Laparoscopy and Robotic Surgery

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1. Introduction

Before the surgeon offers a patient a laparoscopic or robotic assisted procedure, it is critical that he or she understand the unique intraoperative physiologic consequences that arise from the pneumoperitoneum. In addition, the endoscopic approach to intra-abdominal surgery exposes the patient to unique risks and complications of which the surgeon must be aware and prepared to manage.

1.1 Key words

laparoscopy, robotic, pneumoperitoneum, complication

2. Physiology of Laparoscopy

2.1 Pneumoperitoneum

Carbon dioxide (CO_2) is the preferred gas for insuflation as it is non-combustible, highly soluble in blood, and thus rapidly eliminated by the lungs. Alternative gases such as Nitrous Oxide (NO_2) support combustion and can cause distension of the bowel. Additionally, inert gases (Helium, Argon, and Xenon) are not readily soluble in blood and risk embolism. **Standard insufflation pressure is maintained at 15 mm Hg** because physiologic effects are minimal and reversible at this level. There have been multiple trials, including a Cochran review, comparing standard pressure (12-16 mm Hg) to low pressure pneumoperitoneum (< 12 mm Hg) with conflicting results. However, most studies have found low pressure pneumoperitoneum not to be inferior. Transient increases in intra-abdominal pressure (IAP) to 20 mm Hg can be used to tamponade venous bleeding, but pressure must subsequently be returned to standard levels as soon as warranted to avoid complications.

Hypercarbia can develop when CO_2 is absorbed through the peritoneum. This is worsened with high IAP, prolonged operative time, and use of Trendelenburg position. In addition, the retroperitoneal approach can also worsen hypercarbia. When compensatory measures are inadequate, **hypercarbia may result in subsequent metabolic acidosis**. Patients with chronic obstructive pulmonary disease and other restrictive pulmonary diseases are at increased risk. Treatment includes reducing IAP from the standard 15 mm Hg to 10-12 mm Hg. If conservative measures are inadequate, open conversion or very rarely, the use of Helium insufflation, may be required. Alternatively, periods of “pulmonary rest” may be taken whereby the surgeon comes to a reasonable stopping point, the instruments are removed, and the pneumoperitoneum completely released. In addition, the patient may be taken out of Trendelenburg to obtain further benefit. The surgery is resumed once anesthesia is able to regain improved pulmonary parameters; however, this maneuver may need to be repeated. An additional maneuver may be to convert to a valve-less system (discussed below) as this offers more consistent IAPs allowing the surgeon to operate at a lower pressure

2.2 Pulmonary changes

Table 1. Changes in Ventilator Dynamics	
Peak inspiratory pressure	↑
Chest wall resistance	↓
Pulmonary compliance	↓
Pulmonary dead space	↔
Functional residual capacity	↓
Vital capacity	↓
Shunting	↑
Ventilation-perfusion mismatch	↑

Table 2. Hemodynamic changes

Heart rate	↔↑
Mean arterial pressure	↑
Systemic vascular resistance	↑
Venous return	↓
Central venous pressure	↑
Cardiac output	↔↓
Arrhythmia	Yes

Table 3. Renal Changes	
Renal blood flow	↓
Glomerular filtration rate	↓
Urine output	↓
Serum creatinine	↔↑
Vasopressin (ADH)	↑

Table 4. Hemodynamic effects of patient position compared to supine position.		
Hemodynamic Parameter	**Patient Position**	
	Head up	**Head down**
Heart rate	↑	↓
Mean arterial pressure	↓	↑
Systemic vascular resistance	↑	↓
Cardiac output	↓	↑
Intracranial pressure	↓	↑

(see **Table 1**)

Changes in ventilatory dynamics are common with pneumoperitoneum. High IAP decreases diaphragmatic excursion, resulting in elevated intrathoracic pressure and subsequent limited lung expansion. In turn, the functional residual capacity (FRC) and pulmonary dynamic compliance are decreased and peak inspiratory pressures are elevated. This leads to **increasing ventilation-perfusion mismatch and shunting**, which may result in hypoxemia, especially in patients with compromised pulmonary reserves. Finally, high peak inspiratory pressures can also cause ventilator induced lung injury. Hypoxia can be limited by optimizing ventilation and oxygenation. However, in patients with poor pulmonary function, such as COPD, open conversion is sometimes necessary if other maneuvers as described previously are not successful

2.3 Hemodynamic changes

(see **Table 2**)

Decreased cardiac preload is secondary to the compressive effects of intra-abdominal pressure on the inferior vena cava and is compounded by hypovolemia. **Increased systemic vascular resistance (SVR)** results in increased cardiac afterload. Hypercarbia stimulates the sympathetic nervous system, which in turn activates the renin angiotensin system leading to **vasoconstriction**. **Decreased cardiac output** results from the combination effects of decreased preload and increased SVR. These effects are somewhat ameliorated by tachycardia and increased cardiac contractility stimulated by sympathetic tone. **Arrhythmias** may occur with rapid insufflation and stretching of the peritoneum, resulting in vagal mediated cardiac dysrhythmia (often bradycardia). Additionally, elevated CO_2 levels stimulates the sympathetic nervous system, which results in the release of catecholamines, leading to vasoconstriction. This, in turn, leads to an increased heart rate and blood pressure, which may trigger arrhythmia. Treatment includes release of pneumoperitoneum and increase in minute ventilation.

2.4 Gastrointestinal changes

Pneumoperitoneum causes decreased mesenteric blood flow to other abdominal organs including the liver, pancreas, stomach, spleen, small intestine, and colon. However, intestinal perfusion is not compromised at IAP < 15 mm Hg. Studies have demonstrated that **postoperative ileus is decreased in laparoscopic compared to open cases.**

2.5 Renal changes

(see **Table 3**)

Decrease in glomerular filtration rate (GFR) and urine output is multifactorial. Postulated mechanisms include: direct parenchymal compression, venous insufficiency, decreased cardiac output, increased activation of the renin angiotensin system, and increased antidiuretic hormone (ADH) release. These effects are **transient and reversible** and may be prevented with adequate hydration prior to and during the surgical procedure. Urine output should return to normal almost immediately upon release of pneumoperitoneum.

2.6 Immunologic changes

There is preservation of systemic immunity with laparoscopy. However, there is depression of peritoneal immunity, which may contribute to port site metastasis. In a study of open versus robotic-assisted radical cystectomy for bladder cancer, while there was no difference in local or distant recurrences, extrapelvic lymph node locations and peritoneal carcinomatosis was more common in the robotic group.[1,2] Larger confirmatory studies are needed. While human studies have demonstrated conflicting results concerning the risks of port site metastasis, animal experiments comparing wound recurrence between laparoscopic, gasless laparoscopic or open procedures suggests pneumoperitoneum does not enhance wound metastases following laparoscopic abdominal surgery for malignant disease.

2.7 Neurologic changes

There is an increase in intracranial pressure secondary to transmission of intra-abdominal pressure via the central venous system and cerebral spinal fluid. The central nervous system maintains cerebral perfusion pressure by secreting catecholamines and vasopressin to increase mean arterial pressure.

2.8 Patient position effects

When compared to the supine position, there are several hemodynamic changes that occur than can have clinical consequences (see **Table 4**).

2.9 Improving the pneumoperitoneum

Often, dry CO_2 gas at room temperature is used for insufflation. However, significant evidence suggests that dry CO_2 contributes to hypothermia and postoperative pain. As such, humid and warm gas has been demonstrated to be effective in reducing these complications. Secondly, improved intraoperative insufflation can be achieved during laparoscopic and robotic procedures using a valve-less trocar insufflation system (AirSeal - developed in 2007). The advantage of the valve-less system is that it allows the IAP to be maintained at a stable pressure when instruments are passed through trocars and with the use of suction. Further, this system allows smoke evacuation to be performed more aggressively while maintaining IAP. In a randomized study comparing conventional insufflation to a valve-less system (AirSeal), the valve-less system provided significantly more stable pneumoperitoneum and lower end-tidal CO_2 during surgery.3 Finally, one way to avoid the potential adverse effects and potential risks of CO_2 insufflation is with gasless laparoscopy.

3. Complications of Laparoscopic and Robotic Surgery

3.1 Patient Positioning Complications

Laparoscopic and robotic surgery can be associated with positioning related complications resulting from significant time in a modified flank or Trendelenburg position. Complications can result from prolonged pressure or stretch applied to a nerve structure or muscle. In addition, patients in steep Trendelenburg or laterally rotated patients can slide partially or completely off the operative table if not well secured. It is imperative that the entire operating room team be involved with positioning, including surgeon, anesthesiologist, and nursing staff. In particular, it is important to involve the anesthesiologist in position of upper extremity, neck, head and shoulders, and verbally confirm the anesthesiologist agrees with the appropriateness of positioning.

3.1.1 Nerve Related Injuries

Risk Factors: Due to the extreme position often employed during laparoscopic and robotic surgery, patients are at increased risk for nerve injuries if special attention is not paid to positioning and padding. Obese patients are particularly at increased risk of such injuries. **Prolonged operative times** also place patients at higher risk. The nerves most prone to injury are: **brachial plexus, femoral, sciatic and lateral popliteal**.

Prevention: Proper positioning and padding is imperative. To avoid injury to the brachial plexus the upper side arm should be supported by a pillow or a folded blanket or, alternatively, an arm board. When indicated, a properly placed axillary/chest roll should be employed. This is particularly important for obese patients and patients in full lateral position, and less imperative for thin patients and/or patients in a modified flank position. When utilized, the axillary roll should be placed inferior to the axilla and underneath the lateral chest wall so that the axilla is elevated and protected from compression injury. Patients must be secured to the table with either padded straps or padded tape at the level of the ankles, knees, hips and shoulders to prevent falling and shifting during rotation of the table. Various commercially available devices now exist to aid in safe positioning, in particular when robotic surgery is performed in steep Trendelenburg position. These devises typically involve a variation of memory foam placed under the patient in addition to various straps and arm wraps. These kits help to standardize positioning, minimizing the need for excessive taping/strapping that can injure shoulders or restrict chest excursion and impair ventilation.

Presentation and Treatment:Neuromuscular injuries typically present with paresthesias and weakness in the affected nerve distribution. Mild injuries will respond to physical therapy and will frequently resolve over several days to weeks; however, severe stretch injuries may result in permanent neurological dysfunction. Examples of nerves commonly at risk include: ulnar, lateral femoral cutaneous, and peroneal. In addition, obese patients are more susceptible to nerve injury and thus extra attention must be taken when positioning these patients.

Corneal abrasions are also encountered and can be prevented with proper eye protection. There have also been case reports documenting ischemic optic neuropathy during laparoscopic/robotic surgery, possibly secondary to increased intraocular pressures during prolonged surgery in the steep Trendelenburg position. Such patients present with visual field loss, which may be permanent.

3.1.2 Compartment Syndrome/Rhabdomyolysis

Rhabdomyolysis is a serious complication of improper positioning and involves **muscle ischemia following prolonged compression**. Rhabdomyolysis may result in **acute renal failure** secondary to **myoglobinuria** and tubular obstruction by myoglobin casts.

Risk Factors: male gender, morbid obesity, large muscle mass, exaggerated intraoperative position, hypovolemia with intraoperative hypotension, operative time more than 5 hours, diabetes, compromised renal function and hypertension.

Prevention: The best prevention strategy is careful padding of all pressure points, minimizing or eliminating the use of a kidney rest and limiting operative times.

Presentation and Treatment: The condition should be suspected in patients presenting postoperatively with **muscular pain, oliguria, dark urine and rising creatinine. The mainstay of therapy is vigorous hydration. Urine** alkalinization (raising urine pH) has been shown to be beneficial in animal studies, but clear evidence of clinical efficacy in humans has not been established.

3.2 Access Related Complications

Access and establishment of pneumoperitoneum can be achieved using one of two techniques. The closed technique involves the use of **a Veress needle** to establish pneumoperitoneum followed by initial trocar placement using an optical dilating trocar. The **open Hasson technique**, is performed by creating an incision into the peritoneum under direct vision, followed by placement of a blunt trocar through which pneumoperitoneum is then established.

Correct technique can prevent the majority of access related complications, and begins with patient selection. Patients with a history of extensive abdominal surgery may not be candidates for a laparoscopic/robotic approach or may be better approached in a retroperitoneal or extraperitoneal fashion. **The number and location of past incisions** should be carefully considered when selecting an open or closed access technique, and when choosing the site for placement of the Veress needle and trocar(s). Review of cross-sectional imaging can also be helpful to plan access. The Veress needle and trocars should be placed away from prior scars ideally into a quadrant which has had no prior surgery. Correct placement of the Veress needle is confirmed in the following manner (i) two "**pops**" felt as the needle traverses the fascia and the peritoneum (ii) **aspiration** that does not reveal blood or bowel contents (iii) **injection** of 5-10 cc of saline and the inability to aspirate back (iv) a "drop test", whereby a bleb of saline left in the hub of the needle falls freely down the needle, and (v) initial **low pressure reading** (<10 mm Hg) with adequate flow (1.5-2.5 ml/min) upon insufflation confirms proper needle position. It should be noted, in general, laparoscopic/robotic surgery yields far less abdominal wall adhesions compared to open surgery and access to a quadrant where previous minimally invasive surgery has been performed is generally safe. Faithfully following, and documenting, these steps is of paramount importance for safe access.

3.2.1 Preperitoneal Insufflation

Veress needle access has been associated with a 0.1% of visceral/bowel injury, whereas the open technique carries a slightly lower 0.06% risk of bowel injury. During access, vascular structures as well as various organs can be injured including: **stomach, intestine, liver, gallbladder, pancreas, spleen, mesentery, and bladder**.

3.2.2 Visceral Organ Injury

Risk Factors/Prevention: Prior abdominal surgery may be associated with distorted anatomy or adhesions to the anterior abdominal wall that can increase risk of visceral injury. **Proper selection of access technique and placement away from prior scars can avoid injury**. The use of orogastric/nasogastric decompression can help avoid gastric injury. Bladder catheter drainage can help avoid bladder injury. Injuries can still occur with the Hasson technique, optical trocars, or a hand-assisted laparoscopic approach and prompt identification is critical.

Presentation: **The aspiration of succus, feces, or bilious fluid indicates gastrointestinal injury**. Upon laparoscopic inspection of the abdomen/pelvis the presence of gastrointestinal contents in the peritoneum are indicative of injury. When visceral injuries do occur during laparoscopic or robotic surgery, delayed recognition is common. The presentation and management are described below in the section on intraoperative bowel injury.

Treatment: **Veress needle injuries can often be managed conservatively as long as there is no evidence of leakage of bowel contents**. That said, if the injury is readily identified, a simple figure-of-eight suture repair to close the injury is a quick way to eliminate further complications. Veress needle injuries to the liver or spleen can usually be controlled by direct pressure, argon beam coagulation or application of hemostatic agents. In contrast, **even small perforations in the gall bladder may result in a bile leak and peritonitis and therefore a cholecystectomy is recommended**.

Small trocar injuries of the bowel can be **repaired laparoscopically**, whereas larger injuries may require open conversion, bowel resection, or even diversion. Veress injury to the bladder can be managed conservatively, whereas trocar injuries to the bladder typically require sutured repair.

3.2.3 Vascular Injury

Veress needle access has been associated with a **0.1%** risk of vascular injury. Vascular injury during access can involve abdominal wall vessels or larger vessels within the abdomen/pelvis.

Risk Factors/Prevention: **Extremely thin patients** are at risk for Veress needle and trocar related vascular injuries. Poor technique, in particular the use of excessive force in placing the needle or trocar, can result in vascular injury. An insufficient incision length/size may lead to trocar injury due to excessive force application to overcome resistance. **Aspiration of the Veress needle should always be performed** to identify vascular injury and prevent insufflation into vascular structures.

Presentation: Veress needle-related vascular injury should be identified during aspiration of the needle with blood being withdrawn. The **right common iliac artery** can be injured by blind Veress needle or trocar insertion at the umbilicus, as the **bifurcation of the great vessels is located approximately at this level**. Bleeding alongside a trocar or on the inner surface of the anterior abdominal wall is suggestive of **epigastric vessel injury**, which can also present in a delayed fashion as pain around a **trocar site with ecchymosis and abdominal wall hematoma**. Excessive bleeding through a trocar, with or without patient de-compensation, raises concern for major trocar-related vascular injury. Veress needle or trocar placement is believed to be the most common cause of gas embolism, but is a rare although potentially fatal complication. Presentation and management are discussed later.

Treatment: If blood is aspirated during Veress placement, the needle must be withdrawn; care should be taken not to torque the needle. The Veress should be repositioned, and its position retested prior to insufflation. **Small Veress needle vascular injuries may not require any repair**, or at most suture repair. If Veress needle-related **bleeding appears to be major, the stopcock should be closed, and the needle left in place** to allow the surgeon to track the needle to the source of bleeding. Major vascular injuries, however, may require immediate open conversion and formal repair. For a major injury with a trocar, leave the trocar in place, close the port, perform immediate laparotomy, and request vascular/trauma surgeon consult if needed. Management of epigastric vessel bleeding can involve the following: direct cauterization, tamponade by placing a Foley catheter down the trocar and the balloon inflated, or the placement of full thickness suture ligature through the fascia and the peritoneum under laparoscopic guidance using a fascial closure device.

3.2.4 Trocar Technologies

There are two trocar classes: (i) cutting/bladed trocars and (ii) axial or radial dilating trocars. They have different risks of bleeding and need for fascial closure.

Hernia Risk and Trocar Diameter: **Dilating trocars produce a defect in the fascia that is one half the size of the trocar diameter**. Cutting trocars result in a fascial defect that is the same diameter as the trocar. **For non-midline dilating/blunt trocars up to 12mm**, closure of the fascia is **not mandatory**, as the risk of herniation is limited. The **surgeon should digitally inspect such defects** and fascial closure should be performed if the defect allows passage of more than the tip of the index finger. Additionally, fascial closure should be considered for midline dilating/blunt trocars and all cutting trocars up to 12 mm fascial defects.

Bleeding Risk For Blunt vs. Bladed Trocar: Cutting/bladed trocars are associated with an increased risk of injury to abdominal wall vessels compared with dilating trocars, and should be avoided for this reason.

3.3 Pneumoperitoneum Related Complications

3.3.1 Subcutaneous Insufflation/Emphysema

Presentation: Subcutaneous insufflation may result from improper Veress needle positioning, as well as from leakage of CO_2 gas around trocars. Patients present with **crepitus** involving the abdomen and/or thorax, as well as pneumoscrotum. Due to the fairly rapid absorption of CO_2 within human tissues, **subcutaneous emphysema typically resolves in 24-48 hours**. If extensive, subcutaneous insufflations can lead to pneumo-mediastinum, pneumothorax, and/or pneuopericardium, as well as lead to hypercarbia. **Pneumothorax typically presents with a sudden rise in mean airway pressure in combination with decreased oxygen saturation levels**. Diagnosis is confirmed with chest X-ray. For a large or symptomatic pneumothorax, tube thoracostomy is required for treatment. Alternatively, accumulation of CO_2 in the thoracic cavity (capnothorax) typically resolves with release of pneumoperitoneum and supplemental oxygen.

Prevention: Proper Veress needle placement is the best way to avoid subcutaneous insufflations. To prevent gas leak around trocars, the use of small skin incisions is recommended, however, skin incisions that are too small lead to the use of excessive force and risk trocar-related injury. Alternatively, the use of balloon tip trocars may be preventive.

3.3.2 Hypercarbia

Occurs particularly in patients with pulmonary disease (COPD), with high insufflation pressures, cases of long duration, the use of the Trendelenburg position, and with extensive subcutaneous insufflation.

Prevention: Minimize Trendelenburg and reduce insufflations pressures to 10-12 mm Hg.

Presentation: Elevated end-tidal CO_2 levels and metabolic acidosis.

Treatment: Includes **reducing IAP** from the standard 15 mm Hg to 10-12 mm Hg and increasing ventilator rate. These efforts may be assisted by converting to a valve-less trocar system (AirSeal). If conservative measures are inadequate switching to Helium insufflation or open conversion may be necessary.

3.3.3 Gas Embolism

Gas embolism is a rare and potentially fatal complication**. The most common cause is direct placement of the Veress needle or trocar into a vessel and subsequently initiating insuflation.**

Prevention: Avoid direct insufflations into veins with Veress needle or trocar. Always aspirate prior to beginning insuflation.

Presentation: Gas embolism can result in **sudden circulatory collapse, tachycardia and arrhythmia**, hypotension, an acute decrease in end-tidal CO_2, cyanosis of the head and upper extremities, elevated right heart pressures and central venous pressure, **and "millwheel" murmur**.

Treatment: The surgeon must have a high index of suspicion for gas embolism given such a rare complication, and prompt recognition and communication with anesthesia colleagues is critical. Treatment involves: immediate release of pneumoperitoneum and cessation of insufflation, administration of 100% oxygen, **placement of the patient in the left lateral decubitus position with the head down (Durant's position)**, and aspiration of the CO_2 bubble with a central venous catheter extending into the right heart.

3.4 Intra-abdominal Organ Complications

3.4.1 Gastrointestinal Injury (Colon, Small bowel, Duodenum, Stomach)

Causes: Gastrointestinal organs can be injured during access, the blind passage of instruments, from sharp or blunt dissection, or during the application of thermal energy (e.g. monopolar cautery, harmonic). Breaks in insulation surrounding a monopolar instrument and poor visualization of cautery contact points can lead to injury outside of the field of vision. Moreover, thermal energy (heat) can spread several centimeters from the point of intended application and result in injury. If thermal injury is suspected (usually seen as blanching of the bowel serosa), a series of interrupted Lembert sutures should be placed to avoid delayed bowel perforation. When mobilizing the colon, care should also be taken to avoid injuries to the colon mesentery. Most defects, particularly if small or medium-sized, should be closed to prevent an internal hernia. Failure to recognize these defects can result in small bowel herniating and becoming incarcerated leading to emergent exploratory laparotomy and bowel resection. Care should be taken when mobilizing the duodenum (Kocher maneuver), which should be performed in an athermal manner. When performing left sided MIS renal surgery, and mobilizing the upper pole and spleen, particular attention should be taken to avoid stomach injury; an orogastric or nasogastric tube is routinely employed on left sided cases to decompress the stomach and avoid stomach injury. Rectal injury can occur when performing laparosopic/robotic prostatectomy and cystectomy. Care must be taken when bedside assistants are inserting laparoscopic instruments during robotic pelvic surgery to avoid sigmoid, or other visceral organ, injury. Instruments should be brought in under direct vision, particularly with inexperienced bedside assistants. Bowel injury can also be the result of trocar site hernia. Non-midline 5, and 12mm radially dilating trocars and 8mm robotic trocars do not necessarily require formal closure in adults. An exception to this may be ports used in robotic surgery that are repositioned or “bumped” during the case that causes these trocars to dilate the fascia further. **The fascia of 12mm bladed trocar sites should be closed with absorbable suture.**

Intraoperative Recognition and Treatment: Injuries to the small bowel, large bowel, and stomach can be recognized by spillage of succus, fecal matter, and gastric contents, respectively. Serosal injuries are identified by direct inspection of the bowel. Small injuries to the bowel can be closed primarily. This can be performed laparoscopically/robotically with the requisite intracorporeal suturing ability; otherwise, conversion is indicated. **Rectal injuries without gross spillage can be closed primarily in two layers, with omental overlay, placement of a pelvic drain**, and consideration of a rectal tube. Larger injuries, or those associated with gross spillage should be managed with colonic diversion. Depending on the severity and location of the injury, general or colorectal surgical consultation should be considered.

Postoperative Recognition: Unrecognized bowel injury can lead to significant morbidity and even mortality. Patients who have sustained an unrecognized bowel injury have a unique presentation **that can lack the typical signs and symptoms of peritonitis, acute abdomen and leukocytosis**.

Presenting symptoms are usually present within 24-48 hours of surgery. Symptoms include diarrhea, abdominal distention, single trocar-site pain without purulence or erythema. Presenting signs include low grade fever, abdominal distention, **leukopenia** with a "left shift"; nausea and vomiting. It is imperative to have a high index of suspicion for unrecognized bowel injury, and low threshold for obtaining a CT scan of the abdomen and pelvis with oral contrast to diagnose an unrecognized bowel injury. If CT imaging does not demonstrate signs of bowel injury, a 6 hour delayed set of images should be obtained which may reveal the site of bowel injury. Intra-abdominal gas can be expected up to 7 days after surgery. If CT imaging indicates a bowel injury/perforation, immediate surgical exploration with bowel repair and/or resection is necessary. In situations where the patient is becoming unstable and is presenting the above signs and symptoms, emergent surgery is recommended and waiting to obtain a CT of the abdomen should not delay care.

3.4.2 Vascular Injury (Abdominal wall vs. Intra-abdominal)

Causes: Such complications can be minor or major, and can occur during access (**75%** of major vascular injuries) or as a result of trauma during dissection (**25%**). During dissection, arterial and venous vessels can be injured as a result of blunt, sharp, or thermal dissection, or can be ligated/transected with sutures, clips, or staplers. Malfunction of vascular stapling devices can also result in major hemorrhage and has been reported to occur in up to **1.7% of cases. It is imperative to avoid clips within the stapler jaws, as this is a significant cause of stapler malfunction**.

Intraoperative Recognition and Treatment: Various approaches exist for the management of vascular injuries, ranging from direct pressure, monopolar coagulation, argon beam coagulation, surgical clips, thermal bipolar sealing devices, hemostatic agents and sutured repair. When confronted with a vascular injury, the surgeon must assess if the injury appears to be minor or major, and venous or arterial. Initial management of vascular injury and hemorrhage can involve **raising the pneumoperitoneum pressure to 20-25 mm Hg, holding direct pressure**, typically with the use of a mini-laparotomy pad, and **ensuring adequate suction** is available. Small bleeding vessels can be handled with cautery or clips. Small venous tears in the renal vein or inferior vena cava can be addressed by applying direct pressure with a mini-laparotomy pad or other hemostatic product for up to several minutes. This simple maneuver will often stop the bleeding. Moderate or severe vascular injury typically requires sutured repair. When needed, the surgeon should add additional trocars, employ a hand-port, or convert to open surgery. If possible laparoscopic bulldog clamps can be utilized to gain proximal and distal vascular control to allow for subsequent suture repair of the damaged vessel. Depending on the severity of the injury and the expertise of the urologic surgeon, consider intraoperative consultation with vascular surgeon as needed. It is also valuable to have a "rescue stitch" prepared and on the field at all times, or immediately available. Such a stitch typically involves a short prolene suture with a vicryl clip on the tail to aid in rapid suturing without the need for knot tying.

Postoperative Recognition and Treatment: Patients can present with hemorrhage while exiting the operating room, in the recovery room, during their admission or after discharge. Symptoms can include dizziness, diminished mental status or syncope, shortness of breath, abdominal pain or distension, ecchymosis, clot colic, and gross hematuria. Presenting signs of postoperative bleeding include **hypotension, tachycardia, oliguria, abdominal distention, high drain output when present, and occasionally syncope**. Diagnosis is most often made by recognizing these clinical signs and symptoms, however, on occasion, angiography or CT imaging can be employed. Hemorrhage with signs and symptoms of shock should be managed with surgical exploration. Patients with suspected arterial bleeding who are clinically stable can be managed with selective angiographic embolization.

3.4.3 Liver/Spleen injury

Causes: The liver and spleen can be injured during laparoscopic/robotic surgery, often a result of the blind passage of instruments, and/or the Veress needle. Care should be taken to follow the insertion of instruments with the laparoscope, particularly for novice surgeons. The capsule of the liver or spleen can be injured when lysing peritoneal attachments to these organs, or from retraction injury. Therefore, incising these peritoneal attachments prior to retracting the liver and spleen will typically mitigate the risk of capsular tears.

Intraoperative Recognition and Management: Injuries are recognized by the accumulation of blood and clots. Small tears can be addressed with **hemostatic agents and/or argon beam coagulation**. Major lacerations with significant bleeding may require open conversion and general surgical consultation. Occasionally, splenectomy is required to manage massive hemorrhage. Standard practice should involve a laparoscopic inspection of the operative and nonoperative field under low IAP prior to laparoscopic exit to visualize organs such as the liver and spleen and rule out unsuspected injury. Further, each trocar site should be observed in succession to rule out vascular injury that had been obscured due to tamponade by the trocar.

Postoperative Recognition and Management: Postoperative signs of hypotension and anemia should raise the suspicion of acute bleeding. Contrast CT scan can be diagnostic and exploratory laparotomy may be required if the patient does not stabilize.

3.4.4 Pancreas Injury

Causes: The tail of the pancreas can be injured during left-sided laparoscopic/robotic renal and adrenal surgery. The use of thermal energy should be avoided in proximity to the tail of the pancreas. **If retraction of the pancreas is necessary, a blunt/wide surface retractor should be employed**. Pancreatic injury prevention is also aided by properly dividing the splenocolic and splenorenal ligaments, and effectively mobilizing the spleen, colon and pancreas medially.

Intraoperative Recognition Management: When injury is recognized intraoperatively, a distal pancreatectomy is indicated and can be performed with the use of a laparoscopic GIA stapler and a closed suction drain is placed. General surgery consultation should be requested for surgeons not experienced with such techniques.

Postoperative Recognition and Management: **Unrecognized pancreas injury can present with abdominal pain, distention, fever, leukocytosis and the presence of a retroperitoneal collection**, sometimes accompanied by inflammation around the distal pancreas on abdominal imaging. Treatment involves the placement of a drain in the setting of a collection, **with elevated amylase/lipase in the drain fluid being diagnostic**, and keeping the patient NPO with NGT and

TPN when indicated.

3.4.5 Bladder/Ureter injury

Causes: Ureteral injuries can occur during urologic, gynecologic/obstetric, and general surgery procedures. Such injuries are **most commonly the result of unrecognized electrocautery injury**. Less often, the ureter can be inadvertently transected, or ligated with a clip or stapler device. The bladder can be injured during access with a trocar, during blunt dissection, or during sharp or thermal dissection.

Intraoperative Recognition and Management: Ureter injury can be recognized intraoperatively by direct inspection, or by the accumulation of urine in the retroperitoneum. During prolapse repair a ureteral injury may be discovered by cystoscopy which may reveal no excretion of urine from the ureteral orifice on the affected side. This can be confirmed with attempting to pass a ureteral catheter proximally or with retrograde pyelography. Bladder injury can be identified by direct inspection, or by the accumulation of air and/or blood in the catheter drainage bag. If needed, confirmation of bladder injury can be made by instilling saline and/or methylene blue in the bladder via the urethral catheter and observing extravasation. **When recognized intraoperatively, thermal injury to the ureter or bladder must be managed with excision of the affected segment** with the location and extent of injury dictating the appropriate reconstruction techniques.

Postoperative Recognition and Management: Presenting symptoms include abdominal distention, abdominal pain, fever, bloating, nausea, and/or vomiting. Presenting signs include fever, leukocytosis, increased output from drains, elevated drain creatinine compared with serum creatinine, urinary ascites, abdominal distention, and ileus secondary to urinary ascites. When injury to the ureter is suspected, the diagnosis and localization of the injury is made with **intravenous or retrograde urography**. **The diagnosis of bladder injury is made with cystography**. It is important to rule out a concomitant bladder and ureteral injury which may occur. Minor ureteral injuries with minimal extravasation can be managed with retrograde or antegrade stent placement or percutaneous nephrostomy drainage. Large injury with significant ureteral loss may require laparoscopic, robotic, or open reconstruction. Extraperitoneal bladder injury can typically be managed with catheter drainage. Intraperitoneal bladder injury typically requires exploration and repair, however, small intraperitoneal injuries in patients without fever, leukocytosis, pain, or peritoneal signs can occasionally be managed conservatively.

3.4.6 Diaphragm Injury

Causes: Diaphragmatic injury during laparoscopic/robotic renal and adrenal surgery is usually the result of electrocautery injury, less commonly from sharp or blunt dissection. Patients with large renal/adrenal masses and inflamed kidneys (e.g. xanthrogranulomatous pyelonephritis) are at particular risk. The most important step in preventing a diaphragm injury is to be thinking about the risk of diaphragm injury, particularly with large and inflammatory/invasive masses. With heightened awareness, take special care in such cases when mobilizing the upper pole laterally to avoid such injury.

Intraoperative Recognition and Treatment: Diaphragmatic injury can be associated with the **"floppy diaphragm" sign, where the diaphragm is seen billowing into the surgical field**. However, due to the pneumoperitoneum, this may not be obvious. Signs can range from subtle decrease in oxygen saturation, increase in airway pressures and hypercarbia, to severe signs with rapid cardiovascular collapse secondary to tension pneumothorax, which must be treated with immediate release of the pneumoperitioneum, and chest decompression with a needle or tube thoracostomy. Often a pneumothorax becomes more obvious when the pneumoperitoneum is reduced, usually to < 5mm Hg. When recognized in the intraoperative setting and with a stable patient, the pleurotomy can be closed robotically or laparoscopically after evacuation of the pneumothorax and suture closure of the defect (often a purse-string suture around a catheter or suction device). Larger diaphragmatic defects may require consultation with a thoracic surgeon for repair.

Postoperative Recognition and Management: Presenting symptoms may include symptomatic pneumothorax or hemothorax, resulting in dyspnea, pleuritic pain, and/or chest pain. Presenting signs include hypoxia, tachypnea, tachycardia, loss of breath sounds to the affected hemithorax. Diagnostic tests initially include careful auscultation of the chest. **Loss of breath sounds is diagnostic of pneumothorax**, and in the unstable patient mandate immediate chest tube placement. In stable patients, chest X-ray is performed. The initial step for the symptomatic pneumothorax or hemothorax is tube thoracostomy. Many pneumothoraces can be managed conservatively in the stable asymptomatic patient with adequate cardiopulmonary reserve by giving supplemental oxygen and obtaining serial chest X-rays.

3.4.7 Pneumothorax

Causes: Pneumothorax may be the result of improper insufflation and tracking of CO2 gas as described above, or from diaphragmatic injury, either recognized or unrecognized.
Intraoperative Recognition and Treatment: Pneumothorax can be recognized intraoperatively due to difficulty in oxygenation of the patient, cardiopulmonary compromise, and desaturation. With equilibration of pressures across the peritoneum and thorax, the diaphragm will “bellow” which pathognomic for injury. Diagnosis is confirmed with auscultation and the recognition of diminished breath sounds. Treatment can be in the form of needle or tube decompression.

Postoperative Recognition and Management: Pneumothorax can present postoperatively in the recovery room or once admitted to patient floor. Presentation can include pleuritic pain, desaturation, cardiopulmonary compromise, and shortness of breath. Diagnosis is suspected based on decreased breath sounds and supported by chest radiograph. Small pneumothoraces typically resolve spontaneously without intervention due to the high absorption rate of CO2 gas. Larger or symptomatic pneumothorax may require a chest tube for decompression.

3.5 Complications Related to Exit

Complications related to exiting the abdomen include herniation and bleeding complications. **It is**

imperative to exit the abdominal wall in a systematic fashion to prevent complications. Key steps include: (i) thorough inspection of the field after a low intrabdominal pressure (e.g. 5 mm Hg) to identify vascular or visceral injury, (ii) perform trocar removal and closure under direct vision, (iii) evacuate all CO2 from the abdomen, and (iv) inspect all trocar sites for bleeding.

3.5.1 Bowel Entrapment/Hernia

Cause: Herniation of bowel and/omentum can occur through trocar sites, hand-port sites, and extraction sites. Blunt trocars are associated with a decreased incidence of hernia compared with bladed trocars (**0.19%** vs. **1.83%**).

Prevention: **Prevention of hernia involves fascial closure for all bladed trocars >10mm in adults and >5 mm in pediatric surgery**. 8 mm robotic trocars rarely require closure although this may be required if significant dilation occurred due to excessive repositioning of the robotic arm. Controversy exists as to whether to close 12 mm blunt trocar sites in the midline, but is generally advisable. Hernia through mesenteric defects can also occur and therefore most mesenteric defects should be closed. Standard practice during laparoscopic exit should involve a “final look” into the abdomen/pelvis after fascial closure of both extraction incisions and trocar sites. Inspection of these fascial closures can help reduce unrecognized incorporation of bowel/viscera into the fascial closure sutures.

Recognition and Diagnosis: Hernias are recognized by abdominal pain/tenderness focused on a particular trocar site, palpable mass around a trocar site, and erythema. For incarcerated and strangulated hernias, patients may also experience fever, leukocytosis, and at times clinical bowel obstruction with distention, nausea and vomiting. Once clinically suspected, the diagnosis of hernia can be confirmed with CT imaging of the abdomen and pelvis with oral contrast.

Management: Management of abdominal wall hernia typically involves surgical exploration. This can involve exploration of the trocar/extraction site by opening the involved incision and reducing the hernia. **It is imperative to inspect herniated bowel for signs of ischemic compromise or suture injury**, and bowel resection may be required. Occasionally, it is necessary to perform laparoscopic or open reduction of an abdominal wall or pre-peritoneal hernia.

3.5.2 Vascular (Epigastric vessels)

The most commonly injured vessel resulting from port placement is the inferior epigastric artery. In order to recognize vascular port-site injuries, **inspection of all port sites** should be performed **laparoscopically at low intra-abdominal pressures (5 mm Hg) prior to exit**. Small bleeding can be addressed with the use of cautery, whereas more significant bleeding requires suture ligation. Postoperatively, bleeding in the abdominal wall is characterized by a painful, swollen and ecchymotic port/extraction site. CT imaging reveals abdominal wall hematoma, and serial blood work may be required if bleeding is significant. Management is most often conservative, and on rare occasions embolization or exploration may be required.

4. Single Port Robotic Surgery

4.1 Background

The da Vinci Single-Port (SP) platform (Intuitive Surgical Inc, Sunnyvale CA) originally gained FDA clearance in 2108. Currently, the SP system "… is only intended to be used for single port urological procedures and for transoral otolaryngology surgical procedures in the oropharynx for benign tumors and malignant tumors classified as T1 and T2…". Nevertheless, the use of the SP system in urology has been applied across a wide array of surgeries as the technology has allowed for greater triangulation and dexterity compared to previous single site platforms . This section will discuss the SP platform in some detail, describe limitations and strategies to overcome these and review the pertinent urologic literature.

4.2 Background

The SP system has 3 multi-jointed wristed instruments and a fully wristed 3D HD camera, allowing 360-degrees of access without the need to redock instruments. This differs from the Si and Xi systems in terms of accessible range and an articulating camera. While the previous models offer only 0 degree or 30 degrees lens, the SP camera can offer any range of viewing and can be continuously adjusted during the surgery. The SP instruments deploy through a single 2.5 cm cannula and can reach up to 24 cm. The SP system allows for 360^{0} access so that all 4 quadrants can theoretically be accessed while docked. With the SP, the surgeon controls the fully articulating instruments and the articulating camera using the same surgeon console as the da Vinci X and Xi systems with some variation. A relocation pedal moves the entire robotic arm while the instruments are maintained in the same position in an attempt to allow for access to a larger working space. Second, the navigation interface offers image overlay which projects the relative position of each instrument during surgery.

4.3 Considerations when using the SP robot

Several limitations have been described with the SP system which require careful attention when considering patient selection. First, the instruments are not as rigid as their Si or Xi predecessors, meaning that retracting heavier tissues can be difficult. Because of their relative weakness, these instruments are more effective when trying to pull tissue rather than push. Second, the working space of the 3 instruments (4 including the camera) is limited to what has been described as the volumetric equivalent of a softball. So while multi-quadrant surgery is in theory possible, this becomes difficult in practice. For example, it is difficult to move from one side of the pelvis to the other without moving the entire system. The relocation pedal can facilitate a larger range of motion, but the range is limited. Because the working space is limited, this also makes retracting structures off screen (into a different quadrant) difficult. When putting an instrument into this extreme position, the working space of the other instruments can become severely limited due to collisions. Third, the instruments need approximately 10 cm of space to deploy correctly from the canula. This means that the target organ or tissue must be beyond 10 cm from the canula tip. This can pose a problem when working in more restricted spaces or when the patient is very thin. A technique dubbed remote docking or “floating the trocar” has been described which can help eliminate this limitation. This involves moving the canula entry point away from the tissue surface while maintaining insufflation. One option is to use the Mini GelPOINT™ (Applied Medical, Rancho Santa Margarita, CA) as the entry point. Once docked to the GelPINT, he trocar can be bumped out of the body thus creating greater deployment space. In addition, the mini GelPOINT also allows the assistant to place a trocar through gel but to the side of the canula. Of note, it is advised to avoid placing the SP cannula through the center of the GelPOINT, rather try and triangulate the canula with any assistant ports that are needed. This allows the assistant to provide suction and introduce needed elements such as suture, clips and clamps into the operative field. Another option is to place a 5 mm trocar lateral to the GelPOINT. This allows for greater mobility when suctioning or applying clips. As with other laparoscopic of robotic surgeries, an Airseal trocar (either 5mm or 8mm) placed either through the GelPOINT or as a lateral assistant port provides stable pneumoperitoneum. Lastly, the SP system does not currently support a dual console. While it is unclear to what degree this impairs training, there is data to suggest that the dual console may improve real-time feedback and technical guidance while teaching. [3]

4.4 Review of literature

To date, SP robotic procedures have been described for nearly all urologic procedures where conventional multi-port robotic procedures have been applied. This includes prostatectomy (radical and simple), partial nephrectomy, cystectomy (partial and radical), and an array of reconstructive procedures (pyeloplasty, vesicle-vaginal fistula repair, ureteral reimplant, etc). Within the urologic literate, the robotic assisted radical prostatectomy is the most performed and most published operation (1). Lai et al published a metanalysis of 12 studies reporting 145 patients. Within this study there were no intraoperative complications reported, and no Clavien grade 3 or higher complications. Just 1 conversion to multiport was reported for a conversion rate of 0.7%. More recently, Hinojosa-Gonzalez et al published a meta-analysis comparing spRALP to mpRALP. [4] The authors identified 324 patients who underwent spRALP and 744 who underwent mpRALP. There were no differences in baseline characteristics, operative time (p=0.34), or margin rate (p=0.15). The only differences identified were a decrease in hospital stay (p=0.003) and a decrease in shot-interval pain score (p=0.06). To date, there are no randomized controlled trials comparing the two approaches.

One of the theoretical advantages of SP robotic surgery has been the possibility of reduced pain and reduced hospital stay. Steinberg et al reported outcomes in their initial series of spRASP showing good tissue yields, no intra-operative or post-operative complication rates and no conversions to mpRASP. The same group compared mpRASP to spRASP in propensity matched series showing spRASP was associated with a reduction in morphine equivalents (5 vs. 11 mg, p = 0.025) and a near 50% decrease in the number of patients requiring post-operative narcotics. Conversely, Glaser et al examined the morphine equivalents in their series of robotic partial nephrectomy (RAPN) comparing 26 spRAPN to 52 mpRAPN. While there was no difference in the ME used (home or in hospital) there was a reported higher conversion to radical nephrectomy (3.8% vs. 9.6%) for spRAPN. Abaza et reviewed their series of 100 initial SP robotics cases, with 59 being spRALP. They found a higher rate of same day discharge favoring spRALP compared to mpRALP (88% vs. 55%, p<0.05). They reported a similar result with statistically more same day discharges for spRAPN sompared to mpRAPN.

While the SP robotic literature continues to emerge, it remains early in the experience and as of yet too early to consider SP robotic surgery equivalent to MP robotic surgery without properly conducted comparative studies. In addition, the advantages of the SP robot are currently conflicting, with the reduction in pain and hospital admission varying depending on the study. Nevertheless, the SP platform represents the next step in further minimizing the invasiveness of urologic surgery.

5. Emergency undocking of robotic system

From 2000-2013 more than 10,000 adverse events were reported in relation to robotic surgery. Greater than 75% of these adverse events were due to device or instrument malfunction.[5] Conversion to open or laparoscopic surgery was reported in a small but consequential number of cases. The reason for conversion was primarily fell into 2 classes: conversion due to anesthetic related issues (e.g. inability to ventilate) or surgical related issues (e.g. hemorrhage, failure to progress). Hemorrhage was the most reported surgery-related robotic emergency causing conversion. [5] There are very few published protocols or studies examining emergent robotic undocking and similarly few validated simulation curricula. Intuitive surgical also has no published recommendations for emergent conversion except to outline the technical workings of the robotic system. Kalipershad et al. published an emergency safety protocol (ESP) coupled with recommendations for simulation training. The following key aspects are included in their protocol, however, for a more comprehensive protocol, the reader is directed towards this publication.[6]

1. Maintain crucial staff in the OR at all critical times during the operation.
2. A time-out should be performed and include a review of anticipated equipment needs, anticipated blood loss (verify type and cross match or blood products available) and potential for open conversion. In addition, a sterile gown, gloves and suction device should be available and on the field throughout the case.
3. Ensure the robot is connected to the uninterruptable power source to mitigate issues in event of power loss.
    a. If power is lost, surgeon should be familiar with the systems default protocols
        i. The instruments will maintain their position if docked during shutdown and when the system restarts (the need to remove the instruments is up to surgeon)
        ii. Once power is restored, the surgeon will have to engage figure grips or switch between the arms before taking control of the instruments
        iii. In some cases, manual release of instruments may be needed with the release tool. This should be stored in a pre-identified location.
4. At the institutional level, identify a trigger phrase such as “Emergency Undocking” which are initiated by the surgeon and puts into action a series of predefined steps as follows:

a. Circulating nurse calls for additional assistance
b. Bedside assist focuses on controlling operative field in situation of hemorrhage and not expected to focus on undocking
c. Scrub technician responds only to surgeon instruction and removes instruments and releases ports only if instructed to do so
d. The bed is moved to a favorable conversion position at the surgeon's direction
e. The surgeon is gowned and gloved by the scrub technician
f. Anesthesia begins to transfusion protocol as needed

As stated previously, the literature across surgical subspecialties lacks consensus on what an ESP for emergent robotic undocking should include and how often these protocols should be reviewed, updated and to what extent simulation should play a role. Kalipershad et al. recommends a review and update of their ESP every 6 months and team simulation training every year.[6] Malnyk et. Al and studied their immersive team curriculum and demonstrated a significant gain in knowledge ($p = 0.004$) and confidence ($p < 0.001$) from baseline with team simulation training.[7] They reported improved undocking time and decreased estimated blood loss with simulation training (decrease of 40 seconds and 500 mL, respectively) but these were not statistically significant. Repeat evaluation at 6 months showed no significant changes from the time of curriculum completion indicating retention of knowledge.

6. Podcasts

Crossfire In Urology - Robotic Reconstruction

References: 8,9,10,11,12,13,14,15,16,17,18

Videos

Malfunction of linear cutting stapler in kidney surgery

COMPLICATIONS OF LAPAROSCOPIC RENAL SURGERIES

Management of Vascular Injuries During Robotic Surgery

Multiport Robot Docking

Multi-Port Docking: Da Vinci Xi

Single-Port Transvesical Robotic Radical Prostatectomy

Extraperitoneal Single Port Robotic Assisted Radical Prostatectomy wuth the da Vinci Single Port Platform: A Step-by-Step Approach

Single Incision Robotic Radical Cystectomy with Orthotopic Neobladder

Single-Port Robot-Assisted Laparoscopic Radical Cystectomy with Ileal Conduit Urinary Diversion

Single-Port Robotic Transvesical Simple Prostatectomy Step-by-Step

Robotic assisted Simple Prostatectomy: single port, Transvesical

Presentations

LAPAROSCOPY AND ROBOTICS Presentation 1

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