Impact of Low-Pressure Pneumoperitoneum on Post-Operative Pain in Robotic Urological Surgery: A Systematic Review

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Abstract:

Introduction: Robotic technology has revolutionised minimally invasive urological surgery, enhancing precision and minimising surgical complications. Recent evidence suggests that utilising lower pneumoperitoneum pressures improves clinical outcomes but the comparative impact on post-operative pain remains uncertain.

Aim: This systematic review analyses the literature on low-pressure pneumoperitoneum to investigate its impact on pain and recovery following robotic-assisted urological surgeries, including prostatectomy, partial nephrectomy, and cystectomy. Post-operative opioid consumption, total operating time, estimated intra-operative bleeding, and total inpatient stay were investigated as secondary outcomes.

Method: PubMed, NHS Knowledge and Library Hub, Cochrane Central databases, and EMBASE were searched between January 2010 and May 2024. Any identified studies were reviewed against eligibility criteria by two independent authors prior to inclusion. The review was written in compliance with Preferred Reporting Items for Systematic Reviews (PRISMA) guidelines.

Results: Nine studies were included: six focused on prostatectomy, two on partial nephrectomy, and one on cystectomy. Low-pressure pneumoperitoneum was found to result in reduced postoperative pain scores, particularly in the immediate recovery period and on postoperative day 1. Despite these improvements, post-operative opioid consumption remained consistent with standard pressures. The surgical workspace was not compromised when pneumoperitoneum pressures were lower.

Conclusion: Lowering pneumoperitoneum pressures in robotic-assisted urological surgery appears to reduce immediate postoperative pain scores without increasing overall complications. This has not led to a noticeable reduction in post-operative opioid consumption. The lack of consistent reduction in opioid use and limited high-quality studies highlight the need for further research, particularly for partial nephrectomy and cystectomy.

Key words:

Low-pressure pneumoperitoneum; urology; robotic-assisted surgery; post-operative pain; prostatectomy; cystectomy; partial nephrectomy; systematic review

Introduction:

The use of robotic technology in abdominal and pelvic surgery has become widespread, revolutionising surgical practice. Robotic techniques play a key role in minimally invasive surgery, offering the surgeon greater dexterity, range of motion and allowing complex procedures in a smaller surgical workspace [1]. This is particularly notable within the field of urology, where the use of robotics has shown to be non-inferior in procedures such as prostatectomy, nephrectomy and cystectomy, even offering benefits such as minimised surgical bleeding, shorter length of hospital admission and fewer post-operative complications [2].

A fundamental component of these procedures is the creation of pneumoperitoneum. An appropriately high pneumoperitoneum pressure allows for adequate visualisation and exposure of the surgical workspace and instruments [3]. Standard pressures of 12 - 15 mmHg have been utilised during robotic-assisted urological operations to achieve desirable visibility however there has been a growing interest in recent years to lower these pressures. When low pressure pneumoperitoneum is utilised, recent studies have suggested improvements in clinical outcomes, for instance, reduced rates of post-operative ileus [4]. Furthermore, the latest research suggests that minimising insufflation pressures during robotic urological surgery can reduce the risks of viral transmission with reduced aerosol generation, a crucial consideration, especially in light of the recent COVID-19 pandemic [6, 7]. Additionally, there has been evidence to indicate that higher pneumoperitoneum pressures negatively impact renal perfusion and function; low pressures may be preferable in this regard [8]. As a result, optimising appropriate pneumoperitoneum levels can present a challenge, requiring a fine balance between maintaining surgical visibility and minimising post-operative complications.

Whilst the literature on clinical outcomes demonstrates consistent findings, there is a distinct lack of research specifically addressing the effects of low-pressure pneumoperitoneum on post-operative pain, an often overlooked outcome. Effective control of post-operative pain plays a crucial role in optimising with patients' overall satisfaction and quality of recovery. In addition, lower levels of pain can allow for earlier discharge and lower opioid analgesia consumption post-surgery [9]. Many theories have been proposed about the mechanism by which pneumoperitoneum contributes to pain. For instance, presence of residual pneumoperitoneum is speculated to cause diaphragmatic irritation, leading to subsequent abdominal pain and referred shoulder pain [10, 11].

Whilst there has been some research on the effects of reduced insufflation pressures on pain, most of this work has occurred in the field of general surgery with promising findings. For instance, in laparoscopic cholecystectomy, lower pneumoperitoneum pressures were found to reduce post-operative pain in comparison with standard pressures, while maintaining similar operative times and leading to earlier discharge from hospital [12]. In addition, Dourado and colleagues have demonstrated that in minimally invasive colorectal surgery lower pneumoperitoneum pressures led to reduced levels of patient-reported pain in the immediate post-operative period without increasing length of hospital admissions or post-operative complications [13]. Unfortunately, research on the effects of reduced insufflation pressures in robotic urological surgery is limited; however, the potential benefits warrant further investigation.

Given the importance of post-operative pain in patient satisfaction and recovery, and the growing interest in optimising surgical outcomes, this systematic review aims to evaluate the impact of lower pneumoperitoneum pressures on post-operative pain specifically within the context of robotic urological surgery.

Methods:

The primary objective of the current study was the effect of different pneumoperitoneum pressures on post-operative pain. Pain was assessed by means of various scoring systems and questionnaires, as well as other metrics of measuring quality of recovery with pain as a key domain. A secondary outcome was the subsequent use of opioids measured as morphine equivalents, as well as total operating time, estimated intra-operative bleeding and total inpatient stay.

The methods for this review were designed in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [14].

The authors liaised with an experienced medical evidence specialist to create an appropriate search strategy utilising the following key words:

Pneumoperitoneum

Insufflation

Abdominal pressure

Robotic Surgical Procedures

Cystectomy

Prostatectomy

Nephrectomy

Post-operative pain

A search was performed across PubMed, EMBASE, NHS Knowledge and Library Hub and Cochrane Central databases. Care was taken to appropriately integrate Boolean operators as well as Medical Subject Headings (MeSH) within the search strategy as appropriate (full search strategy available in supplementary material). Searches were performed between January 2010 up to May 2024 by one author and the medical evidence specialist. All retrieved records were uploaded onto Endnote, a reference management software acting as a database to manage papers. A single author manually excluded duplicates records. Two independent authors reviewed the titles and abstracts of all identified records to confirm they met the eligibility criteria (YB and RW). The focus of this systematic review was on the following three robotic-assisted procedures (prostatectomy, partial nephrectomy and cystectomy). An extensive literature search revealed no studies directly examining post-operative pain in robotic-assisted radical nephrectomy with low-pressure pneumoperitoneum, and, as a result, this was not discussed in this paper. The studies varied in their methods for quantifying postoperative pain and the timing of measurements. Additionally, the definition of low-pressure pneumoperitoneum differed across studies. Due to the heterogeneity of the results obtained, no formal statistical or meta-analysis was conducted in this review. The results of eligible, included papers are outlined below (Table 1).

Eligibility:

Inclusion criteria were:

1. Studies focusing on robotic-assisted urological operations (robotic-assisted radical prostatectomies, partial nephrectomies and radical cystectomies)

2. Studies reporting post-operative pain or post-operative opioid use (measured as morphine equivalents) as either primary or secondary outcomes
3. Randomised controlled trials or case controlled studies

Exclusion criteria were:

1. Studies focusing on physiological variables or haemodynamic parameters (e.g. arterial oxygen saturation scores, perioperative interventions and recordings).
2. Non-human models.
3. Non-English studies.
4. Systematic reviews, meta-analyses or conference abstracts

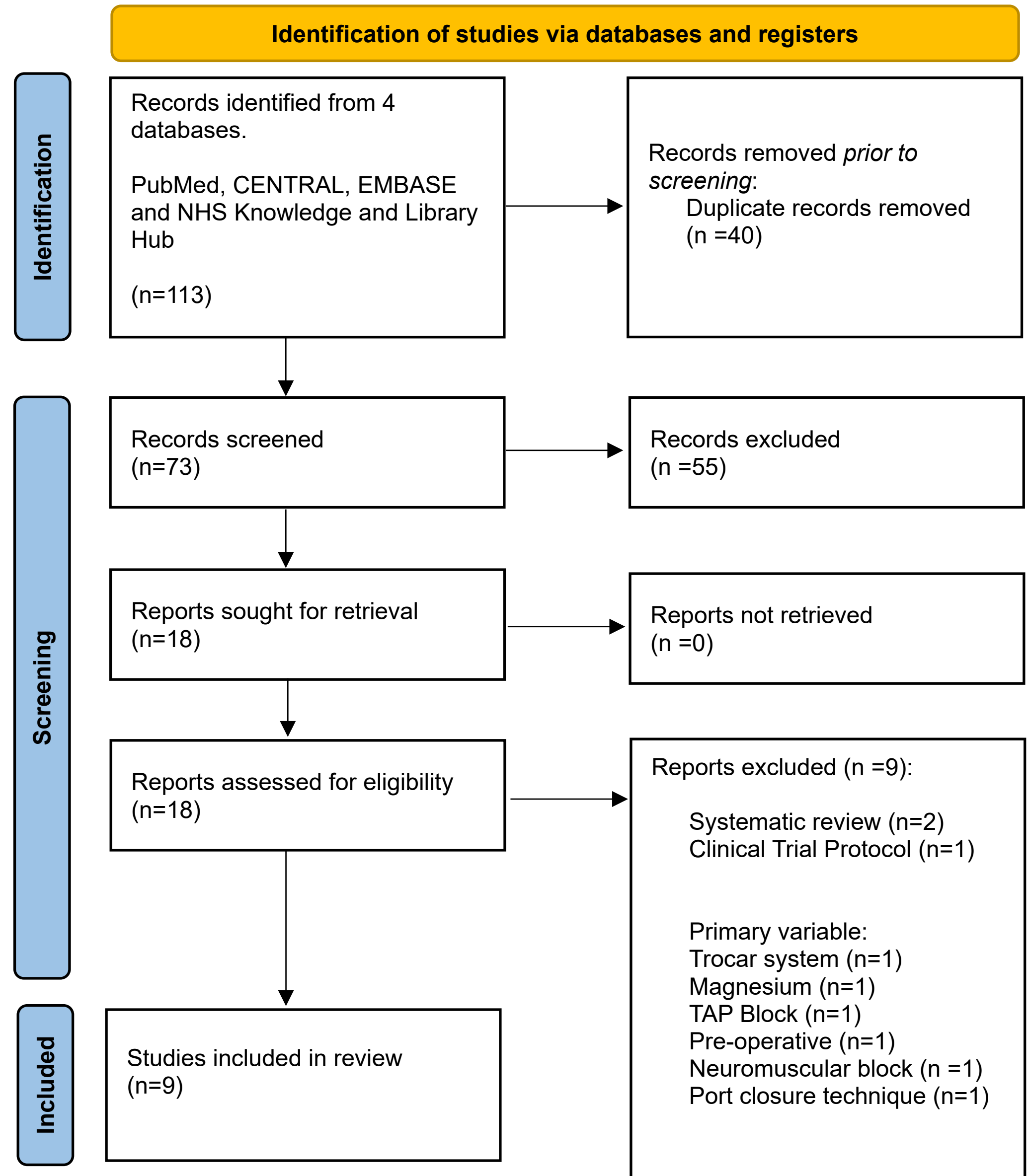


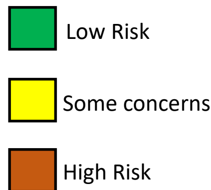
Figure 1. PRISMA flow diagram

Risk of Bias:

Each of the nine studies identified by the search were assessed for quality. The six randomised controlled trials were assessed via the RoB-2 tool [15] and the remaining non-randomised trials by means of the ROBINS-I tool [16]. The risk bias conclusions for each paper are illustrated below in Figure 2 as well as a breakdown of each domain contributing to each judgement. From the six randomised trials, five had concerning levels of bias and one being judged to have a considerable risk. In addition, all three non-randomised papers had at a minimum, a serious risk of bias. These limitations must be considered on interpretation of the results.

Randomised Trials – RoB-2:

Study	Bias from Randomisation	Deviations from intended interventions	Bias due to missing outcome data	Measurement of outcomes	Bias in selection of reported result	**Conclusion**
Abaza. (2022) [17]						Some concerns
Alhusseinawi. (2023) [18]						Some concerns
Reijnders-Boerboom. (2024) [19]						Some concerns
Desroches. (2024) [20]						High Risk
Feng T. (2021) [21]						Some concerns
Keating. (2024) [22]						Some concerns



Non-Randomised Trials – ROBINS-I

	Pre-intervention		**At intervention**		**Post-intervention**			
Study	Bias due to Confounding	Bias in Selection of participants	Classification of intervention	Deviation from intended intervention	Missing data	Measure ment of outcomes	Selection of reported result	**Conclusion**
Ferroni. (2019) [23]								Serious
Ippolito (2024) [24]								Critical
Kostakopoulos, (2022) [25]								Serious

Figure 2. Risk of bias evaluation for all included studies.

Results:

Prostatectomy:

Ferroni M, Abaza, and colleagues examined the influence of ultra-low pneumoperitoneum (PNP) pressure on clinical outcomes in robotic-assisted laparoscopic prostatectomy (RALP) patients [23]. They retrospectively compared data on 300 patients undergoing RALP at ultra-low PNP (6 mmHg) to data from a previous cohort of 300 consecutive patients who had RALP at the standard PNP of 15 mmHg. To evaluate the practicality of earlier discharge, a protocol was introduced when the ultralow PNP procedures began. Patients were offered same-day discharge if they could ambulate, had adequate pain control, and were tolerating a standard diet. No patients were excluded from the study.

The outcomes compared between the groups included patient characteristics, post-operative pain scores (measured via visual analogue scales), post-operative analgesic usage, and rates of readmissions and complications. In the ultralow PNP group, all procedures were successfully completed without pressure adjustments. Pain scores were measured immediately post-operatively at 4 hours, between post-operative hours 5-12, and on day 1.

Despite a large number of RALP patients (43.3%) in the ultralow PNP group being discharged on the day of the operation, the proportion of patients in this group who had subsequent admissions in the first 30 days post-surgery was lower compared to the 15 mmHg group (1.0% readmitted vs. 5.7% respectively; $p < 0.01$). A large reduction in complication rates were observed at ultra-low PNP (4.0% vs. 8.7%; $p = 0.02$). However, they found that at 6 mmHg, operative times were longer compared to the standard PNP of 15 mmHg (155.2 minutes vs. 145.7 minutes, $p < 0.001$).

Average VAS scores were worse in the post-operative hours 5 to 12 in patients who underwent standard PNP RALP relative to those who had ultralow PNP RALP (3.9 vs. 3.2, respectively; $p < 0.001$). The VAS scores of the patients did not differ at other time intervals; however, pain appeared to be generally reduced at ultralow pressures. In particular, in the immediate post-operative hours, mean pain scores were 5.2 vs. 5.1 ($p = 0.87$), and on post-operative day 1 (POD1), pain scores were 3.3 vs. 2.9 ($p = 0.07$) in favour of the 6 mmHg group. This was not reflected in the mean morphine equivalents used post-operatively, which were largely similar. In conclusion, RALP at ultralow pneumoperitoneum pressure was found to be non-inferior to standard pressure with regard to complications. The data suggested lower rates of complications and readmissions, as well as a potential pain benefit.

Abaza and colleagues later conducted a randomised study evaluating the impact of robotic prostatectomy (RP) at ultra-low pneumoperitoneum vs standard pneumoperitoneum [17]. Consistent with their previous study, ultra-low pneumoperitoneum was defined as 6mmHg compared to standard at 15mmHg. 138 patients were allocated, using randomisation software, to RP at either 6mmHg (n = 67) or 15mmHg (n = 71). All operations were undertaken by one robotic surgeon using the AirSeal insufflator (Conmed Corporation, NY, USA) in all cases. Both the surgeon and the anaesthetists in the PACU treating the patients were blinded.

The primary outcome assessed was patient's levels of pain within the initial post-operative hours. Unlike their previous retrospective study which utilised VAS scores, this investigation required the

patients to quantify their perceived pain on a numerical scale ranging from 0-10. Other outcomes assessed included postoperative analgesic requirements, operative time, and complications.

Patients in the ultra-low pressure group had reduced pain scores compared to standard PNP in the immediate 4 hours after surgery (2/10 compared to 3.5/10, respectively, $p < 0.01$). When all reported pain scores were reviewed, the maximum scores were also found to be lower in the ultralow PNP group (3/10 vs. 5.2/10, $p < 0.01$). Shoulder and groin pain were significantly reduced at ultra-low pressures ($p = 0.01$).

Despite the improvements in reported pain scores, this was not reflected in post-operative opioid consumption which did not differ regardless of the PNP pressure. The average console duration was 7 minutes longer at ultralow PNP pressure ($p = 0.02$); however, the overall length of operation remained unchanged. Intra-operative bleeding did not increase at ultralow PNP, and no transfusions were required. One patient in the ultralow PNP group was readmitted for a pulmonary embolism on postoperative day 8, but there were no other significant complications that required inpatient admission. In conclusion, they found that ultralow PNP pressures in their study contributed to reduced postoperative pain, but this did not affect the length of stay or postoperative opioid consumption.

Alhusseinawi and colleagues carried out a randomised study to assess outcomes of patients undergoing RALP operations at a major hospital in Denmark [18]. The study involved 98 patients and was performed by two experienced surgeons. The primary outcomes assessed included the patient's post-surgical recovery following surgery, measured using the QoR-15 questionnaire at a fixed number of checkpoints within the first month post-operatively, and the surgical workspace (SWS), evaluated intraoperatively using a validated SWS scale. Secondary outcomes included blood loss, duration of hospital admission, complications within the first 3 months, and post-operative opioid consumption (POD1).

Patients were equally allocated using web-based randomisation to either undergo RALP at low-pressure PNP (7 mmHg) or conventional PNP (12 mmHg). Pressure designations were assigned in the operating theatre and then allocations were placed in sealed envelopes that were handed to a designated member of the theatre team. Prior to the introduction of pneumoperitoneum, surgical ports were initially set to a default pressure of approximately 10 mmHg. Subsequently, the ODP, having been assigned the task, adjusted the pressure as required. As a result, surgeons were blinded to the assigned study group. Additionally, two medical students who administered the questionnaires were blinded as well.

The results indicated that patients in the lower pneumoperitoneum pressure group had markedly improved recovery on POD1, with QoR-15 scores of 124.8 compared to 114.8 in the 12mmHg ($p < 0.001$). Specifically, the domain score centred around pain was considerably improved in the low-pressure group on POD1 (13.7 vs. 16.0, $p = 0.001$). Improvements were also observed in comfort ($p = 0.007$) as well as patient reported emotional wellbeing ($p = 0.006$) on POD1. Notably, these improvements did not persist beyond the first post-operative day. No significant differences in surgical workspace or opioid analgesia consumption were found.

In contrast, patients undergoing RALP at 7mmHg had increased intra-operative bleeding (67 mL higher on average; $p = 0.01$). From this study, they concluded that patient recovery on the first day post-operatively is higher when lower pneumoperitoneum pressures are used, without compromising the surgical workspace, although this is accompanied by an increase in blood loss.

Ippolito and colleagues conducted a retrospective investigation involving 135 robotic-assisted radical prostatectomy (RALP) patients [24]. They examined the effects of moderate insufflation pressure levels on post-operative inflammation and pain. Unlike some other studies, patients were not categorized into groups with different pneumoperitoneum pressures. Instead, all patients had a standard pneumoperitoneum pressure of 10 mmHg, with an increase to 15 mmHg for up to 3 minutes during manipulation of the prostatic plexus, and a reduction to as low as 5 mmHg towards the end of the procedure.

Most patients were placed in the steep Trendelenburg position, while the remaining 3 patients were positioned laterally. The researchers documented the length of time pneumoperitoneum was maintained (hours), the mean and peak pneumoperitoneum pressure levels, and statistically analysed these factors against post-operative outcomes, including visual analogue scale (VAS) pain levels, shoulder pain, C-reactive protein (CRP) levels, and opioid consumption. Visceral fat was estimated using the waist hip ratio. Some patients were given dexamethasone, for preventing operative nausea and vomiting.

Outcomes assessed included CRP as a marker for post-operative inflammatory response, post-operative pain measured by the VAS, as well as post-operative opioid administration.

The study found no statistically significant correlation between pneumoperitoneum duration or pressure and POD1 CRP levels. In addition, there was no association found between pneumoperitoneum pressure and pain scores or post-operative opioid consumption. The amount of visceral fat, determined by waist-hip ratio, was also not associated with postoperative inflammation. While giving dexamethasone did not notably impact CRP levels or pain scores after surgery it's worth noting that all patients who experienced shoulder pain had not received dexamethasone. The authors concluded that while patients can tolerate moderate pneumoperitoneum pressure during RALP, further research, including randomized trials, is needed to determine the clinical implications of these results.

Reijnders-Boerboom and colleagues conducted a study involving 96 patients at a large hospital in the Netherlands to assess use of reduced pneumoperitoneum pressures assisted by deep neuromuscular blockage (NMB) on post-operative recovery [19]. Participants were randomised using digital randomisation techniques to undergo RARP in one of two study arms: low PNP pressures (8mmHg) with deep NMB or a default pneumoperitoneum pressure setting with moderate NMB (14 mmHg). 46 patients received RARP with 8mmHg compared to 50 patients at 14mmHg. Patients as well as all clinical staff and researchers involved in the patient's care were blinded. Only the researcher present in the operating theatre was not blinded to ensure consistency in procedure.

Primary outcomes included quality of recovery and effect on immune function. They also hypothesised that overall vascular supply to the parietal peritoneum would improve when insufflation pressures were reduced.

The researchers used several methods to assess recovery. They conducted pre-operative and post-operative assessments using QOR-40 questionnaires to evaluate various domains of patient recovery outcomes. Furthermore, three other questionnaires and numerous scoring metrics were utilised to explore reported pain and quality of life at predefined time points: before surgery, on post-operative day 1 (POD1), POD12, and at 3 months post-operatively. Additionally, they monitored various intraoperative parameters and clinical outcomes to allow for comprehensive analysis.

Both study arms were generally well matched with the exception of age where patients undergoing standard pressure RARP were on average 3 years older (p = 0.013). The authors found that overall surgical visibility, assessed using the Leiden Surgical Rating Scale, was not impaired at lower pressures with deep NMB. Also, there was no increase in surgical complications. The QoR-40 scores on POD1 were comparable irrespective of the study group (p = 0.54). Pain scores, including referred shoulder pain, were comparable, as was mean opioid consumption on POD1 (1.3 mg vs. 0.9 mg in morphine equivalents; p = 0.45). Interestingly, parietal peritoneum perfusion was better in the 8mmHg group although this did not correspond with improved post-surgical recovery.

Keating and colleagues compared the rates of various post-operative complications at a lower pneumoperitoneum pressure in patients undergoing RARP [22]. The study included 198 patients treated at a single institution under the care of a single high-volume surgeon. Patients were randomly allocated to undergo RARP procedures at 12mmHg or 15mmHg. 105 patients were assigned to receive lower pressure pneumoperitoneum (12mmHg) and 93 to receive standard pressures (15mmHg). During this study, efforts were made to blind the surgeon to the study arm under which the patient underwent RARP. Interestingly, after each case was completed, the researchers took note of surgeon's perception of the pneumoperitoneum pressure. A standardised pain regimen was used for all patients post-operatively.

The primary outcomes assessed were the rates of post-operative ileus (POI) and complications. Other outcomes included narcotic use intra-operatively and post-operatively (measured in total morphine equivalents) and estimated intra-operative blood. Baseline characteristics of patients between groups were comparable.

Postoperative ileus was a rare complication. The incidence of POI did not significantly differ irrespective of the study arm occurring only 1.9% of the time at 12mmHg vs. 3.2% at 15mmHg. Additionally, no significant differences found in post-operative opioid consumption and estimated intra-operative bleeding when low-pressure pneumoperitoneum was applied.

The study had some limitations. Whilst post-operative opioid consumption was measured, data on pain scores were not collected which could have provided further insight into patient's quality of recovery. Furthermore, the study may have underestimated the incidence of POI, where some patients may have sought care at outside hospitals. Pneumoperitoneum pressure was accurately identified in 54.6% of RARP procedures, raising potential challenges in effectively blinding surgeons in this type of study.

Whilst post-operative opioid consumption did not appear to be influenced at lower pneumoperitoneum pressures, the authors acknowledged the value of investigating patient reported pain scores to draw a more robust conclusion.

Partial Nephrectomy:

Two studies were identified from our search which investigated robotic partial nephrectomy (RPN). In both papers a standard insufflation pressure was defined as 15mmHg, with the lower pressure at 12mmHg. In each study, the groups also varied the insufflation system used; RPN was performed either using an AirSeal system (AS) or a conventional system (CS).

Desroches and colleagues investigated the performance and complication rates of valveless insufflation systems at reduced pneumoperitoneum pressures, compared to conventional insufflation and pressures, in patients who underwent RPN [20].

202 patients were randomised into three groups: AirSeal at low pressure, AirSeal at standard pressure and CS at standard pressure. The study did not investigate 12 mmHg with conventional systems due to concerns about visibility and patient safety during partial nephrectomy. The authors discuss a randomisation sequence being used although this is not further elaborated on; additionally, it was unclear whether blinding took place in this study.

The operations were conducted by four highly skilled robotic surgeons across three hospitals over multiple years. Primary outcomes included subcutaneous emphysema rates and various postoperative complications, such as pneumothorax and pneumomediastinum. Postoperative pain was measured by means of the VAS at regular intervals within the first post-operative day, as well as at discharge. Data on general and shoulder pain were also collected through a questionnaire. Secondary outcomes included additional postoperative complications and length of hospital admissions.

A significant proportion of procedures utilized a retroperitoneal approach due to tumour locations and complexities, necessitating a secondary analysis. The results showed that SCE rates were lower when RAPN was performed with AirSeal at 12mmHg as opposed to the conventional group (4 vs. 7; p=0.003). In general, VAS scores did not significantly differ between study arms. However, there was an indication that valveless insufflation at either pressure might reduce shoulder pain compared to conventional insufflation, with the 15 mmHg AIS group showing a statistically significant reduction (P = 0.02) and the 12 mmHg AIS group showing a trend towards significance (P = 0.07).

The authors concluded that valveless insufflation for robotic partial nephrectomy is non-inferior to conventional methods and that using a lower pneumoperitoneum pressure may improve postoperative outcomes.

Feng T and colleagues also conducted a study to investigate outcomes following RPN when different insufflation pressures and systems were utilised [21]. Ninety-three RPN patients were equally randomised into three study groups using digital allocation techniques: AirSeal at low pressure, AirSeal at standard pressure, and CS at standard pressure, with 31 patients assigned to each study group. Assignment envelopes were used in this process and opened by the study coordinator just prior to patient intubation. Similar to the study by Desroches et al. [20], an additional planned arm using CIS at 12 mmHg was not implemented due to suboptimal visibility observed in a pilot study.

The main parameter investigated was the frequency of sub-cutaneous emphysema in each group. Other outcomes assessed were overall pain scores, shoulder pain scores, analgesia usage and other complications such as pneumothorax and pneumomediastinum. Pain was reviewed using the VAS scoring system within POD1 and at discharge. Pain medication usage was quantified as morphine equivalents.

Baseline characteristics of patients between groups were comparable. RPN patients whose procedures utilised the AirSeal system at 12mmHg showed a less frequent rate of SCE in contrast to those using conventional systems at standard pressure (19.4% vs. 48.4%; p = 0.03). VAS scores measured 12 hours post-RPN were also lower in the AirSeal group at 12 mmHg, with a mean of 3.1, while the CS group at 15 mmHg had a mean of 4.4 (p = 0.03). Additionally, shoulder VAS scores were significantly reduced in AirSeal insufflation at either pressure compared to the conventional group at

8 hours (AirSeal at 12mmHg vs. CS: 0.6 vs. 1.6, p =0.01; AirSeal at 15mmHg vs. CS: 0.6 vs. 1.6, p =0.02) and at 12 hours (AirSeal at 12mmHg vs. conventional: 0.4 vs. 1.4, p = 0.003). Other outcomes assessed including opioid consumption and length of hospital admission demonstrated no significant differences.

The study also found that the AirSeal systems maintained more stable intra-abdominal pressures with fewer instances of surpassing the fixed, pressure threshold. In comparison, CIS exhibited pressures exceeding the preset limit by 1.5 mmHg or more, 12.3% of the time. Multivariate analysis suggested that patients undergoing RAPN through a retroperitoneal technique were at increased risk of developing SCE.

The study's findings suggest that using valveless insufflation systems like AirSeal at lower pneumoperitoneum pressures can significantly reduce the rate of SCE and post-operative pain, particularly shoulder pain, when compared to standard insufflation systems at higher pressures during robotic-assisted partial nephrectomy.

Cystectomy:

Only a single paper was identified that discussed patient-reported pain as an observation within the context of robotic-assisted radical cystectomy (RARC).

Kostakopoulos and colleagues investigated the effects of lower pneumoperitoneum pressures on post-operative comfort in patients undergoing RARC with intracorporeal urinary diversion (ICUD) [25]. Their study included procedures completed by one surgeon between January 2021 and February 2022. This study reviewed 24 patients who'd had standard pressure pneumoperitoneum (12mmHg) RARC/ICUD while 25 patients underwent the procedure with low-pressure pneumoperitoneum (8mmHg). As a retrospective study, the study was non-randomised and unblinded.

All patients adhered to an enhanced recovery protocol post-operatively [26], receiving the same standard analgesic regimen, administered regularly or as required.

Outcomes assessed included intra-operative bleeding, perceived levels of pain on POD1 and 3, length of operation as well as various post-operative complications. Neither VAS scores nor objective questionnaires were utilised; patients generally reported their pain levels as mild, moderate or severe.

Baseline characteristics of patients between groups were comparable. In two cases, the operations could not be completed at low pneumoperitoneum pressure due to bleeding, requiring a switch to standard pressure. On POD1, higher levels of moderate to severe pain were observed in the standard pressure RARC/ICUD group (95.8% vs. 48.0% at low pressures, p =0.000). This trend persisted on POD3, with 62.5% of patients in the standard group experiencing moderate to severe pain relative to 16% in the 8mmHg group. Severe post-operative pain was rare in RARC/ICUD patients. Additionally, patients who underwent low-pressure RARC/ICUD were medically optimised for discharge sooner, with a median of 5.0 days, compared to 8.5 days for those receiving standard-pressure RARC/ICUD (p =0.001). Despite this finding, all RARC/ICUD patients in the study had a similar overall length of admission. Other assessed outcomes were comparable irrespective of study arm.

The study concluded that RARC/ICUD procedures performed at 8mmHg are safe and may result in lower levels of immediate post-operative pain and earlier discharge.

Operation	Study (Year)	Study Design	Pneumoperitoneum pressures (mmHg)	Patients	Pain score method	Pain scores (POD0: 0-4 hours)	Intermediate pain scores (POD0: 5-12 hours; paper dependent)	Pain scores (POD1)	Pain scores (POD3)	Morphine equivalents; paper dependent (mg)	Estimated blood loss (ml)	Operating time (mins)	Total Length of stay (hours)	Subcutaneous emphysema rate (SCE)
Prostatectomy	Keating. (2024) [22]	RCT	15	93	Pain scores not assessed					18.9	42.5	143.1	24.0	
			12	105						17.4	58.1	144.2	24.0	
			p-values							*0.6*	*0.30*	*0.76*	*0.75*	
	Abaza and Ferroni (2022) [17]	RCT	15	71	Numerical pain rating scale	3.5				4.1	72	142	8.6 ± 0.25	
			6	67		2.1				3.9	63	148	8.2 ± 0.21	
			p-values			***< 0.01***				*0.8*	*0.36*	*0.1*	*0.6*	
	Alhusseinawi et al (2023) [18]	RCT	12	49	Quality of recovery-15 questionnaire (QOR-15)			13.7	15.5	0 (IQR 0-25)	159.9	152.1	31.2	2
			7	49				16.0	15.7	0 (IQR 0–15)	227.0	156.1	28.8	1
			p-values					***0.001***	*0.75*	*0.45*	***0.01***	*0.64*	*0.18*	*0.56*
	Reinjders-Boerboom. (2024) [19]	RCT	14 (Moderate NMB)	50	Numerical pain rating scale	3.9	2.3	2.0		0.9	214.4	183.9	29.8	
			8 (Deep NMB)	46		4.1	2.3	1.9		1.3	312.8	198.6	31.2	
			p-values			*0.68*	*0.91*	*0.77*		*0.49*	*0.087*	*0.42*	*0.42*	
	Ferroni (2019) [21]	Retrospective study	15	300	VAS	5.2	3.9	3.3		5.0	119.3	145.7	24.0	
			6	300		5.1	3.2	2.9		4.5	139.9	155.2	13.68	
			p-values			*0.87*	***<0.001***	*0.07*		*0.14*	***<0.001***	***<0.001***	**<0.001**	
	Ippolito (2024) [24]	Retrospective study	10	135	VAS			2.0	1.0					
			p-values					-	-					
Partial Nephrectomy	Feng T. (2021) [21]	RCT	AIS12	31	VAS	3.9	3.1	2.7		86.9		180.6	30.24	6
			AIS15	31		3.3	3.4	2.2		79.1		184.2	27.12	12
			CIS15	31		3.8	4.4	2.9		82.4		169.8	28.56	15
			p-values (AIS12 vs CIS15/AIS15 vs CIS15)			*0.86/0.41*	***0.03**/0.13*	*0.67/0.19*		*0.95/0.39*		*0.40/0.28*	*0.65/0.50*	**0.03**/0.61
	Desroches. (2021) [20]	RCT	AIS12	65	VAS									9
			AIS15	68										21
			CIS15	65										21
			p-values (AIS12 vs CIS15/AIS15 vs CIS15)											***0.02**/1.00*
Cystectomy and intracorporeal ileal conduit urinary diversion	Kostalopoulos. (2022) [25]	Retrospective case-control study	12	24	Mild/Moderate/Severe			Moderate:14, Severe: 1	Moderate:14, Severe: 1		240	315	240	
			8	25				Moderate: 10, Severe:2	Moderate:4, Severe: 0		200	300	192	
			p-values					***0.000***	***0.001***		*0.554*	*0.218*	*0.122*	

Table 1: Summary of papers comparing pain scores, morphine equivalents used, operative time and blood loss in robotic urological procedures at different pneumoperitoneum pressures. Bold values indicate significant results. AIS-AirSeal; NMB-Neuromuscular blockade; RCT-Randomized Controlled Trial; VAS- Visual analogue Scale

Discussion:

Managing post-operative pain is a crucial aspect of surgical recovery, yet often remains under addressed. Effective post-operative pain control not only improves patient comfort and quality of recovery but has been shown to reduce the burden of chronic post-surgical pain and the need for prolonged opioid use [27, 28]. In recent times, greater attention has been directed toward optimising multimodal analgesic strategies. These regimens allow clinicians to adequately address post-surgical pain whilst also minimising the use of opioids - drugs which have been historically overprescribed and currently pose significant public health challenges [29].

This review aimed to examine the effects of reducing pneumoperitoneum pressures on post-operative pain following robotic urological surgery. Papers which did not investigate post-operative pain as a key objective were not discussed. Nine studies met the criteria to be discussed in this review; the available literature largely focused on robotic-assisted prostatectomy. Two papers discussed robotic-assisted partial nephrectomy and a single study was identified looking at robotic-assisted radical cystectomy.

Several papers in this review suggested an association between low pressure pneumoperitoneum and a reduction in post-operative pain; this was true across various urological procedures, including prostatectomy, partial nephrectomy and cystectomy. Specifically, in prostatectomy, significant reduction in pain were observed in the immediate post-operative period and POD1. In addition, three papers highlighted specific reductions in shoulder pain when low pressure pneumoperitoneum was utilised. In partial nephrectomy, the combination of and low pressure pneumoperitoneum and valveless insufflation systems, such as AIS, produced the most favourable outcomes in terms of pain relief. The ability to maintain more stable intra-abdominal pressures with valveless insufflation systems likely contributed to this.

Two papers focusing on prostatectomies identified an increase in estimated total blood loss at lower pressures; however, this did not lead to a significant increase in complications. Interestingly, in one of these studies, despite increased blood loss, the 30-day readmission rate was a lot lower. The mean increase in estimated blood loss of 67 mL in this study, though statistically significant, is unlikely to hold clinical relevance. In this review, there were no indications that the surgical workspace was compromised when lower pressures were employed. Despite notable reductions in pain scores with lower pneumoperitoneum pressures, this did not translate into a corresponding decrease in post-operative opioid consumption. Opioid analgesia use remained largely consistent between low and standard pressure pneumoperitoneum groups. This may be attributed to various factors; patients may request opioids pre-emptively, before pain intensifies, meaning their consumption may not accurately reflect the current severity of their pain. In some studies, patients were scheduled to receive regular non-steroidal anti-inflammatory drugs (i.e. ketorolac), which potentially influenced overall analgesia requirements [17, 23].

Low pressure pneumoperitoneum generally was not associated with significantly longer operating times. Most papers in this review demonstrated an increase in total operative time but this was only statistically significant in one paper (Ferroni et al. 2019). A recent review of robotic-assisted radical prostatectomy found that operating times were not significantly prolonged with pressures below 12mmHg, aligning with our findings [30]. In contrast, another review performed by West et al. of minimally invasive urological surgery found that low pressure pneumoperitoneum was associated with longer operating times [4]. The authors speculated that possible reasons for this were impaired

surgical visibility and challenges in blinding the surgeon. In the current study, randomised controlled trials have been discussed where the investigators and clinical staff were successfully blinded. As previously mentioned, there was also no suggestion of any compromise in the visible surgical field. Clinical outcomes should be reviewed collectively rather than in isolation; the potential increase in total operative time could be justified given the benefits in pain reduction, faster discharge and improved quality of recovery. Nonetheless, further research is required to corroborate these findings.

The largest strength of this review lies in it being the first to directly examine post-operative pain across different robotic urological procedures; this allowed for a comprehensive overview of the current evidence on low pressure pneumoperitoneum. There are some limitations to be acknowledged. The methods used to assess post-operative pain and quality of recovery were heterogenous and lacked consistency between studies thus creating a challenge to pool and compare results directly. As a result, a meta-analysis could not be performed. Furthermore, there was variation in the definition of 'low-pressure pneumoperitoneum' with more recent studies, for instance those by Ferroni and Abaza, investigating 'Ultra-low pneumoperitoneum' at 6mmHg. Additionally, the quality of the included studies varied with the majority exhibiting at least a moderate risk of bias. Whilst the search strategy was designed to be as robust as possible, the inclusion of additional databases would have strengthened the comprehensiveness of the review; this was not possible due to lack of institutional access.

An important consideration is that the surgeons in all included studies were highly experienced; this may have mitigated some of the challenges associated with low-pressure pneumoperitoneum, such as increased operative times or impaired surgical visibility. As a result, the data is limited on the impact of lower pneumoperitoneum pressures on operative duration for surgeons earlier in the learning curve. This remains an avenue for further research.

In the current body of evidence on low pressure pneumoperitoneum, post-operative pain has typically been considered in conjunction with broader surgical outcomes rather than as a central focus. Most studies reported pain as a secondary outcome, alongside metrics such as insufflation-related complication rates, blood loss, and overall recovery. Only two of the included papers specifically identified pain as a primary outcome. This highlights the need for further research, particularly in the form of higher-powered randomised controlled trials, where pain is the primary focus. This is especially true for procedures like partial nephrectomy and cystectomy, where the currently limited availability of literature hinders the ability to draw clear conclusions.

Conclusion:

This review demonstrates early evidence that low pressure pneumoperitoneum in robotic-assisted urological surgery is associated with reductions in immediate reported pain scores, without increasing overall complication rates. Low pressure pneumoperitoneum appears to enhance quality of recovery and potentially allow for earlier discharge. However, despite reductions in reported pain scores, there was no observed decrease in post-operative opioid consumption. The limited amount of literature available on this topic, as displayed in this systematic review, is an invitation for further research.

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