The Role of Minimally Invasive Surgery in Pediatric Trauma

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KEYWORDS

• Minimally invasive surgery • Trauma • Laparoscopy • Thoracoscopy

KEY POINTS

- Laparoscopy and thoracoscopy possess high levels of diagnostic accuracy with low associated missed injury rates.
- Minimally invasive surgery (MIS) is used in pediatric trauma patients who are hemodynamically stable.
- MIS offers diagnostic and therapeutic capabilities in pediatric trauma patients.
- MIS confers a lower postoperative morbidity profile than traditional open approaches.

The role of minimally invasive surgery (MIS) in the management of blunt and penetrating injuries to the chest and abdomen has evolved over the last 3 decades. In 1972, Gans and Berci first demonstrated the diagnostic capacity of laparoscopy in 16 children and shortly after Carnevale and associates published a broad experience with laparoscopy in trauma patients.[1,2] Subsequently, several groups published case series demonstrating both the safety and efficacy of laparoscopy in trauma, and perhaps more importantly its effect on reducing nontherapeutic laparotomy rates by up to 60% in both blunt and penetrating injury.[3–5] Although early technical limitations precluded the full diagnostic and therapeutic potential of MIS, this was quickly overcome. MIS is now routinely used as a therapeutic strategy encompassing the full spectrum of traumatic injuries, including repair of lung, diaphragm, bowel, pancreas, and solid organ injuries.[6–10]

Disclosures: The authors do not have any commercial or financial conflicts of interest that interfere with the production of this article.
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Surg Clin N Am 97 (2017) 75–84
http://dx.doi.org/10.1016/j.suc.2016.08.005
surgical.theclinics.com
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The current gold standard therapeutic intervention for an unstable patient with blunt or penetrating abdominal injury remains exploration through a midline laparotomy; similarly, a sternotomy or thoracotomy may be required in the unstable patient with a thoracic injury. It is important to note, however, that negative open exploration carries with it a significant mortality of up to 5% and an 18% incidence of morbidity. Most notably, this includes the risk of future adhesive intestinal obstruction and potential for abdominal wall hernia.[11] Across pediatric and adult case series, diagnostic and therapeutic laparoscopy has demonstrated significant benefit for the treatment of traumatic injuries. In hemodynamically stable patients requiring exploration, MIS offers a safe diagnostic or therapeutic alternative with several advantages, including less pain, shorter recovery time and hospital stay, and decreased financial burden, as well as decreased morbidity and mortality through avoidance of unnecessary procedures.[12,13] In an examination of the National Trauma Data Bank, Zafar and colleagues[14] evaluated 916 patients at 467 trauma centers undergoing therapeutic laparoscopic interventions for blunt and penetrating trauma, including diaphragm repair, bowel repair or resection, and splenectomy. The authors found that patients treated with therapeutic laparoscopy had a significantly shorter hospital stay with no increased risk of mortality or morbidity compared with patients undergoing laparotomy. In addition, the accuracy of MIS in diagnosing traumatic injury approaches 100%, with several studies documenting zero missed injuries in pediatric trauma patients.[12,15,16] Further, maintaining the intestines within the peritoneal cavity prevents tissue desiccation and minimizes fluid and temperature shifts.[8] Across pediatric and adult case series, diagnostic and therapeutic laparoscopy has demonstrated significant benefit for the treatment of traumatic injury to the abdomen and thorax.

Children suffer higher rates of solid organ injury than adults from both blunt and penetrating trauma because they have proportionally larger solid organs, less subcutaneous fat, and less protective muscle.[17] Blunt abdominal trauma related to motor vehicle collision is the most common cause of unrecognized fatal injury in children, and approximately one third of children with major trauma will suffer intraperitoneal injuries.[18] The Advanced Trauma Life Support system outlines the initial evaluation and management of children with traumatic injuries and follows the same sequence as that in an adult: primary survey, resuscitation, secondary survey, and definitive care. The management of children with solid organ injury after blunt abdominal trauma has evolved significantly since Upadhyay and Simpson[19] in 1968 first suggested the nonoperative management of splenic trauma in children. Hemodynamically unstable children with free fluid identified on ultrasound examination proceed immediately to exploratory laparotomy, whereas hemodynamically stable children with free fluid on ultrasound examination undergo computed tomography. This strategy has demonstrated accuracy in identifying greater than 95% of intraabdominal injuries.[20] Diagnostic peritoneal lavage in the pediatric population has become relatively obsolete owing to the diagnostic accuracy of high-resolution computed tomography and Focused Abdominal Sonography for Trauma examinations. Currently, children who suffer blunt abdominal trauma with solid organ injury involving liver and/or spleen are now managed according to the ATOMAC guideline used at many pediatric trauma centers.[21] The ATOMAC protocol for the management of blunt liver or spleen injury guides the surgeon along a nonoperative management pathway until the child develops recurrent hypotension, bleeding, or fails to have a sustained response to blood transfusion. When surgery is indicated, MIS offers diagnostic and therapeutic equivalency to open surgery in the hemodynamically stable child.

LAPAROSCOPY FOR THE DIAGNOSIS AND TREATMENT OF ACUTE TRAUMATIC INJURY

In a recent analysis of the use of MIS for trauma, Alemayehu and colleagues[15] characterized the practice patterns at 6 pediatric trauma centers across the United States. The retrospective study included 200 patients, each receiving laparoscopy (94%), thoracoscopy (4%), or both (2%). The most common mechanism of injury was all terrain vehicle or motor vehicle collision (37%) followed by stab wounds (17%), bicycle crashes (14%), gunshot wounds (12%), and falls (11%). The most common indications for laparoscopy included penetrating injury (32%), peritonitis (16%), and free fluid with abdominal pain (14%). Of the 192 children undergoing laparoscopy for abdominal trauma, 120 operations (63%) were completed without conversion, including 77 diagnostic and 43 therapeutic procedures. The conversion rate to laparotomy was 37%. Most of the repairs performed after conversions were related to intestinal injury. As a diagnostic tool, laparoscopy provided insufficient information to exclude an injury in only 6 (3%) of the 192 procedures. Additionally, using MIS as an extension of the diagnostic evaluation for trauma resulted in zero missed injuries, a testament to its efficacy.[22,23] In a sense, diagnostic laparoscopy has become an extension of the secondary survey.

As a therapeutic tool, the most common operations performed included bowel resection or repair of enterotomies, distal pancreatectomy, splenectomy, or repair of traumatic hernias. If a bowel resection or complex repair of an enterotomy was required, 73% of these cases were converted to laparotomy. Repair of hollow viscera is more difficult laparoscopically, but it has been reported in several studies as a safe option.[7,24,25] The success of this approach depends on the expertise of the surgeon. Even when conversion is necessary, the incision is typically much smaller than that for a primary trauma laparotomy, because other potential sites of injury have been explored and excluded. In a metaanalysis of 51 studies evaluating the use of laparoscopy in penetrating abdominal trauma as both a diagnostic and therapeutic modality, 51.8% of patients were spared a nontherapeutic laparotomy, with most studies reporting 100% sensitivity for the detection of injury.

A separate study from an American College of Surgeons–designated level 1 pediatric trauma center reviewed 20 years of experience using MIS in the management of trauma patients.[12] The authors found that, in addition to its diagnostic capabilities, MIS therapeutic interventions are possible in up to 65% of cases without conversion to an open procedure. Furthermore, 19% of negative laparoscopies did not require any further intervention, thus avoiding the morbidity of a negative laparotomy. In a 13-year analysis of 16,321 trauma admissions with 119 patients requiring abdominal exploration for blunt and penetrating injury, Tharakan and colleagues[16] retrospectively reviewed 38 hemodynamically stable children who underwent diagnostic and therapeutic laparoscopy. In 13 children (34%), laparoscopic exploration ruled out injuries and avoided the need for a negative laparotomy. In 9 children (24%), laparoscopy identified an injury for which no surgical intervention was necessary and in another 9 children (24%) an injury was repaired laparoscopically. The authors identified 7 children (6%) who required conversion to laparotomy and concluded that in the hemodynamically stable patient with a concerning examination and inconclusive imaging, laparoscopy is a sensitive diagnostic modality that provides the opportunity for therapeutic intervention with substantially less morbidity than open exploration.

Diagnostic laparoscopy is an established surgical approach in penetrating abdominal trauma with sensitivity, specificity, and accuracy of up to 100%.[26] The screening, diagnostic, and therapeutic potential of MIS in the management of

penetrating injuries to the abdomen was well-documented in a recent retrospective analysis by Koto and colleagues.[27] In a series of 114 patients including 81 stab injuries and 33 gunshot wounds, hemodynamically stable patients or hemodynamically unstable patients who responded to initial resuscitation were managed with MIS with only a 7% conversion rate. Of the patients converted to an open procedure, extensive bleeding was the most common surgical indication. Liver injury not requiring repair was the most common finding during nontherapeutic diagnostic laparoscopy and the most common therapeutic procedure was diaphragm repair. The use of laparoscopy for the repair of diaphragm injuries can be done entirely intracorporeally or via a laparoscopic assisted technique.[24] Bowel injuries were either managed laparoscopically with intracorporeal suturing of the enterotomy or by a laparoscopic-assisted technique with a small, focused incision. Current guidelines recommend the use of laparoscopy only in hemodynamically stable patients; however, other studies have demonstrated the safety of diagnostic laparoscopy in adults in both the hemodynamic responder and nonresponder to resuscitation.[7,26–28]

The hemodynamic changes induced during laparoscopy are well-described. Pneumoperitoneum reduces lung volumes and cardiac index with systemic hypercapnia, increased cardiac filling pressures and increased systemic vascular resistance.[29] These physiologic changes may lead to greater hemodynamic instability in the underresuscitated or unstable trauma patient. Cherkasov and colleagues[28] reviewed 1332 adult patients with abdominal trauma with varying degrees of hemodynamic instability (51%, 25%, and 16% of patients were in mild, moderate, and severe shock, respectively). Diagnostic and therapeutic laparoscopy was taken to completion in 89% of patients irrespective of hemodynamic status. Gasless laparoscopy has been proposed as an alternative to the use of pneumoperitoneum as a tactic to avoid hemodynamic instability as well as the other complications of pneumoperitoneum, including hypercapnia, acidosis, gas embolism, pneumothorax, and deep venous thrombosis.[30] In a review of 15 adult patients sustaining intraabdominal trauma, gasless laparoscopy was used successfully to manage both blunt and penetrating injury with no effect of hemodynamic status. In our hospital, we continue to manage hemodynamically unstable pediatric trauma patients with open exploration by midline laparotomy and believe this remains the safest strategy for the critically injured child.

Children selected for an MIS approach to traumatic abdominal injury should not have an absolute contraindication to laparoscopy such as hemodynamic instability (**Box 1**). Relative contraindications such as peritonitis, evisceration, or multiorgan injury should be weighed carefully. Other relative contraindications to consider include an inability to tolerate abdominal insufflation, increased intracranial pressure, uncorrected coagulopathy, or congestive heart failure. These factors must be reviewed by the anesthesia and trauma team in the multiply injured patient before an MIS approach is undertaken. Clear indications for diagnostic and/or therapeutic laparoscopy include penetrating injuries to the anterior abdominal wall, thoracoabdominal trauma, suspected hollow viscus injury, and presentation suggestive of a diaphragm injury. Children with blunt trauma and a worsening abdominal examination with free fluid on ultrasound examination or inadequate imaging may be candidates for laparoscopy. A common pediatric scenario demonstrating the usefulness of laparoscopy is a child with a Chance fracture and worsening abdominal examination after a motor vehicle collision. Bowel injury is present in a significant number of these children and this injury pattern occurs with enough frequency to warrant a standardized minimally invasive approach.

Box 1
Indications and contraindications for minimally invasive surgery in pediatric blunt and penetrating trauma

Indications

Penetrating injury abdominal wall

Suspected diaphragm injury

Thoracoabdominal trauma

Suspected hollow viscus injury

Worsening abdominal examination

Contraindications

Absolute
- Hemodynamic instability

Relative
- Increased intracranial pressure
- Congestive heart failure
- Uncorrected coagulopathy
- Peritonitis
- Evisceration
- Multiple organ injury

TREATMENT ALGORITHM FOR THE USE OF MINIMALLY INVASIVE SURGERY IN BLUNT AND PENETRATING TRAUMA

Many algorithms have been developed for the triage of patients for MIS in blunt and penetrating abdominal trauma.[23,27] In a retrospective review of 7127 trauma admissions with 113 children requiring surgical exploration, 32 patients with initial diagnostic laparoscopy were reviewed in detail and a clinical decision making tree was created.[23] Hemodynamically stable children with blunt abdominal trauma and a concerning abdominal examination, elevated liver function tests, or a positive Focused Abdominal Sonography for Trauma examination should undergo a computed tomography scan (**Fig. 1**). If injuries are limited to solid organs, a nonoperative management pathway should be chosen. Children with clear evidence of hollow viscus or diaphragm injury should undergo laparoscopy for either diagnostic or therapeutic purposes. The child without solid organ injury who has free fluid and an equivocal examination may be managed with serial abdominal examinations or upfront laparoscopy.[23] Hemodynamically stable children with anterior abdominal stab wounds or tangential gun shot injuries with questionable fascial penetration are excellent candidates for diagnostic laparoscopy (**Fig. 2**). If at any point the child is unstable hemodynamically, exploratory laparotomy is the procedure of choice.

TECHNICAL CONSIDERATIONS IN TRAUMA LAPAROSCOPY

After the decision has been made to proceed with surgical intervention, the patient is taken directly to the operating room with cross-matched blood available and induced with general anesthesia. After surgical preparation with chlorhexidine gluconate solution, access to the peritoneum is achieved via the umbilicus using either a Veress needle or Hassan technique. The initial approach begins with CO_2 insufflation of the abdomen to 9 to 12 mm Hg with a flow of 0.5 to 2 mL/min. A 4- or 5-mm port is placed at the umbilicus. Additional port placement is tailored to the nature of the injury.

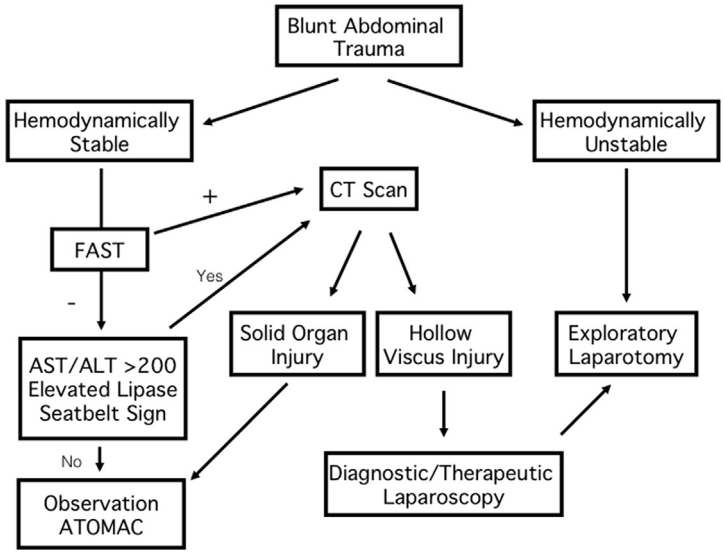


Fig. 1. Management algorithm for blunt abdominal trauma. CT, computed tomography; FAST, Focused Abdominal Sonography for Trauma.

Common configurations include a 5-mm port in the right and left mid abdomen, or 2 additional 5-mm ports placed in the left flank. The latter triangulates the approach for running the entirety of the small bowel, although in some cases a 5-mm port in the right lower quadrant is necessary for additional exposure. If an injury clearly penetrates the peritoneum, this wound may be used to establish laparoscopic access. Once ports are safely established, the peritoneal cavity is evaluated with a 30°

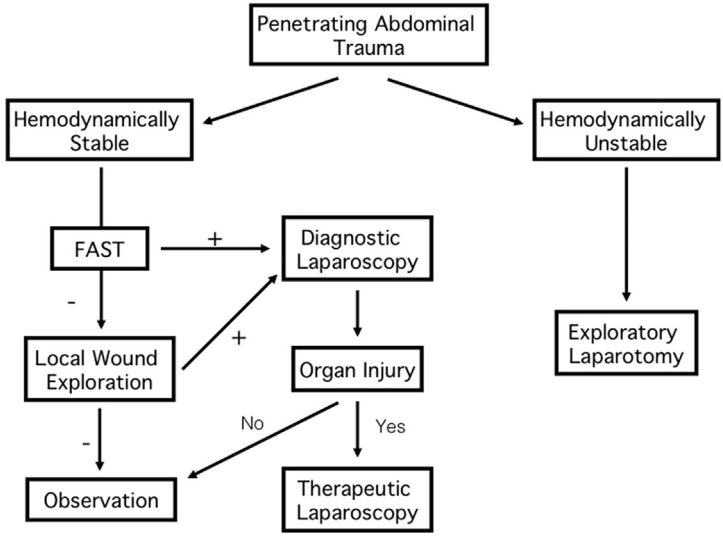


Fig. 2. Management algorithm for penetrating abdominal trauma. FAST, Focused Abdominal Sonography for Trauma.

telescope for the presence of blood, bile, or enteric contents. A systematic evaluation of the peritoneal cavity and its contents has been shown to be reproducible, reduce the incidence of missed injury, and increase the safety and efficacy of laparoscopy in trauma patients.[31] The rate of missed injuries can be decreased significantly by following 3 strategies[1]: systematic and careful inspection,[2] changing the patient's position to optimize evaluation,[3] and using atraumatic graspers to handle the bowel. Intraabdominal contents are evaluated systematically beginning with the liver, spleen, stomach, diaphragm, pancreas, and abdominal wall in the reverse Trendelenburg position. The patient is then positioned in the level supine position and using atraumatic graspers, the transverse colon is elevated superiorly. The small bowel and its mesentery should be examined in segments beginning at the ligament of Treitz, proceeding distally until the ileocecal valve is reached. By crossing the graspers, the reverse side of the bowel is brought into view, because a detailed inspection of all surfaces of the intestine and its mesentery is necessary to avoid missed injuries.[32] The large intestine is then examined, followed by the rectum and pelvic contents with the patient in the Trendelenburg position.

Once an injury is discovered, the surgeon must judge whether the repair can safely be completed laparoscopically. Simple gastric, small bowel, and colon perforations (<50% of bowel wall circumference) are repaired with 3-0/4-0 absorbable sutures sewn intracorporeally.[8] If more complex injuries exist requiring bowel resection, a "minilaparotomy" of greater than 4 cm is extended from the nearest trocar or umbilicus and an extracorporeal resection with stapled or hand sewn anastomosis can be performed (after the entire abdomen has been fully explored for additional injuries). Using these techniques, Streck and colleagues[8] retrospectively evaluated 50 hemodynamically stable children explored for suspected bowel injury. The authors noted that children sustaining penetrating trauma were operated on shortly after arrival (4.2 hours), whereas patients with isolated bowel injuries after blunt abdominal trauma had a delay in diagnosis and treatment (16 hours after arrival). The decision to operate was made based on a worsening abdominal examination or the presence of pneumoperitoneum or a progression of free air or fluid on serial radiographs. In this study, laparoscopic repair was completed in 6 children and an additional 6 children found to have complex intestinal injury underwent laparoscopic-assisted bowel resection. No patient undergoing laparoscopic exploration and repair experienced an early (missed injury, wound infection, bleeding) or late (need for reoperation) complication. In addition to bowel injury, myriad other therapeutic procedures have been documented as safe and efficacious in the hands of an experienced surgeon with advanced laparoscopic skills.

Although laparoscopy is safe and efficacious, it can be associated with significant risks, including access-related complications, equipment failure, inadequate visualization of injuries, insufflation-related injuries, intraoperative injuries, and postoperative complications.[33] The physiologic consequences of CO_2 insufflation have been described and include impaired venous return, pneumomediastinum, venous gas embolism, and subcutaneous emphysema. These changes may have an effect on preload, causing bradycardia and hypotension. Access-related complications include injury to the abdominal wall or intraabdominal vessels as well as solid and hollow organs with associated sequelae. Hemorrhagic complications during laparoscopy occur during 0.3% of cases with an associated mortality of 15%. Omental injuries occur in as many as 1.6% of laparoscopic cases, although most do not require repair. Visceral injuries occur in up to 0.5% of cases. Importantly, up to one-half of visceral injuries caused by iatrogenic laparoscopic intervention go undiagnosed during surgery, leading to significant morbidity or mortality.[33] These injuries may be attributed to trocar insertion, direct mechanical instrument injury, and thermal injury from electrocautery.

Other potential complications include bladder puncture by trocar insertion, port site hernias, and inadequate visualization or missed injuries.

MINIMALLY INVASIVE SURGERY AND THORACIC TRAUMA

The resuscitation and clinical management of the child with thoracic and thoracoabdominal trauma remains a clinical challenge and treatment algorithms are poorly defined in the pediatric population. In the adult population, thoracoscopy has been used at an increasing rate over the last decade for both diagnosis and treatment of trauma to the chest cavity. Authors have demonstrated reduced rates of postoperative complications, bleeding, drainage, and a shortened hospitalization when comparing thoracoscopy to open thoracotomy.[34] In a recent metaanalysis of 26 studies of adult chest trauma, the authors found that video-assisted thoracoscopic surgery is an effective and better treatment for improving preoperative outcomes of hemodynamically stable patients with reduced postoperative complications. The range of thoracoscopic interventions that have been successful include, but are not limited to, hemostasis of bleeding vessels, decortication and evacuation of hemothorax, repair of lung laceration or pulmonary wedge resection, repair of diaphragm injury, control of air leak, removal of foreign bodies, and widening of pericardial lacerations. Contraindications to thoracoscopic management of chest trauma include obliterated pleural spaces, inability to tolerate single lung ventilation, hemodynamic instability, circulatory shock, and life-threatening thoracic injury.[34]

The management of thoracic trauma by video-assisted thoracoscopic surgery has not been studied exhaustively in the pediatric literature and data are limited to small case series and reports. In a single institutional review of a 20-year experience using MIS for trauma, the authors reported just 2 children with diagnostic thoracoscopy after trauma with successful thoracoscopic repair of a diaphragmatic repair in 1 child and conversion to open thoracotomy for repair in the other patient.[12] In a much larger study including 6 pediatric trauma centers, Alemayehu and colleagues[15] reviewed 13 patients that underwent video-assisted thoracoscopic surgery repair for penetrating injury, failed chest tube management, or a large hemothorax. In this cohort, the rate of conversion was only 11%. Interventions included evacuation of hemothorax, repair of diaphragmatic injury, and wedge resection for lung injury. Perioperative thoracic complications included complex hemothorax, pleural effusion, and empyema. Thoracoabdominal trauma presents a particular challenge to the trauma surgeon, who must decide which cavity to explore, especially if occult injuries may be present and not identified on imaging. In a recent review of 30 adult patients with thoracoabdominal stab wounds who underwent thoracoscopy to identify a possible diaphragmatic injury, 17% of patients were found to have injuries and the accuracy of thoracoscopy reached 100%.[35]

In the multiply injured child, the minimally invasive treatment paradigm is expanding into the realm of vascular surgery as well. Although still in its development phase, the advent of resuscitative endovascular balloon occlusion of the aorta and other wire-based or catheter-based interventions make it conceptually possible that in the near future children with severe thoracic and abdominal injuries will be treated using techniques that are entirely minimally invasive.

SUMMARY

MIS in the management of blunt and penetrating pediatric trauma is finding its place in the armamentarium of the pediatric trauma surgeon. Several studies have demonstrated the safety and efficacy of laparoscopy and thoracoscopy with diagnostic accuracy

approaching 100% and a missed injury rate of 0% to 1%. Although some studies have shown safety in the management of patients who are hemodynamically unstable or who are transient responders to initial trauma resuscitation, the currently available data advocate limiting the use of MIS to blunt or penetrating injuries in the hemodynamically stable child. In the pediatric trauma population, MIS offers both diagnostic and therapeutic potential, as well as reduced postoperative pain, a decreased rate of postoperative complications, shortened hospital stay, and potentially reduced cost.

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