28 Anesthesia for Adrenal Surgery

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28.1 Introduction

The successful diagnosis and treatment of patients with adrenal tumors requires a well orchestrated multidisciplinary approach. This chapter emphasizes the perioperative anesthetic concerns associated with adrenal resections. While not meant to be all-inclusive, it highlights important factors in anesthetic decision-making. The surgeon's appreciation of anesthesia-related concerns can facilitate the patient's evaluation and avoid delays in assessment. The goals of the anesthesiologist include: (1) gathering information about the patient's adrenal disease and general health status, (2) identification of specific problems associated with the patient's condition, (3) institution of interventions that will minimize perioperative risks and (4) development of a concise anesthetic and perioperative plan tailored to the patient's individual needs.

In general, anesthesia for non-functional adrenal tumors follows the principles for general abdominal surgical cases. Functional tumors, though, require special considerations and are discussed.

28.2 Pheochromocytoma

Preoperative Evaluation and Considerations ▶ Approximately 50% of pheochromocytoma related deaths in the hospital occur during induction of anesthesia or during surgery for other causes [1], underlining the important role the anesthesiologist assumes in the treatment of this disease. The patient's clinical presentation is usually related to massive release of catecholamines originating from chromaffin tissue. The typical symptom complex (headache, tachycardia and diaphoresis) is secondary to the secretion of catecholamines, which results in paroxysmal or sustained hypertension, tachydysrrhythmias and ectopic electrocardiographic (ECG) patterns [2, 3]. About 30% of patients with pheochromocytoma will present with left ventricular dysfunction secondary to catecholamine induced cardiomyopathy [4]. Intravascular hypovolemia requiring fluid resuscitation may necessitate insertion of a pulmonary artery catheter to carefully monitor left ventricular filling pressures [5]. Preoperative cardiac workup including an echocardiographic examination may be indicated in addition to the routine preoperative testing. A search for hypertension induced end-organ damage should be included in the assessment. Careful physical examination including fundoscopy may reveal valuable information. Basic central nervous system (CNS) and renal function can be assessed through a precise history and basic laboratory testing. An extremely nervous and tremulous patient, with muscle weakness and weight loss, may often be encountered and may require sedative therapy.

Glucose levels may be elevated as a result of increased sympathetic discharge [6]. Concomitant alpha-adrenergic blockade for hemodynamic treatment (see below) can prove beneficial because it supports endogenous insulin secretion. Exogenous insulin therapy may be necessary. A blood count may reveal polycythemia reflecting hemoconcentration, indicating

the need for fluid resuscitation. Its adequacy can be monitored by a decrease in the hematocrit of 5% [6]. Rarely, pheochromocytomas are associated with medullary thyroid cancer as part of the multiple endocrine neoplasm (MEN) 2 syndrome. In these cases a careful airway examination to rule out tracheal involvement and displacement is indicated.

Further testing and examination should be directed by the patient's history and physical examination.

Preoperative Therapy ▶ Preoperative sympatholytic therapy with alpha- and beta-adrenoreceptor blockers and fluid resuscitation remains the standard of care for the patient with pheochromocytoma. Phenoxybenzamine has been in use for over 50 years [7] and has proven to be safe and cost-effective [8]. While its covalent, non-competitive binding to alpha-1-adrenoreceptors results in the intended sympatholytic effect, its non-selectivity results in potential problems that need to be addressed by the anesthesiologist. Blockade of presynaptic alpha-2-adrenoreceptors leads to an interruption of the feedback loop regulating the release of norepinephrine in presynaptic nerve endings. This disinhibition can lead to detrimental effects in the heart such as tachycardia. Beta-adrenergic blockade may become necessary [2, 4], but requires caution in patients with myocardial depression. The irreversibility of the blockade, secondary to alkylation of the receptor by the drug, makes the synthesis of new receptors the rate limiting step for its reversal [9]. This may lead to prolonged hypotension in the immediate postoperative period. In addition, CNS effects, primarily somnolence in patients receiving phenoxybenzamine, have been described [4]. This observation may be secondary to its clonidine-like effect on alpha-2-adrenoreceptors and may require the anesthesiologist to adjust anesthetic drug dosing.

The selective, competitive alpha-1-adrenoreceptor blocker doxazosin has the advantages of reversible binding at the receptor, not crossing the blood brain barrier, and obviating the drug-induced need for concomitant beta-blockade in the preoperative period [2, 10]. Other drugs in current use include prazosin, terazosin and metyrosine. The latter interferes with the synthesis of catecholamines and has proven an valuable adjunct to antiadrenergic blockade [11]. Continuation of alpha-1-adrenoreceptor blocker therapy until the day of surgery is recommended [6].

In addition to the use of beta-1-blockers to counteract the presynaptic effects of phenoxybenzamine, these drugs may be utilized to prevent epinephrine secreting tumor-induced tachycardia [2]. It is strongly recommended that beta-blockade should be instituted only after alpha-blockade, to prevent cardiac failure secondary to drug induced myocardial depression in the setting of increased afterload [6].

Anesthetic Management ▶ The most commonly employed anesthetic technique for the resection of pheochromocytoma is general endotracheal anesthesia with or without neuraxial blockade via an epidural catheter [2]. The main goal of the anesthetic management is to anticipate and treat surges of sympathetic discharge. Despite preoperative adrenergic blockade, labile intraoperative hemodynamics are common [12]. The anesthesiologist's familiarity with the procedure and cooperation with the surgeon is important to identify and anticipate phases of increased stimulation. Intubation, positioning, incision and surgical manipulation of the tumor are only a few points during the procedure that warrant increased vigilance [13]. Availability of fast acting antihypertensives and the avoidance of drugs that stimulate the sympathetic autonomic system are necessary.

Preoperative medication can be useful to treat the anxious patient, thus reducing the level of sympathetic output. Benzodiazepines like midazolam seem a likely choice and can be titrated to effect without major impact on hemodynamics. If opioids are used, synthetic derivatives, such as fentanyl and sufentanil, should be favored over morphine, which can release histamine and stimulate catecholamine release [6]. Under adequate sedation and local anesthesia, invasive hemodynamic monitoring with a peripheral arterial line should be established prior to induction of anesthesia. If central venous and pulmonary pressure monitoring is deemed necessary as per the patient's cardiovascular status, the placement pre-induction has to be balanced against the hazards of potential adverse hemodynamic derangements. In the hands of the experienced practitioner this procedure can be performed safely at this time. The same is true for the potential insertion of an epidural catheter [2, 13].

Induction of anesthesia is achieved by intravenous injection of propofol, etomidate or barbiturates in combination with synthetic opioids. Ketamine should not be used, due to its ability to stimulate the sympathetic nervous system and cause hypertension and tachycardia. Once loss of consciousness has been induced, anesthesia can be deepened by ventilation of the patient's lungs with an inhalational agent. While virtually all anesthetic gases have been successfully used in the past, halothane and desflurane should be used with caution. Halothane has the potential to sen-

sitize the myocardium to catecholamine and increase the risk for arrhythmias. Desflurane, although quickly titratable, can stimulate the sympathetic nervous system, especially when concentrations are being increased rapidly [6, 14]. Iso- and sevoflurane are common choices.

Paralysis to facilitate endotracheal intubation and ventilation can be achieved with a variety of drugs, such as *cis*-atracurim and vecuronium, both of which are virtually devoid of histamine releasing effects and are hemodynamically inactive. Pancuronium, which has sympathetic properties, and atracurium and mivacurium, which are associated with histamine release, should be used judiciously. Although probably not clinically significant, the choice of succinylcholine for rapid sequence induction may theoretically lead to hypertension due to tumor compression by abdominal muscle contraction or histamine release [6]. In this setting, rocuronium should be considered as an alternative.

Placement of an endotracheal tube should only be performed in the setting of adequate levels of anesthesia. The use of intravenous boluses of esmolol, lidocaine or additional opioids just prior to intubation may help to blunt the reflexive sympathetic discharge associated with laryngoscopy [6].

Maintenance ▶ Following induction, anesthesia is usually maintained by administration of a volatile anesthetic with or without the addition of nitrous oxide. Opioids are supplemented as needed. If an epidural catheter is in place it may be dosed with local anesthetics, opioids or a combination, thereby decreasing systemic requirements for pain medication. Local anesthetics may be useful in the control of hypertension. Opioids administered alone may have the advantage that they do not cause the degree of sympathectomy seen with local anesthetics and, therefore, will not aggravate potential hypotension after the pheochromocytoma is resected.

Hypertensive episodes during the procedure should be anticipated and can be treated with the combination of: (1) changes in the concentration of the volatile agent used and (2) infusions of intravenous drugs with rapid onset and short half-life. Commonly, nitroprusside, phentolamine, trimetaphan, nitroglycerine or nicardipine are used, the choice being dependent on the anesthesiologist's familiarity and comfort with the drug [13]. Intravenous magnesium infusions have also been used successfully [2]. If difficulties in controlling blood pressure are persistent, cessation of manipulation by the surgeon should be requested.

Although preoperative adrenergic blockade may have been satisfactory, additional administration of direct adrenoreceptor blocking drugs is often indicated intraoperatively. Labetalol and esmolol lend themselves to intraoperative use, because of their relatively short action [15]. Careful titration of beta-blockers is necessary to prevent cardiac pump failure in patients with catechol-induced cardiomyopathies. Transesophageal echocardiography may be indicated in this select patient population [16]. In addition to the hemodynamic monitoring, electrolyte and glucose monitoring should be available. Hyperglycemia preoperatively may be followed by hypoglycemia after isolation of the tumor [17]. The ability to treat either abnormality should be readily available.

Conclusion of Surgery and Postoperative Considerations ▶ The use of short acting drugs is especially advantageous in light of frequently encountered hypotension after resection of the tumor. Lightening of anesthetic depth, intravenous fluid administration and use of vasopressors, such as phenylephrine, are often necessary and are guided by invasive monitoring. In contrast, many other patients remain hypertensive and require continuation of sympatholytic therapy. In the otherwise healthy individual and in the absence of complications, extubation is usually performed at the conclusion of surgery. Electrolyte and glucose monitoring should be continued until values have stabilized.

28.3 Conn's Syndrome

Preoperative Evaluation and Considerations ▶ Primary hyperaldosteronism results from the uninhibited secretion of aldosterone from either hyperplastic adrenal glands, mineralocorticoid-secreting adenomas or, rarely, cancers. Clinical sequelae are hypokalemia, hypomagnesemia, alkalosis, weakness, paresthesias, tetany, nephropathy induced polyuria and refractory hypertension [3, 6, 18, 19]. Fluid retention secondary to sodium absorption by the kidneys may result in an extracellular volume increase of up to 30% [18], thus contributing to the possibility of congestive heart failure in these patients. Other mechanisms have been proposed by which aldosterone may be involved directly in the propagation of cardiac dysfunction [20]. Electrolyte abnormality induced arrhythmias are additional concerns [18]. Inverted T-waves and U-waves may be visible on the ECG [3]. If surgery is planned and myocardial compromise is suspected, a thorough

cardiac workup is indicated. Invasive monitoring with a pulmonary artery catheter or transesophageal echocardiography may be indicated during the procedure. A potentially increased sensitivity to neuromuscular blockade should be considered in the patient with muscle weakness [18]. Respiratory muscle weakness may lead to decreased pulmonary reserve and cough reflexes.

The anesthesiologist should be aware that chronic hypokalemia by itself can lead to cardiomyopathy with fibrosis, nephropathy, depression of baroreceptor activity and antagonistic effect on insulin secretion [18]. Careful consideration when administering drugs and anesthetics that can further impact these systems is warranted.

The occasional presentation of primary hyperaldosteronism with pheochromocytoma or acromegaly should alert the anesthesiologist to the possibility of unexpected phases of paroxysmal hypertension or a difficult airway [21]. The presence of concomitant osteoporosis warrants special care during positioning of the patient.

Preoperative Treatment ▶ The goals of preoperative management are: (1) control of hypertension, (2) optimization of cardiac function, (3) restoration of the intravascular fluid status and (4) correction of acid-base and electrolyte abnormalities.

The aldosterone antagonist spironolactone has been recommended for the treatment of hyperaldosteronism. One to 2 weeks of treatment may be necessary for the onset of effects [14, 22]. Spironolactone may also be helpful in those patients receiving prolonged treatment with ACE inhibitors for hypertension and heart failure. Increased aldosterone levels ("aldosterone escape") have been found in this patient population [18]. Overall, an individually tailored combination of antihypertensives and diuretics is indicated. Of interest, it has been suggested that intraoperative hemodynamics may be more stable when electrolytes and hypertension are controlled with preoperative spironolactone therapy when compared to other antihypertensive drugs.

In addition to hypertension, hypokalemia-related problems are responsible for most other complications in this population. Hypokalemia should be corrected preoperatively, realizing that completely normal values may not be achievable. The total body deficit may be as high as 400 mEq, requiring at least 24 h for repletion to avoid cardiac toxicity [14]. Potassium depletion may be higher in patients with a high sodium intake [18]. Potassium repletion may be difficult without concomitant repletion of magnesium stores. Development of tonic muscle contractures has been reported to occur secondary to potassium repletion in Caucasians with Conn's syndrome [23]. Hypovolemia from excessive use of diuretics should be corrected.

Anesthetic Management ▶ General endotracheal anesthesia is most commonly used for patients with Conn's syndrome. Epidural use of local anesthetics requires definitive intravascular volume repletion preoperatively in order to avoid sympathectomy-induced hypotension.

Preoperative Medication ▶ Administration of benzodiazepines may be indicated in the anxious, hypertensive patient. Preoperative opioids, which depress the respiratory drive, should be administered with caution and with monitoring in the patient with pulmonary muscle weakness. If bilateral adrenal resection or manipulation is planned, a stress dose of cortisol should be considered preoperatively and continued for 24 h [6].

Induction ▶ Induction agents should be chosen according to the patient's hemodynamic status. Intravenous barbiturates and opioids should be titrated carefully. Previously hypertensive patients may become profoundly hypotensive if hypovolemia is inadequately corrected. Depressed hypokalemia-induced baroreceptor function may contribute to this problem. The necessity for insertion of invasive hemodynamic monitoring prior to induction is dependent on the patient's cardiovascular status. Etomidate is characterized by the absence of hemodynamic effects, but can suppress adrenal function even after a single dose [24]. Although the clinical significance is not clear, this fact should be kept in mind in the patient in whom postoperative hypocortisolism is expected.

Excessive hyperventilation after loss of consciousness may lead to aggravation of hypokalemia and should be avoided [6]. When choosing a paralytic agent the increased sensitivity of patients with Conn's syndrome should be kept in mind. Hypokalemia and alkalosis can potentially lead to a prolonged effect of non-depolarizing neuromuscular blockers [18]. Thus, drugs of shorter action like vecuronium and *cis*-atracurium should be favored over ones with a longer half-life like pancuronium. Careful monitoring of neuromuscular blockade with a twitch monitor may be helpful in the further titration of drugs.

Maintenance ▶ Inhaled anesthetic agents, with or without the addition of nitrous oxide or intravenous anesthetics, are acceptable. Sevoflurane and enflurane, which are burdened with potential nephrotoxicity, should probably be avoided in the patient with nephropathy [6]. The myocardial depressive effects of halothane should be kept in mind when treating patients with cardiomyopathy.

The intraoperative use of an epidural catheter should include careful consideration of its hemodynamic consequences. Intravascular volume assessment, a preoperative problem in this patient population, may become even more difficult in the setting of positive pressure ventilation, vasodilatory effects of anesthetics and intraoperative fluid losses. Intravascular monitoring may become necessary at this point [6]. Glucose and electrolyte levels should be checked frequently.

Conclusion of Surgery and Postoperative Considerations ▶ Neuromuscular block reversal and assessment of patient strength should precede extubation, especially if preoperative weakness is encountered. A sustained head lift or a strong hand grip for a minimum of 5 s can be considered sufficient. Tidal volumes should be observed to ensure adequate ventilatory effort. If an epidural catheter is in place, it should be dosed to allow for lung excursions not inhibited by pain, thereby avoiding systemic opioids. Careful observation of electrolytes should continue, since potassium deficiency may be observed as long as a week after surgery [25]. Temporary or permanent mineralocorticoid or glucocorticoid therapy may become necessary, depending on the extent of the resection. Hypertension may persist into the postoperative period and pharmacologic treatment should continue [18].

28.4 Cushing's Syndrome from an Adrenal Source

Preoperative Evaluation and Considerations ▶ Surgery for Cushing's syndrome carries the highest perioperative mortality risk among the indications for adrenalectomy discussed in this chapter [14, 26]. Adrenalectomy for hypercortisolism requires the anesthesiologist's full understanding of all aspects of the clinical complex associated with Cushing's syndrome. The inappropriate secretion of cortisol can lead to weight gain, hypertension, diabetes, myopathy, renal calculi, osteoporosis and psychologic changes often requiring pharmacotherapy [3, 6].

There are many anesthetic considerations. The patient's typical physique (i.e. obesity concentrated centrally with facial fat thickening [6]) presents the anesthesiologist with the potential of a difficult airway. A thorough evaluation with a back-up plan for emergency surgical airway access (tracheostomy) must be devised should conventional modes of intubation fail. The presence of obstructive sleep apnea should be considered and integrated in the perioperative plan [27]. Additional considerations related to obesity involve multiple organ systems. Decreased chest wall compliance and functional residual capacity in the presence of increased oxygen consumption results in a severely reduced pulmonary reserve. Increased carbon dioxide production requires increased minute ventilation to maintain normocarbia and further contributes to the likelihood of perioperative pulmonary complications [28]. Pulmonary function testing and a chest X-ray may be indicated preoperatively to rule out any additional and reversible compromise. Steroid myopathy involving ventilatory muscle may further aggravate pulmonary function. If chronic hypoxemia is present, polycythemia may develop and increase the risk for thromboembolic events.

Cardiovascular aberrations include hypertension, cardiac dysfunction secondary to chronically increased blood volume and cardiac output. Pulmonary hypertension may develop in the presence of obstructive sleep apnea. Sudden death is a known complication of morbid obesity and thorough preoperative cardiac work-up is strongly suggested [28]. Obesity and chronic exposure to high levels of steroids and glucose can damage the vasculature and make it difficult to obtain vascular access.

Glucose intolerance is common and should be treated perioperatively. Liver function may be affected and implications for drug metabolism should be kept in mind. Liver function testing should be considered.

Increases in weight should be differentiated from the loss of muscle mass. Myopathy and resulting muscle weakness should lead to a careful titration of neuromuscular blocking agents. Intravenous drugs should be dosed according to ideal rather than actual body weight and titrated to effect.

Abnormalities involving the intestinal tract include increased intra-abdominal pressure, intragastric fluid and increased probability of the existence of a hiatal hernia, all of which put this patient population into a high risk category for pulmonary aspiration [28].

Steroid-induced osteoporosis warrants caution during positioning for surgery.

Hypokalemia and fluid retention are common features of Cushing's syndrome [14].

Preoperative treatment options for hypercortisolism secondary to adrenal etiology are limited and focus on optimizing the patient's intravascular fluid status, electrolyte balance and glucose levels. Spironolactone may be used to treat aldosterone-induced hypervolemia and potassium wasting. Inhibitors of steroid production such as metyrapone and mitotane have limited use. Hypertension should be controlled with pharmacotherapy as needed [14].

Anesthetic Management ▶ General anesthesia, with or without epidural anesthesia, is used for the patient with Cushing's syndrome and management is tailored towards problems related to obesity. Epidurally delivered analgesia should be used whenever possible during the postoperative course in order to minimize systemically administered respiratory depressant opioids. This allows for early breathing exercises and helps to decrease the chance of pulmonary complications arising from atelectasis and hypoventilation. In light of both the difficulties in identifying landmarks and the potential vertebral collapse secondary to osteoporosis in the obese patient with Cushing's disease, an epidural catheter should be inserted preoperatively in the sitting position and should be tested for satisfactory function [28].

Preoperative medication should be kept to a minimum to avoid compromise of the patient's respiratory status. If preoperative medication is deemed necessary, careful monitoring, especially for the patient with sleep apnea, is indicated. Intramuscular injections should be avoided because of the chance of erroneous injections into fatty tissue. Aspiration precautions should include strict adherence to fasting guidelines, administration of non-particulate antacids by mouth, and use of prokinetic drugs and intravenous antacids. A combination of H2-receptor blockers, metoclopramide and sodium citrate can be given [28]. Hydrocortisone replacement therapy may be necessary and should be started at the time of resection of the tumor [14]. Chronic suppression of the contralateral adrenal gland or resection of both glands can lead to acute hypocortisolism.

Induction ▶ The combination of a potentially difficult airway and the increased chance of pulmonary aspiration may warrant an awake fiberoptic intubating technique with the patient in the sitting position [28]. A well informed patient will usually understand this safety maneuver. The procedure can be performed using the nasal approach under mild sedation and after anesthetizing the nasal and oropharyngeal cavities. Intranasal phenylephrine spray may reduce the risk of bleeding while intravenous glycopyrrolate may improve visibility by reducing secretions. Surgical backup for emergency tracheostomy should be available. If the patient's airway allows for standard intubation with a laryngoscope, a rapid sequence induction with cricoid pressure becomes mandatory. Pre-oxygenation is ever more important due to the decreased functional residual capacity that predisposes the obese patient to faster hypoxemia than their non-obese counterpart [29]. Initial administration of neuromuscular blockers should be reduced and effects monitored in light of the common occurrence of myopathy and hypokalemia. Cardiovascular monitoring pre-induction is dictated by the patient's cardiovascular status.

Maintenance ▶ After induction of anesthesia and confirmation of endotracheal tube placement a nasogastric tube should be placed and intragastric contents suctioned. A combination of epidural local anesthetics with a volatile inhalational anesthetic is acceptable for maintenance of anesthesia. When dosing the epidural, the dose should be reduced by up to 25% compared with a patient of normal weight. This phenomenon reflects a decreased volume of the epidural space secondary to higher intra-abdominal pressures leading to a larger space occupation by engorged vessels [30]. It should be kept in mind that lipid soluble drugs may be stored in fatty tissue and undergo prolonged clearance when administered repeatedly or for a prolonged time. In this context, an inhalational anesthetic agent with relatively low lipid solubility such as desflurane or sevoflurane may be preferred to isoflurane and halothane. Nitrous oxide should be avoided in patients with pulmonary hypertension as aggravation of symptoms can result from its use. Its potential to distend the bowel in the setting of already difficult surgical exposure makes it an unlikely choice. Intravenous drugs with short half-lives and low lipid solubility should be chosen. The use of propofol or barbiturates may lead to a prolonged time for awakening [31].

Ventilation may prove problematic and the use of large tidal volumes and positive end-expiratory pressure with acceptance of high peak airway pressures may become necessary. The laparoscopic approach with increased intra-abdominal pressures is of particular concern and necessitates complete cooperation between the surgeon and anesthesiologist. A reverse Trendelenburg position, if feasible, may be helpful in alleviating difficulties. Careful monitoring of the in-

travascular fluid status, serum glucose and electrolytes perioperatively is indicated.

Conclusion of Surgery and Postoperative Considerations ▶ Neuromuscular blockade should be reversed and the patient should be fully awake and following commands before extubation of the trachea can be considered. The upright sitting position and dosing of the epidural catheter can facilitate improved breathing dynamics. The patient with sleep apnea may be electively transferred intubated to an intensive care setting to allow for careful monitoring of arterial blood gases and clearance of residual anesthesia. Extubation should be performed in the presence of a physician skilled in airway management. Satisfactory levels of analgesia can be achieved with epidural use of local anesthetics. Opioids, even when used neuraxially, can cause respiratory depression in the susceptible patient with sleep apnea [32]. Supplementation with non-steroidal analgesics may be beneficial.

Steroid replacement therapy becomes necessary, especially after bilateral adrenalectomy. Cardiovascular instability can occur secondary to adrenal insufficiency. Monitoring of electrolytes and glucose levels needs to be continued until stable levels have been achieved.

28.5 Addison's Disease

Hypocortisolism per se is not an indication for adrenal gland resection and will be mentioned only briefly. Nevertheless, destruction of the adrenal cortex by cancer, granuloma or hemorrhage may rarely require adrenalectomy. Management of anesthesia follows many of the aforementioned principles and does not involve any special considerations other than cortisol replacement and therapy. With the exception of etomidate, which can depress remaining adrenal function, all other anesthetic drugs may be used without special consideration, unless concomitant diseases need to be considered [6]. The involved clinicians should be familiar with signs and symptoms of hypocortisolism and be ready to treat the problems arising from it.

28.6 Monitoring

The monitoring for adrenalectomy procedures varies with the pathology and general health status of the individual patient and has been discussed, in part, above.

ECG, blood pressure and pulse oxymetry monitoring should be employed on a standard basis. An arterial line should be placed pre-induction in patients with pheochromocytomas in order to be able to assess and treat the cardiovascular response to induction and intraoperative stimulation. Postoperative surveillance should be continued. The respiratory management of the patient with Cushing's disease and sleep apnea may be facilitated by the knowledge of a pre-induction arterial blood gas. Frequent arterial blood gas analysis may be facilitated by the presence of an arterial line. In all other cases, the insertion of invasive hemodynamic monitoring, including central venous and pulmonary artery catheters, should be considered according to the patient's cardiopulmonary status and the need for invasive volume monitoring. Transesophageal echocardiography may be indicated in selected patients. Urine output monitoring with a Foley catheter may assist in the assessment of intravascular fluid status. Warming devices should be employed and patient temperature monitored. Hypothermia may delay awakening, reversal of neuromuscular blockade and may increase bleeding. A twitch monitor is useful, especially in patients with preoperative muscular weakness. Continuous end-tidal CO_2 monitoring should be used and may reveal valuable information during laparoscopic procedures and in patients with compromised lung function. Electrolyte and glucose monitoring is advised in patients with functional adrenal tumors.

28.7 Adrenalectomy Related Perioperative Complications

Adrenalectomies have become relatively safe procedures over the last few decades. Advances in anesthetic monitoring and surgical technique have contributed to this safety. Nevertheless the perioperative physician should be familiar not only with possible problems arising from the patient's specific pathology, but also with problems related to the procedure itself.

The rate of pneumothoraces approaches 20% [3, 14] and a high level of suspicion should prevail. Intraoperative evaluation can often prevent surprises and emergent intervention in the recovery room. Signs in the intubated patient are related to the size of the pneumothorax and can include increased peak airway pressures as well as hypoxemia. The extubated patient may complain of chest pain and difficulty breathing. Insertion on a chest tube may be necessary.

Estimated blood loss is usually below 300 ml [2], but hemorrhage after difficult resection should be expected. Retroperitoneal bleeding may not become obvious until late if one relies on drainage output as an indicator of hemorrhage. Hemodynamic depression may be secondary to inadequate fluid resuscitation, bleeding and hypocortisolism, especially after bilateral procedures. Cardiogenic causes should be in the differential diagnosis, in view of the high incidence of cardiomyopathies in this patient population. Respiratory complications warrant vigilance especially in the obese patient with Cushing's disease. Complications related to laparoscopy are discussed separately.

28.8 Pain Management

The visual analogue pain score varies by surgical technique and lies between 6–9 with the open approach [3]. Diaphragmatic function is depressed after upper abdominal surgery and contributes to the development of atelectasis [33, 34]. Pain management can improve respiratory function and contribute to the prevention of pulmonary complications secondary to splinting [33]. Successful analgesia can help the patient with early ambulation and thus may decrease the chance of thromboembolic events. The risk of adverse cardiac events may be reduced as well [35].

The epidural technique has the advantage that it can be used intra- and postoperatively. The major advantage of an epidural catheter for pain management is the relatively low dose of opioids needed in comparison to the systemic dose that would be necessary for satisfactory analgesia. In our experience, epidural patient-controlled analgesia with a continuous baseline rate provides good pain relief and high patient satisfaction. The combination of a low concentration of local anesthetic such as bupivacaine 0.08% with or without the addition of an opioid has a high success rate. At this concentration of local anesthetic, sympathectomy and hypotension, as well as involvement of motoneurons, are negligible. The most commonly encountered problems are pruritus, nausea and breakthrough pain. The first two are related to the use of opioids and can be treated with antihistamines, antiemetics or low dose infusion of naloxone. If complaints persist, the opioid can be removed from the infusion.

Contraindications are an uncooperative patient and the inability to treat complications from inadvertent intrathecal or intravascular migration. Coagulopathies preclude the instrumentation of the epidural space due to the risk of epidural hematoma formation and neurologic complications thereof. The use of low dose heparin or NSAIDS at the time of epidural catheter insertion is controversial [33]. In experienced hands, the small risk of neurologic deficits from epidural catheter placement should be significantly lower than that of pulmonary embolism in this patient population. Heparinization should probably be withheld for some time if a bloody tap is encountered during placement. If removal of the catheter is planned, the last dose of prophylactic unfractionated heparin should not be given within 6–12 h. Neurologic assessment and inspection of the catheter site for signs of infection and bleeding should be routinely employed.

Complications include postdural puncture headache and intrathecal or intravascular injection. Aspiration at frequent intervals can help exclude the latter two. Care should be taken to adjust dosing for obese patients as discussed earlier.

If an epidural catheter is not available, the intravenous administration of opioids and NSAIDS can be considered. Morphine or hydromorphone are commonly delivered via patient-controlled analgesia with good result. Although respiratory depression may be a concern, the use of patient controlled analgesia is considered to be safe, and the incidence of respiratory depression has been reported to be between 0.31% and 0.7%. Old age, hypovolemia and the use of a continuous infusion may be risk factors [33]. Skilled staff should be available to monitor and treat respiratory depression.

NSAIDS such as Ketorolac may decrease the overall requirements for opioids. Caution in patients with renal dysfunction, peptic ulcer disease and its antiplatelet action must be considered when using these drugs.

28.9 Anesthetic Implication of Laparoscopic Surgery for Adrenalectomy

The laparoscopic approach for adrenalectomy has become a successful and safe alternative to open surgical removal over the last decade [36, 37]. The advantages are faster postoperative recovery, earlier ambulation, shorter hospital stays and less pain [38, 39]. Special concerns are raised when using this technique for the resection of pheochromocytomas. The compression of the tumor by the pneumoperitoneum has been associated with increased secretion of catecholamines and intraoperative hemodynamic changes [40, 41].

This problem though can be managed safely in the hands of a vigilant anesthesiologist and pheochromocytoma resection can be successfully performed with this approach [38,41]. Catecholamine release by direct manipulation may actually occur less during laparoscopy [38].

General endotracheal anesthesia with or without the adjunct use of an epidural is usually favored for laparoscopic adrenalectomy. The proximity of the surgical field to the diaphragm and the addition of a pneumoperitoneum is usually not well tolerated from a respiratory point in the spontaneously breathing patient. Anesthesia can be maintained with inhalational agents or be conducted as a total intravenous technique (TIVA). It has been suggested that inhalational agents may be more appropriate for functioning adrenal adenomas while TIVA may have benefits in nonfunctioning tumors [42].

Regardless of the technique, both anesthesiologists and surgeons should be familiar with the physiologic changes and complications associated with a pneumoperitoneum.

Respiratory changes include a decrease in compliance and functional residual capacity and an increase in peak airway pressures [43]. All are secondary to the elevation of the diaphragm. The insufflation of CO_2 results in systemic absorption and is related to the level of intra-abdominal pressure [44]. The combination with impaired ventilation leads to CO_2 retention, necessitating hyperventilation by increasing the respiratory rate in order to maintain normocapnia. Patients with chronic obstructive pulmonary disease (COPD) may be particularly challenging to treat.

Hemodynamic changes include a reduction in cardiac output that is partially attributed to decreased venous return [45,46]. Preoperative intravenous volume administration may help alleviate this problem. The increased peripheral vascular resistance seen with the institution of a pneumoperitoneum may be deleterious for patients with limited cardiac reserve [47]. Decreases in renal perfusion and venous stasis in the lower extremities should be kept in mind. Avoidance of nephrotoxins and deep venous thrombosis prophylaxis should be considered.

Complications from pneumoperitoneum include subcutaneous emphysema, as well as pneumothorax and pneumomediastinum. Endobronchial intubation from cephalad movement of the carina may occur. Gas embolism secondary to intravascular or intraorgan gas injection is a feared complication. The severity of clinical sequelae are related to the volume and rate of gas entry [48]. The formation of an air-lock in the right ventricular outflow tract constitutes the worst scenario and can lead to cardiovascular collapse and paradoxic gas emboli. Diagnosis and treatment are similar to those of air embolism. Cessation of gas insufflation, head-down and right-side-up position to displace the air, hyperventilation with pure oxygen and aspiration of gas through a multi-orifice central venous catheter are recommended. Cardiopulmonary resuscitation with vasopressors may become necessary. Rapid absorption of CO_2 is of benefit but this complication can nevertheless be fatal [45].

Vagal tone can increase during insufflation secondary to activation of peritoneal stretch receptors and bradycardia or asystole may result. Release of the pneumoperitoneum and atropine administration may be required [45].

In conclusion, the laparoscopic technique for adrenal surgery is safe and offers advantages over the open approach. Complications are rare, but mandate the close cooperation of anesthesiologists and surgeons for successful management and outcome.

References

1. Sutton MG, Sheps SG, Lie JT (1981) Prevalence of clinically unusual pheochromocytoma: Review of a 50-year autopsy series. Mayo Clin Proc 56:354–60
2. Prys-Roberts C (2000) Pheochromocytoma – recent progress in its management. Br J Anaesth 85:44–57
3. Weigel RJ, Oberhelman HA, Steven K (1999) Endocrine surgery –adrenalectomy. In: Jaffe RA, Samuels SI (eds) Anesthesiologist's manual of surgical procedures, 2nd edn. Lippincott Williams and Wilkins, Philadelphia, PA, pp 481–484
4. Hull CJ (1986) Pheochromocytoma: diagnosis, pre-operative preparation, and anesthetic management. Br J Anaesth 58:1453–68
5. Mihm PG (1983) Pulmonary artery pressure monitoring in patients with pheochromocytoma. Anesth Analg 62:1129–33
6. Stoelting RK, Dierdorf SF (2002) Endocrine disease – adrenal gland dysfunction. In: Stoelting RK, Diedorf SF (eds) Anesthesia and co-existing disease, 4th edn. Churchill Livingstone, Philadelphia, pp 425–434
7. Iseri LT, Henderson HW, Derr JW (1951) The use of adrenolytic drug, regitine, in pheochromocytoma. Am Heart J 42:129–36
8. Witteles RM, Kaplan EL, Roizen MF (2000) Safe and cost effective preoperative preparation of patients with pheochromocytoma. Anesth Analg 91:302–4
9. Hamilton CA, Dalrymple H, Reid JL (1982) Recovery in vivo and in vitro of α1-adrenoreceptor responses and radioligand binding after phenoxybenzamine. J Cardiovasc Pharmacol 4 (Suppl I):S125–8

10. Babamoto KS, Hirokawa WT (1992) Doxazosin: a new α1-adrenegic antagonist. Clin Pharm 11:415–27
11. Steinsapir J, Carr AA, Prisant LM, Bransome ED Jr (1997) Metyrosine and pheochromocytoma. Arch Intern Med 158:901–6
12. Kinney MAO, Warner ME, van Heerden JA, Harlocker TT, Young WF Jr, Schroeder DR, Maxson PM, Warner MA (2000) Preanesthetic risks and outcomes of pheochromocytoma and paraganglioma resection. Anesth Analg 91:1118–23
13. Bogdonoff DL (2002) Pheochromocytoma: Specialist cases that all must be prepared to treat? J Cardiothor Vasc Anesth 16:267–9
14. Roizen MF (2000) Anesthetic complications of concurrent diseases. In: Miller RD (ed) Anesthesia, 5th edn. Churchill Livingstone, Philadelphia, PA, pp 903–1015
15. Nicholas E, Deutschman CS, Allo M, Rock P (1988) Use of esmolol in the intraoperative management of pheochromocytoma. Anesth Analg 67:1114–7
16. Ryan T, Timoney A, Cunningham AJ (1993) Use of transesophageal echocardiography to manage beta-adrenoreceptor block and assess left ventricular function in a patient with pheochromocytoma. Br J Anaesth 70:101–3
17. Levin H, Heefetz M (1990) Phaeochromocytoma and severe protracted postoperative hypoglycemia. Can J Anaesth 37:477–8
18. Winship SM, Winstanley JHR, Hunter JM (1999) Anaesthesia for Conn's syndrome. Anaesthesia 54:564–74
19. Danforth DN, Orlando MM, Bartter FC, Javadpour N (1977) Renal changes in primary aldosteronism. J Urol 117:140–4
20. Zannad F (1995) Aldosterone and heart failure. Eur Heart J 16:98–102
21. Seidman PA, Kofke WA, Policare R, Young M (2000) Anaesthetic complications of acromegaly. Br J Anaesth 84:179–82
22. Weinberger MH, Grim CE, Hollifield JW, Ken DC, Ganguly A, Kramer NJ, Yune HY, Wellman H, Donohue JP (1979) Primary hyperaldesteronism: diagnosis, localization and treatment. Ann Intern Med 90:386–95
23. Gangat Y, Triner L, Baer L, Puchener P (1976) Primary aldosteronism with uncommon complications. Anesthesiology 45:542–4
24. Wagner RL, White PF, Kan PB, Rosenthal MH, Feldman D (1984) Inhibition of adrenal steroidogenesis by the anesthetic etomidate. N Engl J Med 310:1415–21
25. Celen O, O'Brien MJ, Melby JC, Beazley RM (1996) Factors influencing outcome of surgery for primary aldosteronism. Arch Surg 131:646–50
26. Welbourn RB (1985) Survival and cause of death after adrenalectomy for Cushing's disease. Surgery 97:16–20
27. Hiremath AS, Hillman DR, James AL, Noffsinger WJ, Platt PR, Singer SL (1998) Relation between difficult tracheal intubation and sleep apnea. Br J Anaesth 80:606–11
28. Vierra MA, Howard KH (1999) Operations for morbid obesity. In: Jaffe RA, Samuels SI (eds) Anesthesiologist's manual of surgical procedures, 2nd edn. Lippincott, Williams and Wilkins, Philadelphia, PA, pp 352–6
29. Berthoud MC, Peacock JE, Reilly CS (1991) Effectiveness of preoxygenation in morbidly obese patients. Br J Anaesth 67:464–6
30. Stoelting RK, Dierdorf SF (2002) Nutritional diseases and inborn errors of metabolism – obesity. In: Stoelting RK, Diedorf SF (eds) Anesthesia and co-existing disease, 4th edn. Churchill Livingstone, Philadelphia, pp 441–51
31. Juvin P, Vadam C, Malek L, Dupont H, Marmuse JP, Desmonts JM (2000) Postoperative recovery after desflurane, propofol, or isoflurane anesthesia among morbidly obese patients: a prospective, randomized study. Anesth Analg 91:714–9
32. Boushra NN (1996) Anaesthetic management of patients with sleep apnoea syndrome. Can J Anaesth 43: 599–616
33. Ready B (2000) Acute perioperative pain. In: Miller RD (ed) Anesthesia, 5th edn. Churchill Livingstone, Philadelphia, PA, pp 2323–2350
34. Ford GT, Whitelaw WA, Rosenthal TW (1987) Diaphragm function after upper abdominal surgery in humans. Am Rev Respir Dis 127:431–6
35. Beattie WS, Buckley DN, Forrest JB (1993) Epidural morphine reduces the risk of postoperative myocardial ischemia in patients with cardiac risk factors. Can J Anaesth 40:532–41
36. Gagner M, Lacroix A, Bolte E (1992) Laparoscopic adrenalectomy for Cushing's syndrome and pheochromocytoma. N Engl J Med 327:1033
37. Jacobs JK, Goldstein RE, Geer RS (1997) Laparoscopic adrenalectomy: A new standard of care. Ann Surg 225:495–502
38. Sprung J, O'Hara JF Jr, Gill IS, Abdelmalak B, Sarnaik A, Bravo EL (2000) Anesthetic aspects of laparoscopic and open adrenalectomy for pheochromocytoma. Urology 55:339–343
39. Duh QJ, Siperstein AE, Lark OH, Schecter WP, Horn JK, Harrison MR, Hunt TK, Way LW (1996) Laparoscopic adrenalectomy. Comparison of the lateral and posterior approaches. Arch Surg 131:870–876
40. Joris JL, Chiche JD, Canivet JL, Jaquet NJ, Legros JJ, Lamy ML (1998) Hemodynamic changes induced by laparoscopy and their endocrine correlates: effects of clonidine. J Am Coll Cardiol 32:1389–96
41. Joris JL, Hamoir EE, Harstein GR, Meurisse MR, Hubert BM, Charlier CJ, Lamy ML (1999) Hemodynamic changes and catecholamine release during laparoscopic adrenalectomy for pheochromocytoma. Anesth Analg 88: 16–21
42. Darvas K, Pinkola K, Borsodi M, Tarjanyi M, Winternitz T, Horanyi J (2000) General anesthesia for laparoscopic adrenalectomy. Med Sci Monit 6:560–63
43. Bardoczky GI, Engelman E, Levarlet M, Simon P (1993) Ventilatory effects of pneumoperitoneum monitored with continuous spirometry. Anaesthesia 48:309–11
44. Lister DR, Rudston-Brown B, Warriner CB, McEwen J, Chan M, Walley KR (1994) Carbon dioxide absorption is not linearly related to intraperitoneal carbon dioxide insufflation pressure in pigs. Anesthesiology 80: 129–36

45. Joris JL (2000) Anesthesia for laparoscopic surgery. In: Miller RD (ed) Anesthesia, 5th edn. Churchill Livingstone, Philadelphia, PA, pp 2003–24
46. Sharma KC, Brandtstetter RD, Brensilver JM, Jung LD (1996) Cardiopulmonary physiology and pathophysiology as a consequence of laparoscopic surgery. Chest 110:810–5
47. Harris SN, Ballantyne GH, Luther MA, Perrino AC Jr (1996) Alterations of cardiovascular performance during laparoscopic colectomy: A combined hemodynamic and echocardiographic analysis. Anesth Analg 83:482–7
48. Mazoit JX, Umbrain V, Romain M, Samii K, d'Hollander A (1996) Effects of carbon dioxide embolism with nitrous oxide in the inspired gas in piglets. Br J Anaesth 76:428–34