Med. Progr. Technol. 6, 23–28 (1978)

Medical Progress through Technology

Computer Angiography: A New Tool for X-Ray Functional Diagnostics

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Abstract. The method of functional imaging is applied to x-ray angiograms. Functional images are generated by inserting at each point of an x-ray image a computed grey or colour value proportional to a dynamic parameter (such as blood velocity) instead of the recorded x-ray absorption value. For this purpose a new system for angiographic image processing has been developed. First results show that the method which we have called Computer Angiography is a tool to extract more information about the blood dynamics in organs in an easier and faster way than with the conventional angiographic technique.

Key words: Angiography – Image processing – Renal bloodflow – Densitometry – Computer assisted diagnosis

1. Introduction

In conventional diagnostic radiology the diagnosis is based on form, size and structure of organs shown in one or more x-ray projections. This morphological diagnostic technique has been substantially improved by computed tomography. In many cases, however, one is interested in the time course of processes in organs, which may contain information on their functions. In the near future, CT-scanners will not have the capability of providing information on the time course of contrast medium propagation, at least not at reasonable expense. Thus for functional diagnostics a series of conventional x-ray projections of the organ is still recorded on film or video tape after the injection of a contrast medium. Conventionally this series is examined by the physician in a qualitative manner. In this paper we demonstrate that in this field too the application of computers may greatly enhance the quality of the x-ray technique.

Several authors have shown that the diagnostic value of angiograms can be substantially improved by quantitative angiodensitometric measurements [4, 5, 7, 9]. Angiodensitometry delivers the time course of the contrast medium density at any region of an organ selected by the physician, which can be used to determine haemodynamic parameters – such as velocity of the blood stream.

In addition to the fact that the procedure is difficult, the interpretation of the results involves the following problems:

1. *Absolute* measurements values are not of any use as long as there are no normal values to which they can be compared (e.g. the fact that a vessel of a kidney has a blood speed of 10.7 cm/s does not help the radiologist in practice).

2. If one searches for *relative* differences between different zones of an organ one measures a parameter at several points. If one makes use of the high resolution of x-ray pictures, the number of measuring points becomes high. Besides the fact that the measurement procedure is laborious, the assessment of the resulting map of numbers is difficult.

The purpose of functional imaging is to enable the radiologist to overcome these difficulties. It allows the assessment of absolute and relative deviations of a functional parameter from an angiographic image series by looking at one single picture. Functional imaging has sometimes been used in nuclear medicine functional studies [1, 3, 6, 8]. To our knowledge it has not been applied to radiographs, because the higher time and spatial resolution leads to complex equipment, the computer part of which is comparable to what is used in computed tomography.

0047-6552/78/0006/0023/$01.20

2. Material and Methods

Method of Functional Imaging

For an explanation of the concept of functional imaging the following considerations are made (refer to Fig. 1):

From an angiographic series of e.g. a kidney one may compute for any picture element the time course of the contrast medium density. The resulting curve, which represents the dynamic behaviour of the contrast medium at that point may be described by a small set of numbers describing physiological parameters such as

– blood velocity, represented by the delay of the contrast medium bolus with respect to the injection time,
– perfusion, given by the maximum of the contrast medium density during the observation time.

A functional image is generated by inserting at any picture element a *computed* grey value proportional to one of these parameters instead of the recorded x-ray absorption value. Figure 4, which is discussed in more detail in Section 3, is an example of a functional image showing at any point the contrast medium delay as a grey value. The purpose of this paper is to show that such an image may help the physician to get

– *more* information, than by sequential viewing of conventional radiographs, and
– *quantitative* information,
– which is *easily interpretable.*

Apparatus

The investigations have been made with a new system for Angiographic Image Processing [2] developed by a collaboration between the Deutsches Elektronen-Synchrotron (DESY) and the Department of Radiology of the University Hospital Hamburg-Eppendorf. Since a detailed description of the system is being published elsewhere, we give only a short summary of its properties.

A block diagram of the system is shown in Figure 2. The x-ray picture series, represented as standard TV-information, is taken from the fluoroscopy unit of the x-ray device or alternatively from a standard video recorder. The TV-signal is fed to the digital-video system,

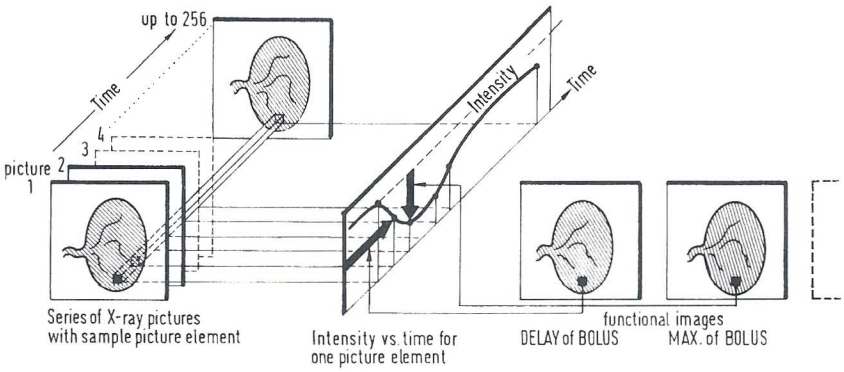

Fig. 1. The principle of functional imaging

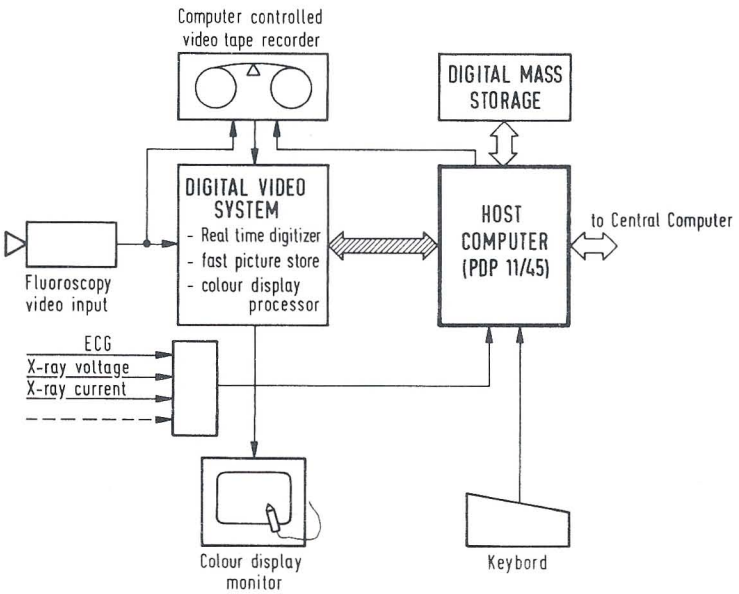

Fig. 2. Block diagram of the apparatus

which under control of the host computer digitizes the images, or regions of them, in real time, and stores them into two fast memories. From there they may be transferred to a digital mass storage by the host computer. At the same time the patient's ECG and the operation parameters of the x-ray-device are recorded. Once in the mass storage the pictures may be retrieved and processed according to the instructions of the physician, who interacts with the system via a colour TV monitor with light pen and a keyboard. The results are shown on the colour TV-monitor in the form of pictures and/or graphics (e.g. curves).

The images are normally digitized and handled as matrices of 256 x 256 (64000) elements, each with one of 256 grey levels. Up to 256 pictures are taken within one series. Using the SIRECORD-2-duplex image-intensifier video unit, one picture element has an area of 0.5 mm^2. Up to 50 pictures/s may be digitized.

Computations

For the analysis of the angiographic image series we have implemented a program system called PROFI-11 (*Pro*cessing and *R*etrieval of *F*unctional *I*mages). Its principle of operation is the following: The pictures are stored one after the other with 256 x 256 elements on a magnetic disk as they are taken from the x-ray device. Since the data are needed as intensity vs. time curves (further referred to as ITC) the first step is to transform the series of pictures into a series of ITCs. Each of the 64000 ITCs then undergoes the following treatment (Fig. 3 – note that the ITCs are inverted –):

1. The rather noisy curve is preprocessed by smoothing and removing solitary points.
2. The measured ITC is replaced by its logarithm.
3. The background not originating from the contrast medium bolus is subtracted.

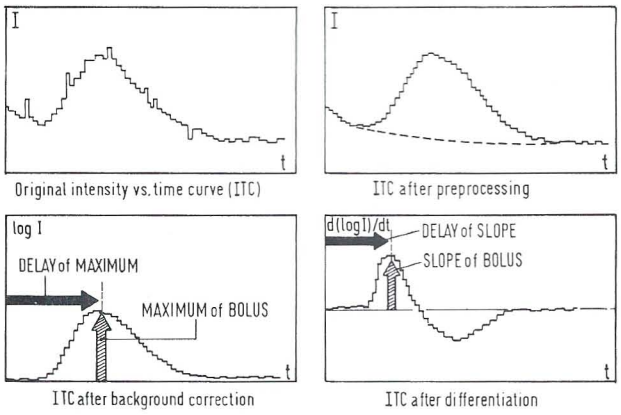

Fig. 3. Treatment of the intensity vs. time curves

4. From this curve the *maximum* and the *delay time of the maximum* are computed.
5. The curve is differentiated to get the *slope of the bolus* and its *delay time.*

These four parameters are inserted into four picture matrices at the corresponding points to give functional images of the types MAXIMUM, DELAY OF MAXIMUM, SLOPE, DELAY OF SLOPE. The computation of functional images of the decay of the ITC is under way. The resulting pictures are displayed on the colour TV-monitor. Major efforts had to be made to implement them with optimum execution speed. At the moment the computation of one set of four images takes 5 min on a PDP 11/45 computer.

Application

For our first investigations we chose angiograms of the human kidney. A catheter was inserted through the femoral artery into the renal artery. 3 ml of Conray-60 was injected by the CONTRAC automatic injector at a rate of 8 ml/s. One second before injection the fluoroscopy unit was switched on and a picture sequence of up to 10 s duration was recorded on the SIRECORD video tape recorder. This series was fed into the angiographic image processing system and the functional images generated as described above.

3. Results

During our first investigations we have computed functional images of about 30 kidneys. Figure 4 shows a functional image of the type DELAY OF SLOPE together with a single frame of the angiographic image series of a normal kidney. In comparing the two one observes the following properties of the functional image:

1. Regions which are not reached by the contrast medium as well as the superpositions from tissue not under observation (such as the bowels), are suppressed. The examined organ is *emphasized.*
2. Although the coarse morphology is the same as in the conventional picture, it gives completely different information, i.e. it gives at one glance information about the blood dynamics during the observation period. In this special case it gives information on the time needed by the contrast medium to reach any point of the kidney. *Functional* abnormalities now can be assessed by looking at *morphological* abnormalities on the functional image rather than by sequential viewing of an image series.
3. A *quantitative* analysis which is difficult in the grey tone image may be achieved by a colour presentation of the functional image as it is shown in Figure 5. By relating the colours in the kidney to the colours in the fidu-

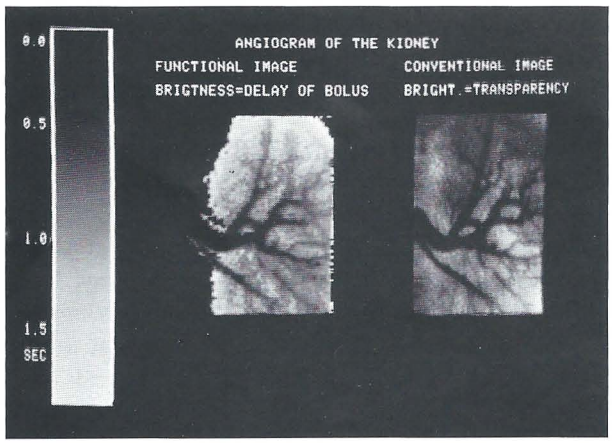

Fig. 4

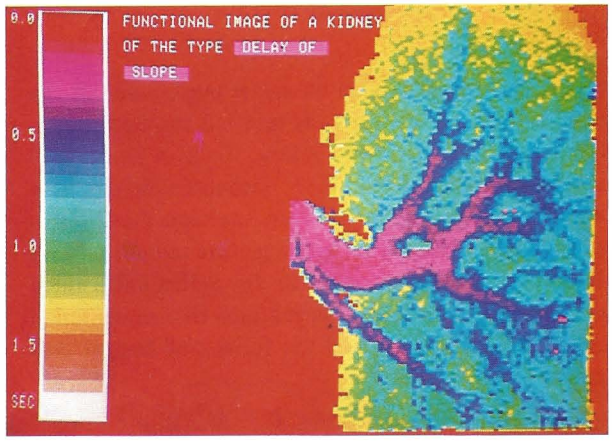

Fig. 5

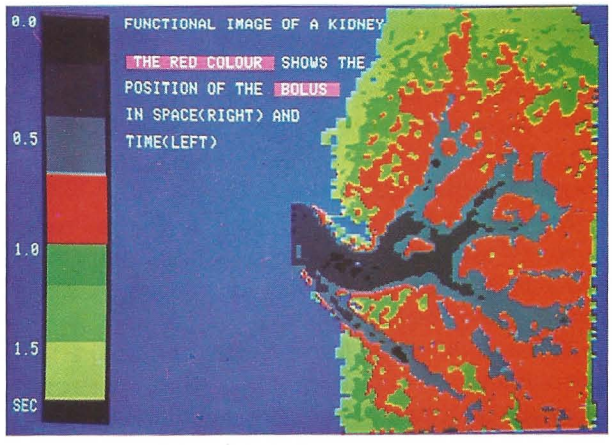

Fig. 6

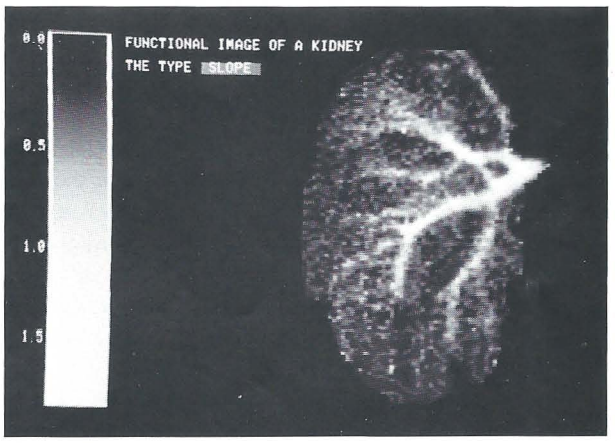

Fig. 7

Fig. 4. Functional image of the type DELAY OF SLOPE of a normal kidney together with one frame of an conventional angiogram

Fig. 5. Colour presentation of the image of Figure 4

Fig. 6. Functional image of the type DELAY OF SLOPE with a labelled zone of equal delay times

Fig. 7. Functional image of the type SLOPE of a normal kidney

Fig. 8. Functional image of the type MAXIMUM of a normal kidney

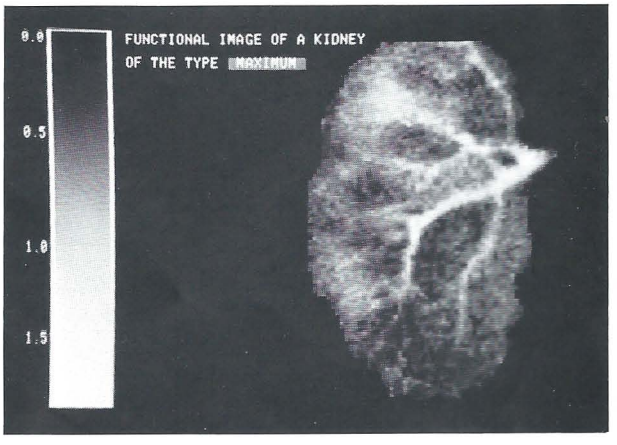

Fig. 8

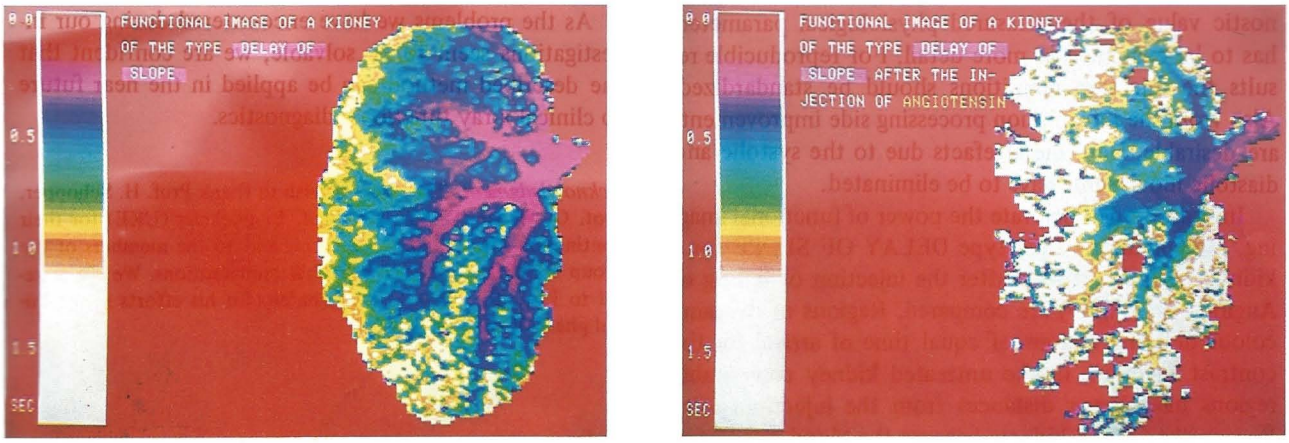

Fig. 9. Functional images of the type DELAY OF SLOPE of a kidney before and after the injection of Angiotensin

cial scale the delay times for any picture element may be determined at once. Another method of quantitative assessment is to label zones of equal delay times with the same colour as shown in Figure 6, where the zones with delay times between 0.7 s and 0.95 s are shown in red.

Our investigation shows that an essential part of the information on the blood dynamics is contained in the image DELAY OF SLOPE. We have verified this by the reconstruction of the image series from this single functional image. Displaying the reconstructed series (Fig. 6 shows a single frame) with the original recording speed gave the same visual impression as the original image series.

To a rough approximation the image DELAY OF MAXIMUM gives similar informations as the image DELAY OF SLOPE. But its interpretation is more complicated, because the maximum is produced by the different layers of the organ with different functions. Here investigations are necessary to find out whether a decomposition of the ITC into parts representing different functions is possible. There seems to be a chance of decomposing the ITC, e.g. into one part representing vessels and one representing the parenchyma.

Whereas the image DELAY OF SLOPE gives the time elapsed during the propagation of the contrast medium to each point of the kidney, the image SLOPE shows a coarse measure of the blood *velocity* at any point of the kidney. This assumption is confirmed by the brightness distribution in Figure 7, where the vessels are bright (= high velocity) and the tissue is darker (= low velocity). The dependence of the velocity on the slope of the ITC is presently being investigated.

The image of type MAXIMUM (Fig. 8) looks very similar to the conventional image, because its intensity corresponds to the contrast medium density. But there are two advantages. The background is eleminated and the maximum uptake of contrast medium for different zones, which is conventionally distributed over several images, is concentrated in one single image. Furthermore, this image can be analyzed quantitatively (similar to the image DELAY OF SLOPE) to get information on the regional perfusion of the kidney.

A common feature of the described images is, that they represent a transformation of functional into quasi-morphological information. It is a decisive property of the functional image that it can be interpreted in a manner the radiologist is accustomed to. Despite the above advantages some of the disadvantages of x-ray projection images remain. For example, the unknown inclination of blood vessels with respect to the direction of view may lead to misinterpretation. Also the spatial resolution, which is substantially better than that in

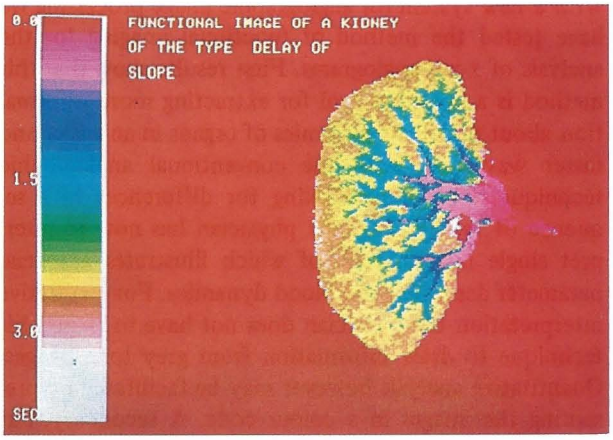

Fig. 10. Functional image of the type DELAY OF SLOPE of a kidney with nephrotic syndrome

nuclear medicine, is still poor compared to conventional radiographs. It could be improved by the utilization of state of the art x-ray equipment (e.g. a better image intensifier) and by developments to come.

To facilitate routine application some further investigations have to be made: from the medical side the diag-

nostic value of the measured physiological parameters has to be examined in more detail. For reproducible results the injection conditions should be standardized. Also from the information processing side improvements are desirable. Here the artefacts due to the systolic and diastolic movements have to be eliminated.

In order to demonstrate the power of functional imaging, two pictures of the type DELAY OF SLOPE for a kidney before and 30 s after the injection of 0,5 µg of Angiotensin (Fig. 9) are compared. Regions of the same colour describe regions of equal time of arrival for the contrast medium. In the untreated kidney comparable regions have larger distances from the injection point than in the treated kidney, because the blood was faster. The comparison of the colour distribution with the aid of the fiducial scale additionaly gives a quantitative measurement of the blood flow reduction at any point in the kidney. Without special training we can see from this single picture that the order of magnitude of blood velocity reduction is 40–50%.

Figure 10 shows the functional image of a kidney with nephrotic syndrome. Also here one recognizes at once a general reduction of the blood velocity. The yellow – brown region however indicates a zone, where the blood is much faster than in the remaining parts of the kidney. This behaviour leads immediately to the diagnosis of a general cortical ischemia.

4. Conclusions

With a new system for angiographic image processing we have tested the method of functional imaging for the analysis of x-ray-angiograms. First results show that this method is a potential tool for extracting more information about the blood dynamics of organs in an easier and faster way than with the conventional angiographic technique. Instead of looking for differences in a sequence of radiographs, the physician has now to interpret single images, each of which illustrates a special parameter describing the blood dynamics. For qualitative interpretation the physician does not have to change his technique to draw information from grey tone images. Quantitative analysis however may be facilitated by presenting the images in a colour code. A secondary, but not unimportant consequence of functional imaging for the future should be more efficient documentation of angiograms. Instead of storing series of pictures or a cinefilm, one needs to store only a set of 3 to 5 functional images which would be sufficient for the documentation of the entire angiogram.

As the problems we have encountered during our investigations seem to be solvable, we are confident that the described method can be applied in the near future to clinical x-ray functional diagnostics.

Acknowledgment. The authors wish to thank Prof. H. Schopper, Prof. G. Weber (DESY) and Prof. E. Bücheler (UKE) for their continuous support of the project, and to the members of the group F58/UKE for their valuable contributions. We are grateful to Prof. D. Novak (Ludwigshafen) for his efforts in the initial phase of the project.

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