MATLAB IN CATHLAB – DENSITOMETRY IN HEART EXAMINATION PERFORMED USING MATLAB

M. Steinhart[1], L. Steinhart[2], P. Šmoranc[3], A. Herman[4]

[1]Katedra fyziky, Universita Pardubice

[2]Katedra radiologie a nukleární medicíny, LFHK, Karlova Universita

[3]Radiologická klinika FN Hradec Králové

[4]KARDIO-TROLL, Krajská nemocnice, Pardubice

Abstract

We have proposed an original method to evaluate the time dependence of the density of the x-ray images of heart, which appears after an injection of the contract medium into one of the main coronary arteries. It has been expected for a long time that this evaluation can potentially yield important information on the biological functioning of the examined tissues. However only recently when normally available computers and programming environments are capable of handling the huge amount of data involved, retrieving of this information can be done effectively, reproductively, anywhere and at any time after the main X-ray examination of the patient. This paper illustrates that Matlab is a particularly convenient programming environment for this purpose. We describe a user-friendly interactive program in the form of a Matlab GUI developed for this purpose and experience with its use.

1 Introduction

The works on cinedensography and videodensography have convincingly demonstrated, that a vasogfraphic contrast medium can be used as an indicator for obtaining indicator dilution curves [1-4,5,6]. These methods did not gain the deserved attention, because they imposed considerable demands on equipment and time and in most applications they prolonged the original investigation of the patient. The methodically older cinedensography was seriously limited in quantification due to its significant dependence on the properties of the film emulsion.

Our contribution lies in working out an original method for creating an interactive and automatic analysis of indicator dilution curves independently on the time and place of the investigation. For this purpose any PC with a sufficient computing power can be employed and data can be transferred using any sort of a common digital carrier like CD, DVD or a flash drive.

Our further contribution or priority lies in starting a systematic research of myocardial microcirculation using our method, enabling an objective analysis of the myocardial perfusion instead of the subjective frame or cycle counting, that have been used for this purpose so far [7,8,9,10,11]. Such a research has not yet been conducted, to the best of our knowledge, by anybody else. Only Harrison in his study of contrast media [12] suggested a possibility of a similar research, but had not performed such a study himself.

We have performed more than a hundred densographic investigations. The information obtained has the expected, logical and explainable character. The present communication deals mainly with the computational, particularly the Matlab related aspects.

2 Method

The Matlab based program Cathlab works on data from investigations performed, in our case by the angiographic equipment GE ADVANTX. The scenes, aimed at evaluation of myocardial microcirculation must be at least 15 seconds long and contain about 190 frames, taken with the frequency 12.5 frames per second. This frequency is a compromise sufficient for this type of investigation, which however halves the radiation burden of the patient and also decreases the amount of data that must be dealt with. The GE ADVANTX is equipped with its own software for construction of dilution curves but further treatment of them is not possible. The software is capable of exporting the data as whole scenes in the AVI format. The usual size of each frame has 512 x 512 pixels with 256 levels of a grey scale, coded in one byte per pixel. The values 0 and 255 represent black and white colours respectively. The particular byte representation depends on the compression used.

We have found out that the most effective evaluation is the interactive one. The potential user should be a physician an expert in heart investigations and the burden of dealing with the data and calculations has to be taken by the program. The program however needs some crucial information from the user. An interactive GUI based in Matlab seems to be an ideal solution.

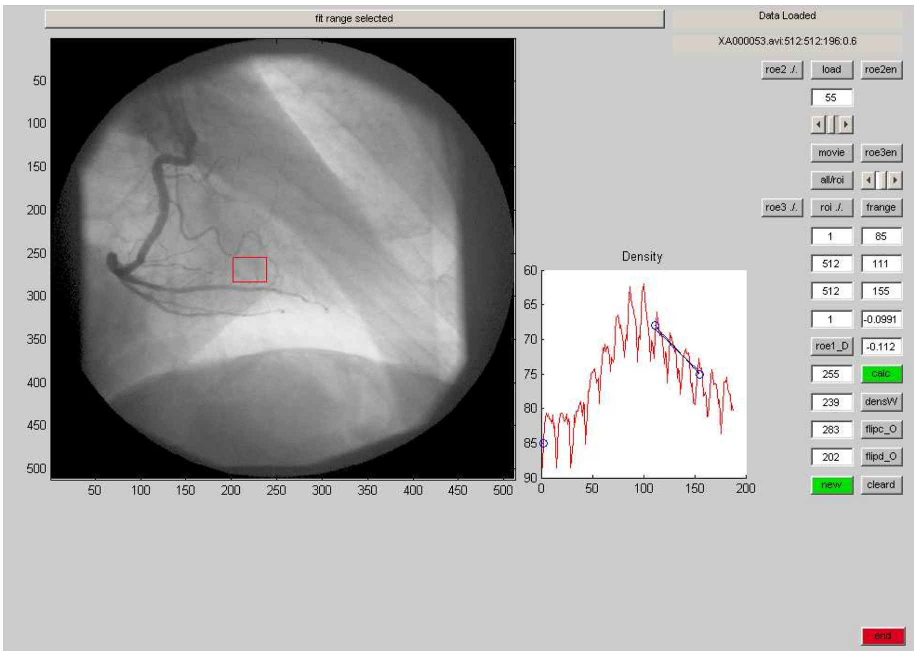

Figure 1: The GUI of the Cathlab program

The typical interface window of the program Cathlab is shown in the Figure 1. It consists of three information strings, two sub-plot windows and three columns of control buttons. All the fields, except the strings, are meant for the interactive control. To help the user and not to distract his attention, only the buttons, relevant to the current situation, are visible and those of them, whose use is the most likely, are green coloured, at the time. Moreover, a simple help is available as the tool tip string for each button.

In the main sub-plot the current frame of the examined investigation is normally displayed. In this field, it is also possible to view the whole scene (or a part of it) as a movie. This helps to select the region of interest (ROI), a region that can be readily expanded to the whole sub-plot, and several regions of evaluation (ROE), from which the data are further treated. In our figure only one ROE, marked as the little red rectangle is used. From this ROE the appropriate dilution curve, which is the time dependence of the density from the selected part of the scene, is calculated and displayed in the density sub-plot on the right with the same colour as its rectangle. In this sub-plot the user has to mark the probable density background (DB) and the slope margins (SM). These are the beginning and the end of the descending interval of the dilution curve, from which the washout slope is then calculated and plotted as a line. Although the functionality of the program is much richer, the most important steps are those mentioned above.

The details of evaluating of the washout slopes can be most conveniently explained using an idealized dilution curve as shown in the Figure 2. Before the injection of the contrast medium the density maintains some background level. After the injection the density increases by ΔD and then starts to decrease, finally reaching some new, higher background level. This end of the down-slope of the dilution curve is influenced by the contrast medium, coming in a later phase of coronarography via sinus coronarius into the cavities of the heart, and, still later, after the systemic recirculation. Only much later, after the contrast medium is absorbed by the body, the density would eventually decrease to the original background level.

Without these phenomena, the descending limb of the curve would be close to exponential and would approach the basic values of blackening and enable us to roughly estimate the time of a complete disappearance of the contrast medium from the microvascular bed.

Apparently, the part carrying the most interesting information on the tissue perfusion is the quickly descending limb of the curve and the above mentioned events come too late to be able to disturb the possibility to use it. The theoretical optimum of evaluation of the rate of the washout of the contrast medium is the point of inflection of this part of the curve.

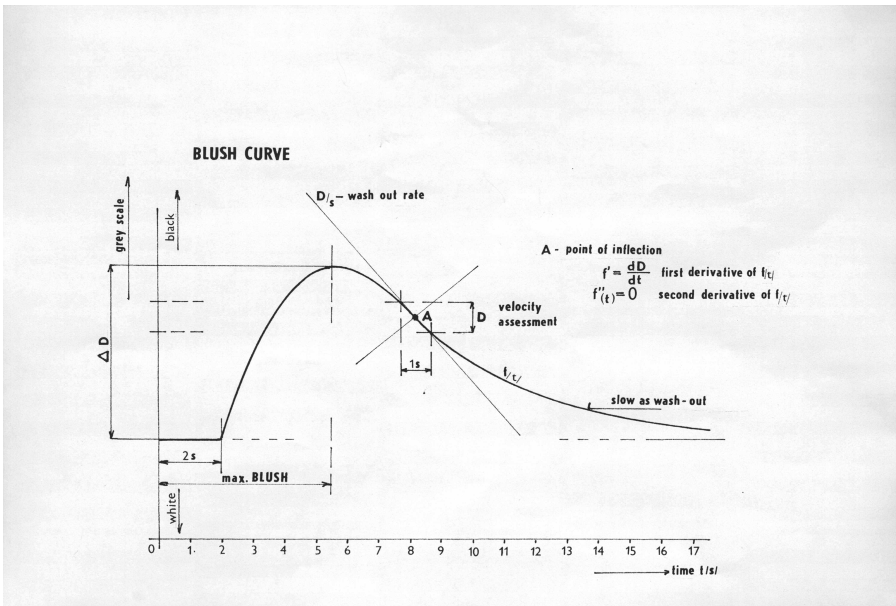

Figure 2. The teoretical dilution or a „Blush“ curve

An important part of our contribution is finding a practical way of evaluation the washout rate from real-world dilution curves. Some rules have to be followed during the examination of the patient, other deal with the evaluation details.

First of all, the patient must neither move nor breathe during the scene taking, which means about 15 seconds. Artefacts, caused by his breathing or movement, are easily recognizable. A curve affected this way is useless and has to be disregarded. However, in such an unfortunate case, still a rough subjective estimation by frame and cycle counting can be done.

The evaluations have mainly to take into consideration that the curves are modulated by the heart pace and they exist in a relative grey scale, depending on many factors, including the influence by the calibration of the automatic exposure system of the GE ADVANTX (or a similar device).

Modulation of the curve by heart action makes a direct calculation of the derivatives impossible. On the other hand, it carries useful information about the frequency of the heartbeat, its regularity and about the efficiency of the heart cycles, expressed by the amplitude of the individual waves.

The influence by the calibration of the automatic exposure system of the GE ADVANTX is very important. The data acquisition must be started about 1 second before the injection to give the exposure automatics time for the auto calibration, which influence the first several frames of a scene, and still have enough frames to find reliably the ground level. After this calibration, the exposure doesn’t change. Due to these facts the calculations must be based on ‘smoothing’ operations and not on the derivatives, which generally lead to further ‘smearing’. Also some reliable normalization leading to reproducible results must be found.

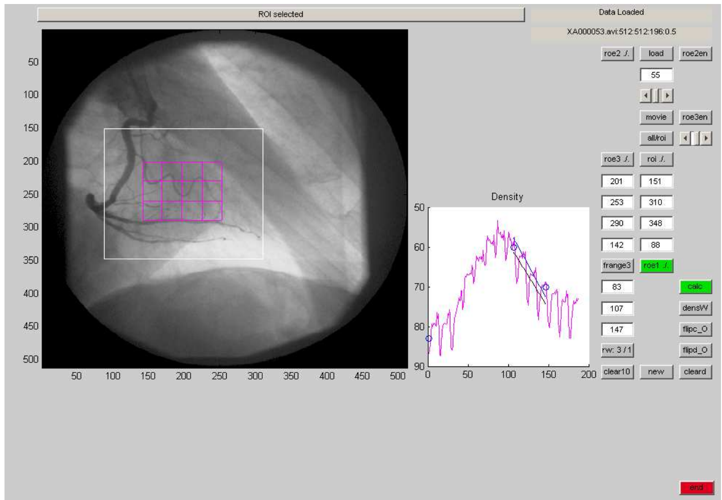

Figure 3a: A frame with ROI and a ROE subdivided into sub-regions

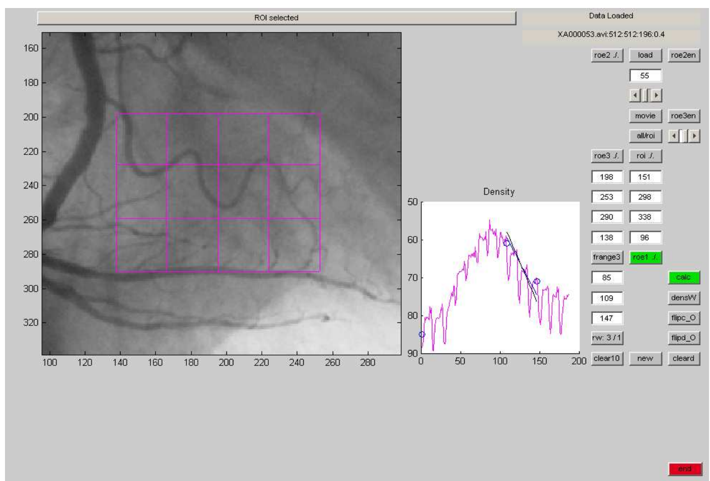

Figure 3b: The same frame with the ROI expanded to the whole main sub-plot

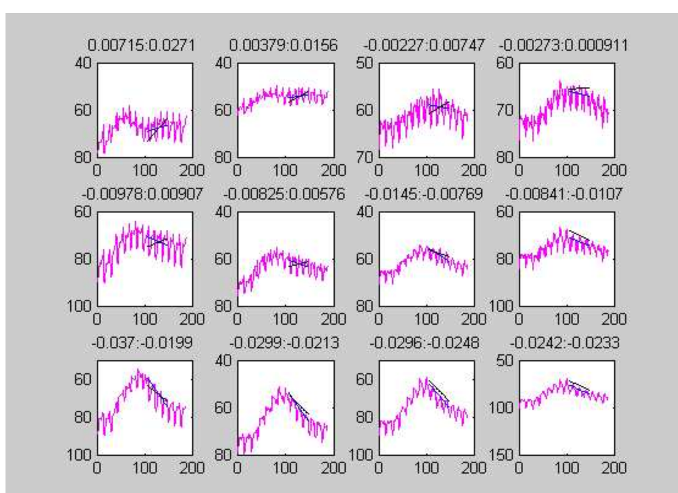

Figure 3c: Simultaneous evaluation of all the sub-regions

The full advantage of using the Matlab and its matrix philosophy is illustrated it the next three figures, where the simultaneous evaluation in several sub-regions, into which ROE can be divided, is shown. The Figure 3a shows a full frame with the ROI marked as the white rectangle and the ROE as the magenta rectangle. In the Figure 3b the previous ROI is expanded into the whole main sub-plot, showing in more detail the subdivision of the ROE into 4 x 3 sub-regions. In the density sub-plot on the right the dilution curve of the representative sub-region (row=3, column=1) is plotted. The DB and SM parameters selected here apply for calculations in all the sub-regions. Their result is displayed in a pop-up window depicted in the Figure 3c. This multi-evaluation property enables to quickly estimate the sub-regions, where the heart tissue behaves normally. This is important for instance to evaluate the success of an intervention (stenting) or medical treatment. Both the sub-region pattern i.e. the numbers of rows and columns and the representative sub-region can be conveniently selected.

3 Results

- Our method is capable of creating and evaluating indicator dilution curves from an investigation, registered on a digital carrier using a reasonably powerful PC at any later time after the investigation.
- The method enables to utilize as an indicator the contrast medium, used for the investigation anyway.
- The curves gained this way are in full agreement with the original curves, obtainable on the GE ADVANTX equipment in the time of the original investigation.
- The results are fully reproducible.
- The quantitative answer is linear in our working range.
- Multiple dilution curves from multiple sub-regions of the ROE can be obtained simultaneously (Figure 3).
- The position and size of the rectangular ROI and ROE is eligible in a user friendly way.
- The presented method is suitable for studying perfusion of the myocardium or other organs and regions.
- The method can bee used in cardiology in the indication of dye dilution curves.
- The details of the curve enable to differentiate individual heartbeats, their frequency, regularity and to roughly estimate their efficiency. Arrhytmias and influence of temporary events like an unintentional Valsalva maneuvre can be recognised and taken into consideration.

4 Discussion

Already in the year 1960 we tried out cinedensography, but by that occasion we realized its limitations for an exact quantification, caused by the variability of the film emulsion and its processing. The use of videodensitometry in the eighties evoked deservedly our attention, but we did not try to use it at that time, as our cardiologists were enthusiastic about using mainly a dye dilution method with Cardiogreen. Only the works, dealing with the evaluation of myocardial perfusion and its microcirculation using „frame counting“ [7,8,9,10] have motivated us to try a digital technique for getting more objectivity and even more detailed information. These advantages of the digital approach fulfilled our expectations and became the subject of our present communication. The possibility of recent digital technology to save and transport huge amounts of data, an interdisciplinary cooperation with a physicist and a programmer and also using an appropriate programming environment enabled us to develop an objective and basically original method with a broad prospective potential in cardiology and other branches of medicine.

References

[1] U. Erikson, G. Helmius, G. Ruhn, T. Aberg. *Determination of pulmonary blood flow by videodensitometry*. Bull Europ Physiopath Resp 16: 663-670, 1980.

[2] U. Erikson, G. Ruhn, L. Bjoerk. *Videodensitometry in angiography*. Medicamundi 25:4-8, 1980

[3] U. Erikson. *Angiographic quantification of the degree of mitral regurgitation by use of videometry. Study in 172 patients.* Ann Radiol 24:320-322, 1981

[4] U. Erikson, O. Smedby. *A mathematical model for assessing mitral incompetence by videodensitometry.* Ann Radiol 24:633-637, 1981

[5] P. Heintzen (Editor). *Roentgen Cine and Videodensitometry. Fundamentals and applications for blood flow and heart volume determination.* Georg Thieme Verlag, Stuttgart, 1971

[6] J.D. Sinclair, W.F. Sutterer, J.L. Wolford, E. Armelin, E.H. Wood. *Problems in comparison of dye-dilution curves with densometric variations at the same site in the circulation measured from simultaneous cineangiograms.* Proceedings of the start meetings of the Mayo Clinic 35:764-773, 1960

[7] C.M. Gibson, C.P. Cannon, D.W. Daley, J.T. Dodge, B. Alexander, S.J. Marble, C.H. McCabe, T. Fortin, W.K. Pool, E. Braunwald, for the TIMI Study Group. TIMI frame count: *A quantitative method of assessing coronary artery flow.* Circulation 93: 879-888, 1996

[8] C.M. Gibson, S.A. Murphy, M.J. Rizzo, K.A. Ryan, S.J. Marble, C.H. McCabe, C. P. Cannon, F. Van de Werf, E. Braunwald. *The relationship between TIMI frame count and clinical outcomes after thrombolytic administration,* Circulation 99:1945-50, 1999

[9] C.M. Gibson, C.P. Cannon, S.A. Murphy, K.A. Ryan, R. Mesley, S.J. Marble, C.H. McCabe, F. Van de Werf, E. Braunwald, for the TIMI Study Group. *Relationship of TIMI myocardial perfusion grade to mortality after administration of thrombolytic drugs.* Circulation 101:125-30, 2000

[10] A.W.J. van´t Hof, A. Liem, H. Suryapranata, J.C. Hoorntje, M. de Boer, F. Zijlstra. *Angiographic assessment of myocardial reperfusion in patients treated with primary angioplasty for acute myocardial infarction: myocardial blush grade.* Circulation 97:2302-6, 1998

[11] The TIMI Study Group. *The thrombolysis in myocardial infarction*, N Engl J Med 31: 932-6, 1985

[12] J.K. Harrison. *Image quality and coronary blood flow assessment: the influence of radiographic contrast*, J Clin Basic Cardiol 4:249-251, 2001

Miloš Steinhart, Department of Physics, University of Pardubice

Studentská 84, 532 10 Pardubice, Czech Republic, stein@mail.upce.cz