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The Influence of Pyeloureteral Peristalsis on Pelvic Pressure During Increase in Flow Rate

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Summary. Thirty-nine normal pig pyeloureters were perfused with 0, 2, 4, 6, 8, 10 and 20 ml/min during continuous measurement of the pelvic pressure. A phasic pressure response was identified with the highest pressure increase between 2 and 4 ml/min. Two groups were analyzed. One consisting of the 10 pyeloureters with the highest pressure increase and the other of the 10 pyeloureters with the lowest pressure increase to a perfusion rate of 4 ml/min. The peristaltic frequency was significantly higher (about 6/min) in the high pressure group than in the low pressure group (about 3.5/min). It is concluded that a high peristaltic frequency is at least partly responsible for the high pressure response to increasing flow because the peristaltic contraction ring opposes the filling flow through ureter.

Key words: Pelvic pressure – Pelvic perfusion – Peristaltic frequency

Introduction

It has been shown that the pelvic pressure increases during increasing diuresis [1, 5, 6, 7]. Recently it was experimentally shown that the relation between pressure and flow in the upper urinary tract in pigs runs through different phases [8, 9]. The first phase is seen in the low flow range 0–2 ml/min, where changes in pressure are small and where transport consequently occurs under low pressure. Phase 2 between 2 and 4 ml/min, displays a sharp increase in pelvic pressure varying, however, in magnitude within pyeloureters. The explanation might be that the preceding peristaltic contraction ring opposes the passive filling flow of ureter. In phase 3 (around 5 ml/min), the pressure increment decreases because the ureteric musculature at rest is stretched beyond the coaptive contraction capability. The peristalsis decompensates and leakage between boli occurs. In phase 4 the flow is continuous and pelvic pressure is proportional to flow rate. Perfusion studies of the transsected ureter have confirmed that this phasic pressure response is caused by the ureter and not by the uretero-vesical or uretero-pelvic junction [10]. This also indicates that peristalsis may be responsible for the pressure increase in phase II. To clarify this question we analyzed the peristaltic frequency in high pressure responding versus low pressure responding pyeloureters.

Material and Methods

Method (Mortensen and Djurhuus [8])

Pigs of Danish Landrace Breed weighing between 30–42 kg were studied. The investigations were performed under general anaesthesia induced by intramuscular injection of 10 mg ketalar (ketamine NFN) per kg b.w. and maintained by halothane 1.5–2.0%. Through a midline incision from the symphysis pubis to the xiphoid process the kidney was exposed retroperitoneally. The bladder was opened in the midline and kept open throughout the investigation. Through the uretero-vesical junction two 6-F catheters with side and end holes were one after the other guided up through the ureter, the renal pelvis and out through the renal parenchyma. They were then withdrawn until the tips with the side and end holes of both catheters finally lay in the renal pelvis. One was used for pressure measurements and connected to a Siemens 746 strain gauge pressure transducer and amplifier with the transducer placed in level with the kidney. The other was used for perfusion and connected to a roller pump. After a resting period of 30 min the measurements were performed. During continuous registration of the pressure pelvis was perfused consecutively with the following flow rates 0, 2, 4, 6, 8, 10 and 20 ml/min. The flow rate was increased when the pelvic pressure had been stable for at least 5 min. Isotonic saline heated to 37 °C was used as perfusion fluid. The lowest pressure in steady state between peristaltic contractions was used for analysis.

Material

Thirty-nine pyeloureters were investigated. The peristaltic frequency per min was found by counting the number of pressure waves on the tracing at stable pressure at each flow rate and then divided by

Table 1. Peristaltic frequency of 10 pyeloureters showing the highest increase in pelvic pressure during perfusion

No	Perfusion rate ml/min						
	0	2	4	6	8	10	20
1	6.0	6.4	6.0	–	7.5	9.0	7.0
2	4.8	5.2	4.8	4.0	6.6	6.0	6.2
3	3.0	10.0	10.0	7.4	6.6	6.6	4.2
4	–	5.6	7.0	9.0	7.3	8.2	6.2
5	7.3	5.7	8.1	8.2	7.7	7.0	5.5
6	7.2	2.8	11.5	9.4	8.4	–	10.8
7	4.2	4.0	3.1	3.7	2.9	3.2	4.0
8	3.4	3.2	4.5	3.5	3.3	4.3	3.1
9	3.1	5.3	2.0	3.7	3.2	2.7	4.7
10	12.0	8.7	8.5	6.3	5.8	6.6	7.5

Table 2. Peristaltic frequency of 10 pyeloureters showing the lowest increase in pelvic pressure during perfusion

No	Perfusion rate ml/min						
	0	2	4	6	8	10	20
1	5.8	4.8	5.5	4.0	7.0	5.8	–
2	5.0	4.0	3.4	2.8	2.3	2.4	4.0
3	2.5	1.9	2.9	2.7	2.7	2.5	7.1
4	3.8	2.9	0.9	3.8	1.9	2.5	5.5
5	3.5	2.4	2.8	2.2	1.8	1.0	2.4
6	2.2	1.4	0.9	4.3	1.0	1.0	6.2
7	1.0	4.8	5.1	4.2	4.5	3.9	4.9
8	5.4	5.5	4.9	2.5	2.0	3.0	5.5
9	3.0	3.4	2.8	3.0	3.1	4.4	8.9
10	5.8	5.8	5.2	5.0	4.2	4.0	4.2

the time spent at that flow rate. In the previous studies [8, 9] the largest increment in pressure was found when the perfusion rate was increased from 2–4 ml/min. Two groups were analysed according to the pressure increase at that flow rate. One consisted of the ten pyeloureters with the greatest pressure increase and the other of the ten pyeloureters with the lowest pressure increase. The mean peristaltic frequency at all flow rates from both groups was compared and analyzed by Student's *t*-test. A significance level of 0.05 was used.

Results

In the high pressure group the baseline pressure ranged from 3.5 to 13.5 cm H_2O (mean 7.1 cm H_2O) and the pressure increase during perfusion with 4 ml/min varied from 11.0 to 18.0 cm H_2O (mean 14.2 cm H_2O). In the low pressure group the baseline pressure ranged from 5.0 to 13.5 H_2O (mean 8.1 cm H_2O) and the corresponding pressure increase at 4 ml/min was 0.0 to 3.5 cm H_2O) (mean 1.4 cm H_2O).

Tables 1 and 2 show the peristaltic frequency at the different flow rates in the high and respectively low pressure groups. The tendency in the single pyeloureter was that the peristaltic frequency was relatively stable regardless of flow rate although variations from this were seen.

In the high pressure group 6 units had a frequency of 6/min or more and only 2 units a low frequency at 4 ml/min. In the low pressure group all units showed a peristaltic frequency less than 6/min. At a flow rate of 20 ml/min the frequencies generally were increased and in fact approximated those of the high pressure group.

Table 3 shows the mean peristaltic frequencies at the different flow rates in the two groups. The frequency was significantly higher in the high pressure group at all flow rates except at 20 ml/min. However, in the high pressure group no direct correlation was found between magnitude of pressure increase and peristaltic frequency in each unit at a flow rate of 4 ml/min. The correlation coefficient was 0.21.

Discussion

The method required that the catheters were introduced into the pelvis through the ureter. Irritative artifacts might have influenced the peristaltic frequency [2]. However, according to others this secondary effect diappears within few minutes of rest [13], and therefore has probably not affected the results.

It might be argued that analysis of pressure curves did not produce a correct measure of the peristaltic frequency. The equipment was sufficient to register dynamic qualities of the pressure contractions occurring in pelvis. Respiratory

Table 3. Mean peristaltic frequency of 10 pyeloureters with the highest respectively the lowest increase in pelvic pressure during perfusion. Distally, significance level between the 2 groups

	Perfusion rate ml/min						
	0	2	4	6	8	10	20
High pressure group	5.67	5.69	6.55	6.13	5.93	5.96	5.92
Low pressure group	3.80	3.69	3.44	3.45	3.05	3.05	5.41
Significance level	$P<0.02$	$P<0.01$	$P<0.001$	$P<0.01$	$P<0.001$	$P<0.001$	$P>0.40$

pressure excursions were in general easy to separate from excursions caused by peristaltic contractions and without doubt nearly all contractions were registered. To make the investigation as non-invasive as possible and thereby obtain the smallest degree of interference with peristalsis, EMG electrodes were omitted in this study. With these reservations it can be concluded that pyeloureters exhibiting a high pressure increase during perfusion have a significantly higher peristaltic frequency than pyeloureters exhibiting a small pressure increase. This indicates that the peristalsis opposes the transport through the ureter at high flow rates. The high frequency was not caused by the increase in flow rate as it existed during basal conditions indicating the genuine frequency of the pyeloureters at that particular moment. To oppose the transport there must be a peristaltic contraction somewhere along the ureter constantly. On the assumption that the transmission rate of the peristaltic onctraction is about 3 cm/s [12] and the ureter is about 30 cm a frequency of 6/min is necessary. The prerequisite was fulfilled in 6 pyeloureters. It has furthermore been shown by others that the transmission rate even at low flow rates may vary and be as slow as 2 cm/s [4] and the transmission rate may slow down at increasing flow rate, especially when it reaches 4 ml/min [11]. Both factors would allow a frequency of less than 6/min to cause obstruction and could explain the high pressure increase in two other pyeloureters with a lower peristaltic frequency.

However, in two units the pressure increase hardly could be explained by peristaltic obstruction. This suggests that in some cases other – perhaps external – factors might be responsible for the pressure increase.

No correlation was found between the peristaltic frequency and the increase in pressure at 4 ml/min, in the high pressure group. This could not be accounted for by the low frequency of two pyeloureters because it persisted after subtraction of them. The pelvic compliance varies from unit to unit [3] and presumably the same variation also occurs in the ureter. That is a different degree of passive distensibility or capacity of the ureter between peristaltic contractions could explain the missing correlation.

The increase in peristaltic frequency at 20 ml/min in the low pressure group to values approximating those of the high pressure group is not directly explicable but might be caused by the excessive stimulation of the pyeloureter. It was not accompanied by an equivalent pressure increase. The peristalsis is incomplete at that flow rate and unimportant to the transport. However, even small changes in ureteric diameter will be registered by changes in pelvic pressure caused by momentary changes in resistance. In conclusion the study has indicated that a high-frequency peristalsis opposes the transport through the ureter at high flow rates and causes the high pressure response in phase II.

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