

# MATLAB IN CATHLAB - DIGITAL DENSITOGRAPHY AFTER FIVE YEARS

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## Abstract

**Our attempts to develop the method of digital densitography employing advanced data treatment technology began in the 2003. Only the choice of the Matlab mathematical environment in the 2004 started a really quick progress and enabled a new branch of systematic research of heart microcirculation. Its first promising results could have been presented already at the TCP 2005 conference. Recent contribution describes the main principles of the method and its development and achievements reached over the last years. Just to name one of them the method is unique in its ability to reveal the so called syndrom X and to evaluate the effectiveness of its treatment by medication.**

## 1 Introduction - Principles of Digital Densitography (DDG)

The injection of vasographic contrast medium into one of the main coronary arteries is used to visualize the blood supply of the heart muscle for already more than fifty years. Quite early the accompanying effect of this operation - gradual appearance and disappearance of so called myocardial blush was noticed. This darkening and subsequent lightening of the image of the heart reflects the change-in-time of the concentration of the contrast medium in the heart tissue and thereby carries information on the quality of its microcirculation in scales below the normal visual resolution of the investigation. Since then attempts to use this information have started as is described in [1] and the references therein. However, only with the development of the advanced data storage and data treatment technology a useful method to accomplish this task could have been developed.

We have chosen Matlab mathematical environment above all for its matrix capabilities, easiness to build GUIs and since we planned to give the method away to other groups, its open policy of simple possibility to deploy the software products officially. We have developed the program Cathlab which works on digitized data a sequence of figures taken from the investigations of heart. It mainly enables to select *active data regions* (ADR) in which the density i.e. darkening information is being treated as a function of time [2]. The time dependence of density in each ADR results in a *washout curve* (WOC) which is in fact equivalent to uncalibrated *indicator dilution curve* (IDC) used in some fields of invasive cardiology. Our contribution, literary priority, lies mainly in formulating the conditions under which the investigation yields data for reliable treatment, in finding out meaningful and reproducible parameters derived from WOC and designing procedures to calculate them and in starting and maintaining systematic research using the DDG method with a feedback to its further development.

## 2 Development – Multi-rectangular Treatment

To illustrate the kind of information our method can give in addition to the standard visual examination we show an example of haemodynamically significant narrowing of the left anterior descending coronary artery (i.e. the ramus interventricularis anterior of the left coronary artery) causing limited perfusion of the region it supplies and the result of its interventional treatment by stenting.

In Fig. 1a one (44<sup>th</sup>) frame of an investigation of a patient before treatment is depicted. The image of heart is divided into the multi-rectangular ADR in the main sub-window on the left. The grid pattern used is 6 x 8 and it can be pre-selected in advance. Note the narrowing of the artery in the rectangle 1/4. To study perfusion it is necessary to select the *representative sub-ADR* which has special functions. Here it is the rectangle 4/6 surrounded by the yellow frame. The WOC from this sub-ADR appears in the density sub-window in the middle. The parameters for further calculations are

selected using this representative WOC. Although entire WOC should be used, recently we employ only information from its wash-out i.e. descending phase. These parameters shown as little blue circles are the density background (DB), slope margin beginning (SMB) and slope margin end (SME). They can be effectively selected by the user after reaching a certain level of experience. This particular WOC is good but far not ideal for treatment. The injection should have been performed few seconds later and the investigation should have taken longer. Anyway, the perfusion in the representative rectangle is apparently reasonable and this fact is also supported by the fit. The WOCs from all the sub-ADRs as well as their fit appear in a separate multi-fit window as shown in the Fig. 1b. The user can select a threshold slope which decides in which rectangles the perfusion is considered automatically sufficient and later manually accept or reject other rectangles after more subtle considerations. The finally accepted regions have white background and in the main sub-window they are surrounded by white frame. This selection is to a certain extent subjective and here for instance some other rectangles such as 3/7 and 4/7 could be accepted if a less strict threshold was selected. This illustrates the fact that absolute information gained by the method is questionable. Let us however look at the examination of the same patient few minutes later after stenting as depicted in the Fig. 2ab. The microcirculation clearly improved as can be seen both from the slopes as well as from the size of the accepted region. Even more dramatic change could be seen after applying medication [1].



Fig. 1a: A patient with significant narrowing of the left anterior descending coronary artery visible in rectangle 1/4 before treatment. Perfusion in the region surrounded by white contours is considered as sufficient. In the density sub-window a washout curve from the representative rectangle marked by yellow frame is depicted. The context sensitive controls on the right hint the idea how the program is controlled.

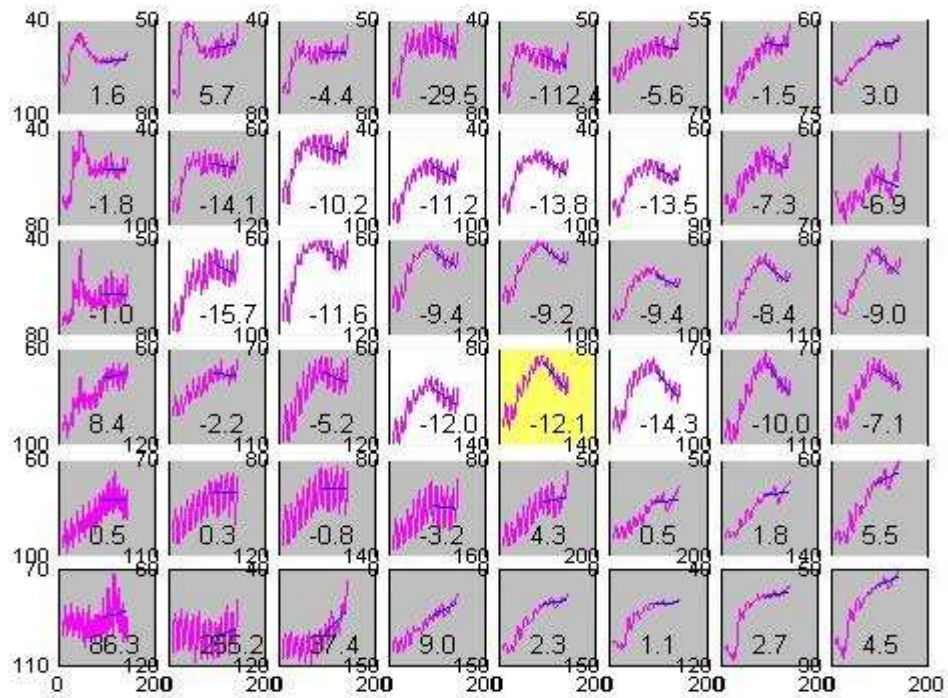


Fig. 1b: The multi-fit window. The shapes as well as fits of slopes of WOCs corresponding to previous sub-ADRs are visible. The accepted regions are highlighted by white background. They are calculated automatically and then the user can manually select or reject regions using more subtle considerations.

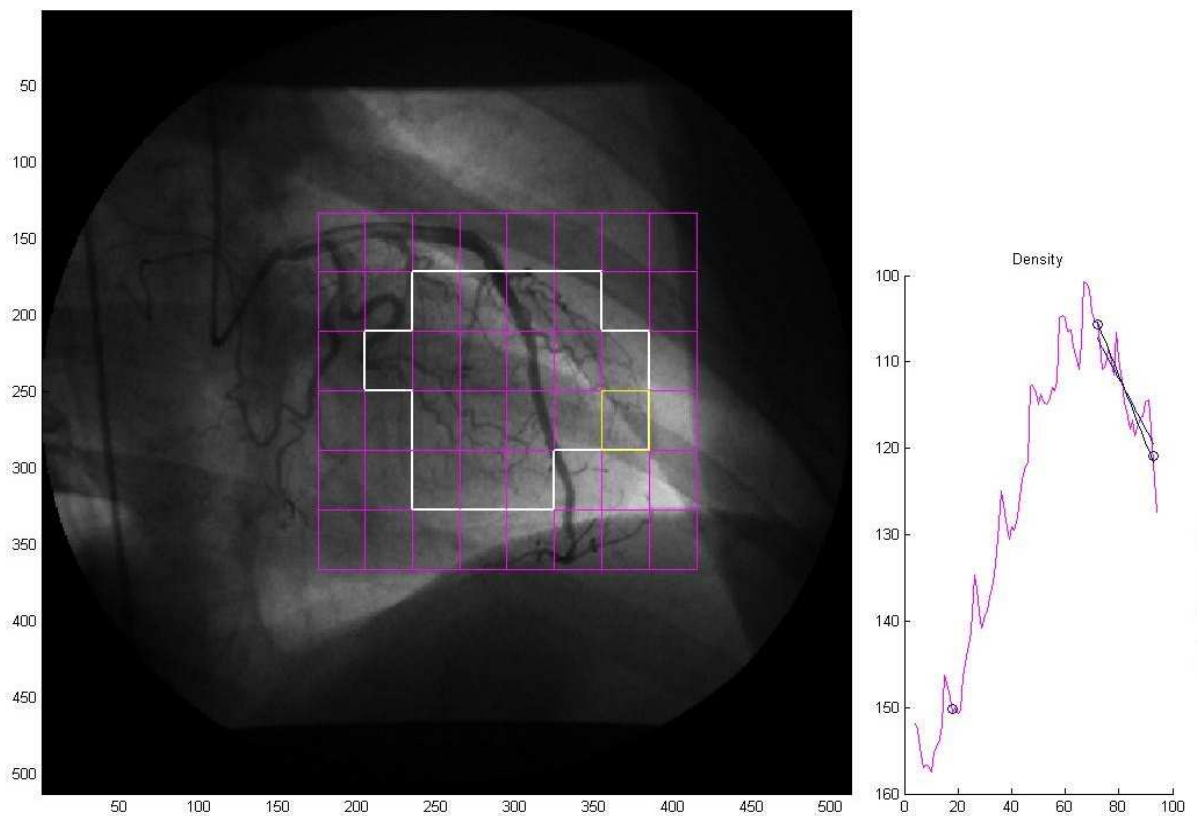


Fig. 2a: The same patient after stenting. The area with sufficient perfusion has clearly enlarged.

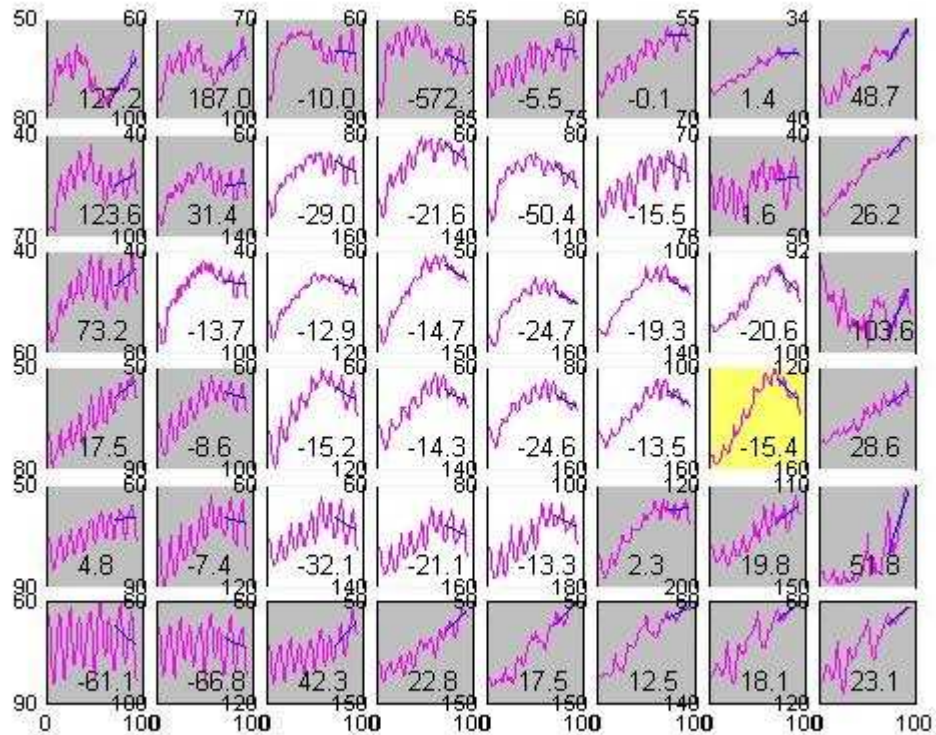


Fig. 2b: The corresponding multi-fit window. Note that the absolute values of the slopes have also considerably increased so several regions which were questionable now represent clearly good perfusion. Moreover, some more rectangles could be accepted.

When visual coronarography shows a problem such as the narrowing in the previous example the role of our method may be considered as only a supporting one. However, treatment of several hundreds of patients has shown that there is a certain group of patients who have objective cardiac problems yet the standard visual coronarography shows normal results i.e. the problem lies beyond its resolution. Even in this case of so called syndrom X the DDG clearly displays the problem as well as the effectiveness of its treatment.

Fig. 3ab show examination of a patient with syndrom X. The coronarography picture is normal. Stenosis can not be seen even by an expert. We have deliberately chosen an examination performed in the early days of the development of our method before we have stressed that the patient wouldn't make a slightest movement. Consequently data treatment in this case is aggravated by the fact that the patient breathed in the beginning. Also the contrast medium was injected too early and the background can be estimated only roughly. The meaning of the absolute values of the slopes is thereby problematic. Still an experienced user can reliably select the regions of acceptable and insufficient perfusion that can be used at least for the comparison with the investigation in the same patient after treatment.

Since the coronarography is normal, stenting is, of course, out of question and treatment by medication must be tried. Fig. 4ab shows an examination of the same patient after medication. Although the original investigation data are of bad quality and the progress caused by the medication lies in finer details of the WOC it is clearly seen by the DDG.

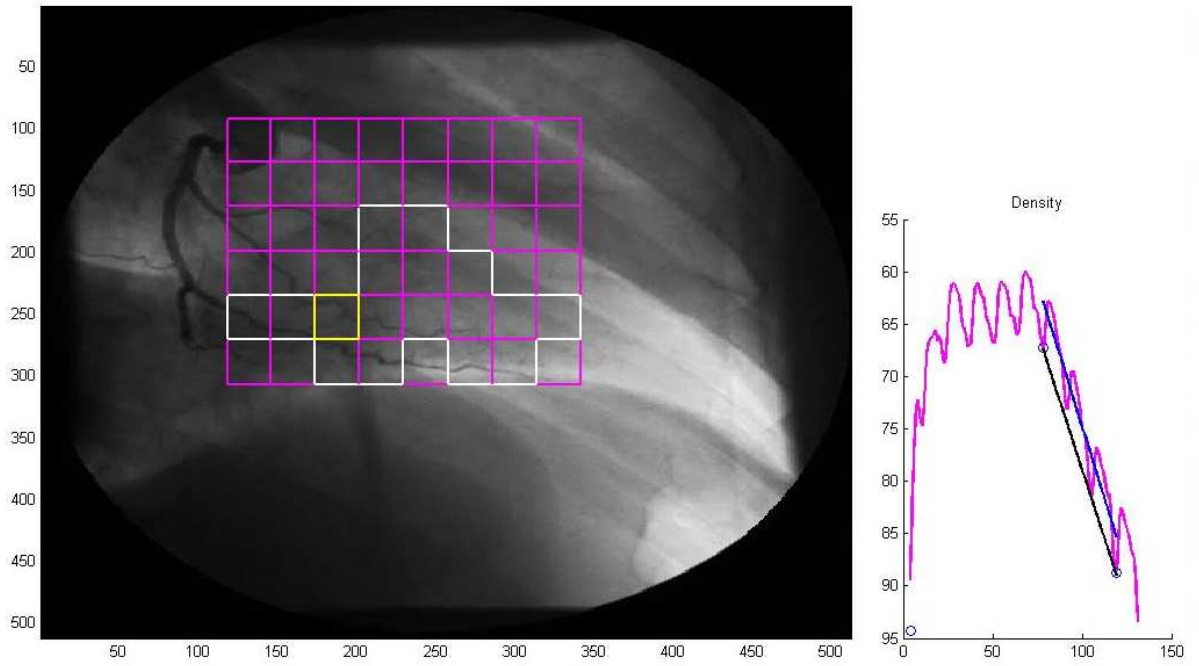


Fig. 3a: A patient with the syndrome X before treatment.

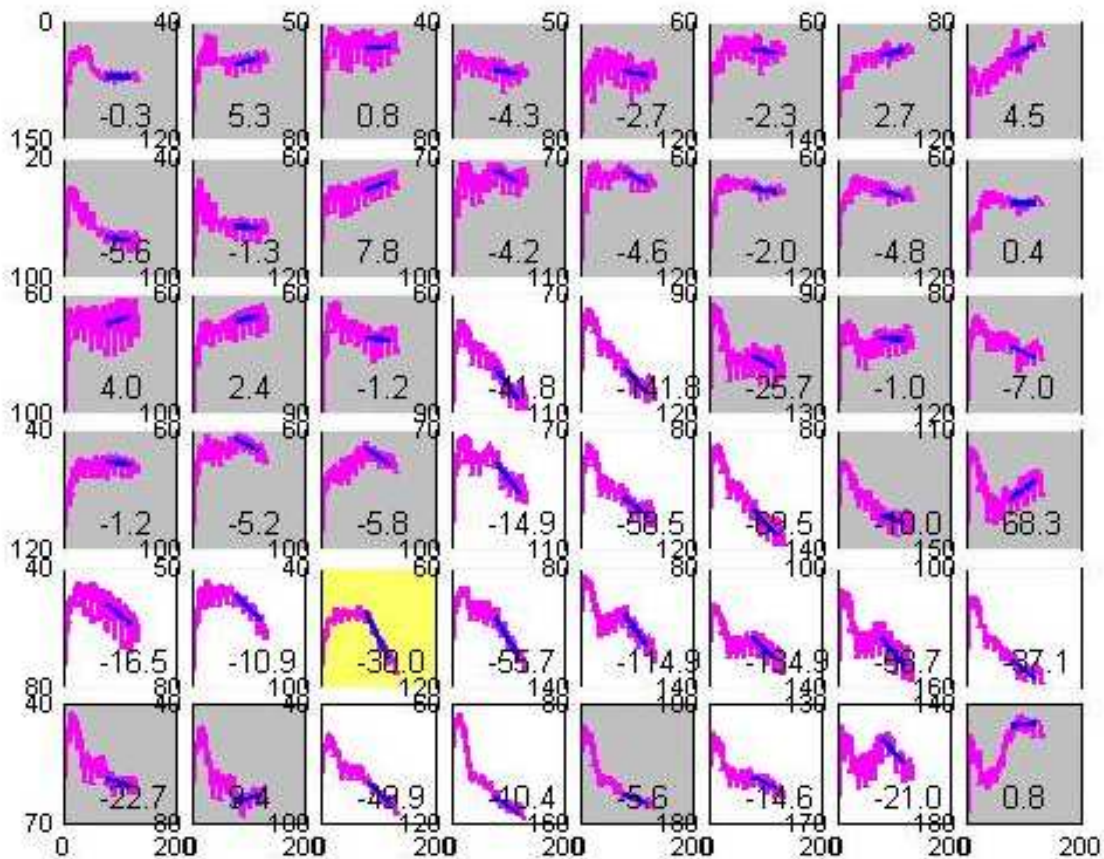


Fig. 3b: The corresponding multi-fit window. Note that data are of very poor quality. The patient has breathed and the background can be only roughly estimated. Still a region with reasonably good perfusion can be plot based on subtle details of the WOC.

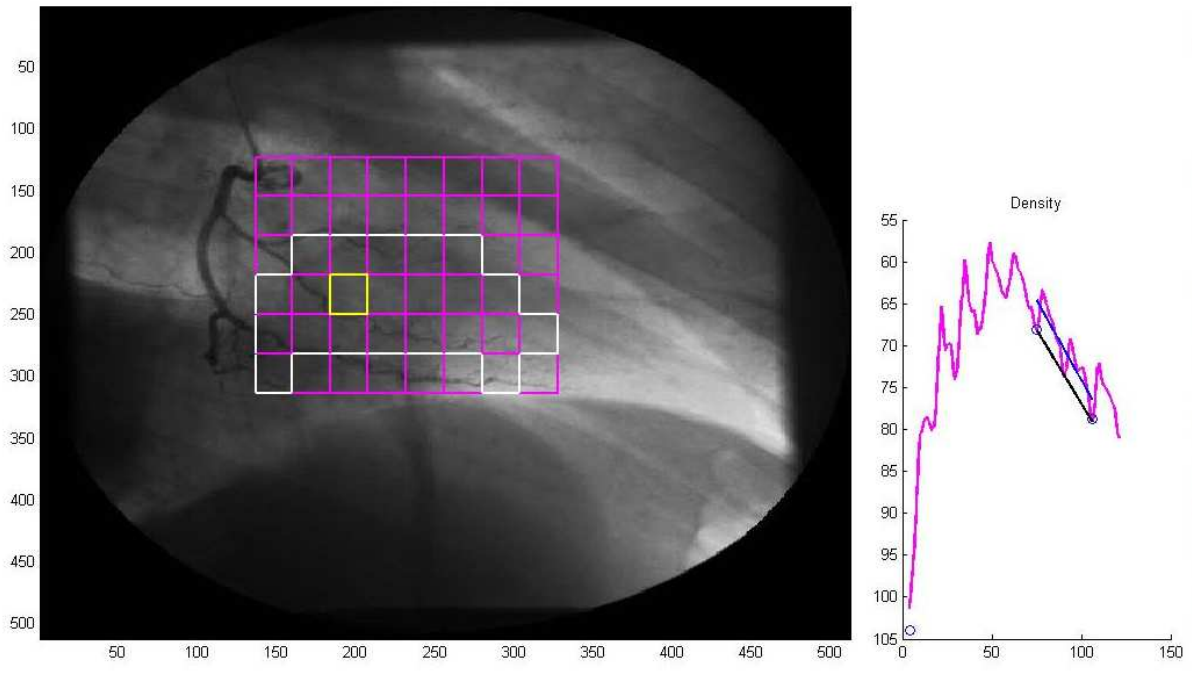


Fig. 4a: The same patient after applying medication. The area with sufficient perfusion has enlarged.

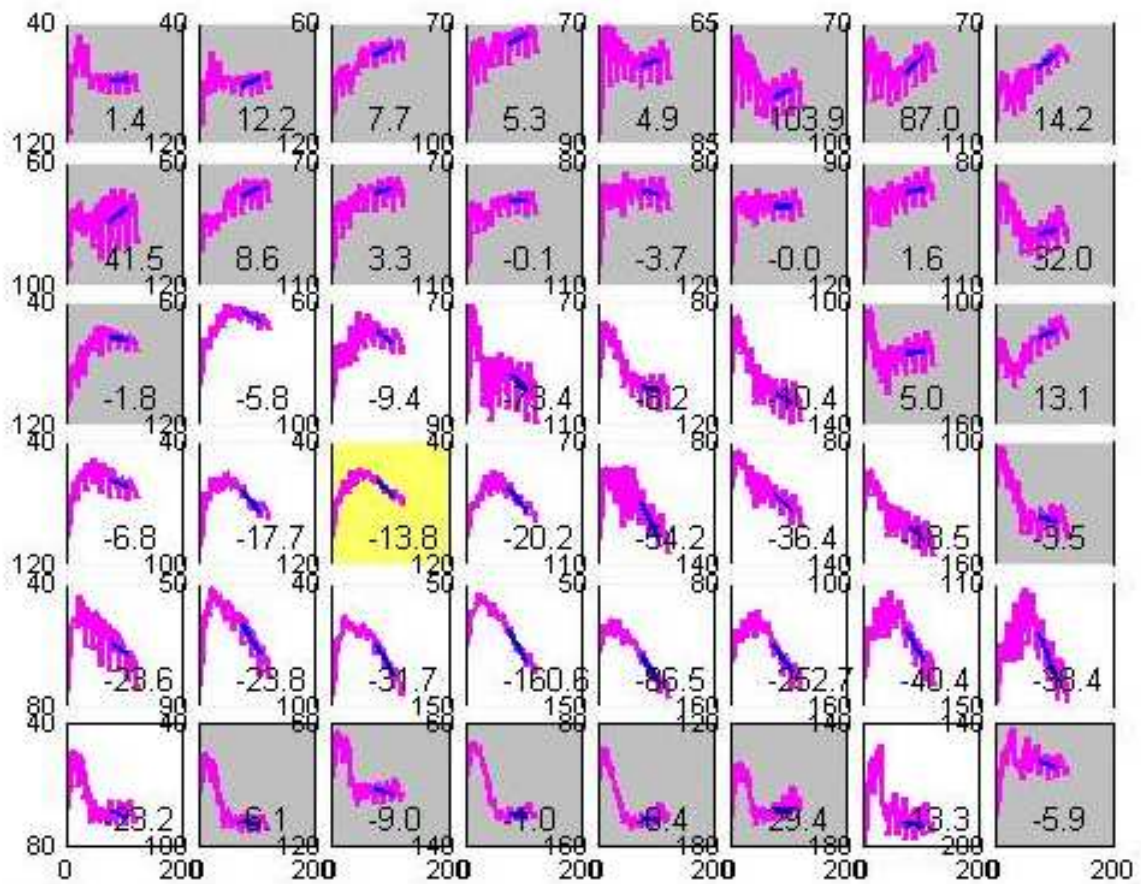


Fig. 4b: The corresponding multi-fit window. Again the accepted area is based on subtle details yet the improvement is evident.

## 4 Conclusions – problems and compromises

We have built a system where the user's experience is combined with high performance automation leads to objective and reproducible evaluation of microcirculation. Let us discuss some important questions and aspects of the method.

*We deal only with 2D projection of a complicated and moving 3D object.* The investigation can use most suitable projection or several projections for investigation of a particular region. The DDG can be used as well for treatment of other, particularly non-moving, organs such as kidneys.

*Both the single or multi-rectangular ADR is fixed and the heart moves behind it.* However we anyway deal with a 2D projection of the heart and a certain sub-ADR still holds information from a certain limited region of it. The ADR grid could in principle be fixed to certain 'orientation' points, e.g. walls of veins and change its size and shape with the hearts movement. Unfortunately, as the contrast medium is washed out the visibility of the orientation points changes and they finally disappear. That would mean to set the model of the movement during the period of good visibility and extrapolate to the time before and after. This would work only if the patient really doesn't move nor breathe during the investigation and his heartbeat rhythm is regular.

*Fit parameters from the representative sub-ADR may not be exactly suitable for all sub-ADRs.* This is a price for quick simultaneous multi-rectangle treatment. Considering other 'problems' the information in all sub-ADRs is surprisingly reasonably synchronized. Anyway more appropriate and exact treatment of any sub-ADR can be performed using a single ADR of a rectangular or elliptic shape.

*So far we evaluate only the slope of WOC in the washout phase.* The main reason is that the build-up-phase is strongly influenced by the speed and volume of the injection of the contrast medium. However in principle a suitable function could be found by fitting of which one could yield information also from the build-up-phase.

## References

- [1] M. Steinhart, A. Herman, L. Steinhart, P. Šmoranc & I. Vavařovský *Digital densitography a method of objective and detailed angiographic evaluation of perfusion of the myocardium.* *Interventional cardiology and acute cardiac care*, 2(7), 54-58 2008
- [2] M. Steinhart, L. Steinhart, P. Šmoranc & A. Herman *Matlab in Cathlab – densitometry in heart examination performed using Matlab.* TCP 2005 p. 114 ISBN 80-7080-577-3

## Abbreviations

ADR	active data region
DB	density background
DDG	digital densitography
IDC	indicator dilution curve
SMB	slope margin beginning
SME	slope margin end
WOC	wash out curve

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