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UROLITHIASIS

Location of ureteral access sheath in the ureter. Does it affect the fluid flow in different calyces?

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Introduction The aim of this study was to evaluate outflow variation in different locations of the pyelocaliceal system with the use of different ureteral access sheath (UAS) sizes and different UAS positioning.

Material and methods The experimental setup included an anaesthetised porcine model, a 7.5-Fr ureteroscope with a 200-µm laser fibre inserted in the working channel, a hand-held pumping irrigating system, and UAS of different sizes, namely: 9.5/11.5 Fr, 12/14 Fr, and 14/16 Fr. Each UAS was placed just below the ureteropelvic junction (UPJ) or in the mid-ureter. The ureteroscope was placed in the renal pelvis, upper and lower calyces, and outflow measurements were obtained with 3-second interval pumping for one minute in every experimental setup.

Results The UAS positioning in the mid-ureter was associated with significantly higher outflow rates in the lower calyx ($p = 0.041$). While the UAS was below the UPJ, we observed a trend of lower outflow rate in the lower calyx, which was completely inverted when the UAS was in the mid-ureter. Increasing the UAS size from 9.5/11.5 Fr to 12/14 Fr led to a significant increase in outflow in the renal pelvis and upper calyx ($p = 0.007$), but not in the lower calyx. A further increase to 14/16 Fr did not produce increased flow.

Conclusions Different locations of the pyelocaliceal system have different fluid mechanics during fURS. In the renal pelvis and upper calyx increasing the diameter of the UAS improved the outflow, whereas in the lower calyx the position of the UAS seems to be the most relevant factor. These variables should be considered when performing fURS, especially with high-power laser lithotripsy.

Key Words: flexible ureteroscopy ‹› outflow ‹› ureteral access sheath ‹› renal pelvis ‹› upper calyx ‹› lower calyx

INTRODUCTION

The field of endourology has been pushed by the advances in flexible ureteroscopy (fURS). Nowadays, the fURS is becoming more popular for the treatment of big stone burden, and it can be expected that the classic stone size limit of 2 cm will probably change in the near future [1]. This technical evolution is mainly driven by new technology, i.e. high-power laser devices, that allow more efficient lithotripsy [2, 3]. Faster stone ablation and shorter operative time, with equivalent postoperative complications have been reported with high-power lithotripsy [4, 5, 6]. Nevertheless, high-power lithotripsy may induce

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renal thermal damage if not met with appropriate fluid flow [7, 8, 9]. It is generally accepted that 43°C is the threshold for thermal damage [7, 10]. Keeping temperature below this limit does not produce any histological change, irrespective of the type of laser being used [11]. In fact, with an adequate flow rate, intrarenal temperatures do not rise above 43°C [9, 12]. Therefore, the flow of the irrigation is fundamental both for visibility in fURS and for laser lithotripsy safety.

The flow rate during fURS has been largely outshined by intrapelvic pressure (IPP) concerns [13, 14]. Nonetheless, both are important for fURS safety, and both are intrinsically connected. They are dependent on fluid inflow, fluid outflow, and renal tissue compliance. The latterhas received the least attention because most studies are performed with the ureteroscope in the renal pelvis. Working inside calyces may present different fluid dynamics depending on the physical properties of the surrounding parenchyma [15]. There is also a lack of data on how the ureteral access sheath's (UAS) position and location in the ureter affects the irrigation flow while working inside the calyces.

Hence, to improve safety during fURS one should maximize flow while maintaining a low IPP. Because the kidney anatomy cannot be controlled, fluid inflow and outflow should be optimized. A standard setup with a hand-held pumping irrigation device and a UAS appropriately matched to the ureteroscope can achieve this goal [16, 17]. However, the optimal combination of factors to improve fluid flow in different locations inside the pyelocaliceal system is not known. In this study, we aim to evaluate the variation of fluid flow with different ureteroscope positions inside the kidney, and how it is affected by different UAS sizes and positions in the ureter.

Methodology

With approval from the Veterinary State Services, one female pig (28 kg weight) was used in this experiment. The pig was anaesthetised and put in a supine position. A cystoscopy and retrograde pyelography were performed bilaterally, and the left kidney was chosen due to more favourable anatomy. After 2 guidewires were inserted, the different ureteral access sheaths (Flexor™, COOK Medical, Bloomington, Indiana, USA) were progressed through the working guidewire, always leaving a safety guidewire. A single-use digital flexible ureteroscope (Uscope 7.5 Fr, PUSEN, Zhuahai, China) was used with a 200-μm laser fibre (Cyber Ho 150, Quanta System, Samarate, Italy) always inserted inside its working channel. The irrigation system utilized was a hand-held pumping system (Ureteroscopy Irrigation System™, COOK Medical, Bloomington, Indiana, USA), which was connected to a 3-L saline bag that was placed 1 m above the level of the pig (Figure 1). Two surgeons performed the experience, with one operating the ureteroscope and the assistant pumping in all experimental setups.

The outflow measurements were performed with different combinations of ureteroscope position (renal pelvis, upper calyx, and lower calyx), UAS size (9.5/11.5 Fr, 12/14 Fr, and 14/16 Fr), and UAS location (below the ureteropelvic junction [UPJ] and mid-ureter). At each setting, the ureteroscope with the laser fibre inside the working channel was fixed and manual pumping was performed at 3-s intervals for one minute. The flow exiting the UAS was collected, aspirated with a syringe, and measured. The results are presented in mL/min and thus refer

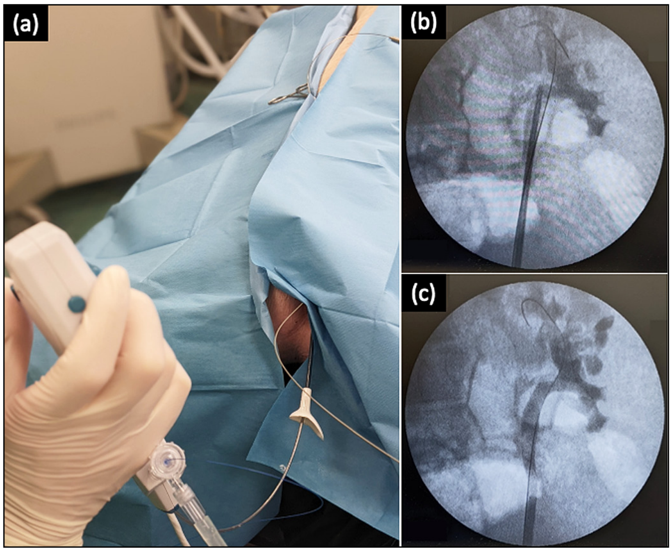

Figure 1.A. *Experimental setup;* **B.** *ureteral access sheath below the ureteropelvic junction;* **C.** *ureteral access sheath at the mid-ureter.*

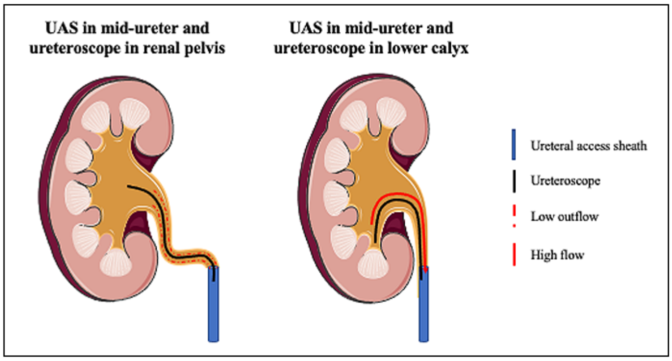

Figure 2. *Effect of ureteral access sheath position in mid-ureter when working in the renal pelvis or in the lower calyx.*

UAS – ureteral access sheath

to the amount of fluid obtained from the UAS in one minute. Five outflow measurements were obtained at each setting and the average was calculated.

Statistical analyses were performed using SPSS statistics v. 23.0 (SPSS Inc., 2015). To evaluate the effect of ureteroscope positioning, one-way ANOVA was performed. To evaluate the correlation of UAS size with outflow, Spearman correlation was performed. Furthermore, data were divided by ureteroscope position, and the different UAS sizes were compared by one-way ANOVA and independent sample t-test. Finally, to evaluate the effect of UAS location, the independent sample t-test was used for each ureteroscope position. Statistical significance was considered for p-values <0.05.

RESULTS

All the experiment combinations tested are summarised in Table 1.

The UAS position below the UPJ or at the mid-ureter did not have any impact on outflow in the upper calyx or renal pelvis (p = 0.890 and p = 0.853, respectively). However, in the lower calyx, repositioning the UAS to the mid-ureter led to significantly higher outflow rates (p = 0.041). Furthermore, when the UAS was below the UPJ, the ureteroscope positioning in the lower calyx was associated with lower outflow than other locations of the pyelocaliceal system, although a statistical significance could not be determined. The inverse trend was noted when the UAS was in the mid-ureter, with the lower calyx presenting the highest outflow values registered in the entire study.

Table 1. *Outflow measurements with different ureteroscope locations, ureteral access sheath sizes, and ureteral access sheath locations*

	Outflow Rate (mL/min)		
	Renal pelvis	Upper calyx	Lower calyx
UAS 9.5/11.5Fr			
Below the UPJ	25	22	17
Mid-ureter	26	24	32
UAS 12/14Fr			
Below the UPJ	38	36	26
Mid-ureter	40	37	49
	#	#	
UAS 14/16Fr			
Below the UPJ	40	38	28
Mid-ureter	41	38	50
	#	#	
P value (between UAS location)	0.853	0.890	0.004*
P value (between UAS size)	0.001*	0.001*	0.597

*statistical significance; #p <0.05 vs. UAS 9.5/11.5 Fr
UAS – ureteral access sheath; UPJ – ureteropelvic junction

The size of the UAS had an overall positive significant correlation with the outflow (p<0.001). In the upper calyx and renal pelvis, increasing the UAS size from 9.5/11.5 Fr to 12/14 Fr resulted in a significant increase in outflow (p = 0.007 and p = 0.007 for upper calyx and renal pelvis, respectively). However, a further increase in the size of the UAS to 14/16 Fr was not associated with increased outflow (p = 0.095 and p = 0.312 for upper calyx and renal pelvis, respectively). In the lower calyx, increasing the size of the UAS had no significant effect on outflow (p = 0.597) (Table 1).

DISCUSSION

In this study, in an anaesthetised porcine model, we demonstrated that both UAS size and location were important determinants of outflow rate during ureteroscopy. However, their effect was different depending on the ureteroscope positioning. Compared to the 9.5/11.5 Fr UAS, both 12/14 Fr and 14/16 Fr UAS increased the outflow rate in the upper calyx and renal pelvis, but not in the lower calyx. On the other hand, placing the UAS at the mid-ureter significantly increased the flow in the lower calyx, while having no effect on the upper calyx and renal pelvis.

The role of fURS in endourology is expanding as it is being fuelled by new technology [3]. The use of UASs has become standardized as several studies have demonstrated its efficacy in keeping IPP lower than 40 cm H_2O [15–19]. To minimize ureteral lesions induced by the UAS [20] there is a trend towards using smaller UASs, which strengthens the need for smaller ureteroscopes [17]. In this study, we used a 7.5-Fr ureteroscope so it could fit the smallest tested UAS, which was 9.5/11.5 Fr. This ureteroscope has a 3.6-Fr working channel, which is equal to the 9.5-Fr ureteroscope model [21]. Therefore, fluid inflow was not compromised by the smaller ureteroscope.

Another important safety factor during fURS is fluid flow. When performing laser lithotripsy, intrarenal temperatures may rise to dangerous levels. Tissue thermal injury starts at 43°C, and the more time spent above this threshold, the higher the cumulative damage [10, 22]. Without good fluid flow, even low-power laser settings can raise the temperature above this threshold quickly [7, 12]. Teng, J et al. [23] monitored temperature during fURS in humans and were able to demonstrate that during laser firing up to 20 W, a fluid flow of 15 mL/min was able to keep the temperature below 43°C. Similarly, Maxwell, AD et al. [24] created an in vitro model and found that 15 mL/min prevented any temperature increase with the laser firing at 40 W. Our group has also designed a different in vitro model, and we found that a flow of 20 mL/min can prevent temperature increase with the laser firing at 60 W [12]. This data is corroborated by our findings in a porcine model, where we tested high-power laser firing with 60 W. With the use of manual pump irrigation and UASs, temperatures did not rise to dangerous levels [9].

Given the relevance of flow in fURS safety, it is important to understand the fluid dynamics during the procedure [25]. The inflow is the amount of fluid entering the system per unit of time, and it depends on the fluid pressure and the ureteroscope working channel. There are several irrigation setups that increase fluid pressure and therefore increase inflow, namely: elevating the fluid bag to obtain higher gravitational pressure, pressurized bag sleeves [26], manual or foot pumping devices [27], or automatic irrigation systems [28]. Inflow is also very dependent on the occupation of the ureteroscope working channel. The presence of instruments in the working channel significantly reduces flow [19]. In this study, every experiment was performed with a 200-μm laser fibre inserted in the working channel, because it is during laser firing that the flow is crucial for fURS safety. This way, even though our flow measurements were reduced by this experimental design, we were able to simulate the desired clinical setting. On the other hand, we have outflow, which is the amount of fluid exiting the system per unit of time. Ideally, the system should be able to drain easily. If there is high outflow resistance, pressure will build up in the system and total flow will decrease. In fact, when the system is filled an equilibrium is reached at a determined IPP and the outflow will equal inflow [29]. Most of the outflow will drain through the UAS, part will be lost between the UAS and the ureteral wall, and a small part will be lost due to kidney backflow. Therefore, in the absence of direct real time monitoring of inflow, the outflow through the UAS is the best indirect measure of the total amount of fluid passing by the system per unit of time.

Different kidneys may have different tissue stiffness, which may also affect the flow. Once the fluid starts to fill the pelvis, the pressure will increase and then plateau [29]. The variation of pressure and flow patterns inside the system is thus dependent also on tissue compliance. Almost every study describes IPP and flow in the renal pelvis. Only recently, Patel RM, et al. [15] evaluated intracalyceal pressure during human fURS and found significantly higher pressure in the interpolar calyx than in the renal pelvis and a trend of higher calyceal pressure in the other calyces. Hence, working inside the calyces is different from working inside the renal pelvis. In this study, we found a trend of decreased outflow in the lower calyx. Furthermore, the use of a bigger UAS did not improve outflow in the lower calyx as opposed to the other locations. The acute infundibulopelvic angle could represent a disadvantage for the lower calyx fluid drainage, which could have contributed to these findings. In any case, it seems that the outflow determinants in the lower calyx are different. This became evident when the UAS was repositioned in the mid-ureter. Outflow increased significantly in the lower calyx, and we saw an inversion of the trend, with the lower calyx presenting the highest outflow measurements in the whole experiment (Table 1). In our view, with the UAS in the mid-ureter, bending the ureteroscope towards the lower calyx straightens the proximal ureter (Figure 2). The ureter in the pig is often tortuous and prone to ureteral foldings that may act as a valve, preventing adequate outflow. This is also a common clinical scenario that may even prevent the progression of the UAS. We hypothesise that bending the ureteroscope may counteract the valvular effect imposed by ureteral folding in the proximal ureter and thus remove resistance to outflow.

There are some limitations of this study that are important to address. We were not able to measure intracalyceal pressure. There might have been some fluid reabsorption that we were not able to measure. We were also not able to measure the flow between the UAS and the ureteral wall. Also, different ureteroscope-UAS combinations would possibly lead to different results. However, we believe that fURS is advancing towards miniaturization, and so we chose to test the smallest ureteroscope available with different combinations of UAS sizes. Finally, we only tested 2 UAS positions. It is also possible that different ureter anatomies and different UAS positions would have a different impact on the outflow. Our pig model might not be generalizable to every clinical scenario, but not even a human model could mimic all possible anatomy variations that could interfere with the results. Nevertheless, our study clearly highlights some overlooked determinants of outflow during fURS, and we hope that our findings may drive future studies in this area.

CONCLUSIONS

The fluid mechanics during fURS are different in different locations of the pyelocaliceal system. In our model, the UAS size had an impact on outflow in the upper calyx and renal pelvis, but not in the lower calyx. For the lower calyx, the UAS position was more important, with the highest outflow registered when the UAS was in the mid-ureter. When targeting lower calyx stones with a tortuous ureter, the clinician should check the outflow rate through the UAS and consider repositioning it in the mid-ureter. In future studies, ureteroscope location and both UAS size and location should be considered important determinants of outflow.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

ETHICAL STANDARDS

The study has been carried out in accordance with the ethical animal standards.

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