lCORONARY ARTERY FLOW CALCULATION BASED ON THE CORONAROGRAPHIC IMAGES: VALIDATION ON THE CLINICAL DATA

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Abstract: The use of the indicator-dilution technique permits the calculation of absolute values of the blood flow in coronary arteries from the densitometric analysis of coronarographic image sequences under some specific conditions imposed on injections of a contrast medium and digital image sequences registration. Our method is based on densitometric measurements carried out in two sequences of images of the same artery. The first sequence is recorded during a routine injection of a contrast, and the other one is recorded during a slow test injection of a contrast with a reduced amount of the indicator. The method was tested on coronarographic images obtained in routine examinations in two groups of control patients. The comparative analysis of 18 pts indicates that there exists a moderate correspondence between the results of our method and the clinical assessment. The results of our studies are strongly dependent on the accuracy of the measurements and method of recording. Our method, tested on a model of an artery and measurements made on control patients, provides grounds for future studies.

Introduction

The knowledge of the absolute values of blood flow in clinical studies plays an important role primarily in the detection and objective assessment of the degree of impairment of circulation in the absence of coronary artery stenosis (X-syndrome diagnosis) as well as in the assessment of coronary reserve and objective and immediate evaluation of the efficacy of percutaneous transluminal coronary angioplasty (PTCA).

It may also be useful in establishing standards in normal and slow blood flow.

Materials and Methods

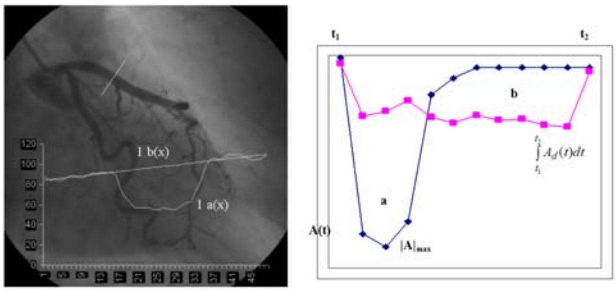
The use of the indicator-dilution technique enables the calculation of absolute values of blood flow (Equation 1) in coronary arteries from the densitometric analysis of coronarographic image sequences under some specific conditions imposed on injections of a contrast medium and digital image sequences registration.

The flow is directly proportional to the amount of the injected contrast medium V and inversely proportional to the area under the indicator's density curve $A_d(t)$ and depends on the radiographic factor A_{max} (1).

$$Q = \frac{V}{\frac{1}{A_{\max}} \int_{t_1}^{t_2} A_d(t)dt} \qquad (1)$$

Our method involves a densitometric analysis of two image sequences of a left or right artery cross-section. The first sequence is recorded during a routine injection of the contrast ensuring complete fill-up of part of the proximal artery, and the other sequence is recorded during a slower injection of a reduced amount of the contrast medium, called a test injection, usually performed prior to the routine examination (Figure1).

This method makes it possible to calculate the radiographic factor based only on densitometric measurements, whereas the analysis of the contrast medium density curve recorded during the slow injection of a reduced amount of the contrast significantly eliminates the effect of the injection of the contrast on artery blood flow [1,4,5].



a) b)

Figure 1: The analysis of brightness distribution $I_a(x)$ across the artery cross-section (a) and the densitometric curves for two image sequences (b)

The method requires that specific conditions be fulfilled as to the execution and recording of coronarographic examinations, some of these conditions being:

- Constant field of vision that subtends the area of the heart muscle.
- Recording that includes the complete process of injection and removal of the contrast.

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- Recording of two injections; the first one being a fast routine injection using a larger amount of contrast, and the other being a test injection of a smaller amount of contrast, coupled with recording of the amount of contrast injected.
- Constant parameters of exposure (voltage and current) in the recording of both types of injections.
- Digital archiving of image sequences.

For positioning of artery cross-section lines in a sequence of moving artery images a semi-automatic method based on the calculation of a intercorrelation coefficient (according to the expression 2) was applied.

$$C(k,l) = \frac{\sum_{i=0}^{m-1}\sum_{j=0}^{n-1} R(i,j) * S(i+k, j+l)}{\sqrt{\sum_{i=0}^{m-1}\sum_{j=0}^{n-1} R^2(i,j) * \sum_{i=0}^{m-1}\sum_{j=0}^{n-1} S^2(i+k, j+l)}} \quad (2)$$

For each pair of regions with m, n dimension from the consecutive images $R(i,j,t)$, $S(I,j,t+1)$, the indices k and l (for which the intercorelation coefficient $C(k,l)$ has a maximum value) indicate a new position of the object to be found (cross-section line) [5].

Results

The experimental verification of our method using a model of an artery was carried out following the specific conditions imposed on the technique of execution and the recording of two injections of a contrast medium has shown that the experimental error was not higher than 20% [3].

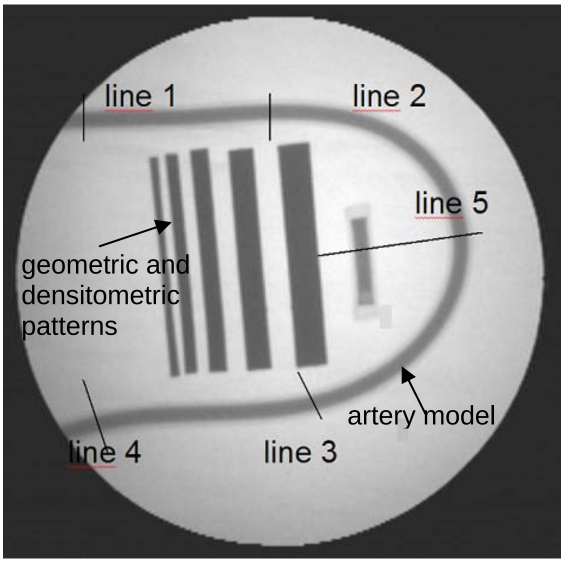


Figure 2: Positioning of the cross-sections lines

The densitometric measurement were made for 5 cross-section lines (Figure 2). Table 1 presents the results for experimental validation.

Table 1: Results for experimental validation

Line	Sum A_d	A_{max}	Q [ml/sec]	Error
Line 1	-83,3	-2,38	12,86	13,187%
Line 2	-85,77	-2,6	13,64	20,08%
Line 3	-91,33	-2,62	12,91	13,64%
Line 4	-81,4	-2,22	12,27	8,03%
Line 5	-86,13	-2,16	11,29	-0,66%

Test clinical examinations carried out in accordance with specific conditions imposed to ensure the usefulness of the method of blood flow determinations incorporated recordings of 32 cases (64 image sequences), including 6 examinations with slow dye progression (SDP) and 26 standard examinations.

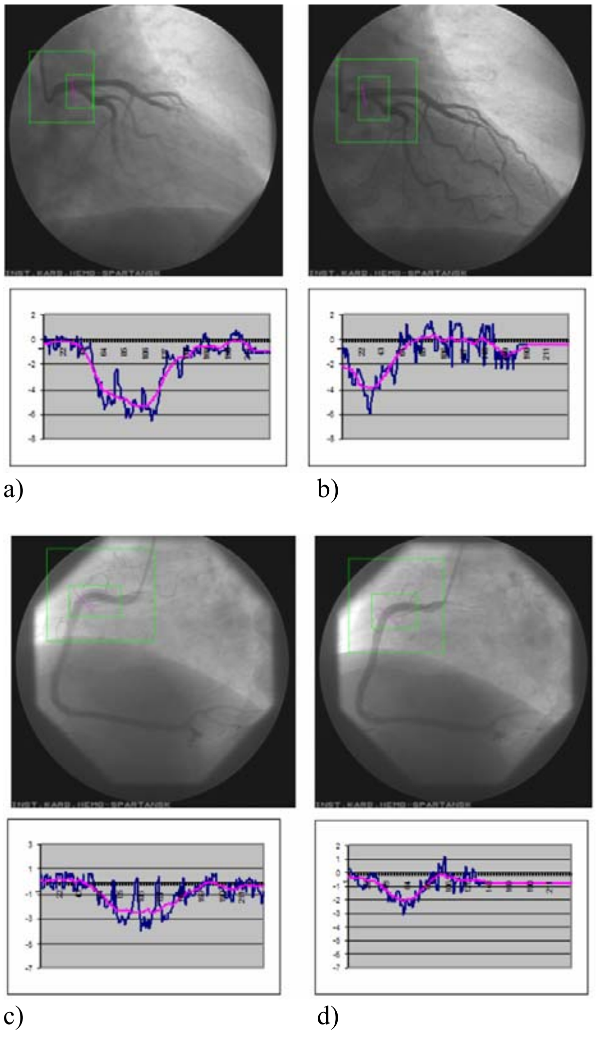
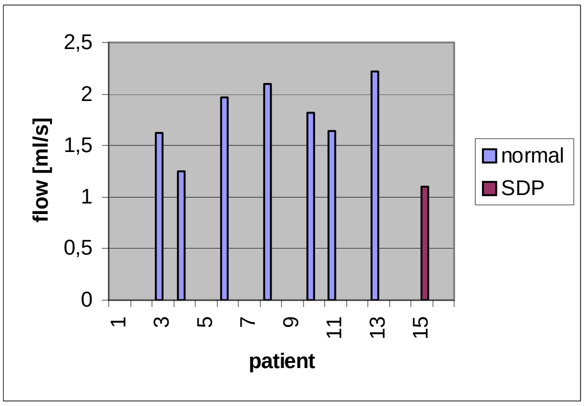


Figure 3: Examples of images of four sequences obtained in a coronarographic examination of one patient and the densitometric curves for each sequence for the left artery: a) standard injection, b) test injection, as well as for the right artery: c) standard injection, d) test injection.

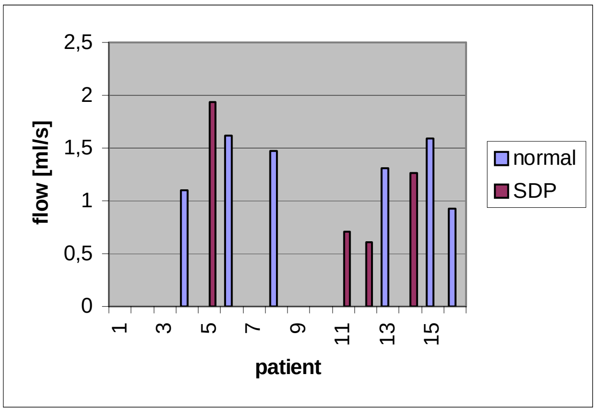
Preliminary analysis of the results made it possible to select 18 recordings, all the other recordings having failed to meet the conditions presented above. Figure 3 shows typical images of the coronagraphic recordings of one patient (four image sequences: two sequences of the left and right artery each and the corresponding densitometric curves).

The results obtained when testing our method on selected clinical data lie within the range of values given in medical literature, and provide a general confirmation of the measurements made. On the other hand, the comparative analysis in 18 patients, including 13 normal flow cases and 5 slow dye progression (SDP) cases indicate a moderate agreement with clinical assessment, the results in two SDP cases exceeding the values qualified as normal.

Shown below is a graphic presentation of the results.



a)



b)

Figure 4: Normal and SDP blood flow values in patients taken from the left (a) and right (b) coronary arteries.

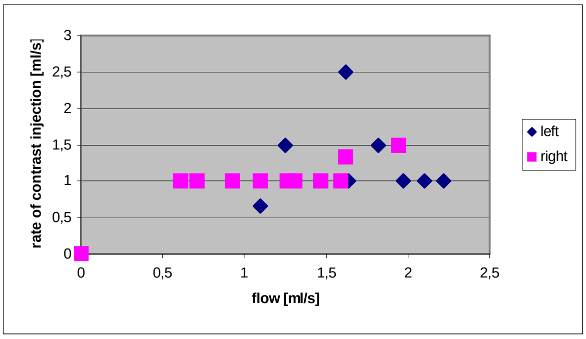
By analyzing the results one may conclude that:

- They are contained within the limits of coronary artery blood flow values quoted in the medical literature of 0.3 to 2.5 ml/s [2,6], which is a good confirmation of our method.
- In the left artery (Figure 4a), the minimum value of blood flow calculated was found in patient No. 15, which corresponds to the clinical assessment of SDP, and for the right artery (Figure 4b) two lowest values were obtained for patients Nos. 11 and 12, which is also in agreement with the clinical assessment of SDP. On the other hand, for patients Nos.5 and 14, also qualified for the SDP group, the values obtained were higher than those in patients with a normal blood flow. It may thus be concluded that a moderate degree of consistency was obtained between the results of the coronary blood flow measurements with the use of an indicator-dilution technique and the clinical assessment of patients.

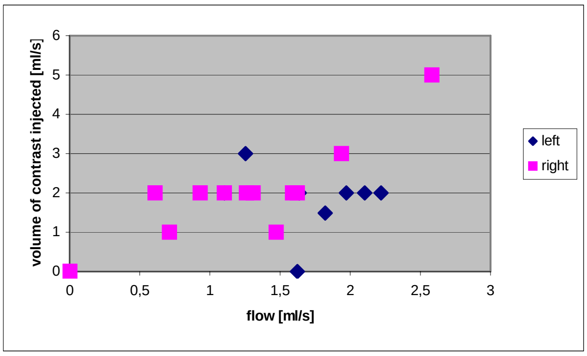
Summary

The blood flow values obtained in our measurements were undoubtedly affected by the following factors:

- Failure to meet one of the fundamental assumptions inherent in our method of administering the test contrast injection (with a diluted indicator), which causes a significant contrast medium reflux to withdraw to the inside diameter of the aorta and disturbance of the flow measured. The presence of the reflux leads to higher results.
- The algorithm used in calculations overestimates the value of A, and thus also the value of the area under the $A(t)$ curve. This factor leads to the underestimation of blood flow.
- The ambiguity in the calculation of A_{max} which corresponds to the area of the cross-section of the artery completely filled-up – in theory – by the contrast, the maximum value of the averaged $A(t)$ function being taken into consideration.
- The analysis of the area under the $A(t)$ curve, which embraces the various number of heart cycles, generally incomplete and differing from patient to patient. When the blood flow is pulsative and is characterised by a high amplitude and the analysis involves a small number of cycles, the mean value of blood flow may be either overestimated or underestimated.
- Different values of exposure parameters, such as high voltage applied in both types of sequences.
- Lack of standarisation for injection procedures, although the preliminary analysis in this case does not indicate a significant correlation between the rate and amount of the contrast injected and the value of the blood flow measured. Below are shown distributions of the rate and volume of the contrast injected as a function of the flow calculated for the left and right artery (Figure 5), confirmed experimentally.



a)



b)

Figure 5: The distribution of the rate (a) and volume (b) of the contrast injected as a function of the blood flow calculated for the left and right artery (lack of any significant relationship).

Discussion

The blood flow values calculated using the method outlined above are strictly dependent on the accuracy of the measurements made both as regards the techniques used and recording of the examinations (the densitometric analysis of the images investigated shows some inaccuracies in the assumptions inherent in the method as well as in the way by which contrast is administered in both types of injections, which leads to both underestimation and overestimation of results) and the calculation algorithms used.

Conclusions

Our studies have led to the following conclusions that affect further studies:

- Recalculation of the blood flow values given in ml/s into those expressed in ml/ heart cycle.
- Clinical assessment using a four-stage TIMI of TFC scales [7], which would provide a more accurate differentiation of patients investigated and a better analysis of the results obtained.
- Verification of the results using other densitometric techniques.
- Testing the above method on technically superior image data (eg. without any visible intertlace) obtained in the studies carried out strictly in accordance with specific assumptions.

The verification on the artery model and the measurements carried out on the test clinical data forms the basis for future studies. However, one should bear in mind that although the requirements imposed on the techniques used reduce the usefulness of the method from the clinical point of view, they do not seem to hamper the development of the method if only due to the inevitable development of X-ray equipment.

Acknowledgements

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