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A comparative assessment of irrigation and drainage characteristics for commercially available urethral catheters

Mamoun Abdelrahman[1], Niall F. Davis[1,3], Barry P. McMahon[2], Michael Walsh[3], Thomas E.D. McDermott[1], John A. Thornhill[1], Rustom P. Manecksha[1]

[1]*Department of Urology, Tallaght Hospital, Tallaght, Dublin, Ireland*
[2]*Department of Medical Physics & Clinical Engineering, Tallaght Hospital and Trinity College, Dublin, Ireland*
[3]*Centre for Applied Biomedical Engineering Research, Materials and Surface Science Institute, University of Limerick, Castletroy, Co Limerick, Ireland*

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Corresponding author
Mamoun Abdelrahman
Department of Urology
Tallaght Hospital
Belgard Road
D24, Dublin, Ireland
phone: 0035314143863
mamoun16@yahoo.co.uk

Introduction We aimed to investigate irrigation and drainage characteristics of commercially available urethral catheters and determined which catheter offers the best flow characteristics.
Material and methods Twelve different commercially available urethral catheters from three companies (Bard™, Rusch™ and Dover™) were investigated to compare their irrigation and drainage properties. Irrigation port, drainage port and overall cross-sectional areas for a 24Fr 3-way catheter was measured and compared. The maximum (Qmax) and average (Qavg) irrigation and drainage flow rates for each catheter was measured for 20–40 seconds using uroflowmetry. The primary endpoint was to determine which catheter offers optimal irrigation and drainage parameters.
Results Overall cross-sectional area, irrigation port cross-sectional area, and drainage port cross- sectional area differed significantly for each 24Fr 3-way catheter assessed (p <0.001). The 24Fr 3-way Rusch Simplastic™ catheter consistently demonstrated the greatest maximal flow rate (Qmax: 5 ±0.3 ml/s) and average flow rate (Qavg: 4.6 ±0.2 ml/s) for irrigation. The 24Fr 3-way Dover™ catheter provided the greatest drainage properties (Qmax: 19.7 ±2 ml/s; Q avg: 15.9 ±5 ml/s). In the setting of continuous bladder irrigation, the 24Fr 3-way Rusch Simplastic™ catheter provided the highest irrigation rates (Qmax: 6.6 ±1.8 ml/s; Q avg: 4.6 ±0.9 ml/s).
Conclusions Three-way catheters demonstrate significant differences in their irrigation and drainage characteristics. The type of catheter selected should be based on the appropriate prioritization of efficient bladder irrigation versus efficient bladder drainage.

Key Words: urethral catheter ‹› 3-way catheter ‹› bladder irrigation ‹› bladder drainage ‹› continuous bladder irrigation

INTRODUCTION

Continuous bladder irrigation (CBI) is frequently used after endoscopic urological procedures such as transurethral resection of the prostate (TURP) and transurethral resection of a bladder tumor (TURBT). Irrigation characteristics of 3-way catheters play an important role for preventing intravesical clot formation after TURP and TURBT surgery. The concept that efficient bladder drainage during CBI is dependent on flow rates rather than the actual size of the lumen of the drainage tube was initially described by Whitaker et al. in the 1970s in bench-top studies [1]. In the 1980s Livne et al. described a simple method for improved flow rate during CBI by irrigating through a standard feeding tube and draining with a 2-way urethral catheter [2]. Subsequently, advanced CBI methodologies were described by Caro et al. in the 1980s where larger (24Fr, 2-way catheters) with high volume (30 ml) anchoring balloons were used to facilitate outflow traction for hemostatic purposes. The irrigating mechanism in this system was provided by a peripheral central venous pressure (CVP) line [3].

At present, a multitude of more complex CBI systems and irrigating methodologies are described in the literature; however comparative data between current CBI systems is lacking [4]. In the present study, we aimed to investigate irrigation and drainage characteristics of commercially available urethral catheters. Our primary endpoint was to determine which catheter offers optimal irrigation and drainage parameters.

MATERIAL AND METHODS

Overview of study design

Twelve different commercially available urethral catheters were investigated to compare their irrigation and drainage properties. All materials were obtained from the Department of Urology, Tallaght Hospital unless otherwise indicated. Three way catheters measuring 22Fr and 24Fr from Bard (Bard Limited™) and Rusch Simplastic (Teleflex Medical™) were included. In addition, 3-way catheters measuring 20Fr, 22Fr and 24Fr from Dover (COVIDIEN™) and Rusch Golden™ were investigated. The irrigation and drainage properties of 2-way commercially available catheters were also investigated and compared (Bard™ 22Fr, Rusch Golden™ 20Fr and Dover™ 20Fr). Irrigation port, drainage port and overall cross-sectional areas (CSA) for each 24Fr 3-way catheter were measured using ImageJ application (https://imagej.nih.gov/ij/).

Measured cross-sectional areas are demonstrated in Figure 1. The primary endpoint was to determine the urethral catheter that offers optimal irrigation and drainage parameters. Two users performed each experiment in triplicate.

Assessment of irrigation

Continuous gravity irrigation was measured by suspending a 2-litre irrigation bag (Baxter Healthcare SA, Switzerland) 120 cm above a level surface

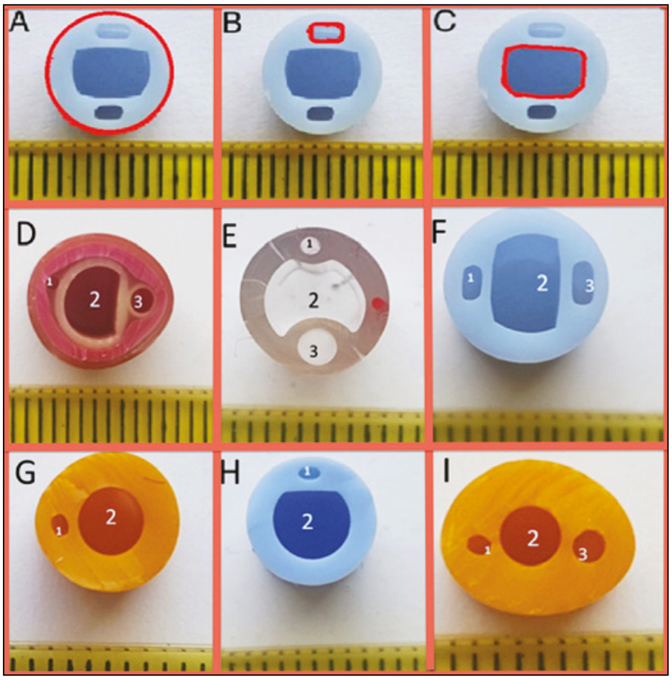

Figure 1. *Measuring cross-sectional areas (CSA) with ImageJ software (https://imagej.nih.gov/ij/).*
Legend: (A) Dover 24 Fr catheter overall CSA measured using 'elliptical or brush' selection on ImageJ. (B) and (C) The irrigation and drainage channel CSA's were measured using the polygon selection. (D-I) CSA for every catheter investigated with 1 indicating the anchoring balloon channel, 2 indicating the drainage port, and 3 indicating the irrigation port.
(D) 24Fr Bard, (E) 22Fr Rusch S, (F) 24Fr Dover, (G) 20Fr Rusch G** two -way, (H) 20Fr Dover two way and (I) 22Fr Rusch G**, S* = Simplastic; G** = Golden*

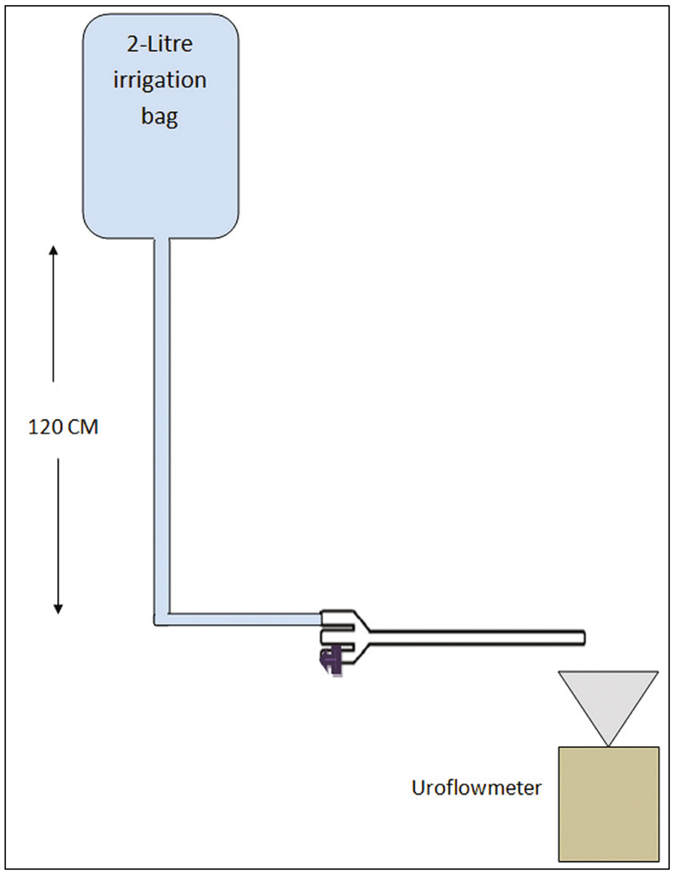

Figure 2. *Simplified schematic of experimental set- up used to study irrigation characteristics for each catheter.*
Legend: The irrigation set was attached to the irrigation channel of the three-way catheter. Qmax and Qavg irrigation flow rates were measured for 20 seconds using uroflowmetry through a fast flow Y-type irrigation set.

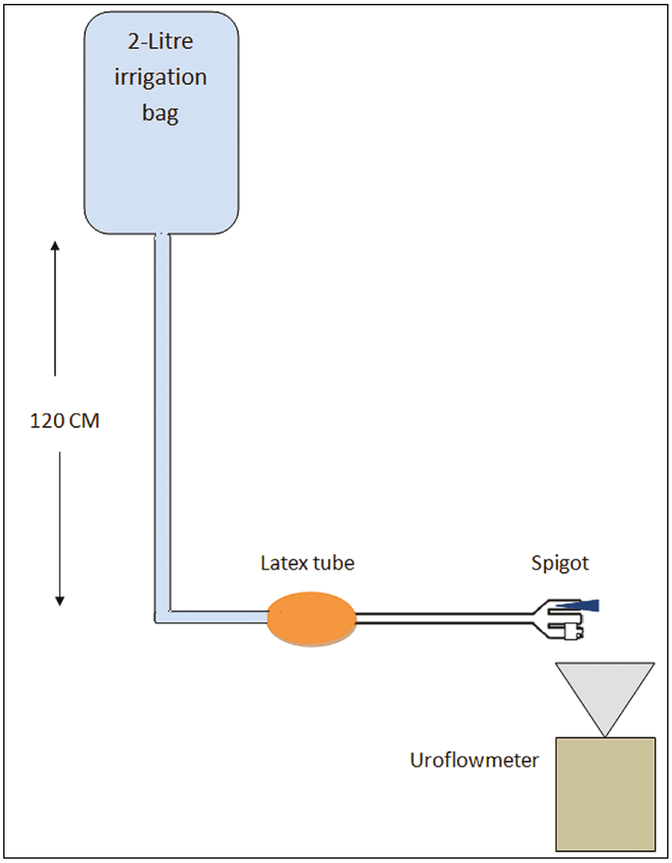

Figure 3. *Simplified schematic of experimental set- up used to study drainage characteristics for each catheter.*
Legend: The irrigation channel was spigoted and a latex balloon was attached and secured to the distal tip of each catheter. The tip of the irrigation set was then inserted into an opening in the latex balloon opposite the catheter and fastened.

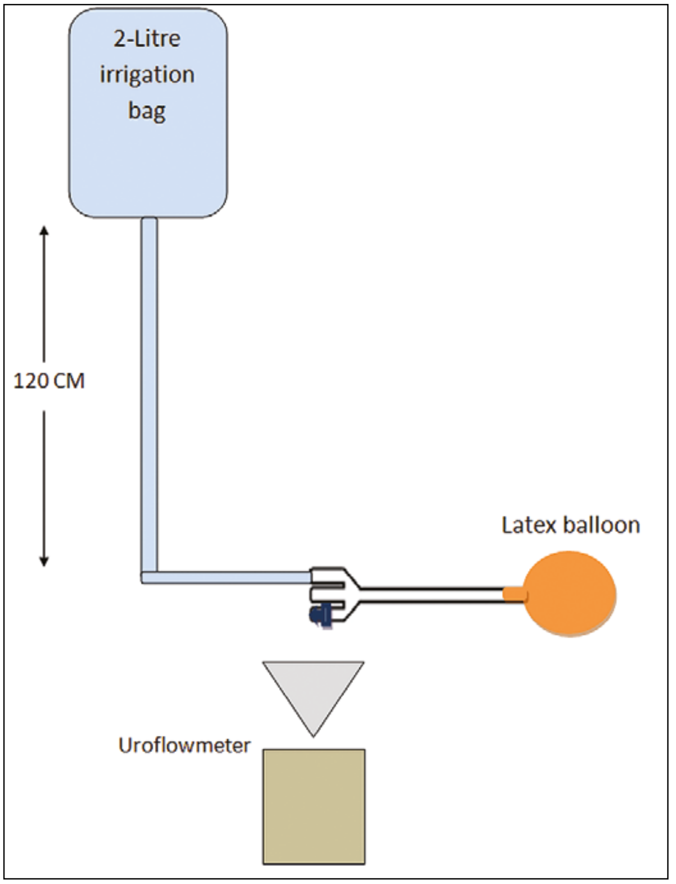

Figure 4. *Simplified schematic of experimental set- up used to study continuous irrigation systems for each catheter.*
Legend: A latex balloon was secured to distal the tip of the three-way catheter and 20 ml of saline was instilled. A 2 litre irrigation bag was connected to the irrigation port for CBI and the drainage port of the catheter was positioned to drain into the uroflowmeter. Qmax and Qavg drainage volumes from each drainage port were recorded for 40 seconds.

on which the catheters were placed. The maximum (Qmax) and average (Qavg) irrigation flow rates were measured for 20 seconds using uroflowmetry through a fast flow Y-type irrigation set that was attached to the irrigation port of each catheter (Baxter Healthcare). A simplified schematic of the developed experimental protocol is illustrated in Figure 2.

Assessment of drainage

The irrigation channels for each catheter were clamped with a spigot and a latex balloon was attached and secured to the distal tip of each catheter. The tip of the irrigation set was then inserted into an opening in the balloon opposite the catheter and fastened (Figure 3). The Qmax and Qavg were measured according to the methodology described in section 2.2. Qmax and Qavg for 2-way catheters were also measured with this methodology.

Assessment of continuous bladder irrigation systems

A latex balloon was secured to distal the tip of the three-way catheter to mimic an artificial bladder and 20 ml of saline was instilled into the balloon (Figure 4). A 2 litre irrigation bag (Baxter Healthcare SA, Switzerland) was connected to the irrigation port for continuous bladder irrigation and the drainage port of the catheter was positioned to drain into the uroflowmeter. The maximal and average drainage volumes from each drainage port were recorded for 40 seconds.

Statistical analysis

Data was expressed as a mean ± standard deviation. Statistical analysis was performed using a one- factor analysis of variance (ANOVA). Student t-tests with unequal variances were performed for pairwise comparisons. Differences were considered significant at $p < 0.05$ (SPSS 16.0 for Windows).

RESULTS

Measurement of cross-sectional area

Table 1 demonstrates the measured cross-sectional area for each catheter investigated. Overall cross-sectional area, irrigation port cross-sectional area, and drainage port cross-sectional area for catheters of the same size differed significantly for each catheter assessed ($p < 0.001$).

Measurement of irrigation properties

Table 2 demonstrates Qmax and Qavg for each urethral catheter for irrigation purposes. Qmax and Qavg varied significantly for each catheter assessed ($p < 0.001$). The 24Fr 3-way Rusch Simplastic™ catheter consistently demonstrated the greatest maximal flow rate (Qmax: 5 ±0.3 ml/s) and average flow rate (Qavg: 4.6 ±0.2 ml/s). The lowest flow rates were found in the 22Fr Rusch Golden™ 3-way (Qmax: 1.7 ±0.3 ml/s and Qavg: 1.4 ±0.2 ml/s). Rusch Simplastic™ catheters were associated with the highest irrigation rates when compared to other catheter brands ($p < 0.001$). Increased catheter size was associated with significantly greater irrigation properties ($p < 0.001$)

Measurement of drainage properties

Table 3 demonstrates the drainage properties for each urethral catheter (Qmax and Qavg respectively). Qmax and Qavg for drainage varied significantly for each catheter assessed ($p = 0.003$). The 24Fr 3-way Dover™ catheter provided the greatest drainage properties (Qmax: 19.7 ±2 ml/s; Q avg: 15.9 ±5 ml/s). The lowest drainage properties were found in 22F Rusch Gold™ 3-way catheters (Qmax: 9 ±3.8 ml/s; Q avg: 6.2 ±2.7 ml/s). Increased catheter size was not associated with significantly greater drainage properties ($p = 0.41$).

Continuous bladder irrigation systems

Table 4 demonstrates continuous irrigation properties for each urethral catheter (Qmax and Qavg respectively). Irrigation rates varied significantly for each catheter assessed ($p = 0.002$). The 24Fr 3-way Rusch Simplastic™ catheter provided the highest irrigation rates (Qmax: 6.6 ±1.8 ml/s; Q avg: 4.6 ±0.9 ml/s). The lowest irrigation rates were found in 20Fr Dover™ 3-way catheters (Qmax: 2.9 ±1 ml/s; Q avg: 1.8 ±0.5 ml/s). Increased catheter size was associated with significantly greater continuous irrigation flow rates ($p = 0.002$)

Table 1. *Overall and individual port cross-sectional areas for each catheter assessed*

Catheter type	Overall area (mm^2)	Irrigation port (mm^2)	Drainage port (mm^2)
20 Fr Dover (2-way)	48.03	N.A.	15.71
20Fr Rusch G* (2-way)	43.20	N.A.	9.74
20Fr Rusch G*	51.47	1.76	6.3
20Fr Dover	54.08	2.75	14.25
22Fr Bard	70.35	2.51	12.12
22Fr Rusch S**	54.89	3.86	17.41
22Fr Dover	54.2	2.35	14.21
22Fr Rusch G*	59.98	1.85	10.49
24Fr Dover	68.26	2.86	20.57
24Fr Rusch S**	65.58	4.23	21.21
24Fr Bard	80.7	2.27	16.59
24Fr Rusch G*	69.46	2	13.09

G* = Golden; S** = Simplastic

Table 2. *Comparing maximum flow-rates (Qmax) and average flow-rates (Qavg) for each urethral catheter for irrigation*

Catheter type	Qmax (ml/s)	Qavg (ml/s)
20Fr Dover	2.1 ±0.4	1.9 ±0.3
20Fr Rusch G*	2.5 ±0.1	2.2 ±0.1
22Fr Bard	2.9 ±0.2	2.5 ±0.3
22Fr Rusch S**	4.8 ±0.2	4.2 ±0.4
22Fr Dover	3.3 ±0.3	2.6 ±0.5
22Fr Rusch G*	1.7 ±0.3	1.4 ±0.2
24Fr Dover	4.1 ±0.5	3.5 ±0.5
24Fr Rusch S**	5 ±0.3	4.6 ±0.2
24Fr Bard	2.8 ±0.3	2.3 ±0.5
24Fr Rusch G*	1.8 ±0.2	1.5 ±0.2

Data is expressed as a mean ± standard deviation.
The 24Fr 3-way Rusch Simplastic™ catheter consistently demonstrated the greatest maximal flow rate (Qmax: 5 ±0.3 ml/s) and average flow rate (Qavg: 4.6 ±0.2 ml/s).
G* = Golden; S** = Simplastic

DISCUSSION

An understanding of the flow characteristics for 3-way irrigation catheters is important as they play an essential role in daily urological practice [5]. A variety of different sizes are available; however, in the presence of significant bleeding size ≥22Fr is usually necessary to prevent large clots forming in the urinary bladder. Moreover, in the presence of significant bleeding manual evacuation of clots is often required

Table 3. *Comparing maximum flow-rates (Qmax) and average flow-rates (Qavg) for each urethral catheter for drainage*

Catheter type	Qmax (ml/s)	Qavg (ml/s)
20Fr Dover (2-way)	17.8 ±4.5	11.2 ±2.1
20Fr Rusch G* (2-way)	11.1 ±1.9	5.7 ±3.3
20Fr Rusch G*	9 ±0.3	6.6 ±1.5
20Fr Dover	13 ±1.6	9.5 ±2.8
22Fr Dover	14.8 ±0.6	11 ±2.3
22Fr Rusch G*	9 ±3.8	6.2 ±2.7
22Fr Bard	12.6 ±1.3	8.9 ±3
22Fr Rusch S**	14.1 ±3.2	9.7 ±4.6
24Fr Dover	19.7 ±2	15.9 ±5
24Fr Rusch G*	12.6 ±2.2	9.5 ±3.1
24Fr Bard	17 ±2.8	12.7 ±4
24Fr Rusch S**	17 ±1.6	11.9 ±4.1

Data is expressed as a mean ± standard deviation. The 24Fr 3-way Dover™ catheter provided the greatest drainage properties (Qmax: 19.7 ±2 ml/s; Q avg: 15.9 ±5 ml/s).
G* = Golden; S** = Simplastic

Table 4. *Comparing maximum flow-rates (Qmax) and average flow-rates (Qavg) for each urethral catheter for continuous bladder irrigation (CBI)*

Catheter type	Qmax (ml/s)	Qavg (ml/s)
20Fr Rusch G*	2.9 ±0.4	2.3 ±0.7
20Fr Dover	2.9 ±1	1.8 ±0.5
22Fr Rusch G*	3.1 ±0.5	1.7 ±0.3
22Fr Dover	3.6 ±0.7	2.2 ±0.6
22Fr Bard	4.1 ±1	2.6 ±0.4
22Fr Rusch S**	4.4 ±0.6	3.8 ±0.8
24Fr Rusch G*	3.6 ±0.8	2.1 ±0.9
24Fr Dover	6.7 ±3.4	3.1 ±1.7
24Fr Bard	4.4 ±1.8	2.4 ±0.4
24Fr Rusch S**	6.6 ±1.8	4.6 ±0.9

Data is expressed as a mean ± standard deviation. The 24Fr 3-way Rusch Simplastic™ catheter provided the highest irrigation rates (Qmax: 6.6 ±1.8 ml/s; Q avg: 4.6 ±0.9 ml/s).
G* = Golden; S** = Simplastic

through the catheter's drainage tube as its increased flow rate has greater capabilities for evacuating clots compared to the irrigation port. Although the advantages of 3-way catheters over 2-way catheters in this urological setting are well described; there is a paucity of studies that have thoroughly compared the irrigation and drainage properties for different 3-way catheters. Braasch et al. compared the flow characteristics of 22Fr and 24Fr Bardex™ and Dover™ catheters during manual bladder irrigation and found that both Bardex™ catheters offered significantly better irrigations flow rates compared to Dover™ catheters [6].

In the present study, we developed this concept to investigate and compare the flow characteristics of 3 different commercially available urethral catheters. Our main findings are that the 24Fr 3-way Rusch Simplastic™ catheter consistently demonstrates the greatest maximal flow rate for irrigation purposes and that the 24Fr 3-way Dover™ catheter provides the greatest flow rate for bladder drainage. This finding may have important clinical implications as efficient bladder irrigation versus efficient bladder drainage can vary in priority levels depending on the clinical scenario at hand. For example, irrigation is not always necessary after TURBT surgery and efficient bladder drainage is perhaps more important. In this clinical scenario, the authors would recommend a 24Fr 3-way Dover™ catheter. However, CBI is almost always required after TURP surgery for enlarged vascular prostate glands and the authors would recommend a 24Fr 3-way Rusch Simplastic™ catheter in this setting.

A notable secondary finding is that overall cross-sectional area, irrigation port cross-sectional area and drainage port cross-sectional area differed significantly when each 24Fr 3-way catheter was compared. The variations in cross-sectional are correlated with each catheter's irrigation flow rate characteristics (Table 1). For example, the 24Fr 3-way Rusch Simplastic™ catheters had the greatest irrigating flow rates) and the greatest irrigation port cross-sectional area (Table 2: 3.14 mm^2). In comparison, drainage CSA variations did not correlate with drainage flow rates (Table 1). Based on these findings, it is arguable that CSA measurements as well as French gauge should be available to urologists when a 3-way catheter is required for irrigation and/or drainage purposes.

Ramaswamy et al. suggested that Rusch™ catheters provide the best drainage properties for manual bladder irrigation [7]. Manual bladder washouts are common practice for preventing clot retention in patients with persistent hematuria as good catheter flow characteristics (from the drainage port) are necessary for effectively evacuating clots in these patients. In this clinical scenario, it is perhaps intuitive that the increased diameter of the drainage port (relative to the irrigation port) results in more effective evacuation as larger clots and/or debris can be evacuated with greater ease from this port. Our study is consistent with these findings as evident by the greater flow rates noted from the drainage ports for each catheter relative to their irrigation ports (Table 2 and Table 3). In fact, some authors have described the use of rectal tubes for the management of severe clot retention based on the principle of increasing the diameter of the drainage port relative to the irrigation port [8]. A unique feature presented in the current study is that drainage characteristics were measured with controlled gravity (by allowing saline to drain from the distal tip of the catheter out through the drainage port). This experimental set-up eliminated user variability associated with manual protocols and mimicked the natural urinary drainage system of a 3-way catheter. It has previously been hypothesized that catheter composition may play an important role for improving irrigation flow rates. A comparative bench-top study by Diz Rodrigues et al. demonstrated that urethral catheters composed of rigid material (e.g. silicone) showed significantly greater irrigation and drainage properties when compared to catheters composed of more flaccid biomaterials (e.g. latex) [9]. We noted a similar trend in our study as 24Fr 3-way Rusch Simplastic™ catheters demonstrated the best flow characteristics for CBI (i.e during continuous irrigation and drainage, Table 4). This finding suggests that the 24Fr 3-way Rusch Simplastic™ catheter is the optimal commercially available catheter for providing CBI.

CONCLUSIONS

24Fr 3-way Rusch Simplastic™ catheters consistently demonstrate the best irrigation characteristics when compared to other commercially available 3-way catheters. In comparison, the 24Fr 3-way Dover™ catheter demonstrates the greatest drainage properties. These findings may have important clinical implications as efficient bladder irrigation and efficient bladder drainage should be prioritized according to the urological scenario that is presented.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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