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THE IMPACT OF PNEUMOPERITONEUM ON RESPIRTORY SYSTEM: COMPLICATIONS AND MANAGMENT STRATEGIES IN LAPAROSCOPIC SURGERY

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Laparoscopic surgery, a cornerstone of contemporary surgical practice, revolutionizes traditional surgical techniques by employing minimally invasive procedures. However, this innovative approach poses intricate challenges, particularly in respiratory management, necessitating a comprehensive understanding of its physiological implications. Pneumoperitoneum involves insufflating the abdominal cavity with carbon dioxide (CO2) to create a suitable working space. The introduction of CO2 into the peritoneal cavity elevates intra-abdominal pressure, prompting physiological adaptations that compromise respiratory function. These alterations, including increased peak inspiratory pressure, decreased dynamic respiratory system compliance, and the promotion of intraoperative atelectasis, underscore the intricate interplay between pneumoperitoneum and respiratory physiology.

Amidst these challenges, positive end-expiratory pressure emerges as a crucial intervention for mitigating the adverse effects of pneumoperitoneum on respiratory mechanics. By maintaining airway patency and preventing alveolar collapse during expiration, positive end-expiratory pressure helps counteract the reduction in functional residual capacity associated with elevated intra-abdominal pressure. Additionally, positive end-expiratory pressure serves to optimize lung recruitment, thereby improving ventilation-perfusion matching and enhancing oxygenation.

Mechanical ventilation during laparoscopic procedures further complicates respiratory management, potentially exacerbating lung injury. The application of protective lung ventilation strategies, such as low tidal volume combined with judicious positive end-expiratory pressure titration, represents a cornerstone in mitigating ventilator-induced lung injury and reducing postoperative pulmonary complications. However, the optimal implementation of these strategies remains a subject of ongoing debate, highlighting the need for personalized approaches tailored to individual patient characteristics and surgical contexts.

Understanding the pivotal role of positive end-expiratory pressure in mitigating the adverse respiratory effects of pneumoperitoneum underscores its importance as a cornerstone intervention in laparoscopic surgery. By optimizing positive end-expiratory pressure levels based on patient characteristics and procedural requirements, healthcare practitioners can effectively mitigate the risk of pulmonary complications and enhance surgical outcomes.

Key words: positive end-expiratory pressure; lung protective ventilation; laparoscopic surgery; pneumoperitoneum

INTRODUCTION

Every year, approximately 230 million patients worldwide require surgical intervention under general anesthesia and MV [76]. Laparoscopic procedures are increasingly becoming the preferred method of surgical intervention each year. This technique involves making minimal surgical incisions to create access ports, insufflating the abdominal cavity with CO2, and placing additional ports under direct visual control through the camera to facilitate the introduction of laparoscopic instruments [74]. Laparoscopic surgery offers numerous benefits to patients, such as improved cosmetic outcomes due to minimized incision sizes, reduced frequency of perioperative complications, decreased blood loss, reduced postoperative pain syndrome, and faster recovery [37, 56, 75]. The use of laparoscopic methods is also associated with a general reduction in hospital stay duration and healthcare expenditure [72].

Anesthesiologists must understand that laparoscopic surgery poses unique risks to patients, requiring a deep understanding of the practical and physiological changes associated with surgical techniques, patient positioning, and pneumoperitoneum application. The demographic composition of patients undergoing various laparoscopic procedures currently encompasses a wide range of body mass indices and comorbidities. Therefore, careful optimization and stabilization of patients' conditions throughout the perioperative period are essential.

Despite the numerous advantages of laparoscopy, it is not without risks. For certain procedures, the benefits of laparoscopy may outweigh intraoperative risks. Absolute contraindications to laparoscopy are rare, but relative contraindications include severe ischemic or valvular heart disease, increased intracranial pressure, and uncorrected hypovolemia. Therefore, understanding these peculiarities and appropriately adjusting the parameters of MV during the perioperative period is of paramount importance.

MV is an integral component of general anesthesia during laparoscopic surgeries. Despite rapid advancements in medicine and the emergence of next-generation ventilators, MV remains a potentially unsafe procedure and can have damaging effects on lung tissue [6, 19, 42]. When inadequately adjusted, MV can lead to damage to both lung tissue (ventilator-associated lung injury – VALI) [77] and respiratory musculature [38, 64], thereby causing injury even to initially healthy lung tissue and exacerbating parenchymal respiratory insufficiency. Furthermore, postoperative pulmonary complications (PPCs) may arise – a group of respiratory system disorders without a clear definition, associated with both surgery itself and anesthesia/MV.

The incidence of PPCs after abdominal surgeries is approximately 5% [12], with 12–58% of patients undergoing abdominal surgery developing PPCs [4, 12]. Moreover, PPCs are significantly associated with prolonged hospital stays and increased mortality risk. The use of protective lung ventilation (PLV) strategies, including low tidal volume (TV) and PEEP, aims to prevent atelectasis development and improve gas exchange [24, 66]. It has also been shown that PEEP reduces mortality in patients with acute respiratory distress syndrome (ARDS) and critically ill patients [2].

In elective abdominal surgery under general anesthesia, atelectasis occurs in nearly 90% of patients [41]. Despite studies showing the positive effects of protective MV on disease outcomes, the role of individual components of this method in improving treatment outcomes remains subject to discussion. PLV during the perioperative period for abdominal surgeries in patients with intact lungs reduces the risk of developing PPCs. The main proven component of PLV is the use of low TV, while the application of alveolar recruitment maneuvers and PEEP in open and laparoscopic interventions in non-obese patients remains debatable. However, a recent meta-analysis of three randomized clinical trials during non-cardiothoracic and non-neurosurgical operations suggests that high PEEP with a recruitment maneuver does not reduce the risk of PPCs [11].

The authors of the Cochrane review published in 2014 concluded that there was insufficient data to justify conclusions about the impact of intraoperative PEEP on mortality and PPCs [8, 10]. Due to the ambiguity of existing data, many authors actively develop the idea of personalized selection of intraoperative PEEP levels [22, 33, 57].

PATHOPHYSIOLOGY OF THE EFFECT OF PNEUMOPERITONEUM ON THE RESPIRATORY SYSTEM

Laparoscopic surgery necessitates the establishment of pneumoperitoneum to create a suitable working space within the abdominal cavity, ensuring safe insertion of trocars and instruments, as well as optimal exposure of the abdominal contents. CO2 insufflation into the peritoneal cavity stands as the prevailing method for elevating the abdominal wall and generating space within the abdominal cavity. CO2, being a clear, non-flammable soluble gas, is introduced at a flow rate of 4-6 L/min, resulting in an elevation of intra-abdominal pressure to 10-20 mmHg. Sustained delivery of gas at a rate of 200-400 mL/min is maintained to uphold this pressure. The primary objective is to sustain intra-abdominal pressure below 15 mmHg, as clinical manifestations of heightened intra-abdominal pressure, such as renal and respiratory impairments, manifest between pressures of 15 to 25 mmHg [51]. Although increased intra-abdominal pressure triggers physiological responses that may be undesirable, especially among patients with limited physiological reserves, these alterations can be effectively managed to mitigate patient morbidity during both intraoperative and postoperative periods.

PNP and the patient's position required for laparoscopy induce pathophysiological changes that complicate anesthesia management [32]. PNP is a complex but well-tolerated physiological condition that significantly affects respiratory mechanics: it creates increased peak inspiratory pressure and plateau pressure, decreases dynamic respiratory system compliance, and contributes to the formation of intraoperative atelectasis [23, 29, 32, 50]. PNP reduces thoracopulmonary compliance by 30-50% in healthy and obese patients [17, 20]. It is expected to reduce functional residual capacity and promote atelectasis due to diaphragm elevation and altered distribution of lung ventilation and perfusion from increased airway pressures [3].

During laparoscopy, CO_2 absorption across the peritoneal membrane may precipitate hypercapnia and acidosis, necessitating meticulous regulation of minute ventilation [28]. Under anesthesia, augmented intra-abdominal pressure and cranial displacement of the diaphragm, coupled with alterations in thoracoabdominal configuration, contribute to compressive atelectasis [34, 68]. Elevated atelectasis, in turn, reduces the alveolar pool available for ventilation, resulting in increased dead space, ventilation-perfusion mismatch, and diminished arterial oxygenation (PaO_2) [49, 71].

Transpulmonary pressure (PL) during positive-pressure ventilation, crucial for lung inflation [3], is determined by lung and chest wall elastance (EL and ECW, respectively), relative to airway opening pressure (PRS). While PL approximates half of PRS in healthy individuals owing to the near equivalence of EL and ECW [25, 67], laparoscopic surgery significantly diminishes PL due to augmented ECW resultant from PNP [13]. This decreased lung pressure compromises gas exchange and lung mechanics, facilitating atelectasis in dependent lung regions. A recruitment maneuver (RM) followed by the application of standard PEEP at 5 cm H_2O is commonly advocated to restore PL [13]. However, physiological evidence underscores the imperative to individualize PEEP immediately post-RM to optimize alveolar recruitment while minimizing alveolar overdistention [46]. Despite these physiological considerations, the optimal level of PEEP during laparoscopic surgery remains unclear.

It is well-established that general anesthesia and mechanical ventilation engender atelectasis in gravity-dependent lung regions [3]. Additionally, pneumoperitoneum, high concentrations of inhaled oxygen, and general anesthetics predispose patients to the formation of atelectasis during laparoscopic procedures [52, 73]. It has already been demonstrated that volatile anesthetics such as enflurane and nitrous oxide reduce the ciliary movement of respiratory epithelium, decrease the stability of surfactants, and increase mucus production [76].

However, the effect of PNP on lung tissue is not straightforward; some studies report that PNP reduces lung tissue compliance, while others do not confirm this. Clearly, during laparoscopic procedures under conditions of carbon dioxide pneumoperitoneum, patient positioning, and relaxation, increased alveolar pressure occurs because of alveolar collapse (resulting in negative transpulmonary pressure). Additionally, with PNP, the end-expiratory lung volume decreases. One method to prevent PNP from affecting lung tissue is adjusting PEEP. The optimal level of PEEP remains contentious, but the use of zero PEEP has been associated with worse outcomes, including increased hypoxemia, ventilator-associated pneumonia, and hospital mortality [44].

POSITIVE END-EXPIRATORY PRESSURE AS A TOOL TO MANAGE ADVERSE EFFECTS OF PNEUMOPERITONEUM

General anesthesia with controlled MV appears to be the safest method for laparoscopic surgeries [32]. Mechanical ventilation is associated with an increased risk of barotrauma, volutrauma, atelectrauma, and biotrauma to the lungs, leading to the development of multi-organ failure consequently [36, 44]. Approximately 30% of surgical patients undergoing general anesthesia with MV, according to large cohort studies, are classified into intermediate and high-risk groups for developing acute postoperative lung complications [4, 5]. Alveolar stretching and atelectasis trigger the release of inflammatory mediators, resulting in lung and organ damage [26]. To date, five damaging factors of MV have been clearly defined through numerous clinical and experimental studies: barotrauma, volutrauma, atelectraumatic injury, mechanotransduction, and biotrauma [69, 70]. However, recent research has identified another mechanism of lung tissue injury known as patient self-inflicted lung injury.

Protective lung ventilation has been developed over the past few decades and has mainly focused on patients with ARDS and ALI. Animal and human data clearly indicate that MV can cause and exacerbate lung injury, hence the current medical standard is the use of protective lung ventilation strategies in patients with ARDS or ALI [63, 77]. Many researchers have conducted several large, randomized trials showing that using low TV is associated with improved outcomes and reduced incidence of ventilator-induced lung injuries [18, 79]. In addition to low TV, increasing the level of PEEP is now considered an integral part of LPV [39].

It is important to note that mechanical ventilation itself is one of the main contributing factors to the development of VALI [45]. To reduce the risk of developing VALI/PPCs, it is necessary to implement protective ventilation during the perioperative period, which includes: low TV – aimed at reducing alveolar overdistension (volutrauma); minimal inspiratory oxygen concentration (FiO_2); alveolar RM - for forced opening of collapsed alveoli; limiting airway pressures and mandatory use of PEEP - to increase functional residual capacity and prevent airway and alveolar collapse during expiration (atelectrauma). These measures improve ventilation-perfusion matching and blood oxygenation.

Ventilation with high TV and low PEEP has been associated with significantly more lung damage as measured by the Lung Injury Score (LIS) [1]. Analysis of changes in the concentration of Tumor Necrosis Factor-alpha (TNFα), Interleukin-1 beta (IL1β), and Interleukin-6 (IL6) mediators showed a significant increase in the concentration of all pro-inflammatory cytokines in the group of patients with «traditional» ventilation compared to the second group [1]. The increase in the concentration of pro-inflammatory mediators in bronchoalveolar lavage fluid indicates the development of biotrauma in patients with «traditional» ventilation [1] [79]. Ventilation in the «traditional» mode, i.e., using unreasonably high tidal volumes and low PEEP in patients with severe trauma and intact lungs, is associated with damaging effects, contributes to an increase in the incidence and severity of nosocomial pneumonia, and increases the duration of controlled ventilation and the length of patient stay in the ICU [1] . However, it does not affect the 28-day mortality of patients.

PNP also plays an important role, often exceeding airway pressures during mechanical ventilation with carbon dioxide during laparoscopic surgery [59]. This pressure gradient typically causes cranial displacement of the diaphragm and collapse of adjacent lung tissues. Additionally, PNP reduces respiratory system compliance and oxygenation [27]. All these factors associated with increased intra-abdominal pressure ultimately led to atelectasis [55]. It is believed that PEEP can prevent atelectasis by keeping the airways open and providing adequate gas exchange at the end of expiration under conditions of high intra-abdominal pressure [26]. However, it is necessary to adjust the level of PEEP individually according to the patient's characteristics, the surgical intervention, and consider the patient's position. Some studies suggest that very low levels of PEEP may potentially contribute to atelectasis formation by promoting repeated closure and opening of small airways, leading to atelectrauma [16]. However, higher levels of PEEP may increase airway pressure and likely have a negative impact on hemodynamics, predominantly by affecting the right heart chambers.

Selecting the optimal level of PEEP can prevent the development of PPC. With high PEEP levels, alveoli may become over-distended, potentially increasing pulmonary vascular resistance. However, using low levels of PEEP may be insufficient to prevent atelectasis [26]. Studies comparing PLV strategy with standard mechanical ventilation (MV) without PEEP have shown a protective effect in patients with normal lung function undergoing abdominal surgery, reducing the incidence of PPCs [23, 62]. Despite the conducted studies recommending the use of low tidal volume [26], the optimal level of PEEP has not yet been established [23, 62]. A multicenter observational study found that approximately 20% of patients do not receive PEEP during routine anesthesia assistance [31].

In the «Intraoperative Protective Ventilation Trial», which included patients undergoing major abdominal surgery with intermediate and high risk of PPC, PLV strategy using lower tidal volumes and PEEP of 6 cm H2O, compared to standard MV practice involving higher tidal volumes without PEEP, was associated with improved clinical outcomes [23]. Another study involving patients undergoing abdominal non-laparoscopic surgery for more than 2 hours showed that PLV strategy with PEEP of 10 cm H2O improved respiratory function and reduced the modified Clinical Pulmonary Infection Score compared to standard ventilation strategy [62]. However, another study found that low tidal volume combined with low PEEP (3 cm H2O) might induce postoperative inflammation and increase the risk of PPC in major surgeries such as hepatectomy [62]. In a multicenter study involving patients undergoing open abdominal surgery at high risk of PPC, a high PEEP ventilation strategy (12 cm H2O) did not reduce the incidence of PPC but was more likely to cause hemodynamic instability [58]. Therefore, the authors recommend a low tidal volume ventilation strategy combined with low PEEP (≤2 cm H2O) [58].

During laparoscopic surgery, various patient positions may be used, including Trendelenburg position (head down), reverse Trendelenburg position (head up), lithotomy position, and lateral position, aimed at facilitating surgical access. Individuals with a high body mass index, severe cardiac or respiratory diseases, as well as elderly individuals, may be particularly susceptible to significant changes in position. This susceptibility is explained by the impairment of their organ function, leading to cardiorespiratory physiological changes.

The Trendelenburg position leads to a decrease in functional residual capacity. In combination with PNP, this position further reduces functional residual capacity, potentially lowering it below the closing capacity. This leads to airway collapse and the development of atelectasis. Such atelectasis can exacerbate existing ventilation-perfusion mismatch. Applying PEEP during ventilation helps prevent this phenomenon. Diaphragmatic displacement caused by increased intrathoracic pressure leads to decreased compliance. Lung displacement in the cranial direction in the Trendelenburg position may result in endobronchial intubation or airway displacement, and repeated movement of the endotracheal tube may cause upper airway edema. Additionally, the Trendelenburg position may increase intracranial pressure, provoke cerebral edema, and contribute to the development of subconjunctival hemorrhage, which is exacerbated by hypercapnia resulting from CO2 absorption during pneumoperitoneum.

The reverse Trendelenburg position can eliminate ventilation-perfusion imbalance, reduce intracranial pressure, and decrease the risk of passive regurgitation. However, it carries the risk of reducing venous return, leading to hypotension, and possibly causing cerebral and cardiac ischemia in predisposed patients. Therefore, it is very important to address any pre-existing hypovolemia before starting the surgical intervention.

During continuous CO2 insufflation during pneumoperitoneum, arterial partial pressure of carbon dioxide (PaCO2) progressively increases after the start of CO2 insufflation in patients under mechanical ventilation during gynecological laparoscopy in the Trendelenburg position or during laparoscopic cholecystectomy in the reverse Trendelenburg position. Due to decreased tidal volume and subsequent minute ventilation, the CO2 level in these patients often increases [15]. Despite a significant increase in PaCO2 after pneumoperitoneum in the standard group (tidal volume 10 mL/kg, PEEP 0) in the reverse Trendelenburg and Trendelenburg positions, no difference was found in the group with low tidal volume (6 mL/kg) and PEEP 5 cm H2O in any position. [7]. The influence of the reverse Trendelenburg position on respiratory mechanics is less known [15, 20], although some studies suggest worsening of respiratory mechanics in obese patients [47, 54].

The study by Russo et al. examined the effects of PEEP on the respiratory system and cardiac function using transthoracic echocardiography [60]. They showed that PaO2 values were improved in the PEEP 5 and 10 groups, while both PaCO2 and end-tidal carbon dioxide (EtCO2) increased after gas insufflation in the control group with PEEP 0. Although both were reduced with PEEP 10 cm H2O, PEEP 5 cm H2O only improved EtCO2 values. In another study, tidal volume 10 mL/kg versus 6 mL/kg and PEEP 5 cm H2O were used, and positive benefits were observed in PaCO2 values and arterial blood gas pH [7]. However, PaO2 values decreased after pneumoperitoneum in both groups; to prevent this, a recruitment maneuver could be performed after PNP [7].

Increased intra-abdominal pressure and the development of compartment syndrome worsen lung biomechanics and gas exchange [43, 48]. In obese patients, pneumoperitoneum does not significantly increase pleural pressure or compress the lungs at resting volume. Adding PEEP of 7 cm H2O resulted in a significant decrease in respiratory system elastance with pneumoperitoneum, but not before, and PEEP did not affect lung elastance [40]. Additionally, no correlation was found between BMI and changes in esophageal pressure with pneumoperitoneum. The main conclusion drawn from these results is that the passive respiratory system has a remarkable ability to adapt to a sudden increase in abdominal volume and pressure without compressing the lungs [40].

It is important to distinguish the effects of pneumoperitoneum during laparoscopic surgery from the effects of gradual increases in intra-abdominal volume caused by less acute conditions such as pregnancy, obesity, and ascites. Although conditions like obesity are associated with increased abdominal pressure [9, 65], they typically do not reach the levels observed with pneumoperitoneum (20 cmH2O). In chronic conditions, there is likely enough time for adaptation of the skeletal muscles of the abdominal wall and possibly the diaphragm to accommodate the additional intra-abdominal volume without causing a significant rise in abdominal pressure. Adaptation of the diaphragmatic muscle length will reduce diaphragmatic tension and transdiaphragmatic pressure, allowing the diaphragm to shift further into the chest, thereby increasing pleural pressure at rest.

CONCLUSION

In conclusion, while the optimal ventilatory support settings for AHRF in the intensive care unit (ICU) are well-established, there remains ongoing debate regarding the appropriate ventilation strategy for patients undergoing general anesthesia in the operating room. Research conducted in the ICU has highlighted the protective benefits of low TV ventilation, along with increased PEEP, leading to improved lung tissue preservation, enhanced survival rates, and shortened hospital stays. However, the application of these strategies in elective surgeries with lower risk profiles, particularly in laparoscopic procedures, requires further investigation. Despite the documented advantages of laparoscopic surgery, including faster recovery and reduced hospital stays, the potential impact of PNP on respiratory function cannot be overlooked. Addressing the role of personalized PEEP levels during laparoscopic procedures may offer promising avenues for improving respiratory biomechanics, mitigating atelectasis formation, and minimizing organ dysfunction. Further research in this area is warranted to optimize perioperative ventilatory management and enhance patient outcomes in the context of laparoscopic surgery.

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D. A. Klyuyev – script writing, and revision.

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ВЛИЯНИЕ ПНЕВМОПЕРИТОНЕУМА НА ДЫХАТЕЛЬНУЮ СИСТЕМУ: ОСЛОЖНЕНИЯ И СТРАТЕГИИ МЕНЕДЖМЕНТА В ЛАПАРОСКОПИЧЕСКОЙ ХИРУРГИИ

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Лапароскопическая хирургия, являющаяся основой современной хирургической практики, привносит революционные изменения в традиционные методы хирургического вмешательства за счет использования минимально инвазивных процедур. Однако этот инновационный подход ставит перед медицинским сообществом сложные задачи, особенно в области управления дыханием, что требует глубокого понимания его физиологических последствий. Пневмоперитонеум, неотъемлемая составляющая лапароскопической хирургии, предполагает инсуфляцию брюшной полости углекислым газом (CO2) для создания подходящего рабочего пространства. Однако это может приводить к физиологическим адаптациям, оказывающим отрицательное влияние на респираторную систему. Изменения, такие как повышение пикового инспираторного давления, снижение динамической податливости дыхательной системы и развитие интраоперационного ателектаза, подчеркивают сложное взаимодействие между пневмоперитонеумом и физиологией дыхания.

В свете этих проблем положительное давление в конце выдоха выступает важным инструментом для смягчения негативного влияния пневмоперитонеума на механику дыхания и газообмен. Поддерживая проходимость дыхательных путей и предотвращая альвеолярный коллапс во время выдоха, положительное давление в конце выдоха помогает противостоять снижению функциональной остаточной емкости, связанной с повышенным внутрибрюшным давлением. Кроме того, положительное давление в конце выдоха служит для оптимизации рекрутирования легких, тем самым улучшая вентиляционно-перфузионное соотношение и повышая оксигенацию.

Искусственная вентиляция легких во время лапароскопических операций сама по себе может потенциально усугублять повреждение легких. Применение протективных стратегий вентиляции легких, таких как низкий дыхательный объем легких в сочетании с положительным давлением в конце выдоха, являются доказанными компонентами для снижения вентилятор-ассоциированного повреждения легких и послеоперационных легочных осложнений. Оптимальное применение этих стратегий остается предметом постоянных споров, что подчеркивает необходимость персонализированных подходов, учитывающих особенности пациентов и хирургические условия.

Ключевые слова: положительное давление в конце выдоха; протективная вентиляция легких; лапароскопическая хирургия; пневмоперитонеум

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ПНЕВМОПЕРИТОНЕУМНЫҢ ТЫНЫС АЛУ ЖҮЙЕСІНЕ ӘСЕРІ: ЛАПАРОСКОПИЯЛЫҚ ХИРУРГИЯДАҒЫ АСҚЫНУЛАР МЕН БАСҚАРУ СТРАТЕГИЯЛАРЫ

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Қазіргі хирургиялық тәжірибенің негізі болып табылатын лапароскопиялық хирургия аз инвазивті процедураларды қолдану арқылы дәстүрлі хирургиялық әдістерге революциялық өзгерістер әкеледі. Алайда, бұл инновациялық тәсіл медициналық қоғамдастыққа күрделі міндеттер қояды, әсіресе оның физиологиялық салдарын терең түсінуді қажет ететін тыныс алуды басқару саласында. Пневмоперитонеум, лапароскопиялық хирургияның ажырамас бөлігі, қолайлы жұмыс кеңістігін құру үшін іш қуысын көмірқышқыл газымен (CO_2) инсуфляциялауды қамтиды. Алайда, бұл тыныс алу жүйесіне теріс әсер ететін физиологиялық бейімделулерге әкелуі мүмкін. Тыныс алу қысымының жоғарылауы, тыныс алу жүйесінің динамикалық икемділігінің төмендеуі және интраоперациялық ателектаздың дамуы сияқты өзгерістер пневмоперитонеум мен тыныс алу физиологиясы арасындағы күрделі өзара әрекеттесуді көрсетеді.

Осы проблемаларды ескере отырып, дем шығарудың соңында оң қысым (ДШОҚ) пневмоперитонеумның тыныс алу механикасы мен газ алмасуына теріс әсерін азайтудың маңызды құралы болып табылады. Тыныс алу жолдарының өткізгіштігін сақтау және дем шығару кезінде альвеолярлы коллапстың алдын алу арқылы ДШОҚ құрсақішілік қысымның жоғарылауымен байланысты функционалды қалдық сыйымдылықтың төмендеуіне қарсы тұруға көмектеседі. Сонымен қатар, ДШОҚ өкпені тартуды оңтайландыруға қызмет етеді, осылайша желдету-перфузиялық қатынасты жақсартады және оттегімен қанықтыруды арттырады.

Лапароскопиялық операциялар кезінде механикалық желдету өкпенің зақымдануын нашарлатуы мүмкін. Өкпенің тыныс алу көлемінің төмендігі сияқты протективті желдету стратегияларын қолдану ДШОҚ-мен бірге өкпенің желдеткішпен байланысты зақымдануын және операциядан кейінгі өкпе асқынуларын азайту үшін дәлелденген компоненттер болып табылады. Бұл стратегияларды оңтайлы қолдану пациенттердің ерекшеліктері мен хирургиялық жағдайларды ескеретін жекелендірілген тәсілдердің қажеттілігін көрсететін тұрақты пікірталас тақырыбы болып қала береді.

Кілт сөздер: дем шығарудың соңында оң қысым; өкпенің протективті желдетілуі; лапароскопиялық хирургия; пневмоперитонеум