Urodynamic examinations of pressure and flow relations of the upper urinary tract

Theses of PhD

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Budapest
2008

Introduction

Several non-invasive examination methods had been developed for indirect examination of rate of ureteric obstruction in the last 50-60 years that has utilized the actual possibilities of the technical advancements (i.v urography, isotope renography, diuretic renography, diuretic US, resistive index ratio). Wide spread of the non-invasive methods had been inhibited by the fact that degree of obstruction could be just defined semi-quantitatively, by a wide gray zone.

These disadvantages lead pioneers of researchers of upper urinary tract to develop first quantitative methods of measuring degree of postrenal obstruction in the ’70-s. Lots of factors of uncertainty, undefined circumstances and technical difficulties of the measurement inhibited spreading these methods.

From the end of the 80’s, by getting percutaneous urine deviation more and more widely, routinely used, a new way opened for antegrád filling up of the collecting system without any additional invasiveness. Advances in computer sciences, wide use of urodynamic equipments and personal computers basically changed technical options. In addition, today’s diagnostic view prefers functional examinations. It seems to become clear that topics regarding motility of the pelvis and ureter belong to basic research, whereas tendencies of exact, quantitative definition of postrenal obstruction form base of clinical research.

Our goals

We defined as the goals of our urodynamic measurements of the upper urinary tract (UDUUT):

- to develop a special urodynamic equipment capable for pressure-flow measurements especially in the upper urinary tract (both hardware and software)
- to develop software for documentation of measurements’ results
- to develop appropriate measuring method for exact definition of pressure-flow relation in the upper urinary tract and to standardize circumstances of measurements

- to define new, indispensable reference pressure level for UDUUT, to revise traditionally used intravesical pressure as a reference pressure
- to develop method of exact measurement of rate of postrenal obstruction
- to define normal values of measurable parameters
- to develop evaluation software to aid calculation of rate of obstruction
- to develop easy-to-use method (even without urodynamic equipment) for basic UDUUT studies that might contribute to spreading this method
- to define the role of UDUUT in diagnostic procedures of obstructions of upper urinary tract

Methods

We are performing UDUUT studies since October of 2001 for functional analysis of upper urinary tract. Based on our plans Andromeda GmbH Germany prepared the prototype transformed from existing Ellipse model. We integrated some supplementary modules in the BIOS and software of the equipment. Both hardware and software are keeping under continuous development.

All of our measurements have been performed using the previously already inserted nephrostomy catheters in patients, in whom no complete obstruction could be proven.

Measurements were started immediately after the patient emptied the bladder so there was no need of bladder catheterization. The routinely performed measurements in supine position were repeated in standing position in cases of suspicion of p-u junction or ureteral kinking. Pressure was always set to zero at the level of renal pelvis.

External filling was performed by using filling solution of body temperature just to minimize pelvic contractions and tonus elevation due to the filling itself, which could adversely influence accuracy of measurements.

During our pressure-flow measurements we were making efforts to minimize diuresis, the intrinsic flow upsetting accuracy; therefore we aimed keeping diuresis of the examined kidney under 1ml/min. In the first period of the measurements we performed them either by constant filling pressure perfusion studies (Vela-Navarrete principle),

where intrapelvic pressure and ureteric flowrate were measured at 30cmH_2O filling pressure, or by constant flow pressure studies (Whitaker principle), where intrapelvic pressure was measured, triggered by a perfusion rate of 10ml/min.

Based on our experiences of the initial period, in order to get more reliable analysis of pressure-flow relation, we switched to multistep measurements in the last three years, where we measured the intrapelvic pressure and ureteric flowrate during stepwise rising filling pressures and intrapelvic pressure and stepwise rising filling rates.

Median values of pressure and flow curves have been defined by the new calculation software routine integrated into the special version of AUDACT evaluation PC program. These mean values have been used to draw pressure-flow curve as exact as possible and to calculate rate of obstruction quantitatively.

Contraindication of UDUUT studies are: UTI associated with fever, haematuria, anticoagulant medication or known hemophilia and renal hypofunction, also if signs of catheter obstruction, kinking, dislocation or if urinary leaking beside the catheter is observed.

Since 2001, 275 UDUUT studies have been performed at our institution. 116/275 were performed in 3 or more steps, and have been included into statistical evaluation. 85/116 were performed by constant pressure perfusion (Vela-Navarrete principle) and 41/116 by using constant filling rate (Whitaker-principle) in 97 patients (there were patients, in whom both methods where used).

Results

Development of urodynamic equipment especially for UDUUT

I. Hardware-developments

The main parts of the urodynamic equipment of the upper urinary tract:

1. Pressure measurement is solved by an electronic pressure sensor, to which pressure is led over a Y joint by an air column; therefore it does not contact corroding filling liquid containing disinfecting agent.

2. Flow rate of filling is measured by an electronic drop-sensor over a drop chamber incorporated into the filling tube. External filling is regulated by the hydrostatic filling pressure or by the perfusion rate of the filling pump.

3. Another drop sensor is used for digital diuresis measurement.

4. We can switch from one to another function using the series of 3-way taps without remounting and disrupting the closed system.

5. The central processing unit receives signs of pressure and flow (drop) sensors, displays and records them in its memory.

6. The basic equipment is connected to a PC over a LAN cable, on which a special version of the Windows based evaluation and documentation software AUDACT Pro is running.

Use of filling fluid of body temperature

In order to minimize measurement artefacts triggered by filling fluid of room temperature we developed a special, concentric, 80cm long double lumen filling tube, in which thermostat tempered heating liquid of 39^0C is circulated using principle of counter flow heat exchange. In the most often used flow range of 5-20ml/min temperature of filling liquid at the tip of the tube varies between 35.5^0C and 37.2^0C depending on the flow rate, which approximates core temperature well.

II. Software integrated into the BIOS and evaluation software AUDACT in order to make measurements more accurate

<u>1. Method of continuous, real time software compensation of flow</u>

Following initial resistance calibration of the nephrostomy catheter software continuously subtracts flow dependent, calculated actual resistance from the pressure measured in the filling tube outside the body, and displays calculated intrapelvic pressure in real time. UDUUT examinations can be accelerated and accuracy improved by using this new method, whereas pressure-flow studies are enabled to be performed through a single lumen catheter at the same time.

2. Mean value calculation of filling rate, measured pressure values and of calculated true intrapelvic pressure by software

Pressure and flow curves registered during UDUUT studies show large variations (waves) due to pelvic contractions (pacemaker activity) and ureteric peristaltic waves. Obstruction rate measurements and quantifications are based on accurate pressure and flow measurements. It was indispensable to work out another method that replaces previously used optical estimation by a completely exact and accurate, automated method. This software integrated into the AUDACT program calculates mean values of pressure and flow curves between two, adjustable markers.

3. PC based software for quantitative measurement of rate of postrenal obstruction

We developed easy-to-use software, which calculates best fitting parabolic curve of pressure-flow relation based on measured flow values and calculated real intrapelvic pressure values. Its coefficient numerically measures rate of postrenal obstruction (obstruction coefficient).

Definition of a new reference pressure level for UDUUT

The conventionally used, generally accepted reference pressure, the intravesical pressure (IVP), suggested already by Whitaker was not found to be reliable; furthermore an invasive catheterization is needed to use it. Measurement of the pressure of perirenal tissues, the perirenal pressure (PRP) directly influences intrapelvic pressure (IPP). It proved in our praxis to a more reliable reference pressure, without need of catheterization.

We developed 4 different methods to define PRP:

1. Indirect measurement of PRP over the pelvic wall by using an electronic pressure sensor at empty collecting system.
2. Estimation of PRP based on body mass index (BMI). According to our observations PRP proved good correlation with the amount of fat tissue surrounding the kidney as well as with the BMI, quantifying constitution type. In order to prove this correlation we measured PRP by using electronic pressure sensor (method 1) in 51 patients (28

male, 23 female), and we calculated their BMI based on the known formula: BMI(kg/m^2)=body weight(kg)/heights(m)^2. Statistical analysis proved a linear correlation, the correlation coefficient=0.76, significant. In everyday praxis the **PRP=BMI-15** is an easy-to-use reliable formula.

3. Hydrostatic measurement of PRP by using a vertical water column
4. Accurate calculation of PRP by using a newly developed, PC based software in cases of complete ureteric obstruction based on pressure-volume relation. Software calculates pressure-volume curve and PRP is defined as the pressure at zero filling volume.

Comparing PRP and IVP in supine and standing positions

We compared PRP and IVP in 18 patients in both supine and standing positions in a prospective study. In supine position PRP and IVP showed slight deviation (9.95 cmH_2O and 8.19cmH_2O), whereas difference gets more expressed in standing positions (20.55 cmH_2O and 24.45cmH_2O). PRP was 22% higher than IVP in average depending in BMI. In standing position PRP rises to its double (207%), whereas IVP gets threefold (299%), PRP elevation is even more expressed in women (355%). In standing position IVP is 19% higher than PRP.

These data prove unreliability of IVP as a reference pressure for UDUUT.

New method of accurate measurement of pressure-flow relation, the multistep pressure-flow measurements

It is necessary to define more points of pressure-flow curve if possible to draw it accurately. To reach this goal, we elevated perfusion rate (Whitaker-principle) in 5ml/min steps up to 20ml/min, and in a similarly multistep manner we elevated filling pressure (Vela-Navarrete principle) in 5cmH_2O steps until SIPP+30cmH_2O intrapelvic pressure was reached. Presentation of measured data on a graph suggested non-linear correlation opposing generally accepted concept.

Statistical-mathematical analysis of pressure-flow relation

We performed statistical analysis of data of 112 multistep pressure-flow studies by using the statistical method of regression-analysis in order to find out if there is a better approximation than the linear one for the description of pressure-flow relation. Analysis

proved that quadratic part is strongly significant ($p<<0.05$). The adjusted R^2 values are 0.715 for the linear and 0.889 for the quadratic model. The second one is clearly superior. Therefore, appropriate, precise description of pressure-flow correlation needs a quadratic model so that it can be better described by using the simple formula of parabolic correlation $\mathbf{Y=AX^2+B}$ in a wide flow range of 2-20ml/min.

We developed an easy-to-use, PC based evaluation program that calculates and displays parabolic curve, and numerically presents the value of A obstruction coefficient (OC) and B ureteric opening pressure (UOP).

Comparing OC with clinical symptoms of obstruction and the antegrade pyelo-ureterograms we found good correlation. Based on this comparing we may diagnose a free outflow if OC=0.03 or less, whereas up to OC=0.1 means semiocclusion, over this value there is a complete occlusion.

Statistical analysis of WT, UOP and OC

According to literature data WT and UOP shows a good correlation with rate of postrenal obstruction.

Using the statistical method of correlation analysis we compared the OC values of 116 multistep UDUUT measurements with IPP values corresponding to 10ml/min filling rates calculated according to the pressure-flow curve and with the IPP value corresponding to the 0 flow rate (UOP). Analysis of data proved that correlation is significant between any two of them; it is weaker between OC and UOP, whereas between OC and WT it is as strong as between UOP and WT.

Based on this triple correlation analysis, clinical applicability of OC can also be proven by this indirect way.

Simplified urodynamic studies of the upper urinary tract

Measurement of spontaneous intrapelvic pressure (SIPP) and its interpretation

At low diuresis rates SIPP practically equals with UOP, which had been proven that it correlates well with the obstruction coefficient measuring the rate of obstruction. Therefore, SIPP is also appropriate for measuring degree of obstruction. According to our experience SIPP does not exceed $5cmH_2O$ in cases of obstruction free clinical cases, higher values imply the presence of obstruction.

Diuretic-test (DT)

If the flow necessary for the pressure-flow studies is covered just by the intrinsic filling, the diuresis itself, there is no need of any external filling. The different IPP-s belonging to different diuretic rates allow us to draw the curve of pressure-flow relation.

We developed the method of obstruction determination based on the principle of changing diuresis, the diuretic-test (DT). Values of spontaneous diuresis, SIPP, diuretically forced diuresis and elevated IPP belonging to this latter provide us sufficient information to calculate the curve of parabolic dependence. To perform it in the praxis, there is no need of electronic pressure-measurement, as being IPP measurement a static examination; it can be well defined by using the simple hydrostatic measuring method.

The OC calculated by multistep constant pressure perfusion studies show good correlation to the OC calculated by diuretic test, although this latter's values seem to be approximately 12% lower.

Conclusions

- One of most important tasks of UDUUT studies is to measure rate of postrenal obstruction objectively, accurately and quantitatively.
- Available non-invasive diagnostic procedures are unable to define intrapelvic pressure and rate of postrenal obstruction.
- Conventional constant flow pressure studies (WT) and constant pressure perfusion studies (NT) just define a single point of the pressure-flow curve, therefore they should be considered as static examinations. Their reproducibility is bound to accurate definition of many parameters (actual diuresis, reference pressure).
- PRP is a new, easier measurable reference pressure for UDUUT by using non-invasive methods; there is no need of additional invasive catheterization. The newly developed four different methods of PRP determination provide a flexible tool of UDUUT that fits demands and possibilities.
- UDUUT studies performed by filling liquid of body temperature let us more accurately perform urodynamic measurements without artefacts thus objectively

evaluate measured data.

- By using the method of multistep, computerized measurement of changes of pressure-flow relations we can perform real dynamic examinations, which allows us to define pressure-flow correlation in the wide flow range of 0.5-22ml/min more accurately than previously used methods.
- The multistep urodynamic studies let us differentiate quantitatively, even in cases of severe obstructions, in which Whitaker-test is not to be performed any more (18% of our cases).
- Mathematical, statistical analysis of measured data proved a nonlinear, parabolic pressure-flow correlation. Coefficient of the formula describing the parabolic curve determinates the shape of the curve.
- We lead in the concept of OC characterizing degree of postrenal obstruction quantitatively, by a single number allowing us to follow up obstructing processes over a longer period.
- At calculation of OC there is no need of any inexact, laborious and discussed reference pressure, thus examination gets faster and by elimination of measurement failure more accurate at the same time.
- In order to easier use this method in clinical praxis, we developed a PC based software that renders possible the fast calculation of OC even without deeper mathematical skill. Software is freely available for anybody, by which we would like to aid wide spread of UDUUT.
- We worked out the method of hydrostatic measurement of IPP, which does not need expensive instrumentation yet let us measure rate of obstruction semiquantitatively.
- Diuretic-test based on changes of diuresis is the least invasive, accurate and easy-to-perform procedure to define obstruction coefficient, therefore this is the most appropriate method in imperiled patients.
- “Just” a shift of paradigm is needed to spread methods of UDUUT.

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