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Original Article

Change in irrigation flow through a flexible ureteroscope with various devices in the working channel: Comparison between an automatic irrigation pump and gravity-based irrigation

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Abbreviations & Acronyms
AIP = automatic irrigation pump
E.A.S.I. = Endoscopic Automatic System for Irrigation
fURS = flexible ureteroscope
RIRS = retrograde intrarenal surgery
UAS = ureteral access sheath

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Objectives: To evaluate the change in the irrigation flow with various instruments in the working channel of a flexible ureteroscope by two automatic irrigation pumps and gravity-based irrigation in an *ex vivo* setting.
Methods: We used two automatic irrigation pumps: the Endoflow II and the UROMAT Endoscopic Automatic System for Irrigation and gravity-based irrigation. A flexible ureteroscope was connected to an irrigation tube with a working channel. The other side of the irrigation tube was attached to each automatic irrigation pump, which was connected with a 2-L saline bag or to a 2-L saline bag directly in case of gravity pressure. The flow volume from the working channel was measured three times for 30 s at various irrigation pressure settings, both when the working channel was unoccupied and occupied with various instruments.
Results: The irrigation flow steadily increased as the irrigation pressure in the automatic irrigation pumps increased and the saline position in gravity became higher ($P < 0.05$). However, the flow decreased as the size of the instrument in the working channel increased ($P < 0.05$). The efficiency of irrigation flow in gravity-based irrigation under the same pressure is significantly lower than one of two automatic irrigation pumps ($P < 0.05$). However, there was no significant difference in the efficiency of the irrigation flow between the Endoflow II and UROMAT Endoscopic Automatic System for Irrigation. The irrigation pressure setting needed to change to maintain adequate irrigation flow when using various working tools.
Conclusions: The efficiency of irrigation flow in gravity-based irrigation is significantly lower than one of two automatic irrigation pumps. The irrigation flow decreases as the size of the instrument in the working channel increases.

Key words: automatic irrigation pump, gravity-based irrigation, retrograde intrarenal surgery, upper urinary tract stone.

Introduction

Adequate maintenance of an optimal surgical field during operative procedures is one of the most important factors to ensure safe performance of the procedure and minimal stress for surgeons. A wound retractor, the surgeon's hand and a hook are the most common methods of maintaining an optimal surgical field during open surgery. In laparoscopic surgery and robot-assisted laparoscopic surgery, however, the optimal surgical field is created by patient positioning and pneumoperitoneum with carbon dioxide to facilitate the procedure.[1] These minimally invasive endoscopic surgery techniques decrease bleeding and contribute to improved visualization for surgeons.

With the recent rapid developments in the field of endourology, RIRS using a fURS has become the standard treatment for upper urinary tract diseases, such as urolithiasis. Endourological procedures in the upper urinary tract usually require irrigation of saline. The surgical field and visualization during the intervention are maintained through optimal irrigation flow with saline. The view of the surgical field during RIRS has changed as a result of increased efficiency of the irrigation flow, which is influenced by the location and size of the UAS, size of the fURS, and irrigation method. Therefore, maintaining an optimal surgical field and good visualization during RIRS is not easy. Most surgeons usually insert the fURS with running saline and without instruments in the working channel through the UAS and into the kidney during RIRS; they then check the disease location and the distention of the renal pelvis to facilitate the procedure. However, the irrigation flow changes depending on the instruments that occupy the working channel. When the renal pelvis collapses as a result of decreased irrigation flow, optimal renal pelvic distention cannot be maintained. A handheld-activated syringe-based system is often used to compensate for this problem, thus reproducing optimal renal pelvic distention and good visualization. However, intrarenal pressure of >40 mmHg increases the risk of pyelovenous and pyelolymphatic backflow of irrigated fluid.[2–5] A handheld syringe-pump often might be in danger of pyelonephritis and sepsis peri-operatively. Therefore, regardless of the type of instrument in the working channel, it is important to maintain a constant irrigation flow from the tip of the working channel of the fURS that is identical to the irrigation flow in the unoccupied working channel. This will ensure optimal renal pelvic distention and prevent the drastic increases in intrarenal pressure that might occur with handheld-activated syringe-based systems.[6] We consider that the use of an AIP might play a role in maintaining an optimal surgical field for easy manipulation of the fURS in the kidney. However, the performance of AIPs during RIRS is still under review. Lama *et al*. recently reported the use of an automatic system for irrigation (UROMAT E.A.S.I.; Karl Storz, Tuttlingen, Germany) that continues the same irrigation flow over time.[3] In the present study, we evaluated the change in the irrigation flow with various instruments in the working channel at several different irrigation pressure settings of two currently available AIPs (Endoflow II and UROMAT E.A.S.I.) in an *ex vivo* setting. Then, we compared the efficiency of irrigation flow in AIPs with one of gravity-based irrigation. Furthermore, we investigated the irrigation pressure setting required to maintain the same irrigation flow in the unoccupied working channel regardless of the type of instrument occupying the working channel.

Methods

Description of AIP devices and gravity-based irrigation

We used two AIPs in the present study: the Endoflow II (Rocamed, Lyon, France) and the UROMAT E.A.S.I. (Karl Storz). The Endoflow II is characterized by a pressure-controlled system that utilizes air compression to ensure continuation of the same irrigation volume. A saline bag (1–3 L) for irrigation is packed in the box of this system, and the irrigation tube is placed into the bag. The other side of the irrigation tube is connected to the fURS working channel. The irrigation pressure (0–190 mbar) is easily controlled by a touch panel. The UROMAT E.A.S.I. is a pressure-controlled double-roller pump that operates according to a preset procedure depending on settings, such as resection, hysteroscopy and upper urinary tract. A saline bag (1–3 L) for irrigation is connected to a double irrigation tube, which is loaded to a roller. The other side of the irrigation tube is connected to the fURS working channel. The irrigation pressure (20–200 mmHg) is controlled by a touch panel. Then, the gravity-based irrigation is natural irrigation based on the height from tip of the ureteroscope to the surface of saline (60–200 cmH_2O; Fig. 1a).

Research setting and measurement of irrigation volume

A 7.5-Fr fURS that equips a 3.6-Fr working channel and fiberoptic scope (Flex-X2; Karl Storz) was used in the present study. The fURS was placed in straight alignment without active deflection on the operating table. The irrigation tube was connected to the three-way valve attached to the 3.6-Fr working channel. The other side of the irrigation tube was attached to each AIP, which was connected with a 2-L saline bag or to a 2-L saline bag directly in case of gravity pressure (Fig. 1b). The irrigation pressure in the AIP was set at 50 mbar (37.5 mmHg) to 190 mbar (142.8 mmHg) in the Endoflow II, and from 30 mmHg (39.9 mbar) to 140 mmHg (186.2 mbar) in the UROMAT E.A.S.I. Then, the height of saline in gravity-based irrigation was placed at a range from 60 to 200 cm (1 mmHg was converted to 1.33 mbar and 1.36 cmH_2O). The flow volume that drained from the tip of the working channel of the fURS was measured three times for 30 s based on each irrigation pressure setting in each irrigation method, both when the working channel was unoccupied and when it contained various instruments, such as 200-, 272- and 365-μ laser fibers (Quanta, Samarate, Italy); a 1.3-Fr OptiFlex stone retrieval basket (Boston Scientific, Marlborough, MA, USA); a 1.5-Fr NCircle stone extractor (Cook Medical, Bloomington, IN, USA); a 1.7-Fr NCompass stone extractor (Cook Medical); a 1.8-Fr Ultra-Catch stone retrieval basket (Olympus, Tokyo, Japan); and a 1.9-Fr Zero Tip stone retrieval basket (Boston Scientific; Fig. 1c,d). The flow volume at each irrigation pressure was measured, and the mean measured value is shown in Figure 2. In addition, we also measured and compared the irrigation flow between with and without full active deflection in each irrigation method.

To compare the difference in the flow volume among the pressure-controlled system compressed by air (Endoflow II), the pressure-controlled double-roller pump (UROMAT E.A.S.I.) and gravity-based irrigation, the flow volume for 30 s at the same irrigation pressure was evaluated among 80 mbar (60.1 mmHg), 60 mmHg (79.8 mbar) and 80 cmH_2O (59.5 mmHg), and among 160 mbar (120.3 mmHg), 120 mmHg (159.6 mbar) and 160 cmH_2O (118 mmHg), respectively. Furthermore, the irrigation pressure setting required to keep the same irrigation flow as that in the unoccupied working channel was also investigated based on the mean measured value, even when instruments were present in the working channel.

Statistical analysis

All collected data were analyzed using SPSS version 21 (IBM Corporation, Armonk, NY, USA). Pearson correlation

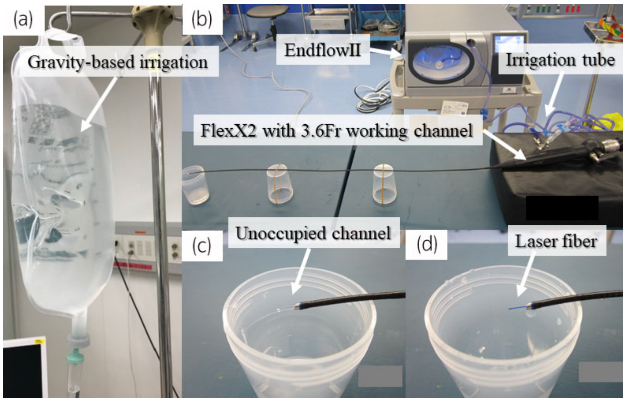

Fig. 1 Research setting of irrigation volume measurement. (a) Gravity-based irrigation setting. (b) fURS with straight alignment on the operating table. (c) Irrigation with an unoccupied working channel. (d) Irrigation with the working channel occupied by a laser fiber.

analysis was used to evaluate the change in the flow volume at each irrigation pressure setting with various instruments present in the working channel. The Kruskal–Wallis test and Mann–Whitney test were used to compare the difference in the flow volume between the Endoflow II, UROMAT E.A.S.I. and gravity-based irrigation, between with and without full active deflection, respectively. A two-sided P-value of <0.05 was considered statistically significant.

Results

The changes in the irrigation flow within the working channel produced by the Endoflow II, UROMAT E.A.S.I. and gravity-based irrigation at each irrigation pressure setting when the working channel was unoccupied and when it contained various instruments are shown in Figure 2a–c. The irrigation flow in the presence of any instruments steadily increased as the irrigation pressure setting in the AIP increased and the saline position in gravity became higher ($P < 0.05$); additionally, the irrigation flow at any irrigation pressure setting decreased as the size of the instrument increased ($P < 0.05$). In particular, the irrigation flow in the unoccupied working channel was significantly higher than that containing any instruments ($P < 0.05$; Fig. 2a–c).

Table 1 compares the irrigation flow among the Endoflow II, UROMAT E.A.S.I. and gravity-based irrigation at the same irrigation pressure setting (80 mbar [60.1 mmHg], 60 mmHg [79.8 mbar] and 80 cmH_2O [59.5 mmHg]; 160 mbar [120.3 mmHg], 120 mmHg [159.6 mbar] and 160 cmH_2O [118 mmHg], respectively). The efficiency of the irrigation flow in gravity-based irrigation under the same pressure is significantly lower than one of two AIPs ($P < 0.05$). However, there was no significant difference in the efficiency of the irrigation flow between the Endoflow II and UROMAT E.A.S.I. ($P = 0.1$). In addition, there was no significant difference in irrigation flow between with and without full active deflection of fURS tip in each irrigation methods, even if any instruments occupied the working channel (Table 2).

The irrigation pressure setting required to maintain the same irrigation flow regardless of instruments in the working channel is shown in Table 3. The irrigation flow rate of the unoccupied working channel at an initial pressure setting of 50 mbar (or 60 or 70 mbar) of the Endoflow II was almost equal to that at 110–120 mbar (or 120–130 or 140–150 mbar, respectively) when using a 200-μ fiber, and at 160–170 mbar (or 180–190 or >190 mbar, respectively) when using a 1.5-Fr basket to maintain the same irrigation flow. Similarly, the irrigation flow of the unoccupied working channel at an initial pressure setting of 30 mmHg (or 40 or 50 mmHg) of the UROMAT E.A.S.I. was almost equal to that at 50–60 mmHg (or 60–70 or 80–90 mmHg, respectively) when using a 200-μ fiber, and at 80–90 mmHg (or 110–120 or 130–140 mmHg, respectively) when using a 1.5-Fr basket to maintain the same irrigation flow.

Discussion

In the present study, the irrigation flow decreased as the size of the instrument in the working channel increased. Therefore, the irrigation pressure setting must be changed to maintain the same irrigation flow when occupying various instruments in the working channel of the fURS. However, the efficiency of irrigation flow in gravity-based irrigation under the same pressure is significantly lower than one of two AIPs. Therefore, there is a different use between AIPs and gravity-based irrigation.

The irrigation methods used during RIRS have evolved during the past few decades. In 1984, Lyon *et al*. described the use of a fURS with irrigation connected to the ureteroscopic working channel and used gravity to maintain the irrigation flow by placing a saline bag 30 cm above the level of the kidney.[7] Since then, the use of handheld-activated syringe-based systems has become more standard to ensure adequate irrigation flow during procedures. A foot-activated syringe-based irrigation system called Peditrol (Wismed, Durban, South Africa) is currently available.[6] Furthermore, pressurized irrigation bags and an AIP that place constant pressure on the saline bag have also been introduced for irrigation during procedures. However, the effect of AIPs in RIRS remains unknown. We consider that maintenance of optimal renal pelvic distention and lower intrarenal pressure are important for safe and successful RIRS.

Establishment of adequate irrigation inflow and outflow through the UAS during RIRS is required to maintain optimal renal pelvic distention, good visualization and lower intrarenal pressure. One of the factors that influence the irrigation flow during RIRS includes the irrigation method. The irrigation inflow from the tip of the working channel in the fURS depends on the irrigation method used. Although a hand- or foot-activated syringe-based irrigation system might produce a drastic increase of inflow through the working channel, which influences the intrarenal pressure, and pressurized irrigation bags in which the irrigation pressure gradually decreases cannot maintain constant irrigation flow during the procedure over time, as well as natural gravity-based irrigation adjusted by the height of the saline bag, the AIP maintains a constant irrigation flow for most of the procedure.[3] In the present study, the efficiency of irrigation flow in gravity-based irrigation under the same pressure was significantly

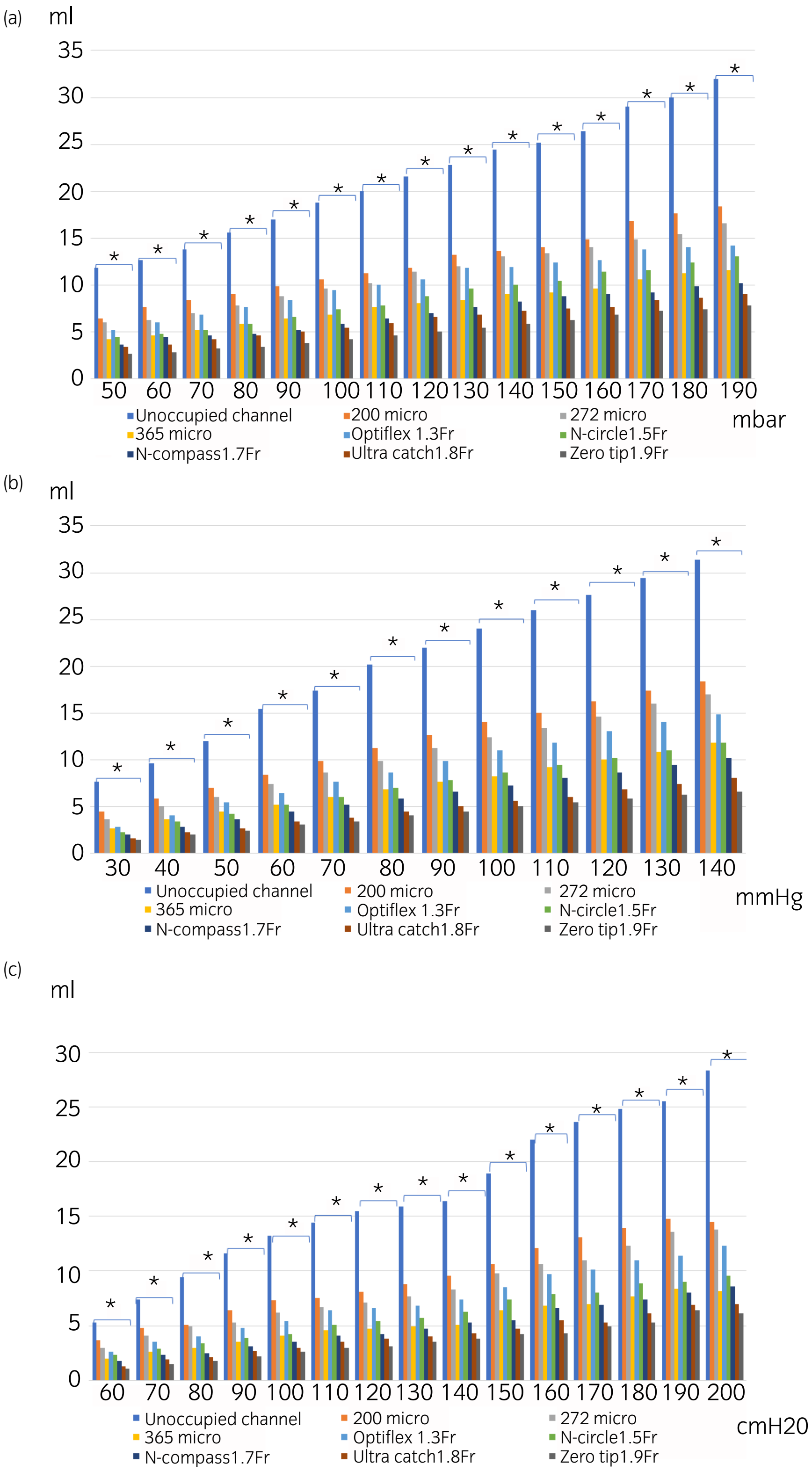

Fig. 2 Change in flow volume in the working channel by irrigation pressure produced by an AIP when various instruments occupied the working channel. (a) Endoflow II. (b) UROMAT E.A.S.I. (c) Gravity-based irrigation.

lower than one of the two AIPs because of the loss of pressure power due to gradually decreasing the height of the saline surface, changing the pipe diameter in the middle of the irrigation tube. In 2005 and 2008, Abdelshehid *et al.*[8] and Bach *et al.*,[9] respectively, showed decreased irrigation flow rates with increased working tool sizes in the fURS when using gravity-based irrigation. The present study showed similar results, even when an AIP was used. Thus, the irrigation flow is influenced by the resistance in the working channel and irrigation pressure from the AIP, as shown by Ohm's

Table 1 Comparison of flow volume among Endflow II, UROMAT E.A.S.I. and gravity-irrigation based on same irrigation pressure

	Gravity irrigation 59.5 mmHg (80 cmH_2O)†	Endflow II 60.1 mmHg (80 mbar)†	UROMAT E.A.S.I. 60 mmHg†	*P*-value‡
(mL/30 s, SD)				
Channel free	9.4 (0.2)	15.6 (0.1)	15.4 (0.05)	0.027
Fiber 200 micro (outer 375 micro)	5.0 (0.05)	9.0 (0.11)	8.4 (0.05)	0.025
Fiber 272 micro (outer 420 micro)	4.9 (0.3)	7.8 (0.05)	7.4 (0)	0.023
Fiber 365 micro (outer 550 micro)	3.0 (0.15)	5.8 (0.1)	5.2 (0.01)	0.027
Optiflex 1.3-Fr	4.0 (0.05)	7.6 (0)	6.4 (0.05)	0.023
N-circle 1.5-Fr	3.4 (0.05)	5.8 (0.05)	5.2 (0)	0.023
N-compass 1.7-Fr	2.5 (0.06)	4.8 (0)	4.4 (0.1)	0.023
Ultra catch 1.8-Fr	2.0 (0.05)	4.6 (0.1)	3.4 (0.1)	0.027
Zero tip 1.9-Fr	1.8 (0)	3.4 (0.05)	3.0 (0)	0.02
	Gravity irrigation 118 mmHg (160 cmH_2O)†	Endflow II 120 mmHg (160 mbar)†	UROMAT E.A.S.I. 120 mmHg†	*P*-value‡
(mL/30 s, SD)				
Channel free	21.8 (0.57)	26.4 (0.05)	27.6 (0.1)	0.026
Fiber 200 micro (outer 375 micro)	12.1 (0.3)	14.8 (0.05)	16.2 (0.1)	0.027
Fiber 272 micro (outer 420 micro)	10.6 (0.05)	14.0 (0)	14.6 (0)	0.02
Fiber 365 micro (outer 550 micro)	6.8 (0.2)	9.6 (0.1)	10.0 (0.05)	0.027
Optiflex 1.3-Fr	9.7 (0.2)	12.6 (0.05)	13.0 (0.05)	0.026
N-circle 1.5-Fr	7.8 (0.05)	11.4 (0.1)	10.2 (0.05)	0.026
N-compass 1.7-Fr	6.5 (0.06)	9.0 (0)	8.6 (0)	0.02
Ultra catch 1.8-Fr	5.5 (0.1)	7.6 (0.1)	6.8 (0)	0.024
Zero tip 1.9-Fr	4.3 (0.1)	6.8 (0)	5.8 (0)	0.021

†1 mmHg = 1.333 mbar = 1.360 cmH_2O. ‡Kruskal–Wallis.

Table 2 Comparison of flow volume with and without deflection of fURS in each irrigation methods

	Gravity irrigation 100 cmH_2O†			Endflow II 100 mbar†			UROMAT E.A.S.I. 100 mmHg†		
	Without deflection	With deflection	*P*-value‡	Without deflection	With deflection	*P*-value‡	Without deflection	With deflection	*P*-value‡
Mean mL/30 s (SD)									
Channel free	13.7 (0.47)	13.4 (0.15)	0.7	18.7 (0.25)	19.2 (0.25)	0.1	24.8 (1.05)	24.4 (0.18)	1
Fiber 200 micro (outer 375 micro)	7.5 (0.2)	7.6 (0.26)	0.7	10.6 (0.2)	10.8 (0.2)	0.2	14.6 (0.55)	14.9 (0.52)	1
Fiber 272 micro (outer 420 micro)	6.4 (0.12)	6.7 (0.12)	0.1	9.7 (0.1)	9.8 (0.1)	0.4	12.6 (0.25)	12.8 (0.26)	0.4
Fiber 365 micro (outer 550 micro)	4.1 (0.1)	4.3 (0.05)	0.1	6.6 (0.2)	6.9 (0.05)	0.2	7.9 (0.2)	8.1 (0.2)	0.4
Optiflex 1.3-Fr	5.6 (0.2)	5.5 (0.11)	1	9.2 (0.2)	9.5 (0.1)	0.1	11.5 (0.49)	12 (0.15)	1
N-circle 1.5-Fr	4.8 (0.56)	5.2 (0.25)	0.4	7.2 (0.2)	7.4 (0.1)	0.2	9.7 (0.46)	10 (0.15)	0.4
N-compass 1.7-Fr	3.6 (0.15)	3.8 (0.05)	0.2	6 (0.2)	6.2 (0.2)	0.4	7.3 (0.15)	7.7 (0.15)	1
Ultra catch 1.8-Fr	3.1 (0.15)	3.2 (0.05)	0.4	5.7 (0.32)	5.9 (0.15)	0.7	5.7 (0.15)	6 (0.2)	1
Zero tip 1.9-Fr	2.8 (0.2)	2.9 (0.15)	0.4	4.3 (0.2)	4.6 (0.15)	0.2	5.5 (0.15)	5.8 (0.05)	1

†1 mmHg = 1.333 mbar = 1.360 cmH_2O. ‡Mann–Whitney.

law ($I = V / R$). The irrigation pressure setting in an AIP must therefore be changeable to maintain adequate irrigation flow when using various working tools. However, the setting that should be used for an AIP remains uncertain. In the present study, we investigated the AIP irrigation pressure setting that is required to maintain the same irrigation flow regardless of the type of working instrument used.

The currently available natural gravity-based irrigation, pressurized irrigation bags and AIPs provide constant pressure on the saline bag for irrigation during RIRS. However, the differences among these systems are under review. Lama *et al*. compared hand-pump infusers, such as pressurized irrigation bags, versus the UROMAT E.A.S.I. with respect to the irrigation flow rate from the working channel in the fURS.[3] They found that the irrigation flow using a hand-pump infuser decreased as time passed, whereas the UROMAT E.A.S.I. continuously provided the same irrigation flow over time.[3] Similarly, the irrigation

Table 3 Irrigation pressure setting to maintain the about same flow volume when inserting working tools in working channel

Unoccupied channel (initial pressure setting)†	Fiber 200 micro	Optiflex 1.3-Fr	N-circle 1.5-Fr
Endflow II, mbar (mL/30 s)			
50 mbar (11.8)	110–120 (11.2–11.8)	120–130 (10.6–11.8)	160–170 (11.4–11.8)
60 mbar (12.6)	120–130 (11.8–13.2)	150–160 (12.4–12.6)	180–190 (12.4–13.0)
70 mbar (13.8)	140–150 (13.6–14.0)	160–170 (12.6–13.8)	190– (13.0–)
UROMAT E.A.S.I., mmHg (mL/30 s)			
30 mmHg (7.6)	50–60 (7.0–8.4)	60–70 (6.4–7.6)	80–90 (7.0–7.8)
40 mmHg (9.6)	60–70 (8.4–9.8)	80–90 (8.6–9.8)	110–120 (9.4–10.2)
50 mmHg (12.0)	80–90 (11.2–12.6)	110–120 (11.8–13.0)	130–140 (11.0–11.8)
Gravity-based irrigation, cmH_2O (mL/30 s)			
60 cmH_2O (5.3)	80–90 (5.1–6.4)	90–100 (4.8–5.4)	110–120 (5.1–5.4)
70 cmH_2O (7.4)	100–110 (7.3–7.5)	130–140 (6.8–7.4)	140–150 (6.3–7.4)
80 cmH_2O (9.4)	130–140 (8.8–9.6)	150–160 (8.5–9.7)	190–200 (9.0–9.6)

†1 mmHg = 1.333 mbar = 1.360 cmH_2O.

flow rate of natural gravity-based irrigation also decreased because of decrease in the height of saline surface as time passed. Therefore, in the present study, the irrigation flow rate in gravity-based irrigation under the same pressure was significantly lower than one of two AIPs. However, there was no significant difference in the efficiency of the irrigation flow between the Endoflow II and UROMAT E.A.S.I., regardless of the working instruments used. Therefore, both AIP systems have the same irrigation function capacity regardless of whether the pressure-controlled system uses compression by air or a pressure-controlled double-roller pump system. Additional clinical research is required to evaluate the advantages of currently available AIPs.

In addition, we evaluated the irrigation flow volume with or without active deflection of fURS in the present study. Our finding showed that there was no significant difference in irrigation flow between with deflection and without deflection of fURS tip. Likewise, Nagele *et al*. investigated the irrigation flow was not influenced by fURS deflection.[10,11]

The present study had some limitations. First, this preliminary research was carried out in unlimited space, unlike the renal pelvis. Therefore, it is not clear whether or not this outcome is accurate in clinical practice. Future research is required. Second, we evaluated flow volume (mL/30 s) based on the irrigation pressure setting instead of irrigation speed in the present study, because irrigation pressure is standard in two AIPs and gravity-based irrigation. To the best of our knowledge, this is the first *ex vivo* study to investigate the irrigation flow with all types of instruments in the working channel and compare the function between two AIPs and natural gravity-based irrigation. In conclusion, the efficiency of irrigation flow in gravity-based irrigation is significantly lower than one of two AIPs. The irrigation flow decreased as the size of the instrument in the working channel increased. Therefore, irrigation pressure setting is required to change to maintain optimal flow.

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Conflict of interest

None declared.

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