Computer Aided Evaluation of Upper Urinary Tract Obstruction

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Abstract. The purpose of this study is to examine a method for quantitative estimation of upper urinary tract clearance rate using conventional fluoroscopic images. To obtain quantitative information proportional to the amount of contrast media in the renal pelvis we used videodensitometric methods. The semi-quantitative densitometry included normalization procedure, logarithmic processing of the system response and non-specific density variations removing. The method was tested by analyzing 7 nephrostogram and 3 retrograde pyelography studies. The clearance rate was estimated by measuring the clearances curve in arbitrary units. Regression fitting of the clearances curve by an exponential decay yielded a correlation coefficient of 0.94±0.02. The integrated radio-density of the contrast media was found to decrease by 6±3% per minute, and the area of the contrast agent in the renal pelvis decreased by 5±2% per minute. The radio-density measurements during the first 10 minutes of the examination were sufficient to yield the overall exponential clearances curve. It was concluded that this method will enable to estimate quantitatively the degree of upper urinary tract obstruction by using only the initial phase of a routine urological modality.

1 Introduction

Obstruction of the upper urinary tract is a common urological pathology that results from obstructing stones, tumor or UPJ stenosis. Patients with this pathology are being evaluated with intravenous urography, antegrade or retrograde ureterography using sequential X-rays imaging to evaluate the contrast media clearance from the upper urinary tract as a clue for obstruction. However, the diagnostic accuracy of this method is debated due to its subjectivity. The purpose of this study is to evaluate an image analysis method that will enable a quantitative estimation for the degree of upper urinary tract obstruction, using conventional fluoroscopic images

When referring to the function of the kidney, clearance of a substance is the inverse of the time constant that describes its removal rate from the body divided by its volume of distribution. Renal clearance can be measured in steady state conditions with a timed collection of urine and an analysis of its composition. Urine flow rate was modelled theoretically by Dole [1] and modern modification and application of this model for dialysis was described by Gotch [2]. In case of contrast agent clearance from renal pelvis the generation rate and intake equals to zero. It follows that the

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differential equation, which models concentration of urea at the end of dialysis, is applicable to describe the contrast media concentration in renal pelvis (upper urinary tract clearance curve). Using these assumptions, the dialysis equation can be rewritten in a form

$$V\frac{dC}{dt} = -KC \tag{1}$$

where

V - volume of renal pelvis,

K - clearance rate,

C – average concentration of the contrast agent in the pelvis.

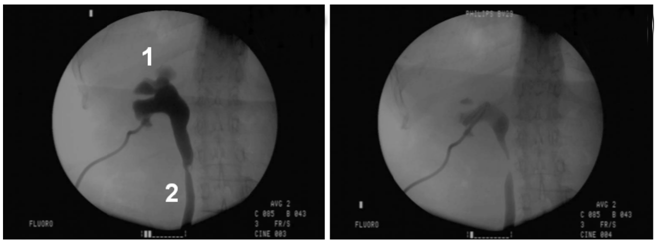
Assuming that the average concentration of the contrast agent in the pelvis is proportional to the integrated radio-density of the contrast media, expression (1) shows that the value of the clearance rate - K can be estimated experimentally by using exponential fitting of the radio-density measurements as a function of time.

Digital imaging, which allows repetitive density analysis of the same region of interest during the transit of contrast media, holds a potential to estimate the dynamic characteristics of contrast dilution curves. This method, which is based on digital X-ray subtraction angiography (DSA) has numerous advantages for the diagnosis, monitoring and quantitative evaluation of blood flow and velocity in cardiological practice [7]. However, temporal subtraction in cases of upper urinary tract sequential X-rays imaging is more complex due to long time interval (minutes) between the two subtracted images. Positioning and body habitus differences between images acquired during urinary tract imaging make DSA problematic for being used in urography practice. Parametric images have been used widely in nuclear medicine, and somewhat more sparingly in X-ray CT. Gallagher have used parametric images [3] to distinguish between transplant kidney rejection and acute tubular necrosis using renal images obtained from digital fluoroscopy. Hackstein with coathors [4] present a technique to measure kidney clearance of the applied contrast media by multiphase helical CT by measurements the time density curve of the kidney after contrast media application.

We assume that changes in the contrast material density in X-ray video-fluoroscopy can be utilized to measure the upper urinary tract clearance rate. This can be performed by analyzing the time dependence of the contrast media radio-density measured in sequential images of the whole renal pelvis area. The indicator–dilution approach (Stewart-Hamilton method) and the first-pass distribution analysis [5],[6] are well investigated for blood flow and velocity measurements. We assume, that these methods can be also used to calculate the contrast agent clearance rate.

2 Methods

In the present study we attempted to evaluate quantitatively the upper urinary tract clearance rate using the sequences of images acquired in routine fluoroscopic imaging of the upper urinary tract during pyelography. The fluoroscopic images were captured after injection of the contrast agent by using the "last-frame-hold" mode of the C-Arm (Phillips BV29) at 3 frames per second, with 2 frame averaging. The captured images were acquired with a resolution of 720x576 pixels. Figure 1 displays digital fluoroscopic images of a right kidney captured during upper urinary tract examination. Figure 1a demonstrates an initial stage of the pyelography, in which the injected contrast agent was already transported by the urine to the ureter.



1a 1b

Fig. 1. Fluoroscopy images obtained during upper urinary tract examination. (1- the contrast agent in renal pelvis, 2- the ureter).

At a more advanced stage of the examination, the radio-density of the contrast agent in the pelvis is higher, but the area it occupies is already reduced. Figure 1b demonstrates the final stage of the examination, in which both the radio-density of the contrast agent and the area it occupies are reduced.

In order to estimate the amount of the contrast agent from the acquired images, the system response calibration and the semi-quantitative densitometry approach were utilized. Linearization of the system response was performed for calibration purposes. The semi-quantitative densitometry approach included a normalization procedure, logarithmic processing of the system response and removing non-specific density variations. In order to implement these approaches, fluoroscopic images were captured with internal standard (the reference sample) which was placed in field of view of the image intensifier. The response linearization was performed using a transformation function. The transformation function was calculated by using radiographic wedges of a constant step height, and fitting the grey levels of the different wedge steps. The calibration curve was obtained by measuring contrast agent concentration standards. The normalization procedure, based on reference samples, compensates for Automatic Brightness Control (ABC) and Automatic Gain Control (AGC) performed by the electronic circuits to modify the system response. The logarithmic processing of the system response was performed for scaling image data to density values. Removing of a non-specific density variations (such as soft tissue density and the X-ray scattered radiation) was performed by subtraction of the data obtained from the template image. The template image was obtained in the beginning of pyelography prior to contrast agent injection.

The semi-quantitative densitometry approach was utilized for measuring of the contrast agent concentration in arbitrary units. The density values obtained by this method must be proportional to the amount of the contrast agent. A brass wedge was utilized as an internal standard.

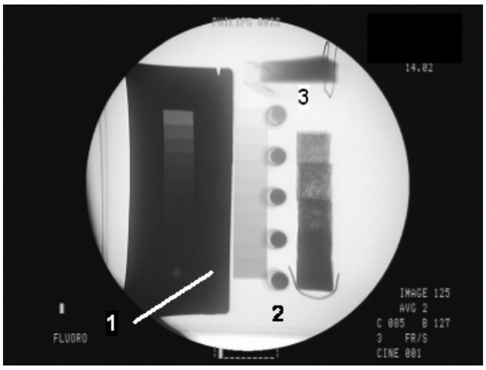


Fig. 2. A phantom image obtained at a tube voltage of 68 keV (1-wedges with constant steps height; 2-contrast agent probes with different heights and concentrations; 3-rectangular container with contrast agent of variable height).

The system response was measured using radio-densitometric phantoms and was tested for the different X-ray exposures and radiation conditions. Figure 2 shows a fluoroscopy image of such a phantom, consisting of the following components: water filled plastic container (water hight of 20cm); different wedges with constant step height; contrast agent probes with different heights and concentrations; rectangular container with a contrast agent of variable height.

Figure 3 shows images acquired with a brass wedge placed in field of view of an image intensifier. The image measurements were performed on the regions of interest (ROIs) which included the contrast agent in the renal pelvis and reference region of the brass wedge. The ROI of the contrast agent in the renal pelvis is traced in the figure and, as can be seen, its area decreases gradually during the upper urinary tract examination.

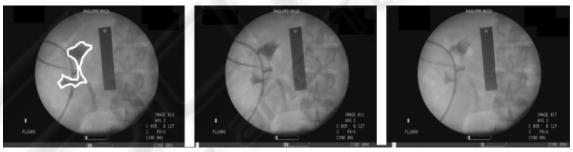


Fig. 3. Fluoroscopy images obtained for semi-quantitative densitometry.

Image processing prior to image analysis included image enhancement in order to perform renal pelvis tracing and to perform background details detection and segmentation. In some cases, spatial calibration and image registration was also utilized. The image processing algorithm included analysis of the electronic noise and of the X-ray scattered radiation. The algorithm was verified using phantom-based modelling experiment, which simulates an examination of the upper urinary tract. The radio-density of the contrast agent was measured in arbitrary units for all of the fluoroscopy images acquired during upper urinary tract examination.

In the current study we analyzed 10 clinical cases without known uromechanical obstruction of the upper urinary tract (7 nephrostogram, 3 retrograde pyelography). The patients underwent contrast agent injection followed by fluoroscopic imaging of 2-5 minutes interval. Fluoroscopic images were acquired with controlled roentgenographic conditions. The contrast agent clearance rate was estimated in arbitrary units by exponential fitting of the integrated radio-density measurements as a function of time.

3 Results

In order to obtain the clearance rate in absolute units (mg/min), the system response linearization and calibration based on grey level matching was performed by using the phantom represented in Figure 2.

Figure 4 shows an example of a calibration curve obtained by using a brass wedge as internal standard (reference sample). The grey levels of the various steps in the brass wedge were calibrated to the grey levels of the contrast agent with known concentrations per unit area, for a tube voltage of 72-84kV.

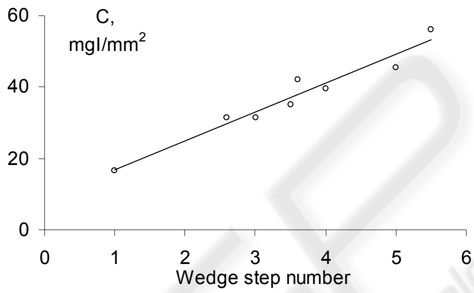


Fig. 4. Example of a brass wedge calibration curve.

Figure 4 demonstrates a significant deviation of the experimental data from the regression line. A relatively low correlation coefficient was found and the calibration accuracy was estimated to be 35%. This result demonstrates that system response linearization and calibration are not sufficient for accurate clearance rate measurements. But this approach is simple for implemention and can be utilized for urinary tract obstruction detection in a clinical enviroment. According to the results reported above, the clearance rate measurements in the present study were obtained only by semi-quantitative densitometry method.

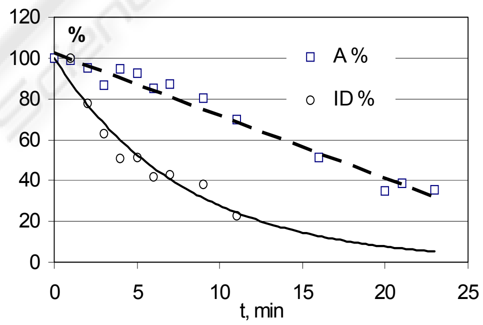


Fig. 5. Example of contrast agent clearance curves measured for a patient without upper urinary tract obstruction.

Figure 5 shows an example of clearance curves obtained by the semi-quantitative densitometry approach. These curves represent the time dependence of the area of the renal pelvis (A) filled with contrast agent, and time dependence of this area integrated density (ID). Clearance curve measurements were performed during pyelography of a patient without upper urinary tract obstruction. The value of area A and the value of integrated density ID in the begining of the examination (the contrast agent occupied all volume of a pelvis) were taken as 100%. The solid curve in Figure 5 represents experimental data fitting of the integrated density and the dashed curve in Figure 5 represents data fitting of the area. The time dependence pelvis area was approximated by a linear curve. The clearance curve was fitted by approximating an exponentially decreasing time dependence of the integrated radio-density.

Regression fitting of the clearance curves displayed in Figure 5 yielded a correlation coefficient of R^2=0.97 for the area as a function of time and a correlation coefficient of R^2=0.96 for the density clearance curves. The time constant for the density clearance curve was found to be 9.1 min, and contrast agent clearance rate in arbitrary units (percents of contrast agent per minute) was found to be 0.11. Clearance curves kinetic, similar to the one presented in Figure 5, was found in all the clinical cases examined in the present study.

Figure 6 shows exponential fitting curves of the measurements for three patients. Curves 1 and 2 represent patients for whom upper urinary tract obstruction was not diagnosed, while curve 3 represents a patient with upper urinary tract obstruction. The regression fitting of the experimental data for the case with upper urinary tract obstruction yielded an exponential decay time constant of 52 min and a clearance rate of 0.02 percent per minute.

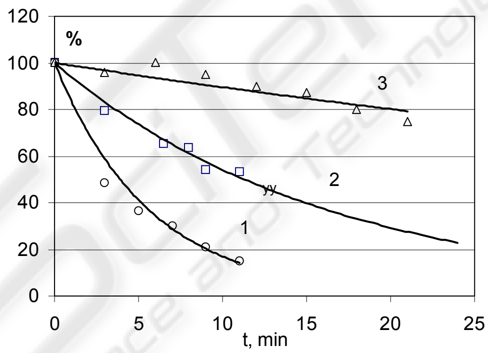


Fig. 6. Example of clearance curves.
1.2 – Upper urinary obstruction was not diagnosed,
3 – Upper urinary obstruction.

4 Discussion

The purpose of the present study was to examine a method that uses conventional fluoroscopic images to estimate quantitatively the degree of upper urinary tract obstruction. Using sequences of images acquired during regular pyelography, the dynamic characteristics of the contrast agent in the renal pelvis was quantitatively analyzed to estimate the clearance rate of the upper urinary tract.

The method was tested on 10 clinical cases without upper urinary tract uromechanical obstruction. All patients underwent contrast media injection followed by fluoroscopic imaging of 2-5 minutes interval. Semi-quantitative densitometry, based on image normalization, was utilized to obtain information on the amount of contrast media in the renal pelvis as a function of time. The clearance rate of the contrast media was estimated in arbitrary units, by exponential fitting of the time-dependence curves.

In all the investigated clinical cases, the clearance curves of the integrated radio-density showed a similar kinetic trend. The integrated radio-density of the contrast media decreased by 6±3% per minute, and area of contrast agent in the renal pelvis decreased by 5±2% per minute. Exponential fitting of the density measurements during the first 10 minutes of the test yielded a correlation coefficient of 0.94±0.02 with the clearances curve.

It was concluded that using the measurements during the initial phase of the examination is sufficient to estimate the overall clearance rate of the injected contrast material. This method will enable to estimate quantitatively the degree of upper urinary tract obstruction, using a routine urological modality in clinical environments.

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