Statistical Descriptors of the Myocardial Perfusion in Angiographic Images

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Abstract

Restoration of coronary flow after primary percutaneous coronary intervention in acute myocardial infarction does not always correlate with adequate myocardial perfusion. Recently, coronary angiography has been used to assess microcirculation integrity (Myocardial Blush Analysis, MBA). Although MBA correlates with patient prognosis there are few image processing methods addressing objective perfusion quantification. The goal of this work is to develop statistical descriptors of the myocardial dyeing pattern allowing objective assessment of myocardial perfusion. Experiments on healthy right coronary arteries show that our approach allows reliable measurements without any specific image acquisition protocol.

1. Introduction

Despite recovering a normal coronary flow after acute myocardial infarction, percutaneous coronary intervention does not guarantee a proper perfusion (irrigation) of the infarcted area [**?**]. This damage in microcirculation integrity may detrimentally affect the patient survival. Visual assessment of the contrast opacification of the myocardial area subtended by the infarct vessel in coronary angiographies allows defining a subjective score (myocardial blush grade [**?**]) of the microvascular function.

Several clinical studies select the myocardial blush grade as an efficient prognosis tool. It correlates with ST-segment elevation index and integrated analysis of both parameters allows an accurate assessment of myocardial perfusion [**?**]. It is one of the best parameters for assessment of the left ventricular function recovery [**?**]. And, therefore, it is a good predictor for long-term mortality after angioplasty [**?**].

Unfortunately, determination of the blush grade might suffer from a significant inter-observer variability [**?**]. This fact questions its reliability [**?**] and its a major limitation for a systematic application in clinical studies. By the relatively novelty of the technique and the poor image quality of contrast angiographies, there is a lack of image techniques addressing objective quantification of the myocardial microcirculation.

In this paper, we approach the objective determination of the myocardial dyeing pattern in contrast angiography. Contrast angiografic sequences show different phenomena: breathing, heart beating, arterial staining, myocardial staining and radiologic noise. On one hand, we characterize the different phenomena that might be observed in an angiographic sequence. On the other one, we introduce a set of statistical descriptors that allow discriminating among myocardial staining pattern, arterial dyeing and background noise.

The paper is organized as follows. In section 2 we describe the different phenomena presented in an angiography and define the statistical descriptors. Section 3 is devoted to the validation of the proposed descriptors and Section 4 to discussions and conclusions.

2. Perfusion descriptors

The microcirculation contrast absorption can be detected by changes in the image gray-values along an angiographic sequence [**?**]. In order to minimize the impact of radiologic noise we will consider the image local mean computed in sliding windows of 32×32 pixels. The variation in the baseline luminosity of images along the sequence distorts the evolution pattern of gray-values. This motivates normalizing image gray values before computing the local mean:

$$ImN(x,y) = \frac{Im(x,y) - \mu(Im)}{\sigma(Im)}$$

where $\mu(Im)$ is the image mean and $\sigma(Im)$ its standard deviation. The values of the local mean of ImN for all frames provides each pixel with a function, namely LM, that describes the average contrast absorbed by the tissue. Figure 1 shows the LM patterns obtained at the white squares on the angiographic plane on the left.

In the general case, the signal obtained (solid line in fig.2) is the contribution of four main phenomena: breathing, heart beating, myocardial dyeing and noise. The first two, especially breathing, are a main artifact that might distort the staining pattern. Each phenomenon has

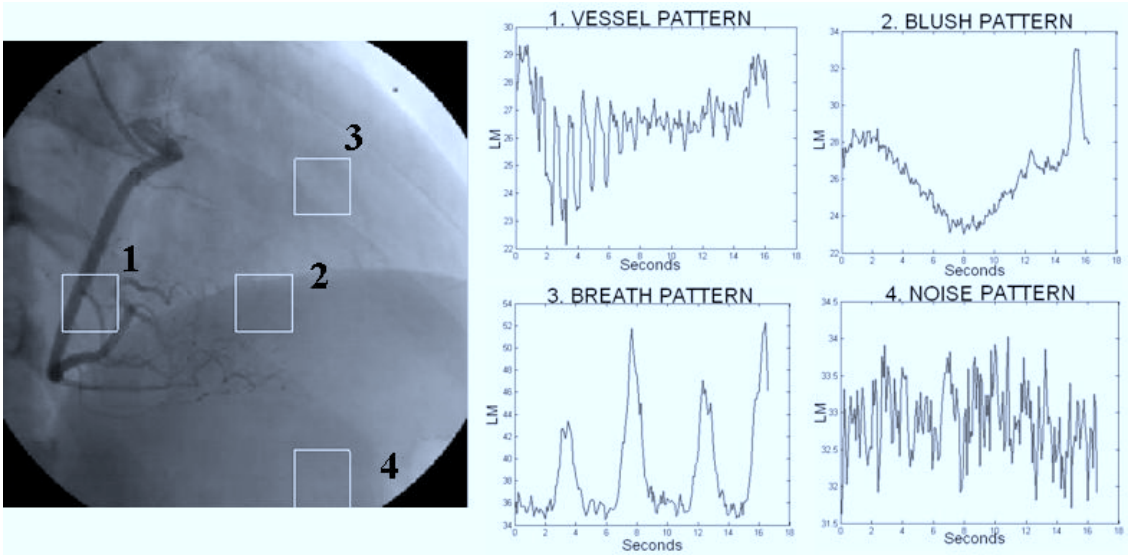

Figure 1. Patterns for the different areas: arterial staining (1), myocardial staining (2), breathing (3) and noise (4).

a distinctive repetition pattern (frequency) and, thus, the Fourier development [**?**] of LM decouples them. Their frequency range is learned by supervised classification of the Fourier development of a training set of signals. The training signals were extracted from sequences obtained as follows. For each patient three different sequences were recorded. A first one without contrast injection in order to capture cardiac and breath movements. A second one recording the contrast with the patient in apnea, so that breathing does not interfere. And a third one with the patient breathing normally.

The analysis of the training sequences shows that the expected frequency intervals with a confidence of 90% are disjoint. Therefore, the myocardial blush can be properly extracted from sequences acquired with the standard protocol. The myocardial staining is a phenomenon that happens only once along the sequence and thus it is given by the frequency 1 of LM Fourier development. Figure 2 shows the differences between the original LM signal (solid line) and the staining pattern (dashed line). We note that patients breathing is the main contribution in LM and hides the weak staining pattern underneath.

The descriptors we propose are the amplitude and phase of the Fourier coefficient of the frequency 1. The amplitude represents the maximum staining and will be noted by I_{max}. The phase corresponds to the time (given in either seconds or number of frames) such maximum was achieved and will be noted by t_{Imax}. This set of descriptors differentiates three different areas on the angiography: arterial staining (A), myocardial staining (M) and area without staining (N). The three classes are better distinguished in the scattered plot given by the values (I_{max},t_{Imax}) as illustrated in fig.3. Each class is shown in a different color: red for arterial staining, green for myocardial staining and black for background noise. The areas used used to compute the descriptors are shown in the same color on the angiography on the right side of fig. 3.

3. Experiments

3.1. Experimental setup

Our experiments have been designed to address two issues. First, showing that the descriptors proposed characterize myocardial staining. Second that they perform equally regardless of breathing. To such purpose we have analyzed 10 healthy right coronary arteries with sequences obtained in apnea and with normal breathing. Angiographies have been recorded in DICOM format at 12.5 frames per second. The recording was done exhausting the acquisition time in order to guarantee that the staining agent is completely absorbed by the microcirculation. The sequences analyzed are clinical cases of the Hospital Universitari Germans Trias i Pujol in Badalona, Spain.

We consider that the descriptors correctly characterize myocardial staining if they discriminate, for each patient, among arterial dyeing (A), myocardial dyeing (M) and noise (N). The discriminating capability of the descriptors has been assessed by cross-validation [**?**]. Cross validation consists in training a classifier with a random sampling of each class and using the remaining pixels as test set. The classification error is the measure we have chosen to assess the discriminating rate of the descriptors. The error considered is the percentage of pixels in each class identi-

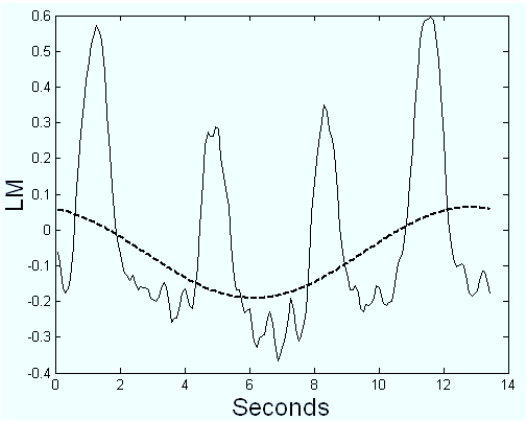

Figure 2. Extraction of the myocardial staining pattern (dashed line) from LM signal (solid line).

fied as belonging to the other classes. We report the error range (given by the mean $\pm$ standard deviation) and the maximum error for the 10 patients under study.

The classifier used was the k-nearest neighbors (k-NN) [**?**] and the training set was a uniform sampling of 500 pixels per class. The manual labelling of image pixels was done as follows. The myocardial blush area was manually traced by a clinical expert. The area swept by the artery during the sequence was labelled as arterial staining. The remaining pixels were considered background noise.

3.2. Results

Tables 1 to 3 summarize the classification error for each of the classes. Table 1 gives errors for myocardial staining with the label 'A in M' for pixels identified as artery and the label 'N in M' for pixels classified as noise. Table 2 gives the errors for arterial staining with the label 'M in A' for pixels classified as myocardial staining and 'N in A' for pixels classified as noise. Finally, Table 3 contains errors for the background class with 'M in N' standing for pixels classified as myocardial staining and 'A in N' for pixels classified as artery. First rows report statistics for the patient in apnea, second ones for normal breathing and last ones show differences between apnea and normal breathing.

The statistical ranges given in Table 1 select myocardial staining as the best characterized phenomena with a maximum error below 5%.

Table 2 shows that arterial staining is the class presenting the lowest rate of discrimination. Arterial staining and myocardial blush are prone to share some areas during the sequence. In our manual labelling such boundary pixels are assigned to the artery staining class, which increases the percentage of miss classification between arterial and blush staining ('M in A'). In sequences at 12.5 frames per second arterial dynamics do not uniformly sweep their influence area but present a jump-wise movement. This background pixels included in the arterial staining class make the number of pixels wrongly classified as noise ('N in A') significantly increase.

Regarding results on background noise (given in Table 3), the maximum source of error is, again and by the above argumentations, the pixels classified as arterial staining ('A in N'). We note that patients in apnea present a higher rate of pixels classified as myocardial staining ('M in N').

Finally, we have that there is not a significant difference between results for patients in apnea and normally breathing, especially for myocardial staining.

Table 1. Classification Error for Myocardial Staining

	$\%$ A in M		$\%$ N in M	
	Range	Max	Range	Max
Apnea	1.50 ± 1.27	3.43	1.09 ± 1.49	4.21
Breath	1.55 ± 1.96	4.96	1.13 ± 1.6	3.85
Diff.	1.43 ± 1.18	3.37	1.06 ± 1.03	2.44

Table 2. Classification Error for Arterial Staining

	$\%$ M in A		$\%$ N in A	
	Range	Max	Range	Max
Apnea	3.6 ± 3.32	9.68	11.84 ± 8.65	20.4
Breath	5.04 ± 5.58	14.15	9.76 ± 5.6	16.85
Diff.	3.84 ± 4.22	11.56	4.92 ± 4.13	11.06

Table 3. Classification Error for Background Noise

	$\%$ M in N		$\%$ A in N	
	Range	Max	Range	Max
Apnea	6.00 ± 3.82	11.6	16.0 ± 6.57	22.45
Breath	4.55 ± 2.63	8.93	13.74 ± 6.05	23.02
Diff.	3.33 ± 3.31	9.41	4.44 ± 3.6	10.9

4. Discussion and conclusions

This paper addresses objectively determining the myocardial staining pattern in contrast angiography. On one hand, we describe the different phenomena observed in an angiographic sequence and determine their influence on the staining pattern extraction. Breathing is selected as a major interferer on the myocardial staining. On the other hand, two descriptors based on the evolution of image gray level local statistics are presented. The set of descriptors detect three main phenomena: myocardial staining, arterial staining and noise.

Experiments focus on two main issues. First assessing the descriptors capability to characterize the myocar-

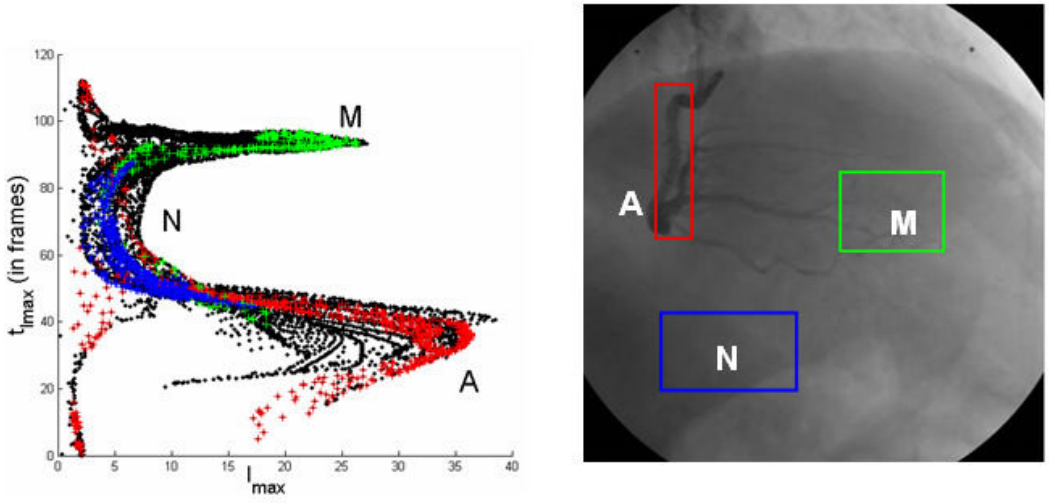

Figure 3. Different Staining phenomena detected.

dial staining. Second wether their performance its affected by patients breathing. In order to address both topics sequences with the patient in apnea and normally breathing were recorded. The discrimination rate of the descriptors among noise, arterial and myocardial staining is the criterion used to assess their performance.

The negligible percentage of miss classified myocardial pixels indicates that the descriptors present a high efficiency to characterizing myocardial staining. The low rate of noisy pixels classified as blush shows their reliability. The large error in classifying arterial staining is mainly due to a difficult manual labelling and area sharing with blush staining. We conclude that the proposed descriptors allow an objective assessment of the myocardial dyeing and, thus, a quantification of the coronary microcirculation.

The increase in the error 'M in N' in apnea is due to small diaphragm movements at the end of the sequence. Therefore we consider that the most sensible choice is recording sequences with the patient normally breathing.

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