Image Processing on Regular Coronary Angiograms for Myocardial Perfusion Measurements

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Abstract

The amount of regional myocardial blood flow, called myocardial perfusion, is useful information when assessing heart conditions. We have been studying to develop a practical method to evaluate regional myocardial perfusion using coronary angiogram images (CAG).

In this kind of method, there are several associated problems: FOV (field-of-view) movement, heart-shape changes in every cardiac cycle, and blood flow through coronary arteries. In order to evaluate myocardial perfusion correctly, these undesirable factors must be overcome.

For this purpose, we developed several image-processing techniques described in this article. We applied them to several CAG data sets, which were obtained before and after circulation stimulation treatment. The results with our method show that myocardial perfusion increases after treatment. Therefore, we confirmed that our evaluation method was effective.

1. Introduction

The goal of our research is to establish a reliable method to evaluate the amount of blood in the myocardium (called myocardial perfusion) using coronary angiogram (CAG) data. Since most functional disorders of the heart are caused by ischemia in the myocardium, it is quite important to measure myocardial perfusion for understanding heart conditions.

Patients with heavy cardiac disease ordinarily undergo cardiac catheterization. This inspection clarifies the degree of coronary stenosis and aneurism size. However, it is impossible to clarify myocardial perfusion from the coronary shape. The reason is that once a stenosis occurs, the other normal coronaries begin to provide the ischemic muscle with blood. As a result, there is scarcely any relation between the coronary shape and myocardial perfusion.

Nevertheless, a method of evaluating myocardial perfusion using CAG data [1,2] is highly expected. The reason is that CAG data are obtained under regular cardiac catheterization. That is, no extra cost or other patient burden is needed for this method. However, in order to carry out this method in practice, there are several problems which must be solved. In this article, we talk about these problems and show how to overcome them.

2. Problems

Under cardiac catheterization, contrast media flowing through coronary arteries finally enters into the myocardial region. The density value of the myocardial region increases according to the volume of blood supplied by coronaries. However, it is practically difficult to evaluate myocardial perfusion by measuring the increase in the density value, because this density value also depends on the thickness of cardiac muscle.

For this reason, we use the washout time of contrast media to evaluate myocardial perfusion. It is well known that there is an inverse relation between washout time and myocardial perfusion [3]. Since the density value decreases exponentially during washout, the washout time can be represented by a half-life period of the density value; we call it "T1/2 time" in this article. T1/2 time is obtainable by drawing a time-density curve of the region-of-interest (ROI) on a target myocardium. Figure 1 shows an ideal example of a time-density curve and T1/2 time.

Obtaining an accurate T1/2 time requires a correct time-density curve. However, three factors listed below deteriorate the accuracy of such a time-density curve:

1) ROI movement in cardiac cycles
2) FOV (field-of-view) movement
3) Blood flowing through coronary arteries

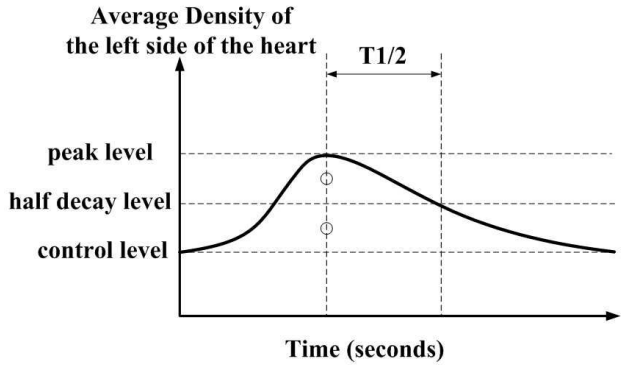

Figure 1. Typical example of time-density curve and T1/2 time.

3. Methods

3.1. Select the appropriate cardiac phase

The shape of the heart changes greatly during a cardiac cycle. The position of the heart also moves markedly per cycle. For these reasons, the region inside the ROI circle at a certain cardiac phase does not correspond to that at the other cardiac phases. In order to ensure that the ROI always indicates the same region, we use only frame images of the same cardiac phase.

There are 15-20 phases in one cardiac cycle in our CAG image. ED (end-diastolic) and ES (end-systolic) phases are easy to detect, but they are not appropriate for this purpose because of their lack of stability. Figure 2 shows the distance of cardiac movement between adjacent phases. This graph shows that the cardiac movement is minimal around the middle phase of ES and the next ED, so we use these phases to construct a time-density curve.

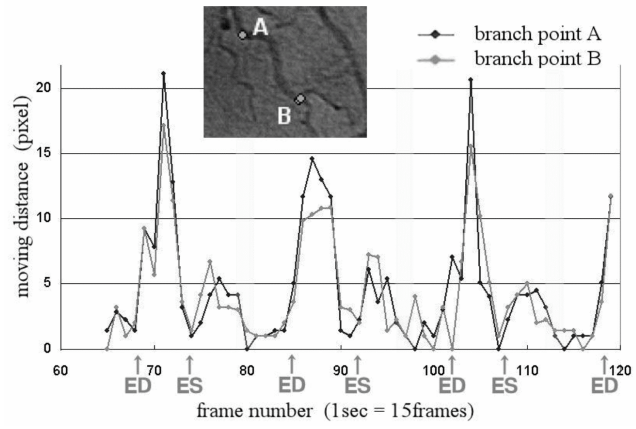

Figure 2. The distance of cardiac movement between adjacent frames.

3.2. Adjust the heart position

The original purpose of cardiac catheterization is to observe the shape of coronary arteries. For this reason, the FOV (field-of-view) of CAG is often shifted to track the contrast media. In such a case, it is necessary to reposition the ROI to its original position.

Here, instead of moving the ROI, we shift the whole image so that the position of the heart always returns to the same position. This process is performed as follows: Figure 3 shows the images in progress.

1) Select two points as reference points on two adjacent frame images.

2) Rotate and shift the latter image so that the two points on both images overlap each other.

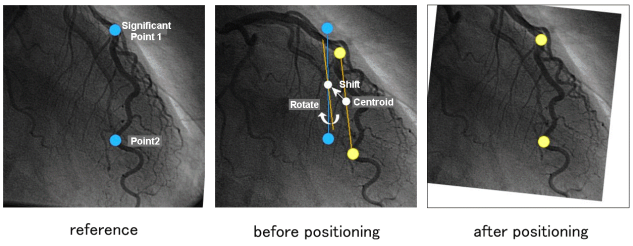

Figure 3. Fitting the heart position between the same phase images of the two different cardiac cycles.

3.3. Remove coronary arteries

If an ROI includes some coronary arteries, the density value of the ROI is increased by the blood flowing through the coronary arteries. Then, the peak of the density value appears falsely earlier, and T1/2 time is no longer correct. In order to obtain reliable results, it is necessary to extract the region of coronary arteries, and then, remove them from the ROI.

Manual segmentation is time- and labour-intensive because of the number of vessels and frames involved. On the other hand, automatic segmentation is almost impossible because coronary arteries in CAG are not clearly displayed. To solve these problems, we developed an interactive, semi-automatic method for coronary segmentation. The procedures are described as follows:

1) Set several points inside the coronary arteries. At the same time, input the widths of the coronary arteries at each point. Only this step is done manually. The following steps are processed automatically:

2) Connect between the adjacent points with straight line, and then, the line is reshaped using the SNAKES algorithm so that it goes along the coronary artery.

3) Expand the width of the curved line to the width of the coronary arteries.

The details of step 2) are described below in Figure 4.

2-1) Divide one section of adjacent points into n-equal parts. In Figure 4, section P_1 to P_2 is divided into points S_1, S_2, ..., and S_{n-1}. Lines l_1, l_2,..., and l_{n-1} are the lines vertical to the section P_1P_2 passing S_1, S_2, ..., and S_{n-1}, respectively.

2-2) Select one of the vertical lines randomly. Here, we suppose l_i is selected.

2-3) Move S_i dot by dot along the line l_i within a certain width to find the position which minimizes the sum of the smooth energy, E_{smooth}, and the image energy, E_{image}.

E_{smooth} is simply calculated as the length of the path $P_1S_1S_2...S_{n-1}P_2$. The value is smallest when the path from P_1 to P_2 is straight. E_{image} is calculated by the following equations (1)-(3). Here, $f_i(x)$ represents a pixel value (the inverse of the density value) on the line, l_i, with the distance, x, from the line P_1P_2.

$$E_{image} = \sum_{i=1}^{n-1} \sum_{x=-\alpha}^{+\alpha} w_i(x) f_i(x) \quad (1)$$

$$w_i(x) = \begin{cases} 1 \quad \dots \quad (|x| \geq r_i) \\ x^2 / r_i^2 \quad \dots \quad (|x| < r_i) \end{cases} \quad (2)$$

where $$r_i = \{(n-i)r_1 + ir_2\}/n \quad (3)$$

2-4) Repeat 2-3 and 2-4 until the shape of the path $P_1S_1S_2...S_{n-1}P_2$ is unchanged.

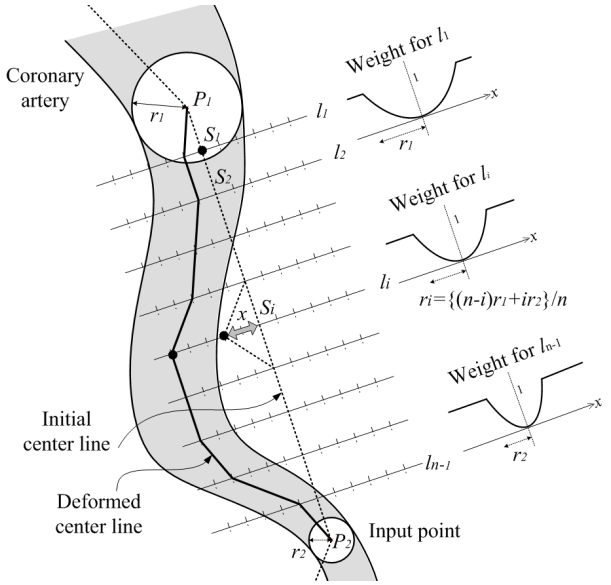

Figure 4 Extracting process of coronary artery

The processing time for one data set is 10-20 minutes. Most of the time is spent on the manual operation in step 1).

Results in progress are shown in Figure 5. An example of the time-density curves of the ROI with and without coronary arteries is shown in Figure 6.

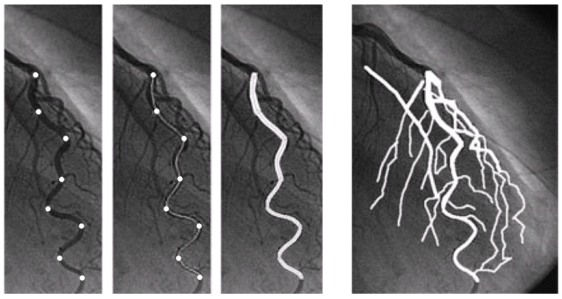

Figure 5. The processing of coronary segmentation

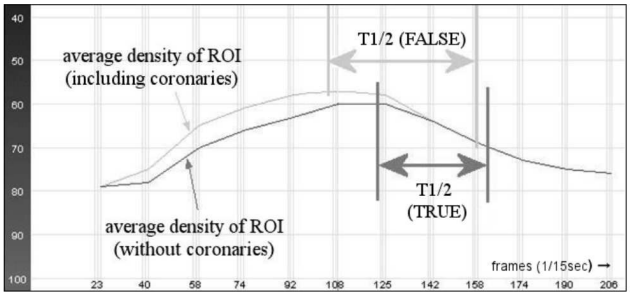

Figure 6. Time-density curves and T1/2s of the same ROI.
Upper line : including coronaries.
Lower line : not including coronaries.

4. Results and discussion

We have applied the method to left CAG data sets of 30 patient studies. The size of the image is 512 x 512 pixels and the frame rate is 15 per second. For each data set, a time-density curve is constructed.

A method to derive the absolute amount of myocardial perfusion from T1/2 time is currently under investigation. Now, T1/2 time is applicable only for the comparison between before and after treatment or operation carried out in the same patient. We have six CAG data sets obtained before and after circulation stimulation treatment by infusing 5'-ATP (adenosine triphosphate). We used them to examine the validity of our method. To minimize local dependencies, six ROIs are set around the left anterior coronary.

We could compare T1/2 time only for two sets of the six CAG data sets. For three data sets, we could not obtain a reliable time-density curve from either before or

after treatment data. The last one was also useless because contrast media flowed into the left cardiac ventricle. Two pairs of time-density curves, both of which seemed reliable, are shown in Figure 7.

In the upper graph, the density peak of before treatment appears at the 110th frame and the half decay time appears at the 134th frame. Therefore, T1/2 time in this case is 24 frames long, i.e, 1.6 seconds. Similarly, T1/2 time after treatment is 1.2 seconds. These results indicate that T1/2 time decreases by 25% via the treatment of infusing ATP.

T1/2 times as to six ROIs of the two data sets are shown in Table 1.

These results show that most of T1/2 times decrease after ATP treatment. (data I: by 14-53% for 5 of 6 ROIs, data II: by 19-53% for 6 of 6 ROIs.) These results clearly correspond to the effect of ATP, so, we can say that the myocardial perfusion measured by our method is consistent with the physiological view.

To improve CAG acquisition method suitable for constructing time-density curves, and to establish the method to evaluate absolute myocardial perfusion from T1/2 time are our future tasks.

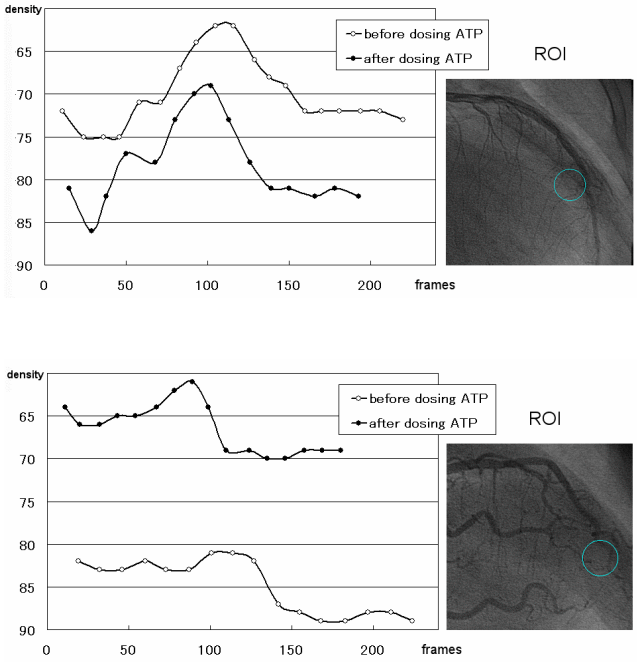

Figure 7. Time-density curves of two patients. The line with white nodes is the curve of pro-treatment with ATP and that with black nodes shows that of post-treatment.

Table 1 Evaluated T1/2 value of each ROI of the two CAG data.

Data	ROI	T1/2 (before)	T1/2 (after)	decrease ratio(%)
1	1	1.9	0.9	53
1	2	1.6	1.2	25
1	3	1.7	0.9	47
1	4	1.4	1.2	14
1	5	1.5	1.1	27
1	6	1.3	-	-
2	1	4.0	1.9	53
2	2	1.6	1.3	19
2	3	1.5	0.7	53
2	4	1.7	0.9	47
2	5	1.8	1.4	22
2	6	1.7	1.0	41

5. Conclusions

We proposed a method to evaluate myocardial perfusion from regular CAG data. In order to evaluate myocardial perfusion from T1/2 time, it is necessary to obtain reliable time-density curves by removing FOV movement, ROI movement, and the effects of blood flowing through coronary arteries. We showed the validity of our method using CAG data sets obtained before and after treatment by ATP dosing.

Acknowledgements

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