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Experimental Study of the Pressure-Volume and Pressure-Time Relations in the Completely Obstructed Pelvis of the Porcine Kidney

Part 1: Introduction and Theory

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Summary. Little is known about pressure-volume and pressure-time relations of the obstructed renal pelvis. In a series of experiments with pigs the completely obstructed renal pelvis was infused with Ringer's lactate at a constant rate of 2 ml/min. On the basis of these experiments a mathematical description is given of the pressure-volume and pressure-time relations that were recorded.

Key words: Research, Ureteral obstruction, Porcine upper urinary tract, Pressure-volume-time relations.

Introduction

Normally intrapelvic hydrostatic pressure is lower than 10 mm Hg.

After acute, complete subpelvic obstruction a complex balance of forces will lead to increased intrapelvic volume at elevated intraluminar pressure and decreased diuretic activity. The pressure increases in an asymptotic manner to maximum values that may vary from 20 to over 40 mm Hg, depending on the hydration of the animal and the diuretic activity of the kidney. The rate of the pressure increase is also in some way related to the diuretic activity via the counterbalance that increasing volume meets from increasing tension in the elastic pelvic wall [1–4, 6–8]. Up until now there is no model that gives an adequate description of the various aspects involved.

In the framework of an experimental study concerning this matter a series of experiments was done to obtain a better understanding of one phenomenon: the relation between intrapelvic pressure and volume.

In the literature only one publication concerning this subject could be found. Olsen [5] concluded that there was a linear relation between volume and pressure in the completely obstructed pelvis of the dog when Ringer's lactate was slowly injected until pressure values of approximately 25 mm Hg were recorded. However, when we tested the method of Olsen there was doubt about the linearity of the pressure-volume relation and it also appeared that the pressure rose with volume only as long as the injection was continued. When the injection was stopped at pressure values higher than 20 mm Hg the intraluminar pressure decreased to a lower asymptotic value and the question arose as to whether this decrease was due to escape of injected fluid or dilatation of the system.

Therefore a series of experiments was performed with pigs in which the completely obstructed pelvis was infused with Ringer's lactate at a constant rate of 2 ml/min under continuous recording of intrapelvic hydrostatic pressure. The significance of the recorded pressure values and their relation to the pelvic volumes measured was investigated in several ways. First a mathematical description is given of the pressure recordings that were obtained when the empty but completely obstructed pelvis was infused until pressures higher than 50 mm Hg were recorded. The results of this study are presented in this part.

Second, a series of experiments was performed in which infused volumes were compared with volumes obtained by rapid extraction of the pelvic content and the relations between changes of volume and pressure were investigated. The results of this study will be presented in the second part.

In the third part a series of experiments is presented in which the reproductivity of the tests and the elastic stability of the pelvicalyceal system was investigated.

The results of a series of experiments in which instability and "blow out" of the porcine pelvis were examined are presented in part four.

Materials and Methods

Seventeen healthy pigs of both sexes, whose weights varied from 25–40 kg, were used. After a period of 12 h without food, but with free access to water, the animals were given a premedication of Thalamonal, droperidol and atropine i.m. Induction of anaesthesia

Fig. 1. Recording of arterial pressure, intraluminar pressure and urine flow. *1*, arterial pressure; *2*, intraluminar pressure; *3*, urine flow

was achieved with Fentanyl and Hypnomidate i.v. After intubation anaesthesia was maintained with Pavulon and Fentanyl i.v. and a mixture of N_2O and O_2 (60/40%).

An external carotid artery and jugular vein were cannulated with polyethylene catheters (8F) for arterial and central venous blood pressure measurements and for administration of analgesics and a Ringer's lactate drip. Next, flank incisions were made on both sides. The ureters were freed from the surrounding tissue and through small transverse incisions the tips of two-channel polyethylene catheters (12F) were passed to the pelvis. The ureters were tied around the catheters with a nylon ligature at the level of the lower pole curvature whereupon the wounds were closed.

One lumen of a two-channel catheter was connected to a Druck pressure sensor and the other to either a urine flow meter or an infusion pump with which the pelvis could be filled at a constant rate. Signals of the pressure sensors (arterial, central venous and intrapelvic) were, together with the urine flow signal recorded continuously on a six-channel Rikadenki chart recorder and presented on digital displays (Fig. 1).

With a Ringer's lactate drip of 10 ml/kg/h all animals were in stable circulatory condition and had a low diuretic activity of 0.1 to 0.4 ml/min/kidney.

Statistical Analysis of Pressure-Volume and Pressure-Time Relations

In a series of experiments the empty pelvis was continuously infused with Ringer's lactate at a rate of 2 ml/min. The recorded pressure and volume values appear to have a gaussian distribution around their mean. Linear regression analysis, based upon the method of the least squares, can thus be used. Mean and standard deviation can, for this distribution, be calculated using the formulas

$$\bar{x} = \frac{1}{N} \sum_{k=1}^{N} x_k \quad \text{and} \quad \sigma^2 = \frac{1}{N} \sum_{k=1}^{N} (\bar{x} - x_k)^2$$

Exponential curve fitting of the experimental dataset is done by a PDP 11-70 computer using a modified linear regression program followed by an iterative program for calculating the constant C_3 in the formula

$$P = C_1 e^{C_2 V} + C_3$$

Before linear regression analysis or exponential curve fitting the preliminary dataset is fed into a computer program that estimates the P–V relation as a series

$$P = C_1 + C_2 V + C_3 V^{-1} + C_4 V^2 + C_5 V^{-2} \ldots + C_{21} V^{-10}$$

The results of this analysis are used for the theoretical model.

Theoretical model of pressure-volume and pressure-time relations at intrapelvic pressure values lower than 50 mmHg.

The pressure-volume relation of the porcine pelvis (Fig. 2) consists of two separate regions:

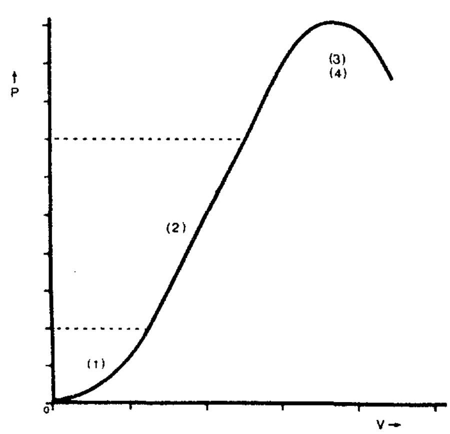

Fig. 2. Theoretical model of the pressure-volume relation

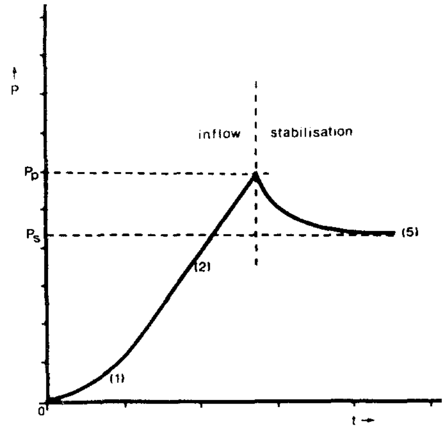

Fig. 3. Theoretical model of the pressure-time relation

a) a logarithmic region (P < = 20 mm Hg) given by the formula

$$P = C_1 e^{C_2 V} + C_3 \quad (1)$$

b) a linear region (20 < P < = 50 mm Hg) given by the formula

$$P = C_4 + C_5 V \quad (2)$$

At pressure values higher than 50 mm Hg, where "blow out" of the pelvis appeares to occur, the P–V relation is difficult to describe. In most cases the P–V relation is parabolic and can described by the formula

$$P = C_6 + C_7 V + C_8 V^2 \quad (3)$$

Sometimes the relation is logarithmic, the formula then is

$$P = C_9 + (P_{max} - C_9)(1 - e^{-C_{10} V}) \quad (4)$$

The type of relation seems to be set by the location and the size of the "blow out" lesion.

The stabilisation part of the curve of Fig. 3, an obstructed pelvis filled with fluid and then left to itself, can be described by the formula

$$P = C_{11} + C_{12} e^{-C_{13} t} \quad (5)$$

In the formulas (1) to (5) C stands for a constant, in the formula (3) P_{max} is the maximum pressure recorded in the pelvis before "blow out" appeared to occur.

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