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Changes in urinary output and electrolytes during gaseous and gasless laparoscopy

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Abstract Urological laparoscopy has gained increasing acceptance recently. Alterations in renal water and electrolyte homeostasis by carbon dioxide peritoneal insufflation, retroperitoneal insufflation and abdominal wall lifting were measured in 30 well-hydrated pigs over a 2-h period. Oliguria was observed after gaseous insufflation but not after lifting the abdominal wall. Return to normal urinary output was observed at 30 min after release of pneumoretroperitoneum, and 60 min after pneumoperitoneum. Creatinine clearance declined, while the clearance rates of potassium, sodium and urea remained unchanged during peritoneal and retroperitoneal insufflation. An elevated serum aldosterone concentration was found which may mediate the increased urinary excretion of potassium and decreased urinary excretion of sodium found during peritoneal insufflation. Renal function remained stable, despite an elevation of serum creatine kinase being elicited after lifting the abdominal wall. In conclusion, significant changes in water and electrolyte homeostasis occurred during gaseous, not gasless, laparoscopy in pigs.

Key words Hormone · Electrolyte · Renal function · Laparoscopy

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Introduction

Pneumoperitoneum distends the abdominal cavity and provides a space for visualization and instrumentation during laparoscopy. Elevated intra-abdominal pressure (IAP) has been reported to cause significant physiological changes [9, 19]. Oliguria and even anuria have been found during conditions when the IAP was elevated, such as in laparoscopy [2, 20]. It has also been reported by the authors that a direct compression effect on the renal parenchyma decreased tissue perfusion of the superficial cortex during pneumoperitoneum [3]. Hypoperfusion may result in renal dysfunction if the ischemia is severe enough. Newer laparoscopic surgical techniques are being developed and are commonly performed in a number of surgical disciplines. These complex therapeutic laparoscopic procedures require longer periods of peritoneal insufflation than did previously reported gynecological procedures [15]. The safety of lengthy laparoscopic procedures is thus questioned. Retroperitoneoscopy has become popular with the advent of dissecting balloons by which an adequate retroperitoneal working space can be easily developed [6]. Pneumoretroperitoneum had been used as an imaging procedure for the diagnosis of retroperitoneal diseases before the application of the computerized scan. Previous techniques for retroperitoneal insufflation differ greatly from the current method for therapeutic retroperitoneoscopy. The insufflation pressure is much higher, and tissue dissection is more extensive in retroperitoneoscopy. Although it was believed that systemic absorption of carbon dioxide was less when the peritoneal membrane was not in direct contact with the gas, there is increasing evidence that hypercarbia occurs frequently during subcutaneous and retroperitoneal insufflation [13]. The detrimental effect of prolonged and high-pressure retroperitoneal insufflation is a topic that has not been critically explored. It is thus extremely important to assess the potential side effects of retroperitoneal insufflation before the

attractive retroperitoneoscopic techniques spread worldwide. Beside gaseous insufflation, laparoscopic procedures could also be performed in a gasless environment with the help of an abdominal retracting device, which would have several advantages over gaseous laparoscopy. Theoretically, there would be no hemodynamic or metabolic derangements since there is no gas insufflation and absorption. To provide guidelines for selecting the best approach with minimal renal functional alteration, this study was performed on 30 pigs undergoing peritoneal insufflation, retroperitoneal insufflation and gasless abdominal lifting, to analyze the changes in renal function, urinary electrolyte excretion and serum aldosterone levels.

Materials and methods

The study was performed on 30 conditioned female pigs (*Sus scrofa domestica*) weighing 15–20 Kg. Each animal was premedicated with ketamine (20 mg/kg) intramuscularly (i.m.) followed by injection of intravenous (i.v.) pentobarbital (20 mg/kg). Endotracheal intubation with assisted ventilation was performed with a respiratory rate of 20–25/min and a tidal volume of 15 ml/kg. The arterial blood level of $PaCO_2$ was measured periodically. The respiratory rate was adjusted to maintain arterial $PaCO_2$ in a range from 40 to 45 mmHg. Systemic blood pressure was monitored via femoral arterial catheterization. Normal saline solution was infused via an aurical vein at the speed of 5 ml/kg per hour by a syringe pump to maintain constant hydration. An 8F urethral Foley catheter was inserted into the urinary bladder to record the urinary output (UO) and collection of urine for electrolyte determination. A femoral catheter was placed into the inferior vena cava, which was used for blood sampling. These animals were hydrated adequately before the experiment, as indicated by an inferior vena caval pressure higher than 5 cm H_2O and a UO of greater than 1 ml/kg per minute.

Pneumoperitoneum study (ten pigs)

A 14G Veress needle was inserted via the midline of the lower abdomen, and pneumoperitoneum was established by insufflating CO_2 at a speed of 1 l/min until a pressure of 15 mmHg was reached. The experiment was divided into three consecutive 2-h phases, pre-insufflation, insufflation and desufflation. Serum concentrations of creatinine (S_{Cr}), sodium (S_{Na}), potassium (S_K), blood urea nitrogen (BUN) and aldosterone were determined at the midpoint of each phase. Urine was collected to measure the urinary output (UO), urinary concentration of creatinine (U_{Cr}), urea nitrogen (U_{UN}), sodium (U_{Na}) and potassium (U_K) in each phase. The selective clearance rates of creatinine, sodium, potassium and urea were calculated, (e.g., $C_{Cr} = U_{Cr} \times UO/S_{Cr}$). Measurement of serum creatine kinase (S_{CK}) was performed in all groups.

Pneumoretroperitoneum study (ten pigs)

Animals were prepared with the some procedures as in pneumoperitoneum group. After a pre-insufflation period of 2 h, the retroperitoneal space was entered through a 3-cm supra-iliac flank incision. The retroperitoneal space was enlarged by inflating 300 ml normal saline into a dissecting balloon, which was created by inserting an 18F Robinson tube into the index finger of a No. 7 latex surgeon's glove. Retroperitoneal insufflation was achieved and maintained at 15 mmHg for 2 h. Parameters including urinary output, serum and urine electrolyte and serum aldosterone concentrations were determined. Retroperitoneal and intraperitoneal pressures were monitored throughout the study. Data were excluded if peritoneal perforations occurred as indicated by a sudden elevation of the IAP during retroperitoneal insufflation.

Abdominal lifting device study (ten pigs)

The left retroperitoneal space, created by balloon dissection, was then approached by a 3-cm subcostal incision, and a 10-cm-long, 1-cm-diameter retractor (Laparofan, Origin, Menlo Park, CA, USA) was inserted into this space. The retracting force of the lifting device was set at a level corresponding to 15 mmHg of the retroperitoneal pressure during gas insufflation. The distance between the inner surface of the flank muscle and the kidney was measured by a calibrated ureteral catheter. We adjusted the force of retraction according to the distance, so that the distance created by these two methods was the same. Urinary output and serum levels of electrolytes and hormones were measured, and serum creatine kinase (S_{CK}) was checked to assess the degree of abdominal muscle damage.

At the end of each study, an exploratory laparotomy was performed to harvest the bilateral kidneys after clamping the renal hilum. The specimens were immersed with 3% formalin solution immediately, and later pathologically prepared for hematoxylin & eosin stain. All animals were treated according to the recommendations of the guidelines for the care and use of laboratory animals at our university. Laboratory data were expressed as means $\pm$ standard deviation ($X \pm SD$). Statistical analyses were performed by Student's two-tailed t test. A probability of less than 0.05 was taken to be significant.

Results

Serum potassium, urea nitrogen and creatinine concentrations remained stable after peritoneal insufflation (Fig. 1a), retroperitoneal insufflation (Fig. 1b) and abdominal wall lifting (Fig. 1c). There were no statistically significant changes between any of the phases. The serum sodium concentration remained stable in the three groups. During peritoneal insufflation, the urinary potassium concentration increased from 82 ± 42 to 95 ± 24 mM/l ($P < 0.05$), the sodium concentration decreased from 78 ± 46 to 52 ± 44 mM/l, ($P < 0.05$), while urinary creatinine and urea excretion remained stable (Fig. 2a). Retroperitoneal insufflation and abdominal wall lifting elicited no change in urinary sodium, potassium, creatinine and urea concentrations (Fig. 2b, c).

A decreased amount of UO was noted during gaseous insufflation, UO decreased from 48 ± 5 to 24 ± 4 ml/h after peritoneal insufflation, and from 38 ± 4 to 28 ± 5 ml/h after retroperitoneal insufflation; both changes were statistically significant, $P < 0.05$. UO remained low until 60 min after the release of pneumoperitoneum. The postinsufflation return to baseline UO occurred 30 min after retroperitoneal insufflation, UO increasing from 28 ± 5 to 52 ± 8 ml/h, $P < 0.05$. UO and urinary electrolyte excretion remained unchanged for a period of 2 h during abdominal wall

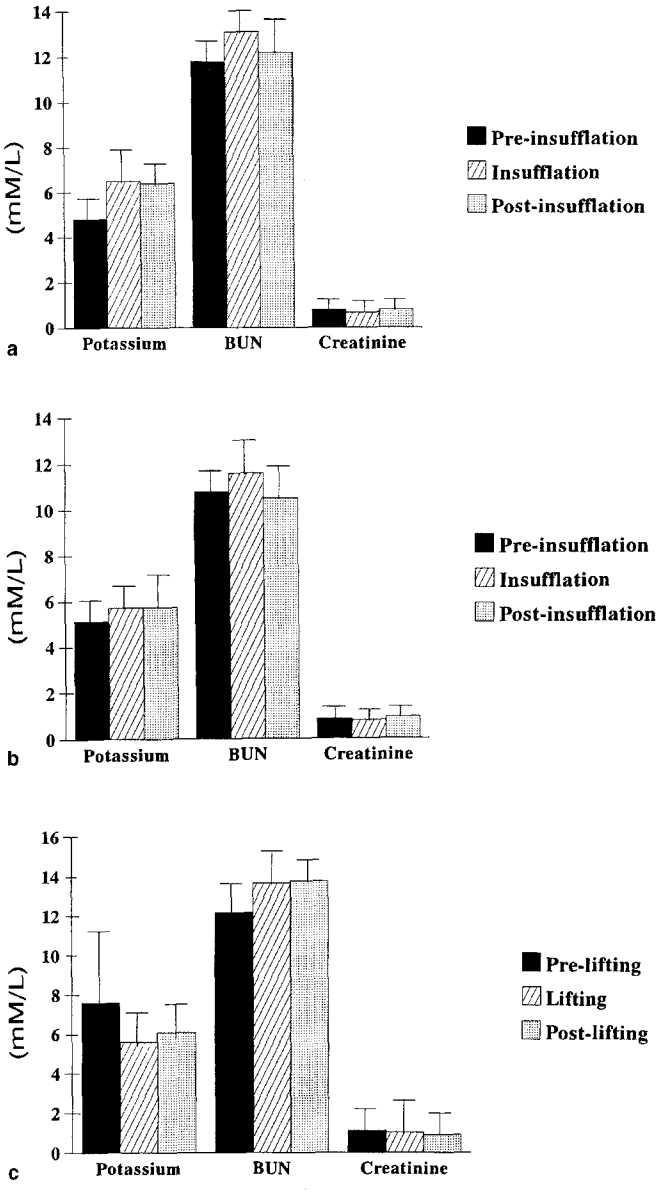

Fig. 1a–c Serum electrolyte levels during peritoneal insufflation (a), retroperitoneal insufflation (b) and abdominal wall lifting (c)

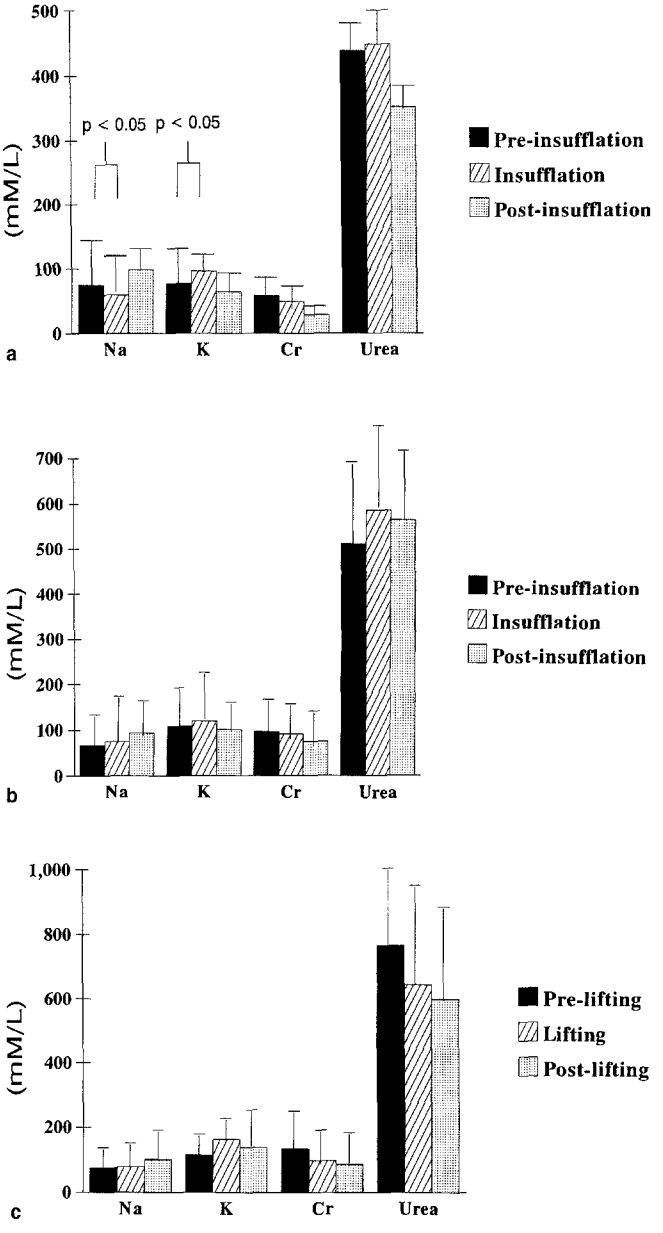

Fig. 2a–c Urinary electrolyte changes during peritoneal insufflation (a), retroperitoneal insufflation (b) and abdominal wall lifting (c)

lifting. Pneumoperitoneum decreased C_{Cr} from 38 ± 11 to 32 ± 10 ml/min, pneumoretroperitoneum also decreased C_{Cr} from 57 ± 13 to 30 ± 11 ml/min, $P < 0.05$ (Fig. 3a, b). C_{Cr} returned to the pre-insufflation level after desufflation in the pneumoretroperitoneum group, 30 ± 11 to 55 ± 12 ml/min (Fig. 3b). However, C_{Cr} remained depressed after desufflation in the pneumoperitoneum group, 32 ± 10 to 22 ± 17 ml/min (Fig. 3a). Potassium and urea clearance were stable under pneumoperitoneum and pneumoretroperitoneum (Fig. 3a, b). The clearance rates of potassium, urea and creatinine were stable during the phase of abdominal wall lifting (Fig. 3c).

Serum aldosterone concentration increased from 56 ± 21 to 78 ± 28 pmol/l ($P < 0.05$) after peritoneal insufflation and from 57 ± 45 to 108 ± 37 pmol/l ($P < 0.05$) after retroperitoneal insufflation. Abdominal wall lifting caused no significant change in serum aldosterone, from 42 ± 41 to 43 ± 45 pmol/l, $P > 0.05$ (Fig. 4). No significant change in S_{Ck} was found during peritoneal insufflation (from 800 ± 325 to 950 ± 210 IU/l), and during retroperitoneal insufflation (from 755 ± 245 to 836 ± 345 IU/l), $P > 0.05$ for both. The abdominal wall lifting caused a significant elevation of S_{CK}, from 1004 ± 291 to 1252 ± 226 IU/l, $P < 0.05$ (Fig. 5). No matter what method was applied to distend the abdominal cavity, pathological examination of the kidney revealed no apparent changes in the renal tubular and glomerular structures. No pathological

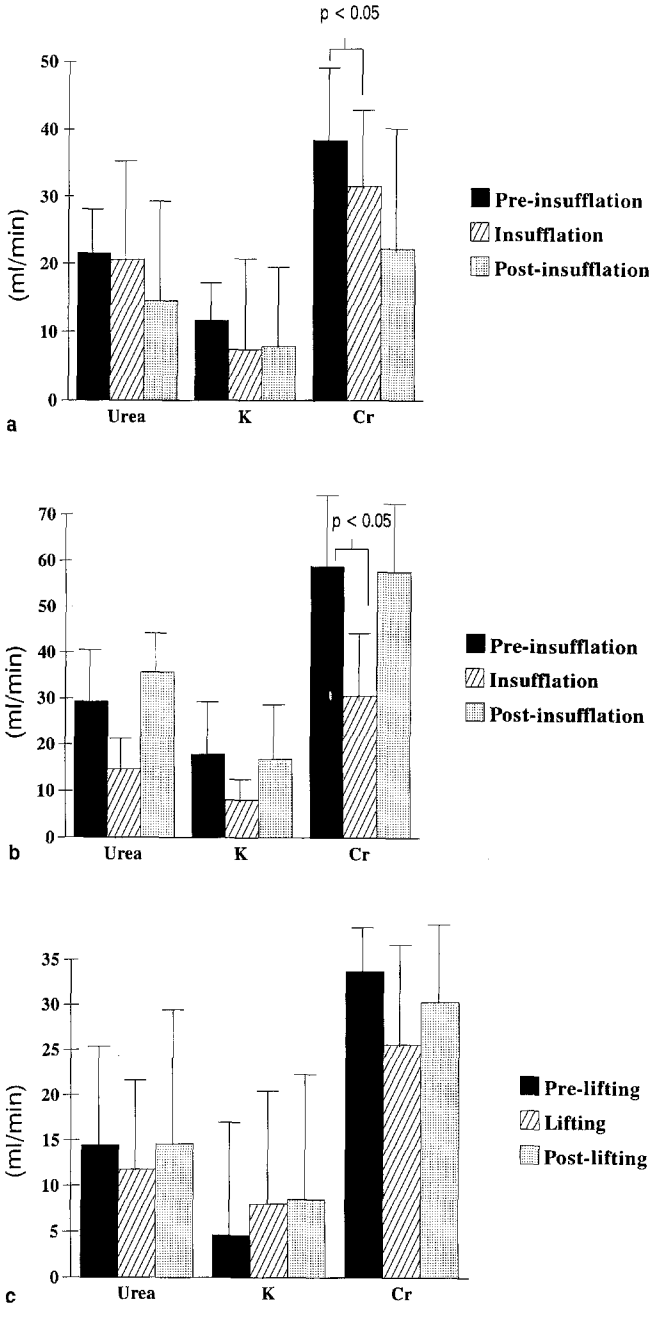

Fig. 3a–c Urea, potassium and creatinine clearances during peritoneal insufflation (a), retroperitoneal insufflation (b) and abdominal wall lifting (c)

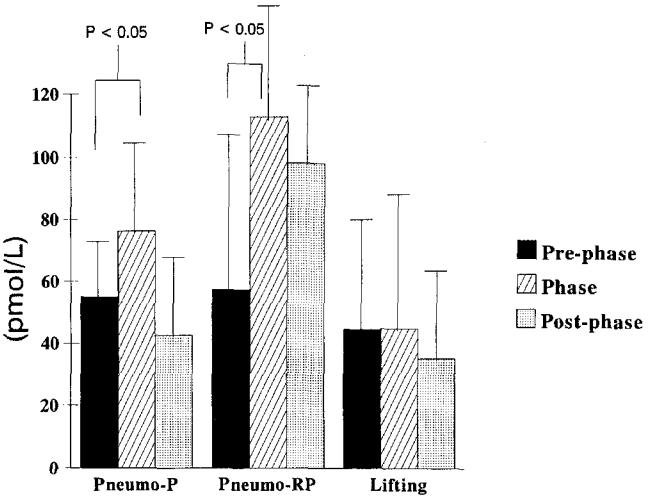

Fig. 4 Serum aldosterone levels during peritoneal insufflation, retroperitoneal insufflation and abdominal wall lifting

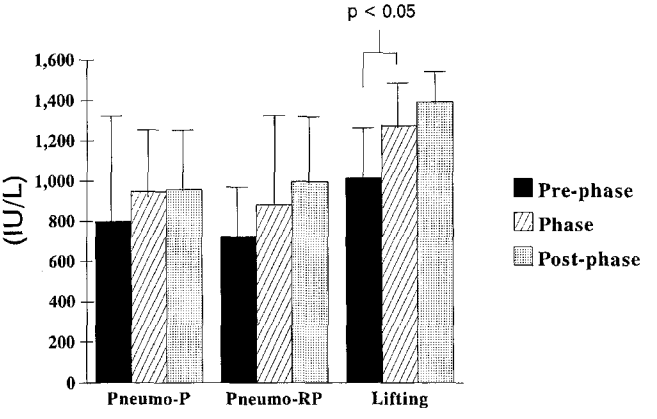

Fig. 5 Serum creatine kinase levels during peritoneal insufflation, retroperitoneal insufflation and abdominal wall lifting

difference could be found in the kidney under retroperitoneal insufflation and the contralateral kidney, which was not directly compressed.

Discussion

As therapeutic laparoscopy becomes more popular and as intraperitoneal and retroperitoneal operations become better adapted to laparoscopic techniques, complications specific to laparoscopy are likely to be seen [11]. Although laparoscopy is an exciting technology which may decrease hospitalization, lessen postoperative pain and shorten convalescence, physiological changes during laparoscopy are both complex and poorly understood [21]. The potential renal hemodynamic and functional insults are of concern now that laparoscopic nephrectomy has become a feasible clinical procedure [10]. The authors have previously reported that superficial renal cortical blood flow decreased significantly following insufflation, and that the blood flow remained depressed throughout gaseous insufflation [3]. Decreased tissue perfusion may cause renal damage and functional alteration if ischemia is prolonged and severe. Renal tubule cells are vulnerable to any ischemic insult, and acute tubular necrosis occurs when renal perfusion is compromised. Although significant hemodynamic and functional

changes occurred during gas insufflation, we found no evidence of acute tubular necrosis in the pathological examinations in this study.

This study further illustrated that although clearance rates of electrolytes remained unchanged, creatinine clearance decreased during pneumoperitoneum and pneumoretroperitoneum. Retroperitoneal insufflation decreased creatinine clearance to a lesser extent. Creatinine clearance returned to the preinsufflation level after the pressure was released in the pneumoretroperitoneum group. Creatinine clearance remained depressed for a longer period after desufflation of the pneumoperitoneum. This difference may be caused by a greater effect of pneumoperitoneum, during which both kidneys are compressed. Oliguria has been reported [2], and it was again found in this study. Theoretically, the alteration in the renal function would be expected to be less in the pneumoretroperitoneum group with only one kidney being compressed. This may also be reflected in the early recovery from oliguria after retroperitoneal insufflation. Urinary output returned slowly after desufflation, taking 1 h for the urinary output to return to normal after release of the pneumoperitoneum. This implied that renal compression may not be the sole factor. Previous investigators have found a rise in plasma antidiuretic hormone level with increased abdominal pressure in dogs [16]. Although the exact mechanism for the increased antidiuretic hormone secretion is still unknown, decreased cardiac output, elevated intracranial pressure and the renin-angiotensin system have all been considered as contributing factors [16, 18]. We further found an elevated serum aldosterone level and a concomitant decrease in excretion of urinary potassium following peritoneal insufflation. Aldosterone production is influenced by the renin-angiotension system [1], which, in turn, is influenced by a variety of other factors. Major factors include renal perfusion pressure, cathecholamine-mediated adrenergic activity, the renal sympathetic nerves and delivery of sodium to the macula densa of the distal renal tubule [8]. Increased plasma renin activity has been reported during pneumoperitoneum in rats [4]. Although renin activity was not measured in this study, it may be a possible mediator for the increased aldosterone production. Aldosterone is known to act on the distal renal tubule to enhance the reabsorption of sodium and excretion of potassium. This effect may explain the increased urinary excretion of potassium noted in this study. Twenty years ago, Shenasky et al. [19] demonstrated a decreased urinary volume and free water clearance in a study evaluating the effect of renal compression. They also noted increased urinary potassium and decreased sodium concentrations, which were suggestive of increased mineralocorticoid activity.

Stimulation of α-adrenergic receptors results in vasoconstriction, and it is also thought to be primarily responsible for renin release from the juxtaglomerular apparatus. Renal nerve stimulation increases proximal sodium reabsorption, whereas renal denervation results in both natriuresis and diuresis. The effect of renin on renal water excretion is likely to be multifactorial [12]. The sympathetic stimulatory effect of carbon dioxide and the vagal stimulation resulting from peritoneal stretch during pneumoperitoneum may be additional influences on renal electrolyte and water homeostasis [5]. Whatever the mechanism, significant alterations in electrolyte and water homeostasis were found and a cautious monitoring may be warranted to avoid their potential side effects. We considered serum aldosterone to be a possible mediator of renal homeostasis during gaseous laparoscopy. Consequently, any attempt to increase urinary output should be guided by a thorough understanding of the underlying mechanisms. It is not only futile to hydrate the patient to increase urinary output during gaseous laparoscopy, but it might be hazardous to overhydrate patients with a poor cardiac performance status. It is particularly easy to overhydrate patients during laparoscopy because there is no open wound and the insensible water loss is minimal.

In a previous hemodynamic study, we have shown that renal cortical perfusion markedly decreased to 50% of the pre-insufflation level following peritoneal insufflation to a pressure of 15 mmHg [3]. Renal compression was considered to be the most important factor contributing to renal hemodynamic changes. Although Schirmer et al. have demonstrated decreased urinary output in kidneys exposed to a renal venous pressure of 23 cm H_2O [17], another group of investigators were unable to show any changes in renal function resulting from a renal venous pressure of 30 cm H_2O [14]. The possible role of ureteral compression as a cause of renal dysfunction following elevation of intra-abdominal pressure has been thoroughly studied with and without ureteral stents. This study failed to demonstrate any association between ureteral compression and hemodynamic changes [7]. The anatomical structure of the human kidney differs greatly from that of the pig. The scanty perirenal fat and absence of Gerota's fascia may be factors contributing to the vulnerability of porcine kidneys as demonstrated in this study to the external compression.

Gasless laparoscopy provides an attractive alternative to insufflation. It allows the use of traditional instruments and the performance of complex surgical maneuvers, such as suturing techniques. In this study, renal function and electrolyte homeostasis remained stable when the abdominal wall was retracted. The muscle trauma from the retraction device was reflected by an increased serum creatine kinase concentration. The evenly distributed pressure on the abdominal muscle from gaseous insufflation may result in less tissue damage. Although the gasless approach may result in an increased abdominal wall trauma and a smaller working space, the gasless approach seems to

be a superior method for laparoscopy with regard to changes in renal homeostasis.

In conclusion, significant changes in renal function were found in gaseous but not in gasless laparoscopy. We speculate that the documented increase in aldosterone production may mediate the altered water and electrolyte homeostasis found in gaseous laparoscopy. The findings of this study suggested that a monitoring of urinary electrolyte and volume may be important for increased safety of laparoscopy, particularly during lengthy procedures.

References

1. Carey RM, Sen S (1986) Recent progress in the control of aldosterone secretion. Recent Prog Horm Res 42:251
2. Chang DT, Kirsch AJ, Sawczuk IS (1994) Oliguria during laparoscopic surgery. J Endourol 8:349
3. Chiu AW, Azadzoi KM, Hatzichristou DG, Siroky MB, Krane RJ, Babayan RK (1994) Effect of intra-abdominal pressure on renal tissue perfusion during laparoscopy. J Endourol 8:99
4. Diebel LN, Wilson RF, Dulchavsky SA, Saxe J (1992) Effects of increased intra-abdominal pressure on hepatic arterial, portal venous, and hepatic microcirculatory blood flow. J Trauma 33: 279
5. Doyle DJ, Mark PW (1989) Laparoscopy and vagal arrest. Anesthesia 44:448
6. Gaur DD, Agarwal DK, Purohit KC (1993) Retroperitoneal laparoscopic nephrectomy: initial case report. J Urol 149:103
7. Harman PK, Kron IL, McLachlan HD, Freedlender AE, Nolan SP (1982) Elevated intra-abdominal pressure and renal function. Ann Surg 196:594
8. Ichikawa I, Brener BM (1984) Glomerular actions of angiotensin II. Am J Med 76:43
9. Kashtan J, Green JF, Parson EQ, Holcroft JW (1981) Hemodynamic effects of increased abdominal pressure. J Surg Res 30:249
10. Kavoussi LR, Kerbl K, Capelouto CC, McDougall EM, Clayman RV (1993) Laparoscopic nephrectomy for renal neoplasms. Urology 42:603
11. Kavoussi LR, Sosa RE, Chandhoke PJ (1993) Complications of laparoscopic lymph node dissection. J Urol 149:322
12. Levens NR, Peach MJ, Vaughan ED Jr, Carey RM (1981) Demonstration of a primary anti-diuretic action of angiotensin II: effects of intrarenal converting enzymes inhibition in the conscious dog. Endocrinology 108:318
13. Mullet CE, Viale JP, Sagnard PE, Miellet CC, Ruynay LG, Counioux HC, Motin JP, Boulex JP, Dargent DM, Annat GJ (1993) Pulmonary CO_2 elimination during surgical procedures using intra- or extraperitoneal CO_2 insufflation. Anesth Analg 76:622
14. Pate JW, Estes JW (1968) Effects of elevated venous pressure on kidney function. Am Surg 34:729
15. Phillips J, Keith D, Hulka J, Hulka B, Keith L (1975) Gynecologic laparoscopy in 1975. J Reprod Med 16:105
16. Roith DL, Bark H, Nyska M, Glick, SM (1982) The effect of abdominal pressure on plasma antidiuretic hormone levels in the dog. J Surg Res 32:65
17. Schirmer HKA, Marshall RE, Jackson MP (1968) The effect of altered renal venous pressure on urine flow and cortical metabolism. J Urol 100:205
18. Schrier RW, Lieberman R, Ufferman RC (1977) Mechanisms of antidiuretic effect of beta adrenergic stimulation. J Clin Invest 51:97
19. Shenasky JH, Gillenwater JY (1972) The renal hemodynamic and functional effects of external counterpressure. Surg Gynecol Obst 134:253
20. Sosa RE, Weingram J, Poppas D, Lyons J (1992) Physiological consideration in laparoscopic surgery in urology. J Endourol 6:85
21. Wolf JS, Stoller ML (1994) The physiology of laparoscopy: basic principles, complications and other considerations. J Urol 152:294