




Special Anesthesiologic Considerations in Robot-Assisted Thoracic Surgery

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Abstract

Purpose of Review This review summarizes the key issues for preoperative, peri- and intraoperative, and postoperative patient management for robotic-assisted thoracic surgery (RATS). It provides practical guidance for anesthesiologists and thoracic surgeons starting a RATS program.

Recent Findings RATS is a new technological approach to execute minimal invasive chest operations. In management of RATS patients, the established ERAS principles for video-assisted thoracoscopic surgery (VATS) apply. In addition, RATS imposes additional conditions on anesthesiologists, nurses, and surgeons alike: The spatial constriction in operation theaters caused by the large robotic equipment longs for a reallocation of the anesthetist's and surgeon's working environment that may vary additionally depending on the type of surgery performed in the individual patient. Additionally, the implementation of a positive pressure carbon dioxide gas cavity in the pleura has a direct effect on patient cardio-circulatory and respiratory mechanics that have to be balanced by the anesthesiologist.

Summary RATS advances by replacing open surgery approaches and will complement—but most likely not replace—video-assisted thoracoscopic surgery (VATS). RATS brings new specific intraoperative requirements to the anesthesiological and surgical team members that have to be implemented into clinical routine.

Keywords Anesthesiology · Arrangement of resources · Intraoperative considerations · Operation room utilization · Robotic-assisted thoracoscopic surgery

Introduction

Minimal invasive surgical approaches by video-assisted thoracoscopic surgery (VATS) have been established in clinical

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practice for the surgical treatment of diseases of the lung, esophagus, and mediastinum [1–3]. Patients benefit from a reduction in the surgical trauma translating into reduced postoperative stress response. Ultimately, postoperative pulmonary complication rates and length of stay decrease and patient satisfaction increase [4••]. Thoracic surgery clinics worldwide make use of these positive effects and combine them with optimized pre- and postoperative anesthesiologic and conservative management to generate comprehensive enhanced recovery programs for their patients to optimize clinical performance and patient satisfaction and to minimize hospital and especially intensive care resource requirements [5••, 6].

In the last decade, robotic-assisted thoracoscopic surgery (RATS) has emerged as a new treatment modality for thoracic surgery patients [7–10] (Fig. 1). The RATS approach is attractive for surgeons since it facilitates complex minimal invasive surgical preparations in delicate and confined anatomical regions. Numerous studies have documented safety as well as oncological equivalence of RATS compared to open surgery and VATS approaches [11–13]. As a result, RATS applications for

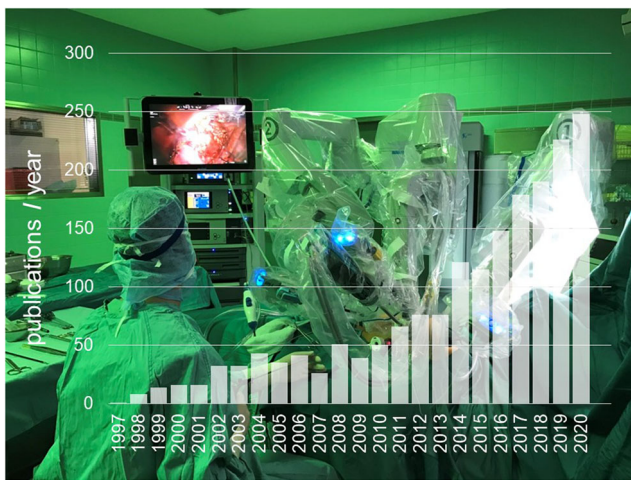


Fig. 1. Timeline of publications on “robot-assisted thoracic surgery.” A Medline research documents a rapid development of this field since the first publication in 1997.

anatomical lung resections including lymphadenectomy, esophageal resections, and resection of mediastinal tumors are continuously increasing [14]. Currently, RATS has to step up to document its added value compared to considerably increased treatment costs [15, 16, 17]. As robotic surgical platforms continue to evolve, this dilemma will eventually be overcome.

For the surgeon, the advantages of RATS include true 3-dimensional imaging with binocular glasses and the use of multiarticular forceps that allow the performance of high-precision operations [18]. For both the surgeon and the anesthesiologist, there is a multitude of perioperative considerations for RATS surgery [19]. This article focuses upon preoperative patient optimization, intraoperative considerations for surgeons and anesthesiologists, and postoperative management of patients undergoing RATS surgery.

Preoperative Considerations

Premedication and Preoperative Assessment RATS of the chest affects—similar to VATS approaches—not only the respiratory but also the cardiovascular system. Preoperative patient evaluation for RATS therefore parallels that for VATS [20]. It is crucial to assess patients carefully regarding preexisting cardiovascular or respiratory disease in order to detect any issues that might jeopardize the outcome and to ensure the optimal anesthetic regime [20]. Electrocardiography is performed for cardiac evaluation. If signs of cardiac malperfusion are detected, further examinations like cardiac ultrasound or coronary angiography are needed [21–22]. Furthermore assessment of right ventricular function can be useful [23]. Pulmonary evaluation should include a chest X-ray and any computed tomography testing needed for surgical assessment and planning. Any signs of

emphysema, pulmonary obstruction, or infection must be taken into consideration when assessing the pulmonary reserve. Lung function tests are required before thoracic surgery [24]. Here, $p\text{CO}_2$, FEV_1 , and diffusion capacity for carbomonoxide are the main parameters that must be considered. As far as capillary blood gases are concerned, the partial pressure of carbon dioxide ($p\text{CO}_2$) and for oxygen ($p\text{O}_2$) are of interest as they reflect the preoperative ventilatory state of the patient. The pH highlights whether the patient is acidotic or alkalotic. Acidosis can be due to the retention of CO_2 or the accumulation of acidotic metabolites, whereas alkalosis can be caused by hyperventilation or renal diseases. Other laboratory findings of interest are the inflammatory state of the patient, pictured by C-reactive protein, interleukins, and leukocytes, as well as the metabolic situation including blood glucose and triglycerides along with the thyroid status [25–27]. As in any other preoperative evaluation, hints towards a difficult management of the airway must be noted (Mallampati score, previous anesthetic management, thyro-mental gap, deviation or compression of the trachea seen in X-rays) [28–30]. Thoracic CT imaging done in diagnostics and planning of the surgery is also useful for the anesthetist [27]. If the patient shows extraordinary high anxiety, a sedating premedication with benzodiazepines is administered as long as there are no contraindications [31]. Finally, the different modalities for postoperative pain control should be discussed with the patient to identify a suitable strategy for the individual patient and prepare the required interventions, if needed (e.g., epidural catheter or patient-controlled intravenous analgesia) [6]. In most RATS interventions, multimodal analgesics combined with local anesthesia of the surgical incisions are considered sufficient for pain control [32, 22]. Intercostal nerve blockade and submuscular analgesic depositories may be applied additionally [33, 34]. Especially patients with an increased surgical likelihood for conversion to thoracotomy should be counselled very differentiated.

Preoperative Rehabilitation and Medical Optimization

Preexisting comorbidities should be controlled, and modifiable risk factors and medications should be optimized before surgery [24, 33]. To minimize postoperative pulmonary complications and impaired wound healing, smoking cessation should be encouraged as far in advance as possible [5, 33]. Previous studies have shown that the risk for these complications including death is inversely correlated with the length of smoking cessation [35]. The medication of patients with symptomatic chronic obstructive pulmonary disease should be optimized to minimize symptoms and the risk of intra- and postoperative deterioration. Exercise prehabilitation has been suggested to improve patients' preoperative health status

and to reduce postoperative complications. However, a recent meta-analysis was not able to show relevant effects on postoperative complication rates in lung cancer patients [36].

Peri- and Intraoperative Considerations

Limited Patient Accessibility Patient positioning in VATS and RATS operations is similar. However, to facilitate RATS interventions, the robotic device has to be positioned directly next to the operation table and connected to the patient. The current large and cantilevered systems inevitably block patient accessibility for surgeon and anesthesiologist, requiring a re-arrangement of equipment (e.g., anesthesia workstation, perfusors) and staff (Fig. 2) [37]. Depending on the spatial conditions in the individual surgical theaters, this may limit anesthesiological accessibility of the head, airways, and upper torso. Extensions for intravenous lines, the arterial line, and the airway circuit may be necessary [19]. It is mandatory that the anesthesiology staff ensure that these vital connections are visible and accessible. In the course of surgery, manipulations of these lines will be very difficult with the robotic system connected to the patient.

Perioperative Antibiotic Therapy No difference has been shown regarding surgical site infections (SSI) for RATS and open thoracic surgery [38]. Currently there are no consented

guidelines for surgical antibiotic prophylaxis neither before VATS nor RATS surgery. The ERAS/ESTS guideline for lung surgery recommends the use of preoperative prophylactic antibiotics in order to decrease the rate of SSI [5•]. However, there was no effect on the postoperative pneumonia or empyema rate. Our hospital policy is to administer a first generation Cephalosporine (e.g., Cefuroxim) intravenously no more than 60 min prior to skin incision, usually at the time of anesthesia induction. Our rationale is that Cephalosporines cover the bacteria identified in the skin and respiratory flora and that the drugs share both low-cost and low allergic potential [39].

Airway Management In general, RATS procedures are performed under single-lung ventilation. For airway separation, double-lumen tubes or bronchial blocking devices are applied [40, 41]. In studies no advantages of either device have been shown [42–44]. The decision how to instrument the airways depends on (1) patient-specific factors (e.g., difficult airway), (2) local hospital standards, and (3) practical experience of the individual anesthesiologist. When choosing a double-lumen tube, the left bronchial version is preferred whenever possible to reduce the risk of tube dislocation by accidental movement. The correct placement of the lung separation device must be controlled after initial placement and must be reevaluated after the patient is positioned by the surgeon.

Patient Positioning Mediastinal tumors are resected either from the right or the left chest cavity with the patient

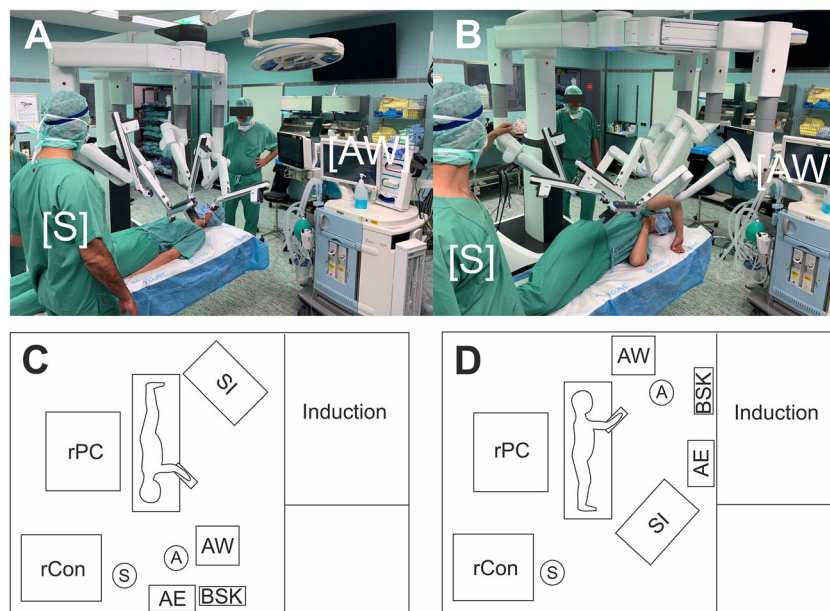


Fig. 2. Spatial constraints in robotic-assisted thoracic surgery require modifications in operation room utilization. The spatial arrangement of anesthesiological equipment and resources may vary according to the particular surgical procedure. **A** RATS intervention for the mediastinum. The patient is positioned on its back, and the surgical instruments may be inserted either from the left or right pleural cavity.

B RATS intervention of the lung. The patient is positioned on its opposite side to grant access to the target organ. **C, D** Arrangement of the anesthesiological and surgical equipment for interventions **C** on the left lung and **D** on the right lung (AW, anesthesia workstation; S, surgeon; A anesthetist; BSK, bronchoscopy equipment; AE, anesthesia equipment; rCon, robotic console; rPC, robotic patient cart; SI, surgical instruments).

positioned on the back. For pulmonary RATS procedures, patients are placed in lateral decubitus position [7–10]. Operation tables may be curved up to 30° to enlarge the intercostal space. To avoid injuries of the cervical spine, the head must be rested carefully. The anesthesiologist must be aware that airway devices are likely to dislocate during these surgical positioning maneuvers. Even small unintended changes may impair single-lung ventilation significantly. To ensure proper airway instrumentation for RATS surgery, bronchoscopy is mandatory after patient positioning is finalized. Only now the bronchial cuff of the double-lumen tube, respectively the balloon of the bronchial blocker, is inflated under bronchoscopic control [40, 41].

Patient Ventilation To maximize the available intrapleural space, CO₂ is insufflated to the upper hemithorax during RATS. This results in increased ventilation pressure, higher pCO₂ with acidosis and hemodynamic compromising by pressure-induced compression of the mediastinal vessels (→ Video). To avoid ventilation trauma, a protective lung ventilation with a VT of 5–6 ml/kgIBW (ideal body weight) and a pressure limit of 30 cmH₂O should be applied. Hypercapnia can be tolerated to a pH of 7.25. Patients should be extubated at the end of surgery.

Patient Monitoring Beside routine monitoring (ECG, pulse oximetry, etCO₂, temperature), the use of an arterial line is mandatory for continuous measurement of the arterial blood pressure and regular blood gas analysis. The usefulness of central venous pressure monitoring in lateral position is discussed controversially. The placement of a central line should be decided upon the patient's cardiac condition and the status of the peripheral veins. It should be kept in mind that it is nearly impossible to place a central line while the patient is positioned for the surgical procedure.

Anesthesia Maintenance General anesthesia with endotracheal intubation is suggested by the requirements for profound immobility and controlled ventilation with lung isolation with capno-pneumothorax. Anesthesia can be conducted either as total intravenous or as volatile anesthesia. The latter have shown to decrease inflammation after one-lung ventilation. To reduce postoperative pulmonary complications, the use of short-acting opioids is recommended in the phase of maintenance.

Vascular Access Adequate large-bore venous access should be in place to perform resuscitation in the event of significant bleeding. At least two peripheral intravenous lines are inserted into the vena basilica or cephalica and securely fixed to prevent dislocation. A central venous line is not usually established unless the patient is likely to need high doses of vasopressors. As one-lung ventilation is required for surgery

which leads to alterations in gas exchange, an arterial catheter is inserted in the radial artery to regularly take blood gas samples and to measure the blood pressure.

Hemorrhagic Complications Injury to the hilar pulmonary and mediastinal vessels and to the aorta may cause fatal hemorrhagic complications. Numerous studies have shown that life-threatening hemorrhagic complications may occur in a small group of patients undergoing RATS surgery [45•, 46]. Most bleedings can be controlled short term by manual compression of the surgical assistant using a swab. For surgical vascular repair, undocking of the robotic device and a thoracotomy are mandatory. The surgical team including anesthesia and nursing teams should be prepared to complete this process swiftly. Therefore, all instruments for thoracotomy should be available in the operation room [19].

Preventing Hypothermia Perioperative hypothermia increases SSI rates, the need for blood transfusions, and cardiac morbidity and mortality. It should therefore be avoided by any means [47]. To optimize patient treatment, numerous patient- and anesthesia-specific factors have to be addressed: (1) patient age, (2) BMI, (3) comorbidities, and (4) length of the operation. Patient temperature management should ideally begin with prewarming before commencing anesthesia: The patient should also be actively warmed if the length of the operation is expected to exceed 60 min (> 30 min without prewarming) [48]. Intraoperative temperature management includes conductive/convective warming techniques, thermal insulation of the greatest possible body surface area, and warming of infusions and transfusions, given at a rate greater than 500 ml/h [49].

Postoperative Considerations

Pain Management Postoperative pain management should include regional and intravenous components as well. A combination of NSAID and long-acting opioids at the end of surgery and regional anesthetic techniques has shown good results in our patient collective. Every patient gets local anesthetic (i.e., ropivacaine) by the surgeon at the surgical incisions. Providing analgesia in the complete chest wall can be accomplished by performing fascial plane blocks, preferably a serratus anterior plane block. While epidural analgesia is a good option in open thoracic surgery, the cost-benefit balance is not appropriate in RATS procedures.

Antithrombotic Treatment Thoracic surgery patients in general are at a high risk of deep venous thrombosis and postoperative thromboembolism. Therefore, the European ERA/ESTS and ESA guidelines for thoracic surgery suggest the use of mechanical and pharmaceutical thromboembolism prophylaxis [5•, 50].

In contrast, the German AWMF guideline does not comment on mechanical thrombosis prophylaxis but recommends pharmaceutical thrombosis prophylaxis in all cancer patients [49]. It exempts younger non-cancer patients that undergo minor RATS procedures (e.g., diagnostic thoracoscopy, pleurectomy) from pharmaceutical thrombembolism prophylaxis. However, all procedures that involve lung resection, mediastinal procedures, or pleural empyema should be treated as medium or major thoracic surgery, and pharmaceutical prophylaxis is recommended. Our hospital policy is the use of low-molecular-weight heparin (e.g., tinzaparin) administered once daily until full patient mobility is restored. Recent studies have discussed the use of extended pharmacological prophylaxis up to 1 month after surgery [52, 53]. However, the level of recommendation for thoracic surgery is weak. Extended pharmacological prophylaxis after RATS should therefore be limited to selected patients with increased risk for venous thromboembolism [51].

Respiratory Physiotherapy Early patient mobilization is considered important to reduce postoperative pulmonary complications [5••, 6]. However, evidence for efficiency of postoperative patient mobilization is small [54, 55]. Ideally, standard mobilization is conducted by the nursing staff on postoperative day (POD) one. The need for physiotherapy is defined individually. Considerations for low thresholds towards physiotherapy are 1) performed surgical procedure, 2) presence of chronic obstructive pulmonary disease, 3) preoperative mobility, 4) body mass index and 5) age [56, 57•]. In our clinic practice, we apply routine incentive spirometry in all patients undergoing RATS even though benefit is lacking evidence [58, 59]. But incentive spirometry has been shown to motivate patients to perform regular breathing exercises by themselves and picks them up to be part of the convalescence.

Chest Tube Removal Timely chest tube removal has been shown to be a critical component of early recovery after thoracic surgery [5••, 6]. However, there are no specific recommendations for RATS. Whereas suggestions for an evidence-based approach to manage the pleural space have been made, clinical practice still varies largely according to surgeon preference and institutional tradition [60–62••]. According to current recommendations, chest tube can be safely removed in the absence of any air leak. Electronic drainage systems are able to quantify air leak and intrathoracic pressures and therefore provide objective standards for chest tube removal [5••, 6, 61, 63]. Regarding pleural fluid output, a threshold of up to 300 ml/24 h of non-chylous, non-hematic fluid has been shown to be efficient [62, 64]. In this context, the use of the pleura/blood-protein ratio has been suggested to be helpful to determine the transition of pleural effusions from the exudative to the transudative phase [65].

Conclusion

Robotic-assisted thoracoscopic surgery (RATS) is becoming increasingly prevalent in thoracic surgery programs. As a new technological approach RATS enables minimal invasive chest operations and helps to replace thoracotomies. For patient management, the well-elaborated interdisciplinary recommendations for early recovery after surgery are applied. Anesthesiologists are part of every RATS treatment team and have to be familiar with those considerations to safeguard optimal treatment results. Moreover, RATS impacts the intraoperative working environment of anesthesiologists significantly and simultaneously has direct effects on patients' cardio-circulatory and respiratory function.

Abbreviations A, Anesthetist; AE, Anesthesia equipment; AWMF, Association of the Scientific Medical Societies in Germany; AW, Anesthesia workstation; BMI, Body mass index; BSK, Bronchoscopy; BW, Body weight; CO₂, Carbon dioxide; ECG, Electrocardiography; ERAS, Enhanced recovery after surgery; ESA, European Society of Anesthesiology; ESTS, European Society of Thoracic Surgeons; *etCO*₂, End tidal CO₂; FEV₁, Forced expiratory ventilation volume; *min*, Minute; NSAID, Non-steroidal anti-inflammatory drug; *pCO*₂, Partial pressure of carbon dioxide; *pO*₂, Partial pressure of oxygen; POD, Postoperative day; RATS, Robotic-assisted thoracoscopic surgery; *rCon*, Robotic console (=component of robotic surgery system); *rPC*, Robotic patient cart (=component of robotic surgery system); S, Surgeon; SI, Surgical instruments; SSI, Surgical site infection; VATS, Video-assisted thoracoscopic surgery; VT, Tidal volume

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