according to a decision tree (Figure 2). This decision tree takes into account the fact that, within the framework of the myocardial infarction, epicardial attack can't occur without endocardial attack.
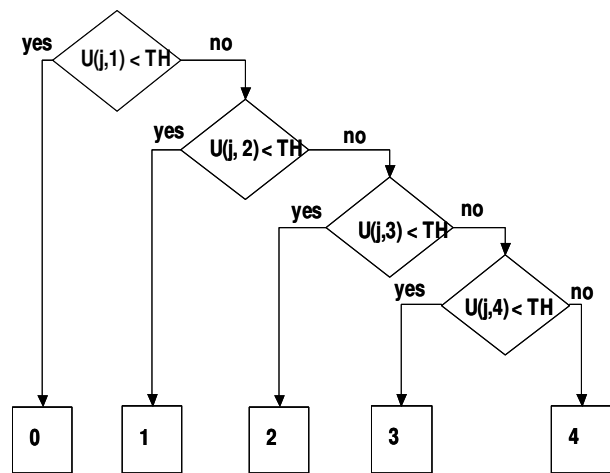

Figure 2: scoring process

For each standard segment three scores are allocated. To take the final decision we use the following analysis:

- If the three sub segments have the same score this one defines the global score of the segment.
- If the three sub segments have three different scores then the highest score defines the global score of the segment.
- If two sub segments present the same score and the third sub segment a different score then there are two possibilities:
    - 1) if the difference between the two scores is equal to one then the score of the two sub segments defines the global score of the segment.
    - 2) if the difference between the two scores is higher than one the highest score defines the global score of the segment.

The last step of this analysis has two main targets: the first one is to avoid artifacts by ignoring slight and isolated differences. The second target is to design a pessimistic method, which is important to avoid serious

errors when this method is used to help in diagnosis.

3.   Results

Classifying on both cavity and myocardium is useful to locate accurately myocardial infarct, but also to affect to the healthy myocardium low membership probabilities to the E class (figure 3).
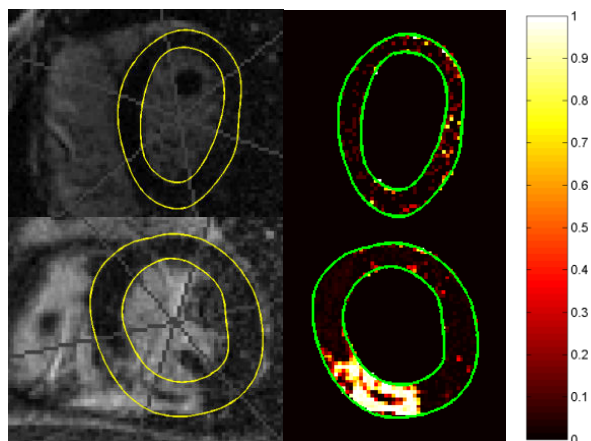

Figure 3: maps of the membership probability for the class (E) on a healthy subject (first line) and on infarcted myocardium (second line).

The segments of the database were classified thanks to a chosen threshold value (TH=37). A variation of 10% around TH has no serious effect on the final diagnosis.

Thus, a head-to-head comparison was performed between the visual classification, done by the expert and the semi-automatic analysis.

Visual assessment

		0	1	2	3	4
	0	20				
		7	3	1		
Fuzzy c-means	1	8	5	4		
	2		9	7	6	
	3			1	8	3
	4	1		2	8	16

Tab.1: Contingency table

Global agreement shows 84% of segments categorized similarly by visual and quantitative analyses.

4.   Discussion and conclusion

In this paper a semi-automatic method for quantifying the infarct extent on delayed enhancement images is proposed. It shows the relevance of using the fuzzy c-means algorithm.

This approach has some limits: first of all, contours of the myocardium were traced manually. This operation is time consuming and it also introduces variability. Indeed, if the endocardial contour particularly is badly placed, pixels belonging to the cavity risk to be placed in the myocardium and to be classified like delayed enhancement because of their strong intensity.

Taking into account the difficulty of positioning endocardial contour on the delayed enhancement images (because of low contrast between the cavity and the infarcted myocardium), the use of the contraction data may help in contour tracing and increase its quality.

Secondly, the developed method is sensitive to the artefacts in the image (1 segment was scored 0 by the expert and 4 by the quantitative method).

In addition, 10 % of the segments are *composite* (part pathological part healthy myocardium): this problem is inherent to the 17 segment model. These segments were taken into account in the developed method by dividing each segment into 3 sub segments. This operation improves the classification of all composite segments except for three segments. Two of them have a part which is scored 4 while the other part is scored less than 4. Given that the developed method is pessimistic (Tab1) these segments are scored 4 while scored 2 by the expert. The last segment has a very small located infarct scored 2 by the expert and 0 by our method. To have a better classification for this segment, we have to divide it into 4 sub segments. In this case the number of pixels within each region will decrease and the effect of noisy pixels would increase. In spite of the problems inherent in acquisitions and in myocardial contours tracing, 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.

In this study, the goal was to estimate the transmural extent of myocardial infarcts on 2D images but 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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