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Anesthesia Management in Robotic-Assisted Surgery: Evaluating Challenges, Benefits, And Patient Outcomes in Geriatric Populations

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Abstract

Background: Robotic-assisted surgery (RAS) has revolutionized surgical practices, particularly in the geriatric population, by offering advantages such as reduced complication rates, less blood loss, and shorter hospital stays compared to conventional approaches. However, the unique challenges posed by RAS, particularly concerning anesthesia management, necessitate careful consideration of patient safety and outcomes.

Methods: This review analyzes the physiological implications of RAS, focusing on the hemodynamic, pulmonary, and neurological challenges associated with pneumoperitoneum and extreme positioning during surgery. A comprehensive literature review was conducted to evaluate the impact of these factors on patient outcomes, with a specific emphasis on the elderly demographic.

Results: Findings indicate that pneumoperitoneum can significantly alter hemodynamic stability, leading to increased systemic vascular resistance and reduced cardiac output, particularly in patients with pre-existing cardiovascular conditions. Additionally, extreme positions, such as steep Trendelenburg, exacerbate these effects, potentially resulting in cerebral and myocardial hypoperfusion. The review also highlights the importance of tailored anesthesia strategies, including fluid management and neuromuscular blockade, to mitigate these risks.

Conclusion: While RAS offers distinct advantages, the associated anesthesia challenges require meticulous planning and coordination between surgical and anesthetic teams. Implementing strategies to minimize

pneumoperitoneum pressure and limiting the duration of extreme positioning can enhance patient safety and optimize postoperative outcomes. Continued research is essential to refine protocols and ensure safe practice in vulnerable patient populations.

Keywords: Robotic-assisted surgery, anesthesia challenges, elderly patients, pneumoperitoneum, patient outcomes.

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1. Introduction

Robotic-assisted surgery (RAS) consistently demonstrates superior results compared to conventional laparotomy in the expanding geriatric demographic, without compromising safety [1]. The primary advantages include a lower complication rate, less blood loss, and abbreviated hospital stays. Lavoie et al. [2] report an overall complication rate for adverse events of 21% in RAS compared to 66% with the open method. Extreme postures, such as steep Trendelenburg for urogynecological surgery and reverse Trendelenburg for abdominal surgery, are used to enhance surgical access. Concerns regarding extended pneumoperitoneum in conjunction with extreme positioning necessitate a thorough evaluation of each patient's comorbidities, especially severe cardiopulmonary disease, intracranial pathology, and advanced glaucoma, to prevent adverse effects on the respiratory, cardiovascular, and cerebral systems while considering the potential benefits of RAS [3,4].

It is crucial to note that once the patient is affixed to the robot, the position cannot be reversed without undocking. Consequently, each surgical team must possess a contingency plan for the prompt undocking of the robot if necessary. This study examines the cardiovascular, pulmonary, ophthalmic, and brain physiopathology during RAS and provides techniques to mitigate particular difficulties that may occur in aged patients.

2. Haemodynamic consequences of pneumoperitoneum

The pneumoperitoneum causes elevated intra-abdominal pressure, resulting in the release of neuro-endocrine vasoactive substances, including catecholamines and vasopressin, in reaction to gas insufflation. This results in an elevation of systemic vascular resistance (SVR) and a consequent reduction in preload and inotropic function, which is further intensified by compression of the inferior vena cava [5]. A reduction in ventricular filling pressures leads to a diminished stroke volume (SV), perhaps resulting in a fall in mean arterial pressure. In individuals with compromised myocardial function, the increase in cardiac workload and myocardial oxygen demand may result in significant cardiac consequences [6].

In RAS, there exists a danger of cardiac arrhythmias, including severe bradycardia, resulting from vagally mediated cardiovascular reflexes triggered by rapid peritoneal distension caused by carbon dioxide (CO_2) insufflation. Restricting intra-abdominal pressure (IAP) to <8–10 mmHg and using a modest flow rate for CO_2 insufflation effectively mitigates pathophysiological alterations during pneumoperitoneum. Additionally, pneumoperitoneum may adversely affect splanchnic perfusion, particularly in the elderly population. Elevated intra-abdominal pressure induces a decrease in hepatic and renal blood flow, therefore altering the pharmacokinetics of medicines processed by these organs. Consequently, the dosages of potentially nephrotoxic or hepatotoxic medications should be decreased [7].

3. Haemodynamic implications of pneumoperitoneum in conjunction with reverse Trendelenburg positioning

The decrease in cardiac output (CO) and mean arterial pressure (MAP) induced by pneumoperitoneum is exacerbated in the reverse Trendelenburg position. Hypotension may result in perilous cerebral and myocardial hypoperfusion. Exercise caution in patients with diminished cardiac reserve and adjust the level of intra-operative hemodynamic monitoring based on the patient's peri-operative risk. In significant abdominal RAS, the use of transoesophageal echocardiography is advised in cases of peri-operative hemodynamic instability [8].

RAS often persists for an extended period, making it crucial to prevent fluid imbalance. Goal-oriented fluid management employing dynamic indices such as stroke volume, stroke volume variation, and pulse pressure variation may facilitate the maintenance of optimal intravascular volume [9]. In the absence of hemorrhagic complications, adherence to a zero fluid balance is advisable to prevent hypervolemia, and dilutional anemia, and mitigate the risk of head and neck edema. Should hypotension arise, the administration of a vasopressor should be contemplated to avert excessive fluid infusion [10].

4. Haemodynamic implications of pneumoperitoneum in conjunction with the Trendelenburg position

The impact of pneumoperitoneum on cardiac output is diminished in the head-down position due to gravitational influences; however, the combination of head-down positioning and pneumoperitoneum can elevate both mean arterial pressure and systemic vascular resistance, as evidenced by Falabella et al. [11] through transoesophageal echocardiography during robotic-assisted laparoscopic prostatectomy (RALP). The alterations result from elevated intra-abdominal pressure exerting compression on the aorta and augmenting afterload. Lester et al. [12] and Danic et al. [13] demonstrated an elevation in MAP of 25% and 17%, respectively. In individuals with diminished myocardial contractility, the head-down posture may induce heart failure. Lester et al. [12] demonstrated that the stroke work indices of the right and left ventricles rose by 65% and 35%, respectively. An elevation in myocardial oxygen consumption may result in various cardiac problems, contingent upon the presence of poor myocardial function or ischemic heart disease. The head-down position may also elevate central venous pressure, as well as pulmonary arterial and wedge pressures. Patients with significant pulmonary hypertension are unsuitable candidates for RAS which necessitates a steep Trendelenburg position. However, to our knowledge, no established threshold of pulmonary artery pressure precludes the use of RAS.

The Steep Trendelenburg position (≥30°) should be employed only for the duration essential for surgery and avoided in high-risk patients. The extraperitoneal approach should be utilized when feasible to minimize the Trendelenburg angle and/or CO2 insufflation pressure [14].

5. Implications for pulmonary health

Pneumoperitoneum is recognized for increasing the rigidity of the chest wall and respiratory system. Lester et al. [12] documented a significant decrease in lung compliance from 60 ml cmH2O−1 to 28 ml cmH2O−1 during RALP. Kalmar et al.15 observed the same outcomes. This decrease leads to elevated inspiratory pressures, increasing the risk of barotrauma [12,15].

The pulmonary consequences of elevated intrathoracic pressure due to pneumoperitoneum include a reduction in pulmonary compliance and functional residual capacity (FRC), with a risk of atelectasis and ventilation/perfusion imbalance. Atelectasis and ventilation/perfusion mismatch may cause hypoxemia. These alterations are more significant in the head-down posture owing to the upward displacement of the diaphragm [16].

A protective ventilation approach using low tidal volume combined with positive end-expiratory pressure (PEEP) is advised to enhance functional residual capacity (FRC) and optimize respiratory mechanics. Alveolar recruitment maneuvers may enhance oxygenation. This method minimizes stress and strain while decreasing postoperative respiratory difficulties. PEEP enhances dynamic compliance, positively affecting damage from alveolar opening and closure, and lowers the incidence of atelectasis. In the elderly, the advantageous benefits of administering PEEP must be weighed against its possible detriment to cardiac output. Numerous single-center studies have shown the advantages of pressure-controlled ventilation over volume-controlled ventilation since it facilitates lower peak pressures and enhances the ratio of arterial oxygen partial pressure to fractional-inspired oxygen [17].

Systemic CO2 absorption must be taken into account in the anesthetic administration. Mechanical breathing must be calibrated to prevent hypertension and dysrhythmias that may arise from hypercarbia. The reabsorption of CO2, in conjunction with impaired ventilation and increased dead space, may result in respiratory acidosis.

Geriatric individuals undergoing RAS often suffer from chronic obstructive pulmonary disease (COPD). Patients experience a higher incidence of intra-operative and postoperative complications, which can result in extended hospitalizations and increased mortality. In high-risk individuals, such as those with COPD, the application of a high-flow nasal cannula or noninvasive ventilation during the peri-operative phase may enhance respiratory function and subsequently diminish the likelihood of atelectasis and re-intubation.

The application of deep neuromuscular block (dNMB) may mitigate the necessity for elevated insufflation pressure, thereby averting associated hemodynamic and respiratory complications. However, dNMB necessitates neuromuscular monitoring and appropriate reversal, via direct or indirect antagonists, to avert postoperative residual curarization, particularly as the elderly exhibit heightened vulnerability to adverse postoperative respiratory incidents [18].

6. Alterations in intracranial pressure and postoperative cognitive impairments

The conjunction of pneumoperitoneum with steep Trendelenburg may elevate intracranial pressure (ICP) to levels above 20 mmHg, although seldom; however, this phenomenon has little clinical significance in individuals devoid of neurological diseases. Kamine et al.19, in a limited cohort of patients (n = 9) having laparoscopy and requiring ventriculoperitoneal shunt installation, established that intracranial pressure (ICP) rose linearly with intra-abdominal pressure up to 25 mmHg [19]. No neurological problems were identified. Robba et al. advocate caution during laparoscopy for individuals susceptible to intracranial hypertension, including those with cerebral tumors or concurrent neurological disorders. Robba et al. [20] suggest that noninvasive evaluations of intracranial pressure (ICP), such as ultrasonic measurement of optic nerve sheath diameter (ONSD) and transcranial Doppler (TCD) techniques, may be beneficial for assessing the risk and potentially managing pathological elevations of ICP through osmotic agents, hyperventilation, or conversion to an open procedure. The optic nerve sheath diameter, the diastolic component of the TCD cerebral blood flow velocity, and the pulsatility index significantly increased following the combination of pneumoperitoneum and head-down positioning. According to Kim et al., in 15% of patients, ONSD increased to levels indicative of an ICP >20 mmHg during this combination; however, Verdonck et al. [22] found no changes in ONSD, implying that the increases in ICP were minimal.

Nevertheless, the often-low occurrence of neurological sequelae after RAS complicates the endorsement of more comprehensive screening protocols for intracranial hypertension. The steep Trendelenburg position, in conjunction with pneumoperitoneum and mechanical ventilation, can result in decreased cardiac output and cerebral hypoperfusion [23]. The elevation of arterial carbon dioxide tension ($PaCO_2$) from CO_2 insufflation may exacerbate cerebral blood flow stasis and intracranial pressure (ICP) due to pulmonary vasoconstriction and central venous hypertension. These alterations may influence the emergence of postoperative cognitive disorders, such as postoperative cognitive dysfunction (POCD) and postoperative delirium (POD) [3].

The correlation between compromised cerebrovascular conditions and surgical neurological results in geriatric anesthesia is now being examined. Nicolai Goettel et al. [24] showed that the autoregulatory plateau in cerebral blood flow is diminished in individuals undergoing sevoflurane anesthesia, irrespective of age. Furthermore, compromised intra-operative cerebral autoregulation does not appear to predict early postoperative cognitive dysfunction (POCD) in elderly patients following major noncardiac surgery [25,26]. Conversely, Chan et al. [27] indicated that patients undergoing robotic-assisted laparoscopic prostatectomy (RALP) may experience increased intracranial pressure (ICP) alongside short-term postoperative cognitive impairment. The interplay of many variables, including anesthesia, age, posture, and CO_2 insufflation during RAS, may predispose older patients to postoperative cognitive impairments; nonetheless, this subject requires additional examination.

In the steep Trendelenburg position, the Bispectral Index (BIS) exhibits a substantial rise. This may result in an exacerbation of anesthesia, adversely affecting cognitive functions in the elderly. In geriatric patients undergoing noncardiac surgery, sustaining a BIS value between 40 and 60 appears to mitigate the risk of postoperative complications. During RAS, elevated thresholds (approximately 60) may be acceptable. It is essential to acknowledge that, while further randomized trials are necessary, BIS values below 40–45 may elevate long-term mortality (>1 year) [28].

7. Fluctuation in intraocular pressure

The elevation of intraocular pressure (IOP) during steep Trendelenburg is a recognized issue. Instances of optic nerve damage have been documented after RALP when patients are positioned in the steep Trendelenburg orientation. Extended head-down postures increase the risk of blindness in people with moderate to severe glaucoma, which is common among the elderly. In certain centers, ophthalmologists may cancel robotic prostatectomy or hysterectomy cases due to advanced glaucoma. Recent literature categorizes glaucoma based on the Hodapp–Parrish–Anderson Classification of Glaucoma Severity; a positive result indicates a mean deviation on the Humphrey visual field test worse than −12 decibels [29].

Strategies to mitigate potential harm in patients with risk factors, including advanced age, hypertension, diabetes, and macular degeneration, have been explored and encompass the following: minimizing head-down positioning to the least extent necessary for optimal surgical conditions; employing dNMB; favoring total intravenous anesthesia and/or dexmedetomidine over inhalational anesthetics; and utilizing the modified Z position with a horizontal alignment of the head and shoulders [30,31]. The 25° Trendelenburg posture markedly reduced the increase in intraocular pressure compared to the 30° position, without elevating the surgeons' exertion. The elevation in intraocular pressure (IOP) seems to be influenced by an increase in arterial carbon dioxide tension ($PaCO2$), resulting in vasodilation of the choroid plexus.

Yoo et al. [32] demonstrated that deep neuromuscular blockade (dNMB), characterized by a posttetanic count of 1 to 2, induces a lesser rise in IOP compared to moderate neuromuscular blockade (NMB) with a train-of-four count of 1 to 2. This observation may be attributed to enhanced relaxation of extra-ocular muscles, facilitating aqueous humour outflow. The elevation of intraocular pressure (IOP) appears to be diminished with propofol compared to sevoflurane during robotic-assisted surgery (RAS) in the head-down position. Furthermore, a continuous infusion of dexmedetomidine (0.4 μg kg−1 h−1) initiated immediately after the induction of anesthesia and maintained until the conclusion of surgery during propofol-based anesthesia in patients undergoing robotic-assisted laparoscopic prostatectomy (RALP) significantly mitigated IOP. Although IOP swiftly reverts to baseline levels, the long-term implications of elevated IOP on ocular structures remain ambiguous [33-35].

Hirooka et al. [36] discovered that while intraocular pressure (IOP) rose during robotic-assisted laparoscopic prostatectomy (RALP), no ocular problems ensued. Mizumoto et al. [37] similarly observed no discernible abnormalities in ocular structural characteristics assessed at three and six months post-RALP. No notable alterations were seen in the ocular characteristics assessed three months post-procedure in individuals with a healthy ocular system. The technique of some organizations attempting to prophylactically reduce intraocular pressure during steep Trendelenburg positioning is controversial. Additional research is required to establish that an elevation in intraocular pressure (IOP) is associated with negative clinical outcomes, particularly in those with already increased IOP.

Prior research highlights a significant issue about patients with compromised ocular systems, as previous damage may be aggravated during RAS, particularly when severe Trendelenburg positioning is necessitated. An ophthalmological consultation for risk assessment may be more secure for patients with ocular pathology, alongside optical coherence tomography to assess retinal thickness. No formal guidelines are available concerning preoperative vision screening or perioperative medication for patients undergoing RAS with known elevated intraocular pressure. It has been recommended that individuals with previous ophthalmological disorders seek consultation before RAS [38,39].

8. Conclusions

Robotic-assisted surgery represents a significant advancement in surgical techniques, particularly for elderly patients who often present with multiple comorbidities and increased surgical risks. This review underscores the necessity of a comprehensive understanding of the physiological impacts of RAS, particularly regarding anesthesia management. The interplay of pneumoperitoneum and extreme positioning introduces considerable hemodynamic and respiratory challenges that can adversely affect patient outcomes.

The elevation of intra-abdominal pressure due to pneumoperitoneum can lead to increased systemic vascular resistance and reduced cardiac output, necessitating vigilant monitoring and management of hemodynamic parameters. Furthermore, the use of extreme positions, particularly steep Trendelenburg, can exacerbate these challenges, leading to potential complications such as cerebral hypoperfusion and arrhythmias. These factors are particularly concerning in geriatric populations, who may have compromised cardiovascular and pulmonary systems.

To address these challenges, anesthetic strategies must be tailored to individual patient needs. This includes goal-directed fluid management and judicious use of vasopressors to maintain hemodynamic stability. Additionally, employing deep neuromuscular blockade may reduce the need for high insufflation pressures, further mitigating associated complications. The implementation of protective ventilation strategies, such as low tidal volume and positive end-expiratory pressure (PEEP), can enhance pulmonary function and reduce the risk of postoperative respiratory complications.

In conclusion, while robotic-assisted surgery offers numerous benefits, it also poses unique challenges that require a coordinated approach between surgeons and anesthesiologists. Ongoing research is vital to refine anesthetic protocols, ensuring that the advantages of RAS are maximized while safeguarding patient safety, particularly among vulnerable populations. The establishment of standardized guidelines and best practices will further enhance the effectiveness of RAS, leading to improved patient outcomes in the surgical landscape.

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إدارة التخدير في الجراحة المدعومة بالروبوت: تقييم التحديات والفوائد ونتائج المرضى في الفئات العمرية المتقدمة

الملخص

الخلفية :أحدثت الجراحة المدعومة بالروبوت (RAS) ثورة في الممارسات الجراحية، خاصة في السكان المسنين، من خلال تقديم مزايا مثل تقليل معدلات المضاعفات، أقل فقدان للدم، ومدة إقامة أقصر في المستشفى مقارنةً بالطرق التقليدية. ومع ذلك، تقتضي التحديات الفريدة التي تطرحها RAS، خصوصًا فيما يتعلق بإدارة التخدير، اعتبارًا دقيقًا لسلامة المرضى ونتائجهم.

الطرق :تحلل هذه المراجعة الآثار الفسيولوجية لـRAS ، مع التركيز على التحديات الديناميكية الدموية والتنفسية والعصبية المرتبطة بوجود الهواء في التجويف البطني ووضعيات الجسم المتطرفة أثناء الجراحة. تم إجراء مراجعة شاملة للأدبيات لتقييم تأثير هذه العوامل على نتائج المرضى، مع التركيز بشكل خاص على الفئة العمرية المتقدمة.

النتائج :تشير النتائج إلى أن وجود الهواء في التجويف البطني يمكن أن يؤثر بشكل كبير على استقرار الديناميكا الدموية، مما يؤدي إلى زيادة مقاومة الأوعية الدموية النظامية وانخفاض الناتج القلبي، خاصةً في المرضى الذين يعانون من حالات قلبية قائمة مسبقًا. بالإضافة إلى ذلك، فإن الوضعيات المتطرفة، مثل وضعية تريندلينبرغ الشديدة، تزيد من تفاقم هذه التأثيرات، مما قد يؤدي إلى انخفاض تدفق الدم إلى الدماغ والقلب. تسلط المراجعة أيضًا الضوء على أهمية استراتيجيات التخدير المخصصة، بما في ذلك إدارة السوائل وحجب الأعصاب العضلية، لتخفيف هذه المخاطر.

الخاتمة :بينما تقدم RAS مزايا واضحة، فإن التحديات المرتبطة بالتخدير تتطلب تخطيطًا دقيقًا وتنسيقًا بين الفرق الجراحية والتخديرية. يمكن أن يؤدي تطبيق استراتيجيات لتقليل ضغط وجود الهواء في التجويف البطني والحد من مدة الوضعيات المتطرفة إلى تحسين سلامة المرضى وتحقيق نتائج ما بعد الجراحة بشكل أفضل. إن استمرار البحث أمر ضروري لتحسين البروتوكولات وضمان ممارسة آمنة في الفئات المرضية الضعيفة.

الكلمات المفتاحية :الجراحة المدعومة بالروبوت، تحديات التخدير، المرضى المسنون، وجود الهواء في التجويف البطني، نتائج المرضى.