Intrarenal pressure study using 7.5 French flexible ureteroscope with or without ureteral access sheath in an ex-vivo porcine kidney model

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Abstract

Introduction:

7.5F digital fURS and 9.5/11.5F ureteral access sheaths (UAS), both conventional (cUAS) and vacuum-assisted (vaUAS), are commercially available. Irrigation increases intrarenal pressure (IRP). This study analyzes the IRP with various irrigation rates using 7.5F fURS without UAS or with either cUAS or vaUAS in an ex-vivo porcine model. Pyelo-tubular backflow was also studied during these experiments.

Materials and methods:

11 porcine kidneys were used. 7.5F digital fURS was tested without UAS and with 9.5/11.5F cUAS and vaUAS. 6F pressure monitor catheters were placed into the upper and lower calyces. IRPs were recorded under different irrigation rates. When vaUAS was used, the air vent was either open or closed. 300mmHg aspiration pressure was chosen. Lastly, contrasted irrigation fluid was delivered until IRP reached above 30mmHg. Fluoroscopy images were obtained at 5mmHg intervals over this threshold to study the pyelo-tubular backflow.

Results:

Using cUAS, IRP reached 30mmHg with irrigation rates between 60 and 70 cc/minute. Using vaUAS with vent closed, IRP never exceeded 10 mmHg with irrigation up to 120 cc/minute. vaUAS with vent open performed marginally better than cUAS. fURS without UAS performed better than cUAS. Pyelo-tubular backflow became prominent at 40mmHg.

Conclusion:

In an ex-vivo porcine model, 7.5F fURS could be used safely without UAS with irrigation rates up to 120 cc/minute. The safety margin dropped to 60-70 cc/minute with cUAS. vaUAS with vent closed maintained IRP <10 mmHg with irrigation rates up to 120 cc/minute. Pyelo-tubular backflow was observed with IRP > 35mmHg.

Key words: Intrarenal pressure, flexible ureteroscopy, ureteral access sheath, ex-vivo porcine model

Introduction

Flexible ureteroscopy (fURS) has become a standard armament in urological surgery. With the introduction of the single-use digital scope, the monetary threshold has been significantly reduced for this procedure; thus, there will likely be an increase in its usage.

Ureteral access (UAS) is often use in conjunction with fURS, especially in urolithiasis treatment. The miniaturization of fURS technology is rapidly advancing. The smallest fURS that has been approved for commercial use is 7.5F in diameter. The smaller size of the fURS increases its safety profile. UAS has also been reduced in size for the same reason. Currently, the smallest UAS that is commercially available has a 9.5/11.5F inside/outside diameter. Intrarenal pressure (IRP) is an important issue in intrarenal surgery. IRP ≥30mmHg may result in pyelo-renal backflow with deleterious effects to the patient[1,2,3]. UAS serves as a conduit for the passage of fURS. There are two types of UAS: conventional (cUAS) and vacuum-assisted (vaUAS) sheaths. vaUAS differs from cUAS in that it has an oblique side branch that can be connected to vacuum equipment (Fig. 1-A). There is a 2x4 mm^2 longitudinal air vent on this side branch (Fig. 1-B) to allow the operator to adjust the vacuum pressure. Closing the vent reduces air leakage and increases the aspiration pressure. The cUAS allows passive drainage of fluid from the kidney, whereas vaUAS causes active drainage. From our previous published IRP studies[4,5], we have established that IRP is directly correlated to the disparities between the rates of inflow and outflow of irrigation fluid in the pyelocalyceal system. Active drainage is superior to passive drainage in maintaining lower IRP. Using UAS for fURS carries an inherent risk of injury to the urinary tract. It is possible that with the smaller fURS, the UAS would be less necessary for the procedure. Furthermore, with a smaller scope, a smaller UAS may be just as effective, but with a greater safety margin. This study will examine IRP using 7.5F single-use digital fURS without UAS or with either cUAS or vaUAS in our established ex-vivo porcine kidney model[4,5]. The protocol was submitted and approved by our Institutional Ethics Committee.

Materials and Methods

1.1 Materials

12 units of adult male hybrid Landrace porcine kidneys with a mean length of 13.5 ± 1.3cm (ranging from 12.5 cm to 17.0 cm) were acquired directly from the slaughterhouse. After the animals were sacrificed and exsanguinated, each animal's entire urinary system except the urethra was harvested using enbloc dissection and preserved in chilled saline solution. Adequate perirenal and periureteral fat were removed with the specimen; the renal capsule was preserved. The experiment commenced within six hours after harvesting to maintain the freshness of the specimens. Each specimen was secured on a pegboard using thumb tacks, tacking only the adipose tissue (Fig. 1C). The ureter of one animal's renal unit was damaged during the harvesting, which rendered it unsuitable for the study. The damaged ureter was ligated at its entrance into the bladder using 2-0 silk sutures. The ureter was divided. The damaged parts were discarded.

A single-use digital 7.5F fURS with 1.1 mm working channel (Hugemed, China) was used with either 9.5/11.5F vaUAS (ClearPetra, Well Lead Medical, China) or cUAS (Well Lead Medical, China), or without UAS. The fURS has a uniform 2.5 mm tip and shaft. There is approximately a 1.0 $mm^2\pi$, or 39%, difference in the surface area between the sheath and the scope.

An adjustable-rate roller pump (WANPump, Well Lead Medical, Guangzhou, China) was used for the irrigation. It has an infusion rate-based design. It delivers selected irrigation rates up to 150 cc/minute with variable irrigation pressures up to 2000 mmHg to compensate for outflow resistance (i.e. through the working channel of fURS). It has ±10% tolerance.

1.2 Methods

Each side of the uretero-renal unit was tested independently but sequentially. The ureteral orifice was identified and catheterized with a 0.035” flexible tip guidewire. The fURS was advanced into the pyelocalyceal system over the guidewire. The guidewire was then removed. The upper and lower calyces were sequentially identified endoscopically and confirmed with fluoroscopy. They were each punctured with a 21-gauge nephrostomy needle using the “puncture toward the light” technique. After seeing and adjusting the puncture needle, a 0.035” guidewire was passed through the hollow shaft of the needle. A 6F tapered and open-end pressure measuring catheter was inserted into the punctured calyx (Fig. 2A). The guidewire was withdrawn. The catheter was connected to a pressure-measuring transducer and monitor (IntelliVue, Philips, Netherlands). An instant glue (502 Glue, China), a Super Glue equivalent, was applied around the puncture site to ensure the sealing of the puncture site. Next, a retrograde pyelogram was performed through the fURS. This was to confirm the position of the catheters and to check for any leakage around the puncture wounds. There was never leakage detected among the freshly harvested kidneys. Both the upper and lower calyces were punctured at the beginning of each experiment. Two transducers and two monitors were used. The pressure transducers were leveled with the kidney, then primed and zeroed to start the experiment. Each transducer was re-primed and re-zeroed after each set of pressure measurements. After placement of the pressure-measuring catheters, 20 cc to 120 cc of irrigation fluid at 10 cc increments were delivered through the working channel of the fURS into the renal pelvis using the adjustable-rate irrigation pump. The IRP was recorded. The irrigation pressure required to infuse 20 to 120 cc of fluid through the working channel of fURS was 10 to 450 mmHg (as the infusion rate increased, so did the irrigation pressure through the working channel of the fURS). IRP generally rose steadily as the infusing rate increases. When the IRP reached 30 mmHg and fluctuated between 29 and 31 mmHg, it marked the maximum allowed infusion rate, and the trial was terminated to avoid damage to the porcine model. Next, a 0.035” guidewire was reinserted through the fURS as the scope was withdrawn. Either a 9.5F cUAS or a 9.5F vaUAS was inserted. The UAS was advanced to about one centimeter below the ureteropelvic junction. The tip of the UAS could generally be seen and palpated. It was marked with black ink. The fURS was reinserted. The same pressure measuring experiment was repeated. When vaUAS was used, the side branch was connected to a vacuum apparatus and the trial proceeded with the air vent either open or closed. The aspiration pressure was set to 300 mmHg. This was found to be the optimal aspiration pressure in our previous works. After completing the pressure study, the UAS was removed. The fURS was reinserted, and the distal ureter was tied with 2-0 silk sutures around the fURS to occlude the space between the scope and the ureter to study the pyelo-tubular backflow. Contrasted irrigation fluid was delivered into the kidney. Fluoroscopy images were obtained at 5 mmHg increments after IRP had reached above 30 mmHg.

1.3 Statistical Analysis

All variables are expressed as means ± standard deviation. The Wilcoxon Rank Sum Test was used to perform both intragroup and intergroup analysis for the non-normal distribution of variances. P value < 0.05 was deemed statistically significant. IBM® SPSS 26.0 software was employed for this analysis.

Results

Summaries of the study are displayed in Table IA, IB, and 1C. With cUAS, IRP reached 30 mmHg with irrigation rates around 60 cc/minute. Using vaUAS with vent closed, IRP never exceeded 10 mmHg with irrigation up to 120 cc/minute. vaUAS with vent open performed marginally better than cUAS. fURS without UAS performed better than cUAS. As irrigation rate increased, IRP rose very gradually but never reached 30 mmHg even with the irrigation rate at 120 cc/minute. However, the variances of the standard deviations were quite large. Pyelo-tubular backflow became evident when IRP reached 35 mmHg. It was prominent at 40 mmHg (Figure 2B). If

IRP was allowed to rise unabated to around 80 mmHg, it could result in renal rupture and subcapsular extravasation (Figure 2C).

Discussion

IRP is an important issue for any endoscopic intrarenal surgery. IRP ≥30 mmHg can result in pyelo-venous backflow. In an infected milieu, the backflow can cause sepsis with dire consequences. Other complications related to high IRP include fluid absorption, renal tubular fibrosis, intrarenal bleeding, perirenal extravasation, and more. During retrograde intrarenal surgery (RIRS) with fURS, IRP is directly proportional to the rate of inflow and the retaining of irrigation fluid in the pyelocalyceal space. The area between the fURS with either ureter or UAS is the venue for outflow and is inversely proportional to the IRP (the larger the area, the faster the outflow; hence, a lower IRP). vaUAS provides active egress of irrigation fluid, whereas fURS without UAS or with cUAS depends on passive egress.

Pyelo-renal backflow occurs in the renal papillae and calyceal fornices; thus, relevant IRP measurements should be undertaken in the calyces rather than renal pelvis. We found in our previous studies that there were only limited differences in the pressures among the upper, middle, and lower calyces[4,5]. Furthermore, the middle calyces of the porcine kidney often are short. Therefore, we chose to measure only the upper and lower calyceal pressures and used their means for the statistical analysis.

IRP is difficult to measure during fURS procedures. Only three prior studies attempted to measure IRP during live RIRS[6,7,8]. One was done through retrograde pressure-measuring catheters[6]. Two were performed through previously-inserted nephrostomy tubes to relieve obstruction or sepsis[7,8]. These kidneys were with pathological conditions. We found that freshly harvested and exsanguinated porcine kidneys are quite suitable for IRP studies. We were able to demonstrate pyelo-renal backflow with retrograde injection of contrast material above 30 mmHg infusion pressure. Using in-vivo and ex-vivo porcine kidneys to study IRP has been previously reported by others[6-16]. Eight studies measured IRP with UAS[9-16], three of them used porcine kidneys[13,14,16]. One pertinent study was by Yoshida[16] et al. They showed that the larger-bore cUAS resulted in lower IRP. There is also one study[17] comparing IRPs between conventional ureteroscopes and micro ureteroscopes without UAS. It showed that the larger ureteroscope had a higher irrigation volume and higher IRP.

In our study, using 7.5F fURS without UAS and an irrigation rate up to 120 cc/minute still maintained IRP <30 mmHg. However, the variances of the standard deviations were quite large after 60 cc/minute irrigation rate. We believe these phenomena were due to the increased pliancy of our ex-vivo porcine kidneys resulting in free outflow of the irrigation fluid from the pyelocalyceal space. The reason for this pliancy might be the loss of pyelo-ureteral peristalsis and the inherent muscle tone and contractions. Thus, these results might not be the same in the in-vivo model and should be interpreted with caution. With cUAS, the safe irrigation rate dropped to 60-70 cc/minute. It appears that the space between the 7.5F scope and 9.5 UAS is smaller than the space between the scope and the ureter itself. vaUAS, on the other hand, maintained IRP < 10 mmHg with irrigation rate up to 120 cc/minute.

While our data may not be convertible to humans, it might provide some insights to surgeons who are performing fURS procedures.

The major limitation of this study is that it is an ex-vivo porcine kidney protocol.

The ex-vivo model does not have the innate peristalsis and the uretero-vesicle junction lacks the natural muscle tone and contraction. Thus, the IRP values without sheaths might not be transferable to humans and in-vivo settings.

Furthermore, the porcine calyces were more numerous, and the infundibula were longer and narrower than those of humans. Thus, porcine IRPs might not be the same as human IRPs.

Conclusion

In our porcine model, 7.5F fURS could be used safely without UAS with irrigation rates up to 120 cc/minute. With cUAS, the safe irrigation rate dropped to 60 cc/minute. vaUAS with vent closed maintained IRP < 10mmHg with irrigation rates up to 120 cc/minute. vaUAS with vent open performed only marginally better than cUAS. Pyelo-tubular backflow became evident when IRP reached 35 mmHg and became obvious with IRP > 40mmHg.

Acknowlegement

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Author's Contribution

Dong Wang: Designing the experiment and writing the manuscript

Zhenyuan Han and Baosen Wang: Performing the experiments and writing the manuscript

Xiaohui Liu and Tao Jing: Data collection

Wensu Yue and Yuliang Wang: Data analysis

Conflict of interest

The authors of this study disclose no conflicts of interest. There was no funded for this study.

Informed consent

This research used commercially acquired animal parts (porcine kidneys). There was no live animal involved. This research was reviewed and approved by the Institutional Ethics Committees of all the institutions involved in this study.

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Figure legends.

Fig 1:

A. Vacuum assisted ureteral access sheath with oblique branch

B. Longitudinal vent on the oblique branch

C. Ex-vivo porcine model

Fig 2:

A. Pressure measuring catheters placement in the upper and lower calyces

B. Pyelo-tubular backflow at 40 mmHg
C. Renal rupture and subcapsular extravasation at 80 mmHg

Fig 1: A. Vacuum assisted ureteral access sheath with oblique branch
B. Longitudinal vent on the oblique branch
C. Ex-vivo porcine model
D. Experimenting model with pressure monitor catheters in place and damaged right ureter ligated
E. Actual experiment set up

Fig 2: A. Pressure measuring catheters placement in the upper and lower calyces
B. Pyelo-tubular backflow at 40 mmHg
C. Renal rupture and subcapsular extravasation at 80 mmHg

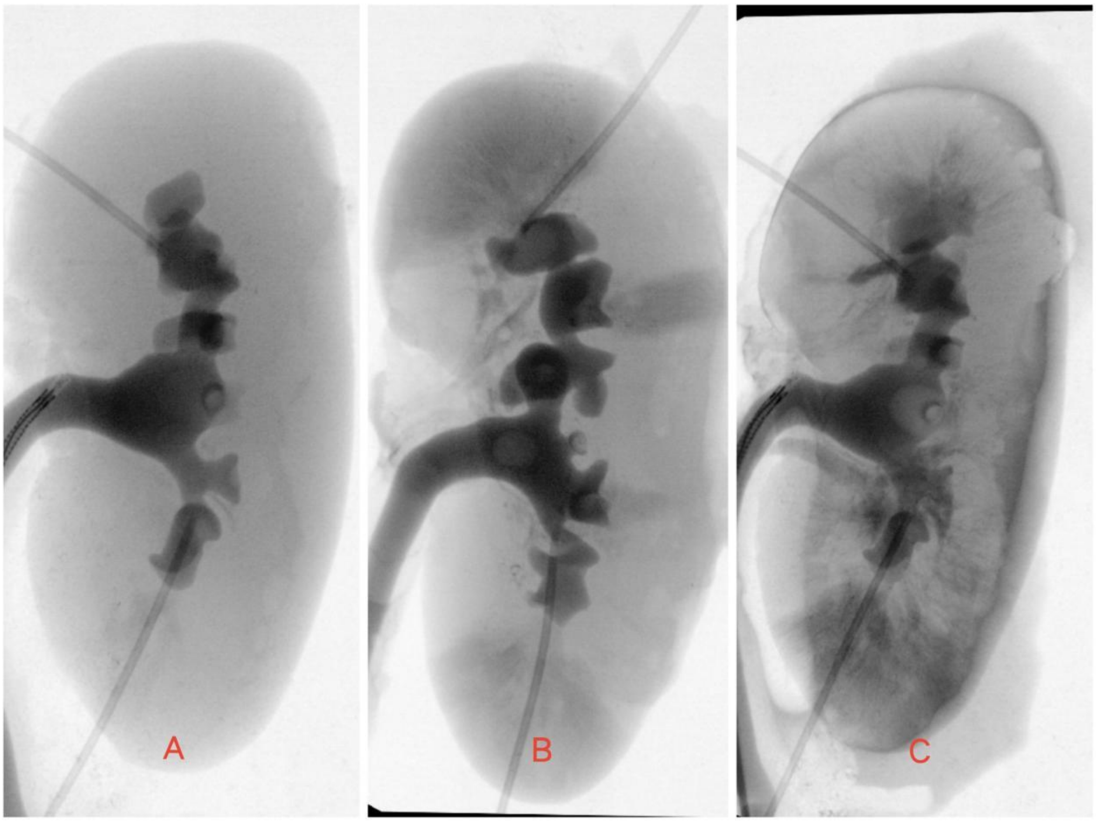


Table 1A: Summary of calyceal pressures

Irrigation rates cc/min		Without UAS	cUAS	vaUAS	
				Vent Open	Vent Closed
40	Upper	14.3±6.7	26.3±4.5	8.8±3.3	5.1±2.7
	Lower	13.8±6.2	24.5±6.7	7.6±2.1	3.0±1.7
	Mean±SD	14.7±6.6	25.4±5.9	8.2±2.9	4.1±2.5
60	Upper	18.1±8.6	28.6±3.0	23.3±6.8	6.5±2.8
	Lower	16.7±9.2	27.7±5.1	21.6±7.7	4.4±2.7
	Mean±SD	17.4±9.11	28.2±4.3	22.5±7.5	5.4±3.1
70	Upper	18.8±8.2	30	27.7±5.4	6.3±2.9
	Lower	17.7±8.8	30	27.5±5.6	4.3±2.8
	Mean±SD	18.3±8.7	30	27.6±5.7	5.3±3.1
80	Upper	19.7±9.6	30	30	6.3±3.0
	Lower	18.7±9.6	30	30	3.9±2.2
	Mean±SD	19.2±9.8	30	30	5.1±3.0
100	Upper	20.5±9.3	30	30	6.9±4.4
	Lower	19.8±9.9	30	30	3.7±2.4
	Mean±SD	20.1±9.8	30	30	5.3±4.0
120	Upper	21.7±8.4	30	30	7.4±7.5
	Lower	21.2±8.8	30	30	4.6±5.0
	Mean±SD	21.5±8.8	30	30	6.0±6.7

Table 1B: Bar graph of the pressure comparisons

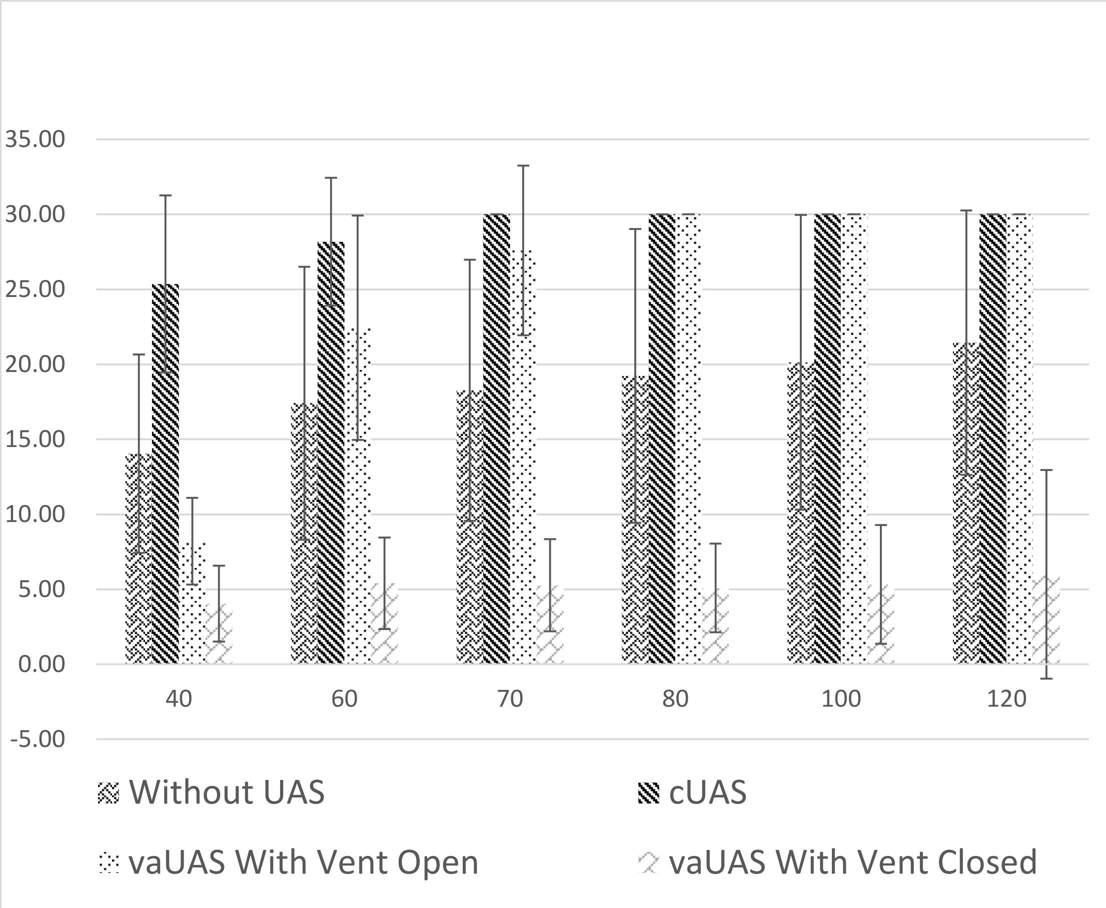
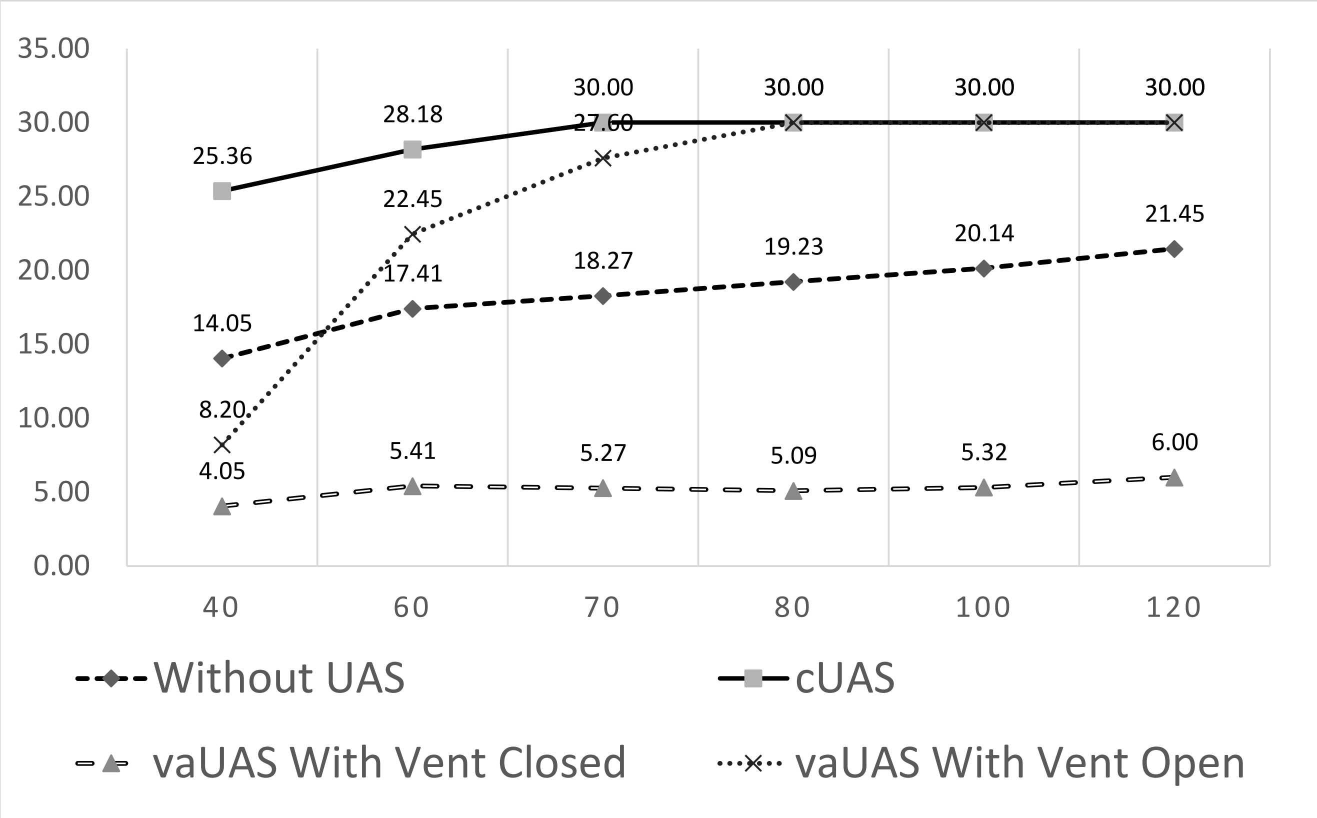


Table 1C: Linear chart of the pressure comparisons



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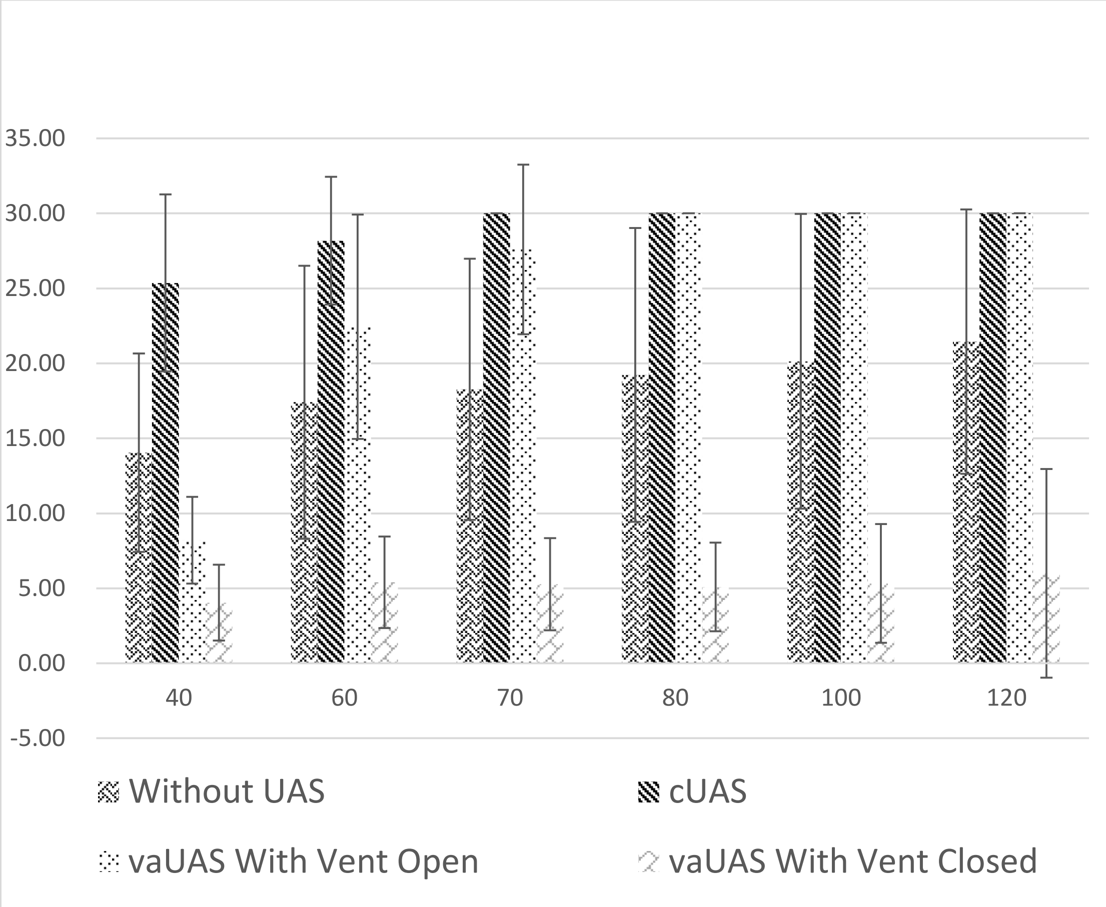
60	Upper	18.1±8.6	28.6±3.0	23.3±6.8	6.5±2.8
	Lower	16.7±9.2	27.7±5.1	21.6±7.7	4.4±2.7
	Mean±SD	17.4±9.11	28.2±4.3	22.5±7.5	5.4±3.1
70	Upper	18.8±8.2	30	27.7±5.4	6.3±2.9
	Lower	17.7±8.8	30	27.5±5.6	4.3±2.8
	Mean±SD	18.3±8.7	30	27.6±5.7	5.3±3.1
80	Upper	19.7±9.6	30	30	6.3±3.0
	Lower	18.7±9.6	30	30	3.9±2.2
	Mean±SD	19.2±9.8	30	30	5.1±3.0
100	Upper	20.5±9.3	30	30	6.9±4.4
	Lower	19.8±9.9	30	30	3.7±2.4
	Mean±SD	20.1±9.8	30	30	5.3±4.0
120	Upper	21.7±8.4	30	30	7.4±7.5
	Lower	21.2±8.8	30	30	4.6±5.0
	Mean±SD	21.5±8.8	30	30	6.0±6.7

Table 1B: Bar graph of the pressure comparisons



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