EDITORIAL COMMENT
UROLITHIASIS

Suction irrigation pressure autoregulating systems (SIPS): Is this the future of endourology?

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INTRODUCTION

Flexible ureteroscopy (fURS) has become more complex in recent years because of larger retrograde-treated stones (up to 2 cm), bilateral procedures, higher laser power, and an ageing patient population. As operative times lengthen, safe control of fluid dynamics becomes increasingly important. Irrigation is central to modern fURS because it maintains visualization, distends the collecting system, regulates temperature, and clears stone fragments [1]. However, prolonged high-pressure irrigation can increase intrarenal pressure (IRP) and promote pyelovenous backflow. This may allow irrigation fluid contaminated with urine to enter the systemic circulation, enabling translocation of bacteria and endotoxins and increasing the risk of systemic inflammatory response and sepsis. [2] There is no universal safe pressure threshold. Although backflow may begin at 20–30 mmHg, patient susceptibility varies with renal compliance and papillary anatomy. Conditions such as hydronephrosis, flattened papillae, medullary sponge kidney, sepsis, and hypotension may lower renal resistance to pressure and increase the risk of backflow and infection even at relatively modest IRP levels [3]. IRP during endourological procedures is influenced by several factors, including irrigation modality (gravity-based, hand-pump, or automated systems), use and size of the ureteral access sheath, ureteroscope calibre, and the presence of suction. Intrarenal temperature is also critical to safety, especially in the era of high-power laser lithotripsy. Laser energy generates heat and overheating can

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cause thermal injury. Irrigation, therefore, serves as an essential cooling mechanism, helping maintain safe temperatures [4]. Logically, higher irrigation rates improve cooling, but also IRP [5]. As a result, modern ureteroscopy is moving toward intelligent fluid management that combines enhanced drainage (such as FANS) and real-time pressure monitoring to optimize intrarenal dynamics. The shift in suction ureteroscopy is now towards ensuring procedural safety, effective stone fragmentation and meticulous temperature and pressure control.

WHY TRADITIONAL IRRIGATION IS NO LONGER ENOUGH

Traditional irrigation relies on gravity, pressurized irrigation bags, or hand pumps [6]. In gravity-based systems, irrigation pressure is determined by the height difference between the saline bag and the ureteroscope, so raising the bag increases both flow and IRP due to uncontrolled distension of the pelvicalyceal system (PCS). Often done to improve PCS distensibility for better visualisation, performance depends on bag height and working channel (WC) patency. However, this approach has limitations: if the bag is too low or the WC is occupied, flow is insufficient and visualization is poor. It is also inflexible, because the surgeon cannot increase flow instantly without physically repositioning the bag. In addition, the absence of a standardized reference level means that small changes in bag height can cause substantial differences in actual flow and pressure. Eventually, a steady high-pressure state is obtained, following which surgeons need to use pumps or pressurised irrigation, which is when forniceal ruptures and tears predominate [7]. Hand-operated pumps offer rapid bursts of irrigation when visibility is compromised by bleeding, dust, or stone fragments [8] but this comes at the cost of markedly higher and less predictable renal pelvic pressures. Reported pressures can exceed 287 mmHg and may approach 440 mmHg, greatly increasing the risk of pyelovenous backflow and even perirenal extravasation [9]. Clinical data support these concerns have been associated with higher rates of postoperative systemic inflammatory response syndrome (SIRS), fever, hypotension with tachycardia, sepsis and even emergency department visits [8]. Pressurized irrigation bags provide a more controlled alternative by combining a gravity bag with an external pressure cuff, usually maintained at 100–150 mmHg, to deliver continuous and predictable flow throughout the procedure; however, they do not actively monitor or regulate IRP and are unreliable for safe ureteroscopy [8]. As suction becomes an increasingly important component of modern endourology, both excessive renal pelvic distension and overly rapid decompression can be harmful. Overdistension may lead to unsafe increases in intrarenal pressure, whereas rapid emptying can cause decompression haematuria and impaired visibility. These challenges highlight the need for smart fluid-management systems capable of maintaining a stable balance between irrigation and suction throughout the procedure.

THE SUCTION IRRIGATION PRESSURE AUTOREGULATING SYSTEMS MECHANISM

Suction Irrigation Pressure Autoregulating Systems (SIPS) may represent one of the first clinically applicable closed-loop fluid-management concepts in ureteroscopy (Figure 1). Their key innovation is not irrigation or suction alone, but dynamic autoregulation of the suction-irrigation ratio (SIR). By combining pressure sensing, automated irrigation control, and suction within a single system, SIPS maintains IRP within a predefined safe range (<30 mmHg) while maintaining PCS distensibility during active stone clearance [10]. Typically, this is achieved through a closed-loop feedback mechanism: pressure sensors within a flexible and navigable suction ureteral access sheath (FANS) dynamically measure pressure changes in the PCS and relay the data to a processor that auto adjusts irrigation inflow and suction outflow in real time. When pressure rises, suction increases or vice-versa. In this way, SIPS aims to maintain clear visibility during laser lithotripsy, help regulate temperature, facilitate stone fragment evacuation without collapse of the collecting system, and keep IRP stable throughout the procedure.

Current commercially available systems include the Elephant IV–Tidor platform and the ZSR–i-MIMERsys platform, while the Inventor Technology pressure-controlled FANS is currently under clinical evaluation and has not yet obtained CE marking [11]. The Elephant IV–Tidor platform*, developed by YiGao Medical Technology (China), incorporates pressure-sensing openings within the flexible tip of the suction sheath. The sheath connects to the Tidor automated control unit. Zhu W. et al. showed that Elephant III substantially reduced IRP despite very high irrigation flow rate pressures (150–250 mmHg). Mean IRP was only 13.8 ±4.7 mmHg, well below the safety threshold. Active suction also allowed higher irrigation flows for better visibility while keeping pressure within a safe range. Larger FANS sheaths (12/14 Fr) were associated with lower IRP than smaller sheaths (10/12 Fr), suggesting that maximising outflow remains important even in suction-enabled systems [12].

The ZSR IRP-monitoring FANS with i-MIMERsys, developed by ZSR Biomedical Technology (China)**, incorporates a 0.5 Fr pressure-sensing channel within the sheath wall, which transmits data to the external i-MIMERsys processor. Real-time pressure readings are displayed continuously during surgery. Its main technical strengths are a wide measurable range (−300 to +300 mmHg), which captures both elevated and negative pressures generated during suction, and an exceptionally fast sampling rate of one reading every 2.5 milliseconds, making it the fastest system evaluated in the study. It also includes an additional safety feature that detects irrigation backflow pressure through the irrigation tubing in the main unit [13].

The Inventor Technology pressure-controlled FANS, developed in Jiangxi, China***, combines a pressure-monitoring FANS with a proprietary pressure-regulating processor. However, this is currently the only device that has not obtained CE marking. Furthermore, the pressure-sensing port is positioned at the junction between the flexible tip and the rigid shaft of the FANS, raising concerns regarding the accuracy and reliability of the recorded pressure measurements. Peng et al. also demonstrated that the system maintained a mean renal pelvic pressure of −4.6 ±2.1 mmHg, a level that may be excessively low and could potentially affect collecting system distension [14, 15]. Unlike pressure-sensing ureteroscopes, which only alert the surgeon when pressure rises, SIPS can autoregulate pressure through integrated irrigation and suction control. This is what differentiates them from just a passive fluid monitoring unit to a dynamic fluid and pressure management entity. Safety features such as built-in alarms and automatic irrigation shut-off when unsafe pressure levels are reached make SIPS a closed-loop system that continuously monitors and adjusts fluid management within the collecting system based on real-time IRP measurements [10].

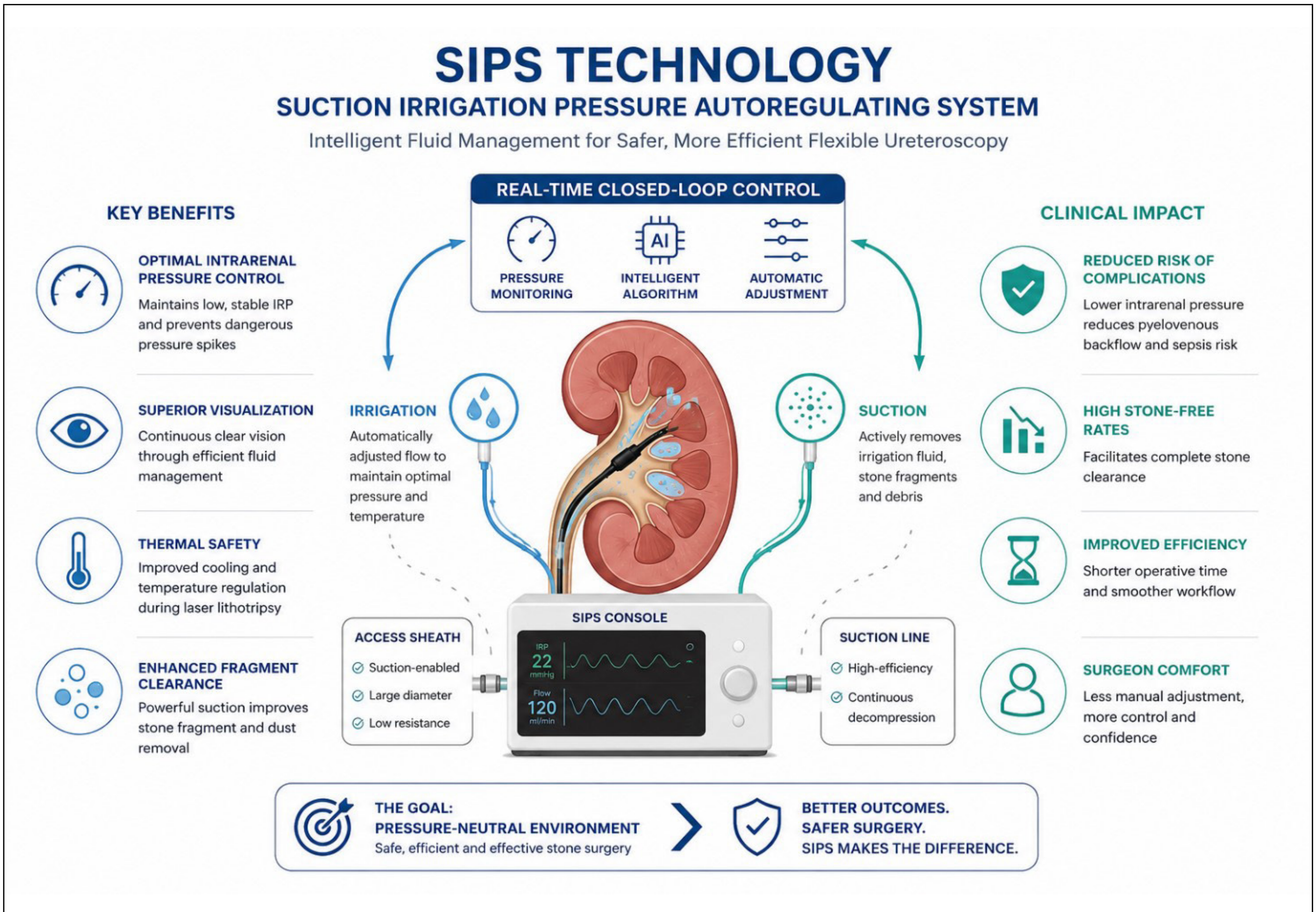

Figure 1. *Conceptual overview of Suction Irrigation Pressure Autoregulating Systems (SIPS).*

The ZSR–i-MIMERsys and Elephant IV–Tidor platforms differ in several technical aspects. The ZSR–i-MIMERsys system incorporates multiple pressure-sensing ports at the sheath tip, whereas the Elephant IV–Tidor platform uses a single sensing port. The two systems also employ different calibration methods, with ZSR using liquid-based calibration and Tidor using air priming. In addition, pressure monitoring in the ZSR system is initiated automatically upon activation, while the Tidor platform offers both automatic and manual operating modes. These design differences may influence system performance and user experience during ureteroscopy; however, comparative clinical data are currently lacking, and the impact of these features on pressure measurement accuracy, reliability, and clinical outcomes remains to be determined.

THE ROLE OF AI IN SUCTION IRRIGATION PRESSURE AUTOREGULATING SYSTEMS

FANS integrated with AI-driven IRP monitoring is a major advance in fURS, bringing FURS closer to the endourological quadrifecta: complete single-stage stone clearance, optimized fluid dynamics, greater efficiency and no pressure- and temperature-related injury [16]. AI is helping automate fluid management, shifting the burden of a surgeon-monitored irrigation to an intelligent, regulated closed-loop system allowing the surgeon to focus on lasing strategies

The key advantages of an AI-driven system are:

- Keeps IRP within predefined safe limits with alarm triggers for active intervention.
- Auto-regulation of irrigation and suction in real time.
- Thermal safety even with longer laser pedal activation, which may shorten procedure time.
- Reduces surgeon cognitive load, allowing greater focus on stone treatment and navigation.
- Improves reproducibility during FURS irrespective of surgeon experience.

Importantly, SIPS does not replace the surgeon's judgement. Instead, it provides real-time feedback and allows the surgeon to adjust irrigation, suction, pressure, and flow as needed, while keeping IRP within a safe range. This helps optimise lithotripsy efficiency during fURS [10].

LIMITATIONS AND FUTURE DIRECTION

One potential limitation of these platforms is their cost. Pricing is not publicly disclosed because it is determined through institution-specific contracts. Costs vary according to purchase volume, distribution channels, and research agreements. However, the initial investment for the console may range from approximately $10,000 to $30,000. Secondly, clinical evidence supporting SIPS remains limited to make absolute conclusions, yet it offers promising clinical potential from in vitro studies, animal models, and small pilot clinical series. Large multicentre studies evaluating key outcomes such as sepsis, complications, and stone-free rates are still lacking. Moreover, the system's sensitivity depends on the reliability of the IRP sensor. Therefore, inaccurate pressure measurements could potentially lead to inappropriate irrigation or suction responses. AI may help overcome these measurement errors by identifying and removing false pressure spikes from the pressure waveform. Similar challenges have been reported with other IRP monitoring systems, such as the LithoVue™ Elite, where contact between the sensor and the urothelium, stone fragments, or debris can generate pressure spikes that do not reflect the true intrarenal pressure. Using AI to filter these artefacts has been shown to achieve a sensitivity of 93.6% for detecting genuine pressure events [17]. There is a lack of consensus on optimal settings, such as best irrigation flow rates, suction pressures, and optimal suction–irrigation ratios due to operator variability in the endoscopes and sheath combinations used. Perhaps attempts at reporting and standardising FANS-based FURS [18] will help standardise SIPS optimised SIR, allowing for a tailored approach in renal stone management. Moreover, recent surveys identified knowledge gaps regarding optimal irrigation and suction practices [19]. Previous studies have also shown that irrigation through a wider 5.1 Fr WC raises the baseline IRP faster than the classic 3.6 Fr working channel, which also needs to be clinically tested [20]. Indeed, successful adoption of these systems requires a learning curve, and adequate training in fluid dynamics, IRP behaviour, and suction principles is essential for their effective use. Finally, although current SIPS platforms provide automated IRP regulation and alarm systems to indicate blockage, declogging debris, blood clots, or stone fragments, the system remains surgeon-dependent, requiring manual intervention. This may be useful to implement in the next-generation AI- driven SIPS aiming to detect and automatically unclog the blockage with possible reverse flow, pulsed irrigation, as we intuitively do in traditional ureteroscopy, but without affecting IRP. Next generation systems should use AI to differentiate physiological and artefact pressure fluctuation. Furthermore, as thermal safety becomes increasingly important, the addition of integrated temperature monitoring may represent the next holistic evolution of SIPS.

CONCLUSIONS

SIPS signals a transition from passive irrigation to intelligent automated fluid management with continuous real-time pressure monitoring. As future clinical studies define suction aspiration parameters SIPS based peri-operative fluid management strategy during suction-integrated fURS could be the real define its role in achieving zero sepsis and zero residual fragment stone free status with complete stone free rates, this could be a gamechanger in peri-operative fluid management strategy during suction-integrated fURS.

CONFLICTS OF INTEREST

Vineet Gahuar: Educational KOL for ZSR and WellLead. Steffi Kar Kei Yuen: No consultant / financial agreements with both ZSR and YiGao. NON-FUNDED research projects involving both ZSR iMIMERsys and Tidor. Bhaskar K. Somani: Educational KOL for ZSR. The other authors declare no conflict of interest.

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ETHICS APPROVAL STATEMENT

The ethical approval was not required.

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