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Original Article

In vivo ureteroscopic intrarenal pressures and clinical outcomes: a multi-institutional analysis of 120 consecutive patients

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Objectives

To evaluate the pressure range generated in the human renal collecting system during ureteroscopy (URS), in a large patient sample, and to investigate a relationship between intrarenal pressure (IRP) and outcome.

Patients and Methods

A prospective multi-institutional study was conducted, with ethics board approval; February 2022–March 2023. Recruitment was of 120 consecutive consenting adult patients undergoing semi-rigid URS and/or flexible ureterorenoscopy (FURS) for urolithiasis or diagnostic purposes. Retrograde, fluoroscopy-guided insertion of a 0.036-cm (0.014″) pressure guidewire (COMET™ II, Boston Scientific, Marlborough, MA, USA) to the renal pelvis was performed. Baseline and continuous ureteroscopic IRP was recorded, alongside relevant operative variables. A 30-day follow-up was completed. Descriptive statistics were applied to IRP traces, with mean (SD) and maximum values and variance reported. Relationships between IRP and technical variables, and IRP and clinical outcome were interrogated using the chi-square test and independent samples *t*-test.

Results

A total of 430 pressure traces were analysed from 120 patient episodes. The mean (SD) baseline IRP was 16.45 (5.99) mmHg and the intraoperative IRP varied by technique. The mean (SD) IRP during semi-rigid URS with gravity irrigation was 34.93 (11.66) mmHg. FURS resulted in variable IRP values: from a mean (SD) of 26.78 (5.84) mmHg (gravity irrigation; 12/14-F ureteric access sheath [UAS]) to 87.27 (66.85) mmHg (200 mmHg pressurised-bag irrigation; 11/13-F UAS). The highest single pressure peak was 334.2 mmHg, during retrograde pyelography. Six patients (5%) developed postoperative urosepsis; these patients had significantly higher IRPs during FURS (mean [SD] 81.7 [49.52] mmHg) than controls (38.53 [22.6] mmHg; $P < 0.001$).

Conclusions

A dynamic IRP profile is observed during human in vivo URS, with IRP frequently exceeding expected thresholds. A relationship appears to exist between elevated IRP and postoperative urosepsis.

Keywords

intrarenal pressure, renal pelvic pressure, pressure guidewire, COMET II, flexible ureterorenoscopy, ureteroscopy, retrograde pyelography, endourology, complications of ureteroscopy, adverse events following ureteroscopy

Introduction

The pressure generated in the upper urinary tract during ureteroscopy (URS) is a topic of growing concern [1]. Research to date is predominantly based on ex vivo and animal studies. The calibre of instruments used, the presence or absence and size of a ureteric access sheath (UAS), the ratio of ureteroscope to UAS size, the background irrigation settings, and the use of additional irrigation pump devices, alongside a patient's baseline intrarenal pressure (IRP) and individual anatomy, can influence the pressure within the ureter and renal collecting system [2]. Current standard URS practice involves continuous inflow of irrigation fluid, with variable outflow drainage, resulting, in the clinical setting, in an IRP that is both unquantifiable and uncontrolled.

The clinical significance of intraoperative IRP has yet to be confirmed; however, early evidence suggests that an elevated IRP may be correlated with adverse patient outcomes. Ex vivo studies of human kidneys have reported the occurrence of pyelorenal reflux at an IRP of 40 cmH_2O, and pyelovenous backflow at 60–100 cmH_2O, in structurally normal kidneys [3,4]. This concept has led to concerns of venous translocation and systemic dissemination of bacteria or endotoxins from infected stones [5]. Furthermore, rupture of the collecting system and subsequent urinoma formation may result from elevated IRPs, whereby a rupture threshold as low as 69 cmH_2O has been observed in an ex vivo study of porcine kidneys [6]. It has been hypothesised that raised IRP may play a key role in post-URS febrile UTI, which has an incidence of up to 18% [7], and may result in severe sepsis [7,8]. An in vivo human study of miniaturised percutaneous nephrolithotomy (PCNL) identified increased incidence of postoperative fever in patients with IRPs of >30 mmHg (40.78 cmH_2O) that were sustained for >50 s [9]. In the context of URS, a human randomised controlled study of pressurised bag vs hand-operated irrigation pumps identified correlation of the latter with systemic inflammatory response syndrome (SIRS), emergency re-presentation and pain, although the actual IRP was not measured [10].

Minimal in vivo human data have been reported on baseline and URS IRP, and correlation of IRP sustained during URS with clinical outcome has not been explored to date. We aimed to prospectively study human in vivo IRP in a consecutive sample of patients undergoing URS, in a multi-institutional setting.

Patients and Methods

Study Design

A prospective, multi-institutional study was designed, measuring IRP and clinical outcomes of patients undergoing URS, enrolling consecutive patients. Operating surgeons were blinded to the IRP recordings. The study was conducted in four Irish hospitals, following ethical approval, with recruitment February 2022–March 2023.

Eligibility

Patients eligible for study inclusion were aged ≥18 years, undergoing semi-rigid URS and/or flexible ureterorenoscopy (FURS) for treatment of urolithiasis or diagnostic purposes, in an elective or emergency setting, who consented to participation.

Measurement Device and Technique

The single-use 0.036-cm (0.014″) COMET™ II pressure guidewire (Boston Scientific©, Marlborough, MA, USA), designed for intra-coronary and peripheral endovascular use, was used to measure IRP in this study (Fig. S1). The wire was positioned retrograde within the renal pelvis and connected to a link device integrating signal from an external pressure transducer incorporating a three-way tap opened to the atmosphere. Prior to intracorporeal placement of the COMET II, the system was zeroed to atmospheric pressure. Wireless transmission of pressure recordings was conducted to the AVVIGO™ (Boston Scientific) system. One researcher (S.M.C.) attended each institution for all conducted cases, managed the recording of pressure traces and ensured standardisation of methodology across sites.

Operative Technique

A preoperative urine sample was obtained for culture and sensitivity. Procedures were performed under general anaesthesia, with standard antibiotic prophylaxis (aminoglycoside in three centres; aminoglycoside + cephalosporin in one). Rigid cystoscopy was performed, and the bladder was emptied in all cases. The COMET II pressure guidewire was then cystoscopically passed via the ureteric orifice to the renal pelvis using fluoroscopy (Fig. S2). The cystoscope was removed and baseline IRP was recorded for 1–2 min. An additional 0.089-cm (0.035″) safety guidewire was placed and URS was performed as per surgeons' usual practice, with ongoing IRP recording. Semi-rigid URS was performed with a 6.5–7.5-F semi-rigid ureteroscope and FURS with a 9.5-F flexible ureteroscope (Lithovue™; Boston Scientific) or 8.4-F Olympus URF-P4™ (Olympus Medical Systems Corp., Tokyo, Japan). Normal saline (0.9%) was the irrigation fluid in all cases, with irrigation bags hung 50 cm above the operating table. A 270-μm laser fibre was used for all stone cases. Where retrograde pyelography was performed, contrast was instilled under fluoroscopy, using the minimum volume necessary (≤15 mL) to delineate the pelvicalyceal system.

Data Variables

Patient Characteristics

Patient demographic details, comorbidity and American Society of Anesthesiologists (ASA) grade, preoperative renal obstruction, and presence/absence of a ureteric stent were recorded.

Operative Characteristics

Recorded technical variables included the type and size of ureteroscope used, the irrigation parameters, the presence and size of a UAS, the presence and size of a laser fibre, operative duration, the placement of a ureteric stent post-procedure, and any complications. Procedural changes were bookmarked on the live pressure trace by the attending researcher (S.M.C.) on communication with the operating surgeon.

Follow Up

Clinical outcome was confirmed at 30 days, by review of hospital records and consultation at time of stent removal or telephone call.

Outcome Measures

Primary Outcome

The primary outcome was the range of the IRP experienced during URS surgery.

Secondary Outcomes

Secondary outcomes were the impact of operative technique on the IRP, the incidence of prolonged hospital stay, re-admission and morbidity following URS, and the relationship of these outcomes with IRP. Complications were classified using the Clavien–Dindo classification [11]. Complications evaluated for a potential relationship and definitions are presented in Fig. S3.

Data Analysis

The IRP profile for each patient was exported and modular arithmetic was applied to extract a pressure reading every 2 s. The overall operative pressure profile was divided into individual pressure traces by key operative events, as relevant to the particular patient (Fig. 1). Accordingly, several pressure traces were produced for each patient, with each representing a unique component of the operation (e.g., retrograde pyelography, semi-rigid URS, FURS). These individual traces and the overall operative pressure profile were analysed for each patient. The mean and maximum IRPs and sample variance were analysed. Sample variance describes the distribution of the dataset from the mean and was used to identify the amount of fluctuance of a pressure profile. The chi-square test, independent samples *t*-test and one-way ANOVA were applied.

Results

Patient Characteristics

Population characteristics are presented in Table 1. Of the 120 participants, 58.33% (n = 70) were male and 41.67% (n = 50) female. The mean (SD) age was 57.48 (13.36) years. Most procedures (90.83% [n = 109]) were indicated for urolithiasis. There were no significant differences between male and female patients regarding age, ASA Grades 1–2, stent status or surgical indication. Preoperative renal obstruction was present in 13 patients (Table 2).

Baseline IRPs

Baseline IRP measurements were available for 95 patients, with a mean (SD) value of 16.45 (5.99) mmHg (Table 2). Male patients had higher baseline IRPs than female patients (mean [SD] 17.64 [5.99] vs 14.57 [4.8] mmHg, P = 0.014). We did not observe a difference in baseline IRPs in obstructed vs unobstructed kidneys, nor when a ureteric stent had been in situ preoperatively.

Intraoperative IRPs

Intraoperative IRP values are presented in Table 3 and Fig. 2. The mean (SD) IRP across the total intraoperative period (including retrograde pyelography, semi-rigid URS and/or FURS) for the 120 participants was 40.1 (22.01) mmHg, with a mean (SD) increase from resting baseline IRP of 22.77 (20.7) mmHg. The mean (SD) variance within each individual pressure profile was 412.73 (570.66) mmHg. The mean (SD) maximum intraoperative pressure experienced by patients was 99 (61.72) mmHg. Retrograde pyelography resulted in the greatest single pressure peak observed (334.2 mmHg).

Impact of Irrigation Settings

The impact of different irrigation parameters was examined according to each category of instrument and/or UAS diameter (Table 3). Increasing irrigation pressure resulted in apparent increased IRP in all categories. In patients with an 11/13-F UAS, comparison of gravity and pressurised-bag irrigation at 100/150/200 mmHg demonstrated a significant relationship between irrigation pressure and IRP (P < 0.001). There were insufficient patient numbers for subgroup analysis in all UAS categories. Manual irrigation, using a hand-operated pump system, was used in nine patients, eight of whom did not have a UAS present, and had a mean (SD) IRP

Fig. 1 Labelled pressure trace. Intraoperative pressure trace divided by operative step. P1 = represents resting baseline IRP; P2 = UAS placement; P3 = retrograde pyelography (RPG); P4 = FURS with gravity irrigation; P5 = FURS with pressurised bag irrigation at 150 mmHg; P6 = IRP at procedure completion with ureteric stent in situ.

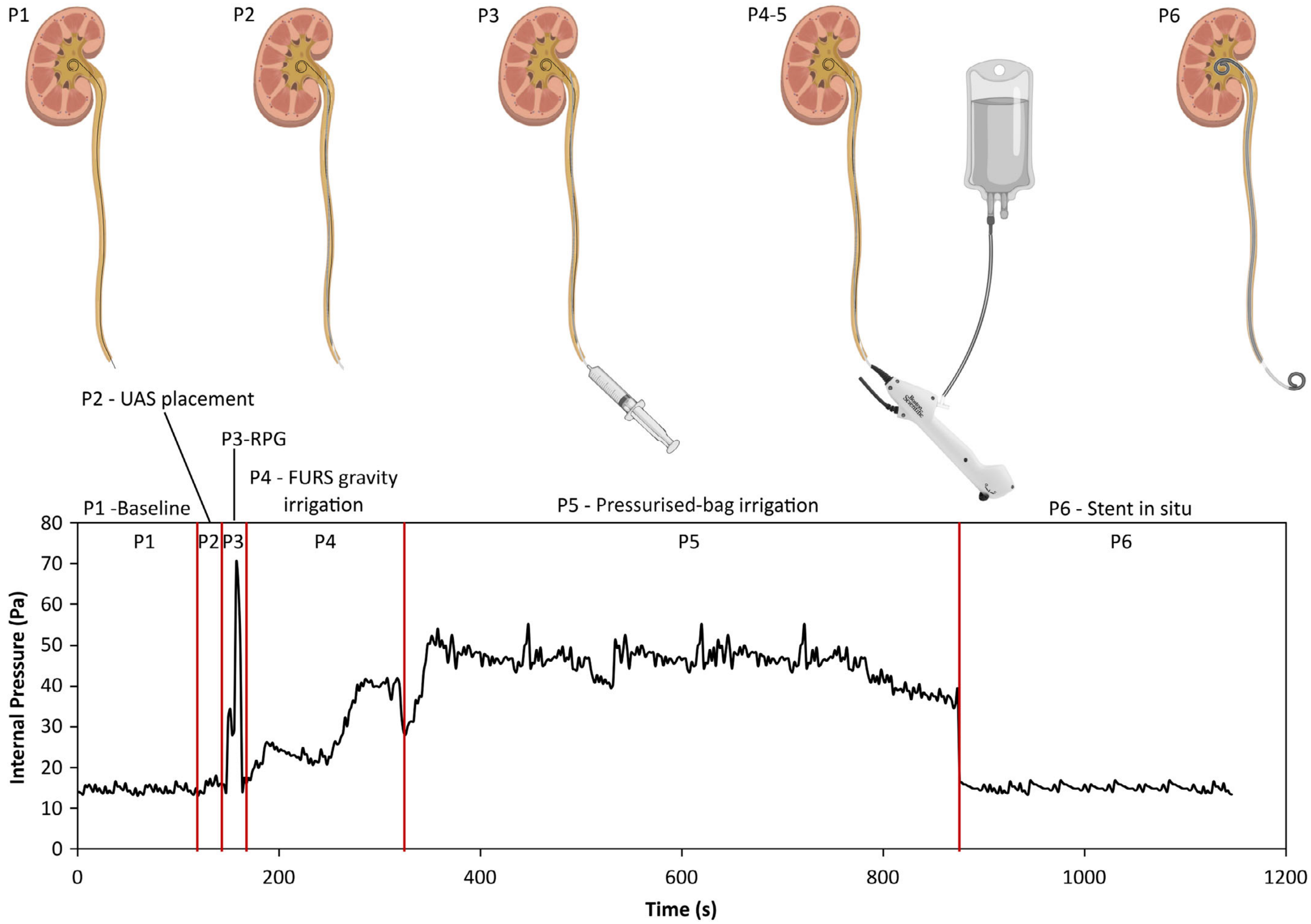


Table 1 Population characteristics.

Variable	Overall	Male	Female	*P*
Patients enrolled, *n* (%)	120	70 (58.33)	50 (41.67)	
Age, years, mean (SD)	57.48 (13.36)	58.61 (13.96)	55.861 (12.42)	0.27
ASA Grade, *n* (%)				
ASA 1	43 (35.83)	23 (32.86)	20 (40)	0.42
ASA 2	66 (55)	38 (54.29)	28 (56)	0.85
ASA 3	11 (9.2)	9 (12.86)	2 (4)	0.09
Indication				
Urolithiasis, *n* (%)	109 (90.83)	63 (90)	46 (92)	0.71
Diagnostic*, *n* (%)	11 (9.2)	7 (10)	4 (8)	
Pre-stented, *n* (%)				
Yes	34 (28.33)	22 (31.43)	12 (24)	0.37
No	86 (71.67)	48 (68.57)	38 (76)	

*Table presents population demographics and surgical indications. There were no significant differences between male and female patients across measured parameters, with the exception of a male preponderance in the ASA Grade 3 group. *Diagnostic URS for indication other than urolithiasis, such as suspected urothelial neoplasm.*

Table 2 Baseline IRPs.

Variable	IRP, mmHg, mean (SD)	P
Population		
n = 95	16.45 (5.99)	–
Gender		
Male	17.64 (5.99)	0.014
Female	14.57 (4.8)	
Obstructed		
Hydronephrosis (n = 14)	18.55 (7.41)	0.14
No hydronephrosis	16.05 (5.66)	
Stent status		
Pre-stented (n = 28)	18.27 (6.81)	0.06
Not pre-stented	15.69 (5.5)	

Table presents resting baseline IRPs (prior to any operative intervention) in 95 participants with available data. No significant difference in IRP is apparent based on gender, hydronephrosis or preoperative stent status.

of 56.6 (15.8) mmHg, with a maximum pressure of 240 mmHg observed.

Impact of UAS

The impact of UAS presence, diameter and length is presented in Fig. S4. Using gravity irrigation, a clear difference in mean IRP during FURS was not seen when comparing no UAS to: 10/12-F UAS ($P = 0.93$), 11/13-F UAS ($P = 0.97$), or 12/14-F UAS ($P = 0.77$). Similarly, a difference was not evident with and without the use of UAS at 150 mmHg pressurised irrigation ($P = 0.53$). However, a limited number of patients underwent FURS without UAS (Table 3).

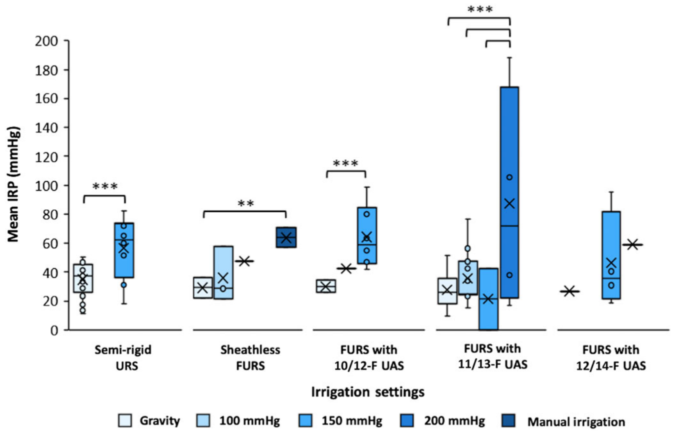
The most frequently used size of UAS was 11/13 F ($n = 89$), thus permitting further analysis.

Table 3 Intraoperative pressures during URS.

Variable	IRP, mmHg		P
	Mean (SD)	Maximum	
Total intraoperative period (n = 120)	40.1 (22.01)	334.2	
Individual variance (n = 100) (mean intra-trace variance across total intraoperative period)	412.73 (570.66)	3495.26	
Mean differential pressure (n = 77) (mean intraoperative − mean baseline IRP)	22.77 (20.7)	105.09	
Retrograde pyelography (n = 58) (peak pressure)	72.9 (81.78)	334.2	
Semi-rigid URS (n = 34)			
All URS (n = 34)	40.08 (17.3)	228.9	
Irrigation			–
Gravity (n = 26)	34.93 (11.66)	158.8	<0.001
Pressurised bag (mean 150 mmHg) (n = 8)	56.81 (20.66)	228.9	
FURS (n = 122 pressure traces; 90 patients)			
All FURS	42.06 (28.02)	240.2	–
Irrigation			
FURS without UAS (n = 15)			
Gravity (n = 2)	29.23 (10.21)	50.8	–
100 mmHg (n = 3)	35.98 (15.57)	68	
150 mmHg (n = 2)	32.66 (14.8)	103.7	
Manual (n = 8)	56.6 (15.8)	240.2	
FURS with 10/12-F UAS (n = 10)			
Gravity (n = 2)	30.1 (6.07)	162.2	–
100 mmHg (n = 2)	47.76 (5.3)	87.8	
150 mmHg (n = 6)	64.34 (19.62)	143.9	
FURS with 11/13-F UAS (n = 89)			
Gravity (n = 35)	29.8 (19.45)	167.3	<0.001*
100 mmHg (n = 18)	38.9 (22.38)	204.1	
150 mmHg (n = 32)	45.83 (28.56)	228.5	
200 mmHg (n = 4)	87.27 (66.85)	236.3	
FURS with 12/14-F UAS (n = 6)			
Gravity (n = 1)	26.78 (5.84)	54.3	–
150 mmHg (n = 4)	46.36 (29.3)	219.9	
200 mmHg (n = 1)	59.11 (10.46)	92.6	
FURS with 13/15-F UAS (n = 1)			
Manual (n = 1)	50.09 (11)	92.7	
FURS with suction-assisted UAS (11/13 F) (n = 1)			
150 mmHg	24.98 (10.16)	75.9	

*Table presents mean and maximum IRP and mean sample variance during the overall operative period for the 120 participants; in addition, mean and maximum IRP generated during specific operative technique and drainage/irrigation parameters are presented. *One-way ANOVA. Post hoc pairwise t-test with Bonferroni adjustment, statistical significance between gravity and 200 mmHg irrigation (P < 0.001); 100 and 200 mmHg irrigation pressure (P < 0.001), and 150 and 200 mmHg irrigation pressure (P = 0.002).*

Fig. 2 Mean IRPs intraoperatively. Figure is a boxplot representing mean (X) IRP according to the choice of ureteroscope and UAS and irrigation settings. *N*, number of patients in each group; Semi-rigid, semi-rigid URS. Pressure values refer to pressurised-bag irrigation settings.



With gravity irrigation, a similar IRP was seen with 36-cm (mean [SD] 30.57 [25.6] mmHg) vs 46-cm (mean [SD] 29.35 [12.29] mmHg) length UAS ($P = 0.89$). With pressurised irrigation at 150 mmHg, lower mean IRP was seen with the shorter (36 cm) UAS used in female patients, compared to the 46-cm length used in male patients (mean [SD] 36.38 [28.09] vs 55.29 [25.77] mmHg, $P = 0.032$). UAS were positioned with the tip at the PUJ in all cases.

Clinical Outcomes

Clinical outcomes are presented in Table 4. Six (5%) of the patients developed postoperative pyrexia and required re-admission; all had flank pain in association with two or more SIRS criteria and were treated as having urosepsis. None developed severe sepsis requiring high-dependency care. Three of these patients had positive preoperative urine cultures (*E. coli* [two] and *E. faecalis* [one]) and three patients had preoperative ureteric stents. Of these six patients, the mean IRP during the overall intraoperative period was significantly higher than the IRP recorded in the 89 control patients who underwent FURS and did not develop pyrexia (mean [SD] 71.16 [36.85] vs 38.62 [22.51] mmHg, $P = 0.001$). All pyrexic patients had undergone FURS. Their mean IRP during the active FURS period was significantly higher than that of the 89 control patients (mean [SD] 81.7 [49.52] vs 38.53 [22.6] mmHg, $P < 0.001$). Sample variance within each patient's overall operative period, a measure of fluctuation around the mean and used as a marker of the frequency and extent of pressure spikes and troughs, was significantly higher amongst patients developing pyrexia (mean [SD] 1042.12 [919.16] mmHg) vs controls (346.62 [495] mmHg;

Table 4 Clinical outcomes.

Variable	Value		
Complications Clavien–Dindo Grade, *n* (%)			
I	7 (5.8); pain and prolongation of hospital stay.		
II	7 (5.8); pyrexia and pain (*n* = 6) and lower UTI treated with oral antibiotics (*n* = 1).		
IIIa	1 (0.8); acute kidney injury in solitary kidney requiring nephrostomy tube insertion. Likely secondary to stent migration and oedema. Full recovery.		
IV	0		
Urosepsis			
Incidence, *n* (%)	6 (5)		
	Urosepsis (*n* = 6)	**Controls (*n* = 89)**	***P***
Preoperative stent, *n/N* (%)	3/6 (50)	24/89 (27)	0.23
Preoperative positive urine culture, *n/N* (%)	3/6 (50)	10/89 (11)	0.007
Diabetes, *n/N* (%)	0/6	12/89 (13)	ns
Stone size (single maximum dimension), mm, mean (SD)	13.6 (11.26)	12 (6.14)	0.6
Mean baseline IRP, mmHg, mean (SD)	18.59 (8.7) 5 observations	16.96 (10.73) 72 observations	0.74
UAS used, *n/N* (%)	6/6 (100)	72/89 (81)	ns
IRP overall operative period, mmHg, mean (SD)	71.16 (36.85)	38.62 (22.51)	0.001
Variance of IRP overall operative period, mmHg, mean (SD)	1042.12 (919.16)	346.62 (495)	0.002
IRP during FURS, mmHg, mean (SD)	81.7 (49.52)	38.53 (22.6)	<0.001
Overall operative duration, min, mean (SD)	24.17 (12.22)	18.87 (10.1)	0.23
Prolongation of hospital stay due to pain (without pyrexia)			
Incidence, *n* (%)	7 (5.8)		
	Pain	**Controls**	
IRP overall operative period, mmHg, mean (SD)	49.04 (22.25)	38.37 (22.8)	0.51
Variance of IRP overall operative period, mmHg, mean (SD)	749.49 (708.98)	344.23 (502.72)	<0.01
Overall operative duration, min, mean (SD)	17.33 (10.39)	18.66 (9.7)	0.84

Table presents data on postoperative complications and compares IRPs and other relevant clinical variables between patients who did and did not experience an adverse event.

P = 0.002). The mean operative duration (mean [SD] 24.17 [12.22] vs 18.87 [10.1] min) did not significantly differ between the pyrexic and non-pyrexic groups (P = 0.23).

Seven additional patients developed postoperative pain causing prolongation of hospital stay (Table 4). The mean IRP experienced by these patients was higher than that of controls, but this did not reach statistical significance (mean [SD] 49.04 [22.25] vs 38.37 [22.8] mmHg, P = 0.51). The mean variance was also higher than that of controls, and this observation did demonstrate statistical significance (mean [SD] 749.49 [708.98] vs 344.23 [502.72] mmHg, P < 0.01).

Discussion

Our study, in which we measured in vivo baseline and operative IRP in a large, consecutive patient cohort undergoing URS, is the first of its kind, and begins to address the knowledge gap regarding 'irrigation flow, intrarenal pressure and effect on post-procedure patient outcomes' highlighted in the 2023 International Alliance of Urolithiasis guideline on retrograde intrarenal surgery [12].

We found live in vivo IRP measurement to be feasible using the methodology described. The system took up to 10 min to set up for each case. As we had a dedicated researcher present in the operating theatre for this purpose, this did not add to the procedure time. Cystoscopic insertion of the COMET II pressure guidewire took <60 s in most cases.

We zeroed the measurement system to atmospheric pressure and then measured baseline IRPs, followed by operative pressures. Intraoperatively, we measured and reported the absolute IRPs, which incorporate the cumulative effect of physiological pressure and the pressure created by endoscopic technique. We feel that this absolute pressure is most relevant when assessing clinical endpoints. However, it is important to highlight the measurement approach for inter-study comparability; our figures, e.g., would not be directly comparable to those produced in studies in which the pressure wire was zeroed to baseline renal pelvic pressure.

We found resting baseline renal pelvic pressures in lithotomy position to exhibit a mean (SD) value of 16.45 (5.99) mmHg, and to be slightly higher in male vs female patients. The baseline values recorded are somewhat higher than some previous reports of mean baseline IRP 10–11 mmHg [13,14], but our findings represent a larger sample size, and we noted significant variability. We recorded baseline IRP for a minimum of 1 min in all patients, during which multiple peristaltic waveforms were observed and these contributed to the overall mean pressure. Whilst instrumentation is unavoidable in obtaining an IRP reading, we chose an extremely small (0.036 cm [0.014″]) wire, placed retrograde to avoid breaching the integrity of the collecting system, to minimise confounding influences. We did not observe a statistically significant difference between hydronephrotic and non-hydronephrotic kidneys, possibly due to small hydronephrotic sample size or other factors such as stone migration or renal adaptation [15]. These baseline values are of interest as they present a URS starting point within 15 mmHg of the 30 mmHg (40 cmH_2O) threshold at which impaired arterial perfusion and pyelorenal backflow have been demonstrated in porcine and human kidneys [4,16,17]. Urologists must therefore question whether this threshold is realistically achievable during URS, or clinically relevant. Whilst normal unobstructed kidneys with bladder drainage may maintain stable IRP with a flow rate of 20 mL/min [18], URS instrumentation introduces variable outflow obstruction.

Intraoperatively, wide SDs were noted, indicating a high level of variability in IRP. This may reflect additional confounders to irrigation settings and outflow drainage, such as baseline renal pressure, renal collecting system and bladder size and compliance, location of intrarenal pathology, and the resultant ureteroscope position relative to UAS if present. Most operative techniques resulted in mean IRPs exceeding the 30 mmHg threshold cited for pyelorenal backflow, and pressures exceeding the 45–60 mmHg cited for pyelovenous backflow were frequently observed [3,4]. The IRP rupture threshold of ex vivo porcine kidney has been reported at 300 mmHg in one study, and as low as 48–92 mmHg in some kidneys in another. Concerningly, we observed pressure peaks of up to 334 mmHg, albeit without evidence of rupture.

Shorter UAS length (36 vs 46 cm; 11/13 F) appeared to result in lower IRP. This potentially reflects enhanced outflow drainage and could be expected from Poiseuille's law. Ex vivo models of PCNL have similarly demonstrated lower IRPs with shorter sheaths [19]. However, this observation is potentially confounded by sex differences in the 36-cm (female) and 46-cm (male) groups – it is possible that additional unidentified factors, such as potential differing collecting system compliance between the sexes, contributed. Furthermore, the importance of UAS position must not be overlooked. We used the 36-cm UAS in female patients only, with the tip positioned at the PUJ. An ex vivo study has shown impaired drainage with a distally positioned UAS [20]. We deduce that the shortest length UAS that reaches the patient's PUJ may result in the most efficient drainage. In this cohort, any ureteric stones were cleared with semi-rigid URS, followed by UAS placement where used, and it was possible to advance the UAS to the PUJ in all cases. We acknowledge that this may not always be possible.

Ex vivo and live animal studies have reported reduced mean IRP with the presence and increasing calibre of a UAS [21–23], as would be expected. We did not confirm this relationship with statistical significance, although we noted a trend towards lower pressures with larger calibre sheaths. In our dataset, an 11/13-F UAS was used in the majority of patients undergoing FURS, and low numbers of patients underwent FURS without a UAS or with 10/12- or 12/14-F sizes. In light of this, and the high variance of data, our study is underpowered to draw definitive conclusions on UAS diameter, and more data are required across groups exposed to different drainage techniques.

This is the first in vivo human study examining the relationship of IRP with clinical outcome following URS. We observed significantly higher mean overall IRP and IRP during the FURS period in patients who developed postoperative urosepsis as compared to controls. This is similar to observations of increased pyrexia in patients experiencing higher IRP during PCNL in several studies, although lower pressure thresholds of 20–30 mmHg were reported in these [9,24,25]. It should be noted that PCNL studies often measure IRP having zeroed the baseline IRP, and actual IRP may therefore be ~17 mmHg higher based on our findings regarding resting baseline IRP. Our data also demonstrate increased variance within the pressure profiles of patients who developed pyrexia. A previous study by Farag et al. [10] identified a higher incidence of pain, re-admission and SIRS in patients who underwent URS with manual hand-pump irrigation compared to pressurised-bag irrigation. Whilst the actual IRP was not measured, higher IRP and greater fluctuations in IRP, represented by variance, would be anticipated with intermittent pump irrigation, and thus our data may help to explain these findings. We also found an increased incidence of pyrexia in patients with preoperative positive urine cultures, as reported by other authors [8,26]. We saw a trend towards higher mean operative duration in patients who developed urosepsis. Whilst this did not demonstrate statistical significance, analysis may have been underpowered to show this given the low incidence of urosepsis. We did not observe a relationship between other variables associated in the literature with postoperative urosepsis, such as a preoperative ureteric stent and diabetes [26].

We also observed higher mean overall operative IRP in patients who required admission from intended day surgery pathway or extended inpatient stay due to pain compared to controls. This did not demonstrate statistical significance, although post hoc analysis confirmed low power (23.3% with alpha 0.05) to do so. However, mean variance between these groups did demonstrate a significant difference, suggesting a possible relationship between highly fluctuant pressure traces and postoperative pain. Absolute length of stay was not interrogated due to differences in surgical pathways between hospital sites and social and logistical factors acting as major confounding variables, preventing meaningful analysis.

The study was designed to minimise bias, with a consecutive patient sample enrolled. No patients approached declined to participate. Surgeons' standard practice was not changed. Whilst this did result in unequal allocation of patients to operative techniques, this was felt to be the most appropriate initial investigation of a variable of unknown significance. Three urologists, each of whom had completed fellowship training in endourology and had >3 years consultant experience, participated, to capture practice variations, whilst limiting the confounding effect of a large and diverse cohort. There is the possibility of a Hawthorne effect, with surgeons using more conservative irrigation pressures during study conduct. The operating surgeon was blinded to the IRP to minimise any influence on practice, and the IRPs were higher than anticipated, suggesting that artificially conservative surgical approaches were not implemented.

We acknowledge a number of limitations to our data. The perioperative analgesia regimen was not strictly standardised in this observational study. All patients did receive intraoperative intravenous paracetamol and were discharged on regimens incorporating paracetamol and a NSAID unless contraindicated. Therefore, anti-pyretic use did not differ between patients who developed pyrexia and those who did not. However, it is possible that some differences in intraoperative analgesia could have confounded the outcome of pain requiring prolongation of hospital stay. We obtained accurate baseline measurements in the majority but not all of the patients (95/120) due to some issues, predominantly during the early phase of the study, such as recording errors and unsatisfactory initial wire placement; in the latter scenario the wire was repositioned to the renal pelvis under direct vision and recording was restarted for the URS component. A single-use flexible ureteroscope (9.5 F) was most frequently used, and an 8.4-F flexible ureteroscope in eight cases. Whilst there may have been some pressure differences related to ureteroscope size, the latter group was too small for statistical analysis. The COMET II pressure guidewire was positioned in the renal pelvis for all cases, for standardisation. We note that renal pelvic pressure may not precisely match intra-calyceal pressure. In one small sample size study (eight patients), interpolar calyx pressures exceeded IRP by ~12 mmHg, although significant pressure differences were not reported between upper and lower pole calyces and the renal pelvis [27]. Manual hand-operated irrigation was used in only nine patients, with conservative technique. Accordingly, we cannot comment on the spectrum of IRP that may occur in the context of vigorous manual irrigation. Similarly, we have limited data on FURS without UAS and across UAS sizes. Larger datasets, reporting outcomes for all combinations of irrigation and drainage parameters are needed to further our understanding in the field, and our initial experience should provide an important foundation for such work.

This was designed as an observational study, to represent and capture current practice and clinical outcomes, and achieved this aim. However, we do note interesting work by other authors regarding interventions that may enhance control of IRP, including the use of pharmacological agents in the irrigation fluid [28,29] and suction-assisted UAS [30], and highlight these as important areas of future research interest.

Conclusions

Human baseline IRPs are higher than previously believed and display significant inter-patient variability. The mean IRP values during URS almost always exceed the 30 mmHg pressure threshold previously quoted in the literature, and this is unlikely to be an achievable target for endourologists in the absence of active suction devices. Nonetheless, this target may be excessively low. We have observed, in the first study of this kind, an apparent relationship between an elevated IRP or a fluctuating IRP profile and adverse patient events, namely pyrexia and re-admission. Further research will aim to determine a safe IRP threshold in humans and further explore the impact of waveform dynamics.

Disclosure of Interests

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Abbreviations: FURS, flexible ureterorenoscopy; IRP, intrarenal pressure; PCNL, percutaneous nephrolithotomy; SIRS, systemic inflammatory response syndrome; UAS, ureteric access sheath; URS, ureteroscopy/ureteroscopic.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Fig. S1 Intraoperative set-up for IRP measurement. Figure displays the intraoperative equipment for IRP measurement. Labels are as follows: (A) Link device; (B) Input socket for COMET II pressure guidewire; (C) External pressure transducer; (D) COMET II pressure guidewire; (E) AVVIGO interface; (F) Sample IRP trace.

Fig. S2 Fluoroscopic image of COMET II pressure guidewire in renal pelvis. Figure presents an intraoperative radiological image of the COMET II pressure guidewire in the renal pelvis.

Fig. S3 Complications examined for association with IRP profile. The graphic outlines the clinical events examined for association with IRP and their definitions.

Fig. S4 Impact of UAS length on IRP. This bar chart presents mean IRP according to both UAS calibre and length, along with irrigation settings.