Historical and Current Trends in Colon Trauma

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Abstract

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The authors discuss the evolution of the evaluation and management of colonic trauma, as well as the debate regarding primary repair versus fecal diversion. Their evidence-based review covers diagnosis, management, surgical approaches, and perioperative care of patients with colon-related trauma. The management of traumatic colon injuries has evolved significantly over the past 50 years; here the authors describe a practical approach to the treatment and management of traumatic injuries to the colon based on the most current research. However, management of traumatic colon injuries remains a challenge and continues to be associated with significant morbidity. Familiarity with the different methods to the approach and management of colonic injuries will allow surgeons to minimize unnecessary complications and mortality.

Objectives: On completion of this article the reader should be able to summarize the management of traumatic colon injuries.

Warfare and combat—and their resultant injuries—have been part of our history. Specifically, traumatic wounds to the colon and their complications have been reported since biblical times: The death of King Eglon of Moab was the result of a suspected penetrating colonic injury from a stabbing by Ehud, an emissary of the Israelites in 1300 BC (Jud 3:21–22).¹ In fact, throughout ancient and modern history colonic trauma in all but the most rare of occasions has traditionally equated to death. In reports of the Civil War, most colon injuries were fatal—not simply from the battlefield injuries themselves—but also from secondary infection and sepsis. These dismal outcomes led to a policy of expectant management when dealing with traumatic colon injuries.² It was not until World War I that larger-scale outcome data were first available for these large intestine injuries, with reported mortality rates ranging from 60 to 75%, depending on injury location and degree.³ In World War II, W.H. Ogilvie described colonic injuries in his 1945 article, “Surgical Lessons of War Applied to Civil Practice”: “The treatment of colon injuries is

based on the known insecurity of suture and the dangers of leakage. Simple closure of a wound of the colon, however small, is unwarranted; men have survived such an operation, but others have died who would still be alive had they fallen into the hands of a surgeon with less optimism and more sense. Injured segments must either be exteriorized, or functionally excluded by a proximal colostomy.” Therefore, during World War II, and in keeping with Ogilvie’s experience with British forces, the United States Office of the Surgeon General mandated surgeons either perform exteriorization or proximal stoma placement with an elective closure at a later date, or suffer a potential court martial.^{4,5} Interestingly, even with the advocacy of Ogilvie, closer evaluation of his own data has demonstrated that mortality rates were similar between primary repair and the diversion/exteriorization groups (53% vs 59%).⁶ Nonetheless, as time went on, this change in surgical technique coincided with even more advances in perioperative care such as decreased evacuation time from battlefield (or civilian) point of injury, more aggressive fluid resuscitation, improved antibiotics, and safe banked blood use that cumulatively led to an even more profound decrease in overall mortality rates of 22 to 35%.^{7,8} Despite many of these advancements, dogmatic approaches to these injuries

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endured, and diversion remained the standard practice for the next 40 to 50 years before the reemergence of primary repair, when feasible, as the treatment of choice.^{9–13} Outcomes in the civilian sector during this period also demonstrated steady improvement: There were additional advances not only in surgical technique, such as a shift from watchful waiting early on to exploration and diversion, as well as experience in understanding methods of repair, but also in understanding, monitoring, and managing the accompanying physiologic changes in the injured patient. Wartime series were slower to mimic the civilian trauma experience, despite evidence that not all colon injuries required a colostomy, with equivalent morbidity and mortality rates following primary repair.^{14–16} Currently, colonic injuries continue to be a source of not only significant morbidity and mortality, but a persistent focus of ongoing debate regarding the optimal management strategy. Unfortunately, this contrast in ideas or philosophies is one that presently does not, and possibly never will, have a definitive “clear” answer. More appropriately, this likely reflects a culmination of an individual surgeon’s variable comfort levels and experience in dealing with colonic injuries, the challenges of managing a multiply-injured and unstable patient, a mixture of simple and destructive injuries, and extenuating circumstances such as operating in a level 1 trauma center versus a remote rural or combat environment.

Incidence and History

The exact incidence of colonic trauma annually is difficult to determine, especially when attempting to separate from rectal trauma. Using large national database studies, the incidence of colorectal-specific injury from all trauma patients is generally <1%, with 43.9% of injuries following blunt trauma and 56.1% after penetrating trauma, with an overall mortality rate of 25.6%.¹⁷ Not surprisingly, with the increase in blast and high-velocity injuries, wartime series have reported a higher incidence of colonic injuries of 5 to 10% as demonstrated in a recent review of over 3,400 patients treated during Operation Iraqi Freedom, which revealed colon and rectal injuries present in 5.1% of patients.^{18–20} The primary mechanism of injury also varies based on the environment (i.e., urban, rural, or combat). A 2010 study of colorectal injuries encountered during the conflicts in Afghanistan and Iraq revealed that 71% of injuries occurred secondary to penetrating trauma, 23% were secondary to blast injuries, and 5% occurred during blunt trauma.²¹ North American civilian studies have published lower rates of injury, around 0.6 to 3%, and though devoid of many of the high-energy and blast mechanisms seen in combat, still have mortality rates ranging from 10 to 25.6%.^{17,22,23} This is in contrast to mortality rates following blunt trauma, which are even lower at 0.1 to 0.5%.^{17,24,25}

The traumatic mechanism and setting also play an important role in determining the pattern and severity of injury. Urban hospitals have reported low rates of blunt trauma (0.02%).²⁶ Despite this low incidence, surgeons must retain a high index of suspicion to avoid the increased morbidity and

mortality associated with a delayed or missed diagnosis. Due to the natural protection of the abdominal wall, blunt hollow-visceral injuries typically occur in the setting of high-energy transfer, and are often accompanied by head, chest, solid organ, and orthopedic injuries.²⁷ On the other hand, high-energy wounds from projectiles that transfer significant energy to adjacent tissues are more commonly associated with military environments, but may also occur in the civilian sector following mass casualty events, motor-vehicle collisions, or industrial accidents. These environmental differences are also a significant factor in dictating the management strategy. For example, given the significant differences in types of injuries and available resources that are contingent upon the surgical environment and location, surgeons must be familiar with the indications and rationale for deciding whether to perform a primary repair and/or fecal diversion of colonic injuries when undertaking surgical exploration in an emergent setting. Clearly, when encountering the multiply injured polytrauma patient in any setting, focus should initially be on airway, breathing, and hemorrhage control prior to turning focused attention to the control of intraabdominal enteric contamination. Military trauma has traditionally been managed with fecal diversion because military trauma has typically been associated with polytrauma caused predominantly by high-velocity weaponry and fragment wounds with multiple associated injuries that include significant energy transfers to adjacent tissue and even coexistent burns. Additionally, supply limitations, availability of critical care monitoring, and remote locales also pose unique challenges not seen in North American civilian hospitals. Therefore, the combat surgeon must consider the patient’s anatomic injuries and physiology as well as the number and severity of other incoming casualties, the availability of resources such as blood products, and the length of postoperative observation required before evacuation to the next level of care can occur. Although the studies in military warfare may not correlate directly to civilian practice in North America, they can reflect expected outcomes with many of the more severe polytrauma patients encountered in modern surgical practice, provide invaluable understanding of treatment modalities available to surgeons encountering the most severe colonic trauma scenarios, and serve as a great baseline reference in understanding the history and management trends of colonic injuries.^{28,29} Furthermore, despite these differences, a history of dogmatic teaching and anecdotal past experiences has somewhat delayed the evolution of colon trauma in military and North American civilian practice.^{30,31}

Based in large part on the military experience during World War II, surgeons returned to civilian practice from the battlefield with the understanding and practice of universal fecal diversion.³² Although life in North America and across Europe and Asia changed and advanced in the postwar era, changes in colonic trauma management did not occur at the same rate. Small individual studies suggested that certain patient factors such as age, concomitant injuries, and fecal soilage all played an independent role in the development of complications, but were independent of the method of colon

management. Subsequent meta-analyses and systematic reviews reported no difference in complications with many of the patient factors or surgical approach—in fact, primary repair was superior in most cases, even when accounting for degree of injury.³³ Yet, despite the evidence supporting primary repair, there continues to be an ongoing, heated debate on the management of left-sided colon injuries. However, surgeons, intensivists, nurses, and even first responders have much improved training in advanced critical and perioperative care; this education and experience likely accounts for at least some of the encouraging trends regarding morbidity and mortality that favor primary repair. It should be noted that military surgeons, traditionally accustomed to using fecal diversion exclusively, have also begun to change their practice in certain situations as well. One study of soldiers sustaining combat-related colorectal injuries who were transported to United States found that 62% underwent fecal diversion with an overall complication rate of 18%, much fewer than the 100% diversion and high mortality rates seen with the World War II stoma mandate. More importantly, the overall morbidity in these patients was unrelated to operative approach.²¹ Additionally, these trends also reflect much of the current surgical practice demonstrated in rural and urban communities; surgeons with more experience in colonic trauma have been shown to be more apt to perform a primary anastomosis or bowel resection with similar outcomes.³⁴

Diagnosis

Evaluation of injured patients with colon trauma begins with standard advanced trauma life support (ATLS) primary and secondary surveys along with appropriate concomitant resuscitation.³⁵ Specific to this injury pattern, all patients should undergo complete physical examination with focused abdominal examination to evaluate for sites of penetrating wounds or peritonitis mandating urgent exploration.³⁵ With colonic injury, an upright chest radiograph may demonstrate free intraperitoneal air consistent with hollow-viscous perforation (▶ Fig. 1). Ultrasound use via a focused assessment

Figure 1 Pneumoperitoneum with colonic injury.

with sonography for trauma (FAST) may demonstrate free fluid, and has been shown to be useful for both blunt and penetrating abdominal trauma. Importantly, this modality is nonspecific for colon injuries, the type of free fluid in the abdomen, and may miss retroperitoneal injuries.³⁶ Computed tomography (CT) has become the predominant radiologic test in many centers, having been shown to be effective in diagnosing colon injuries in stable patients without vital sign instability or immediate indications for laparotomy. CT has the advantage of demonstrating not only signs such as a pneumoperitoneum, but can also demonstrate secondary signs of injury (i.e., extravasation of contrast, fluid, thickened bowel), as well as help identify patients with abdominal penetration of fragmentation wounds without any intraperitoneal or retroperitoneal injuries that would require exploration.³⁷ CT has also proven useful in identifying colon injuries in a military wartime setting, with the increasing availability of advanced technology in combat locales.³⁸ Shanmuganathan and colleagues reported in their study of the use of triple-contrast helical CT in penetrating trauma a 100% sensitivity, 96% specificity, 100% negative predictive value, and 97% accuracy in evaluating peritoneal violation, colonic, major vascular, and/or urinary tract injuries following penetrating trauma.³⁹ They further validated the use of triple-contrast CT in 200 patients with penetrating trauma and reported greater than 95% sensitivity, specificity, and accuracy for both peritoneal violation and visceral injury.⁴⁰

Although not used as frequently with the advances in readily available radiographic imaging techniques, diagnostic peritoneal lavage (DPL) continues to be a viable modality in identifying injuries, with sensitivities of 84 to 97% for the detection of intestinal injury, and should remain as an adjunct in the management of abdominal trauma, especially in the combat setting.^{41,42}

Minimally invasive surgical techniques such as diagnostic laparoscopy also have an emerging role in the diagnosis of traumatic colon injuries.^{43–45} For tangential injuries, those in which peritoneal penetration is indeterminate, and patients with an equivocal radiologic workup and inability to adequately examine (i.e., altered mental status), laparoscopy can help identify intraperitoneal injuries. It also provides the additional ability to help identify more difficult to diagnose injuries using current imaging modalities (i.e., diaphragm and small bowel) that may be concomitantly present but initially less symptomatic, while avoiding the morbidity of a laparotomy when these injuries are not present. Finally, laparoscopy has been shown to be extremely useful in a variant of colorectal trauma—perforation by colonoscopy—with reported lower morbidity rates and shorter hospital length of stay.⁴⁶ As surgeons continue to grow more facile with advanced laparoscopic techniques, minimally invasive diagnosis and management of traumatic injuries is likely to increase.

Management

The evolution in management of colonic injuries was hampered largely by the inflexible approach mandated by the then present-day circumstances. Following World

War II, surgeons returned from the battlefield with the understanding and practice of near-universal fecal diversion. Although this is not to say that primary repair was not being performed at all, the study from Stone and Fabian in 1979 in many ways signified the beginning of a paradigm shift in managing penetrating colon injuries. In this prospective, nonblinded study, 139 patients were randomized to primary repair or diversion, finding equivalent rates of infection (48% vs 57%, $p > 0.05$) and mortality (1.5% vs 1.4%, $p > 0.05$).^{8,9} Despite excluding 129 patients who received an obligatory colostomy due to either shock, blood loss >1000 ml, more than two intraabdominal organs injured, significant peritoneal contamination, delay > 8 hours after injury, destructive colon wounds, or major abdominal wall loss, demonstration of similar morbidity and death rates was a tremendous leap forward. Subsequent studies demonstrated successful primary repair in as many as 73 to 85% of civilian injuries and 11 to 72% of military injuries.^{5,18–20,47–49} Unfortunately, most of these series were retrospective in nature, and were subject to the inherent biases of this type of review (i.e., patient selection, nonstratification, degree of injury differences) that accompanied many of these early studies. In 1991, 12 years after the release of the Stone and Fabian article, a well-designed prospective trial was conducted on 56 patients with penetrating colon injuries randomized to either primary repair or diversion.⁵⁰ Unique to this study, the authors chose to avoid the “obligatory colostomy” requirement, and man-

agement of the colonic injury was independent of many of the traditional risk factors for complications such as of the number of associated injuries, transfusion requirement, degree of fecal contamination, or hemodynamic stability on presentation. Septic complications were similar between the primary repair cohort (21.4%) and the diversion cohort (17.9%), and there were no anastomotic leaks observed in the primary repair cohort. Other retrospective and prospective studies conducted in the 1990s found similar results, with each concluding that primary repair was safe and avoided the additional morbidity associated with stoma construction and eventual closure.^{51–53} Surprising to many, even destructive colonic wounds (encompassing a much larger degree of wall injury; **Fig. 2**) and those cases with concomitant shock, excess blood loss, fecal contamination, and multiple organ injuries appeared to have no benefit from diversion, though some authors still recommended stoma placement for high-risk patients.^{54–56} Based on the results of these studies, practice guidelines began to change. In 1998, the Eastern Association for the Surgery of Trauma (EAST) practice management guidelines advocated that only patients with destructive colon wounds with a penetrating abdominal trauma index > 25 , significant comorbidities, or hemodynamic instability, benefited from diversion.⁵⁷ Yet they were one of the first major societies to state, “There is sufficient class I and class II data to support a standard of primary repair for nondestructive (involvement of $< 50\%$ of the bowel wall

Figure 2 Proposed management strategy for the treatment of traumatic colonic injury.

without devascularization) colon wounds in the absence of peritonitis." Although subsequent updates are still pending, more recent small retrospective studies have confirmed these practice guidelines and have led authors to similarly conclude that the best candidates for primary repair or resection and anastomosis are those patients with a penetrating abdominal trauma index < 15, minimal peritoneal contamination, and absence of arterial hypotension.⁵⁸

Ultimately, the goal is to avoid an anastomotic leak and the high morbidity (and mortality) that accompanies it. Reported anastomotic leak rates following the primary repair of colonic wounds in civilian trauma centers still range from 0 to 15%, with one of the largest retrospective reviews consisting of 2,964 patients demonstrating a leak rate of 2.4%.¹⁴ Military series reveal slightly higher leak rates of 13 to 30%, which may reflect the type and severity of the inciting mechanism and primary injury, as well as physiologic effects created by the concomitant injuries.^{16,18,20,23,24,59–65} Multiple risk factors have been associated with the development of anastomotic leaks following primary repair in the trauma setting, including severe fecal contamination, shock, excessive blood loss, multiple transfusions, concomitant intraabdominal organ injuries, and delayed presentation or time to surgical treatment.^{9,66} In addition, the degree of colon injury (destructive vs nondestructive) has been identified as a potential indication for diversion due to a higher risk for anastomotic breakdown.²⁴ Although most surgeons intuitively agree that a tangential or small puncture injury has less associated morbidity risk than one that takes out a majority of the colonic wall and associated vascular supply, there is less agreement about how to manage the latter type. Further studies looking at a subgroup analysis of destructive injuries reported no difference in colon-related complications or death.^{5,67} Of the other major risk factors listed above, only hemodynamic instability or shock has consistently been associated with increased overall infectious complications (although not specifically anastomotic leak), with prolonged hypotension being a predictor of mortality as well.⁶⁸

The technique used to repair the colonic wall injury for primary anastomosis has also been evaluated. In a separate prospective, nonrandomized trial of 217 patients, there was found to be no difference in overall colon-related complications (26.6% vs 20.3%, $p = 0.3$) or anastomotic leak rate (6.3% vs 7.8%, $p = 0.69$) comparing stapled versus hand-sewn anastomoses, respectively.⁶⁹ Although some variables have been associated with both infectious and noninfectious complications, no single risk factor has consistently been demonstrated to be specific for anastomotic leak following primary repair, especially with nondestructive wounds.

As practice pattern changes emerged, studies published at the turn of the century pushed for primary repair even further. Leading the way was the previously mentioned large multicenter prospective trial involving 19 trauma centers and 297 patients with destructive colon injuries requiring resection. Although critics cited its lack of randomization, closer examination of this trial revealed that although the management of the injury was left to the discretion of the attending surgeon, two-thirds of these extensive wounds were man-

aged by primary anastomosis.⁶⁷ Furthermore, colon-related mortality was significantly lower in the primary anastomosis group (0% vs 4%, $p = 0.012$), with no difference in colon-related complications (22% vs 27%, $p = 0.373$). On multivariate analysis, the authors found that the presence of severe fecal contamination, transfusion of greater than 4 units of packed red cells within the first 24 hours, and single-agent antibiotic prophylaxis were all independently associated with increased complications, yet outcomes were not related to the whether or not they were diverted or repaired primarily. Additional studies have demonstrated similar results for penetrating colon injuries.⁷⁰ A Cochrane Review found only five prospective randomized trials from 1966–2001 and analyzed these studies collectively.^{71,72} This systematic review found that overall there was no difference in mortality between primary repair versus diversion, although total complications, total infectious complications, abdominal infections including dehiscence, abdominal infections excluding dehiscence, wound complications including dehiscence, and wound complications excluding dehiscence all significantly favored primary repair.

Despite the broad support for primary repair, it is important to keep in mind the subpopulation of patients that likely do still benefit from diversion. A 1994 study demonstrated that preoperative or intraoperative transfusion of more than 6 units of packed red blood cells or those patients with severe comorbid disease developed suture line failure more often following primary anastomosis (42% vs 3%).⁵⁹ Even more concerning is that almost one in three patients died after sustaining an anastomotic leak.⁵⁹ Based on this data, the authors found it imperative to identify those patients at risk and developed a clinical pathway such that presence of either of these two conditions would prompt an end colostomy, while those without either risk factor would undergo resection of the destructive injury with primary anastomosis.⁵ Other authors have brought up similar concerns about the need to remember a diverting stoma still has its place, and may simply represent good judgment.^{64,73,74} For example, stomas likely are the proper management strategy in situations such as military injuries where evacuation requirements are present, cases in which technical problems with anastomosis occur, and though not evidence-based, there is nothing to replace proper surgeon intuition at the time of the operation. Although meta-analyses exist, such as the 2009 review evaluating all available level I data, stating that primary repair of all colorectal injuries should be attempted, irrespective of associated risk factors,⁷⁵ we are likely far away from a management algorithm that fits every situation.

As such, it is not surprisingly to find that there remains a perceptual difference and strong opinions in managing left- and right-sided colonic injuries. In 1981, a study analyzed right and left-sided colonic injuries and found similar rates of primary repair and stoma use, with nonsignificant differences in morbidity and mortality, regardless of the surgical management employed.⁷⁶ A 1998 survey of 449 trauma surgeons, with a 73% response rate, found that 54% would perform diversion for high-velocity gunshot wounds, whereas 55% of them favored resection with primary anastomosis when the

isolated colon injury was either a contusion with possible devascularization, laceration greater than 50% of the diameter, or transection.⁷⁷ Despite utilizing primary repair more often in a survey situation, studies of practice patterns have demonstrated varying results. In one analysis of colonic wounds in an urban trauma center, surgeons used fecal diversion in 22% of right colon injuries versus 39% of left-sided injuries ($p < 0.05$).⁷⁸ A 2002 study specifically evaluated patients with destructive colonic injuries, which they defined by need for resection, and found increased use of diversion with a left versus right colon injuries (38% vs 18.5%).⁵ More recently, a 2004 study demonstrated an even greater difference, with right colon wounds managed by primary repair in 69% versus only 12% of left colon wounds.⁷⁰ This discrepancy was largely secondary to clinical pathways developed around the patient-specific factors calling for mandatory diversion with either a large transfusion requirement or significant medical comorbidities—more often occurring in those with left-sided injuries. With these pathways removed, a 2004 study found more comparable use of primary repair in right-sided versus left-sided colon injuries (55% vs 48%; $p = 0.52$).⁷⁹ Others have since confirmed the impact of injury location on treatment, despite no apparent improvement in outcomes.⁸⁰

These same differences in management also occur in the combat theater. Wartime studies looking at Operation Iraqi Freedom found a trend, though not statistically different, in diversion rates based on location with left colon versus right colon injuries (36% vs 19%, $p = 0.07$).²⁰ Although these studies help to shed light on practical surgical teaching in residency, there are no good prospective randomized trials analyzing the differences in right- and left-sided outcomes based on the method of repair. More likely the variations in treatment are largely based on individual surgeon comfort and experience, as demonstrated in the 1998 trauma surgeon survey, in that surgeons treating six or more traumatic colon injuries each year are more comfortable with primary repair.⁷⁷ Other possible explanations include long-held surgical dogma, even carrying back to World War I and II, where primary repair should be avoided in the face of certain mechanisms of injury, severity to the bowel (i.e., destructive vs small tangential wounds), and higher bacterial soilage—all of which are felt to be worse with left-sided injuries. Yet, the observed outcomes may simply reflect sound surgical judgment and application of appropriate management strategies given the nature of injury, patient stability, and other factors that are difficult to ferret out in a study.

Damage Control Techniques

In an attempt to reduce overall morbidity and mortality, the techniques of damage control surgery have been routinely incorporated into the care of multiply injured patients.^{81,82} Using this technique, surgeons delay definitive reconstruction in the unstable, hypothermic, and coagulopathic patient with the main primary surgical focus being on stopping hemorrhage and controlling enteric contamination (—Fig. 2).⁸³ The overarching goal of damage control surgery

is to avoid or rapidly correct the lethal triad of hypothermia, coagulopathy, and acidosis.^{84,85} After accomplishing the initial objectives, the patient can be warmed, fully resuscitated, and stabilized in the intensive care unit prior to proceeding with a definitive surgical procedure over the next 12 to 48 hours. This application of damage control surgery has expanded to the patient with colon and rectal pathology in both the elective setting and following trauma.⁸⁶ An evaluation of 11 patients undergoing delayed primary anastomosis from an initial cohort of 22 patients that initially had a damage control procedure for destructive colonic injuries, found similar anastomotic leak rates (0% vs 5%), abscess rates (36% vs 24%), and colon-related death rates (9% vs 0%; all $p > 0.05$) compared with those undergoing immediate primary repair.⁸⁷ Not surprisingly, as has been a consistent theme in many aspects of trauma, other authors have reported opposite findings. A 2009 study found higher colon-related complications (abscess, suture or staple leak, and stoma ischemia) in patients undergoing damage control laparotomy compared with single laparotomy; however, there was no difference in the damage control laparotomy group between resection and anastomosis compared with those that underwent primary repair or resection and colostomy.⁸⁸ Thus, this may be more of a reflection in the underlying severity of patients requiring a damage control procedure (i.e., selection bias), than the effectiveness of it alone. It also serves as a reminder that although the patients are stabilized and brought back to the operating room for an attempt at definitive reconstruction, this may not always be possible. However, it does often avoid the need to make a decision whether to perform diversion versus primary repair in these extremely sick patients, as the initial surgery focuses solely on control of hemorrhage and fecal contamination. Following stabilization, operative re-evaluation can then take into account all the other factors that typically weigh into this decision of management strategy, as well as the condition of the bowel following what may have been a massive volume resuscitation. It should be noted that there is a lack of high-quality data outlining a “safe window” in which anastomosis can be routinely performed. However, what is important to glean from the published studies is that most patients undergo anastomosis within 12 to 48 hours after the initial damage control procedure. Patients with an open abdomen (—Fig. 2), particularly outside of the 36- or 48-hour window, have not been adequately studied. Therefore, patients unsuitable for anastomosis by this mark should likely undergo fecal control with a diverting stoma.⁸⁹ Although not a surgical panacea, it is yet another tool in the surgeon’s armamentarium for the most severely injured patients.

Perioperative Care

Multiple other factors play a significant role apart from the handling of the bowel itself. Given the high bacterial counts in the colon, infectious complications are not uncommon following colon trauma.⁹⁰ The underlying etiology of infection includes not only the local sequela from the initial injury, but also subsequent development of nosocomial infections from

long-term critical and hospital care. However, there are many steps that can be implemented to help minimize infectious complications following colonic trauma. The first measure is early administration of broad-spectrum intravenous antibiotics that includes anaerobic coverage. Similar to the elective setting, they should be administered expeditiously, though most often only continued for 24 hours postoperatively. Unlike previous practice, there is no benefit to longer periods of administration, and prolonged use for longer than 24 hours has not been shown to decrease surgical or nonsurgical infectious complications, even in prospective randomized studies.^{91–93} The decision to continue antibiotics beyond 24 hours should therefore be based on hard clinical evidence of an ongoing infection that mandates prolonged treatment.^{91–94} Historical data from civilian trauma centers has demonstrated that postoperative infectious complications can range from 30% following general intraabdominal injuries, and up to 70% when the colon is injured and antibiotics are administered postoperatively only. On the other hand, this rate is lowered significantly (~11%) when appropriate antibiotics are administered preoperatively.⁹⁵ Even further, ensuring proper anaerobic coverage will reduce the risk of postoperative infections from 27% to 10% or less.⁹⁶ Following a recent review of all combat injuries, consensus guidelines were established in 2008 that broad-spectrum antibiotics that include anaerobic activity should be administered following identification of the hollow visceral injury, and continued for 24 hours after definitive control of all enteric contamination.⁹⁷ A subsequent update in 2011 confirmed the importance of this, as well as focusing on the addition of anaerobic coverage, and other adjuncts such as negative pressure wound therapy and supplemental oxygen.⁹⁸ Other associations have followed suit in the civilian arena, with the Eastern Association for the Surgery of Trauma Guidelines advocating prophylactic antibiotics in penetrating trauma as a single preoperative dose with broad spectrum aerobic and anaerobic activity and continuation for only 24 hours.⁹⁴ Postoperatively, patients should be appropriately resuscitated, keeping in mind recent trends have demonstrated a benefit to avoiding overresuscitation, as excessive fluid volumes (> 10.5 L within the first 72 hours) have been associated with a fivefold increased risk of anastomotic leak in retrospective studies.⁹⁹

Operative Approach

Despite reports of negative laparotomy in 5 to 27% of abdominal gunshot wounds and up to 53% of stab wounds, penetrating abdominal injuries are still predominately managed with open exploration, especially in the combat setting, where minimally invasive equipment is essentially unavailable.¹⁰⁰ The complications from unnecessary laparotomy must be weighed against the potential severe morbidity and mortality from missed injuries. Although the overriding goal is to repair the damaged segment of colon and avoid the increased morbidity and mortality associated with delayed diagnosis, anastomotic leak, or infectious complications, nontherapeutic laparotomy is not without its own consequences.

With appropriate surgical indications, understanding the anatomy of the colon is essential in properly treating traumatic injuries. The average colon measures around 4 to 5 ft with the ascending colon ~15 cm, transverse colon averaging 45 cm, the descending colon averaging 25 cm, and the sigmoid colon—with the most variability—averaging 38 cm.⁸⁹ The posterior portion of the ascending and descending colonic segments are retroperitoneal, with the fusion of the mesentery and peritoneum classically referred to as the white line of Toldt, a crucial avascular plane important in surgical mobilization of the colon. The anterior ascending and descending colon, as well as the entirety of the transverse colon, are all intraperitoneal with complete encirclement by the visceral peritoneum.¹⁰¹ Recognizing the mobile and relatively fixed portions of the colon, as well as the adjacent structures such as kidneys, duodenum, and pancreas that are often concomitantly injured,¹⁰² may help predict injury patterns and minimize missed injuries.¹⁰³

As the spectrum of colonic damage has a wide array of different presentations that can significantly affect management, there are several colonic injury scales including the American Association for the Surgery of Trauma (AAST) to help determine severity and help guide the decision-making process.¹⁰² In the simplest form, the injury may be as minor as a mesenteric hematoma or colonic wall hematoma (AAST grade Ia). These injuries may be observed for the most part, unless the hematoma is expanding or the bowel wall appears devascularized.¹⁰⁴ Simple partial thickness laceration (AAST grade Ib) or small full-thickness lacerations (< 50% of circumference), are usually amenable to simple suturing and primary repair (AAST grade II). Peritoneal contamination from this pattern of injury will likely have little bearing on the healing of a repair if soilage is rapidly controlled and proper technical aspects are adhered to, with only the incidence of postoperative infectious complications, such as abscesses, slightly increased. Large lacerations involving more than 50% of the bowel wall circumference (grade III), transection of the bowel wall (grade IV), and transection with segmental tissue loss (grade Va) or devascularized tissue (Vb) are more advanced injuries where the surgeon's judgment and experience is paramount. The guiding principles in these cohorts remain removal of all devascularized tissue and consideration for primary anastomosis versus diversion based on the management criteria outlined previously. Although management strategies based on injury severity are useful guidelines, it is worth noting that colonic injury scores > 4 have been predictive of intraabdominal and wound complications; however, no difference in outcomes for higher grades was identified when stratified by primary repair or diversion in a review of 130 consecutive patients.⁴⁹

Even in stable patients with limited injuries, the principles espoused in damage control surgery including hemorrhage control and containment of fecal contamination still apply. Debridement of devitalized tissue and primary repair can often be performed safely when there are smaller injuries. For injuries to the colon that are not amenable to simple suture repair, proper mobilization and resectional approaches should follow established surgical procedures (► **Fig. 2**).

Significant injuries to the colon are best approached by ensuring identification of the entire injury complex, which may entail damage to the vasculature that supplies surrounding noninjured bowel, or through-and-through injuries that may not be readily apparent at first glance. Unlike elective surgery, in trauma, many surgeons find a lateral mobilization for ascending and descending colonic injuries easier to more fully evaluate the bowel and extent of injury. Surgeons should typically avoid extensive mesenteric resections like those performed in oncologic cases, though large mesenteric hematomas normally need to be evaluated in penetrating injury to avoid missed vascular injury. As mentioned previously, the anastomosis is fashioned based primarily on surgeon preference (stapled vs hand sewn), though in polytrauma, many surgeons prefer a stapled anastomosis as it may be performed quicker and outcomes are relatively equivalent. When anastomotic reconstruction is chosen, the mesentery does not need to be closed and may even contribute to increased complications.¹⁰⁵ With all injuries where an anastomosis is chosen, the key is to adhere to the age-old principles of a tension-free anastomosis, healthy tissue, and adequate blood flow. Specifically, in trauma, special attention should be made to ensure there is no damage to the underlying vasculature that may result in the last of these principles being compromised. When in doubt about ischemia to the anastomosis, surgeons should either revise the anastomosis or use a damage control approach and inspect the anastomosis at subsequent operations. For left-sided anastomosis, a rigid proctoscopy with an air-insufflation or other leak test should be performed to ensure immediate anastomotic integrity. Finally, for patients that require a stoma, surgeons must ensure adequate length and blood supply exists to allow appropriate maturation without ischemia to this segment of bowel. As such, this may require more proximal vessel ligation in the mesentery and avoidance of resecting the mesentery adjacent to the bowel. If there is any question, use of temporary placement of bulldog clamps may provide information to the adequacy of collateral circulation.

Closure of the wound has many different approaches. There are a few studies that specifically address outcomes following closure, with a study from 1977 citing infectious rates following primary closure at 56%, delayed primary closure at 19%, and intraperitoneal abscess rates of 73%.¹⁰⁶ However, modern management of wounds following trauma has dramatically changed, especially with the introduction of negative pressure dressings and dramatic technologic improvements in nursing wound care.¹⁰⁷ There are some data that indicate that abdominal wall closure for open abdomens beyond 5 days may impact subsequent leak rates,¹⁰⁸ and surgeons should be diligent in following the wound for early signs of problems.

Colostomy Reversal

Although colostomy use is imperative in select patients, it is not without its own independent set of problems. In fact, it has been shown that creation of a stoma or penetrating abdominal trauma index > 30 were the two independent

risk factors associated with the development of trauma-related infections (defined as abdominal abscesses, peritonitis, wound infections, missile tract infections and fistulas), though this may be simply a manifestation of the severity of injury.¹⁰⁹ An opposite view comes from an older Cook County Hospital study that advocated adherence to the conservative principle of “no anastomosis” in patients with colonic injuries, citing their low rates of morbidity and mortality with this method of management.¹¹⁰ Despite these polar views, what is clear is that additional morbidity and even mortality risks are present following colostomy reversal, which is often not part of the overall cohort comparative analysis in most studies. Overall complication rates vary from 25 to 44%, with mortality rates being lower at 0.65 to 4.3%, though they have been reported as high as 4.7% following a Hartman procedure reversal.^{111–114} Specific complication rates vary even more widely, such as minor wound infections (21.8%), ileus (5.7%), anastomotic leak (13.0%), small bowel obstruction (11.5%), anastomotic leak with enterocutaneous fistula formation (3.8%), and intraabdominal abscess (1.1%). Importantly, all these rates are significantly increased in patients with hypoalbuminemia and steroid-dependence.^{112–115} Additionally, up to 55% of patients may never have their stoma reversed.¹¹² Although this exact percentage is unknown in trauma, a large population-based series in diverticular disease demonstrated 44% ended up with permanent stomas.¹¹⁶ Furthermore, colostomy closure following traumatic colon injuries has a broad range of published morbidity rates at 5 to 55%, with no difference in complication rates between early and late closure.^{5,51,117–119} When looking at specific infectious complications, there is a 9.1% intraabdominal and 3.6% wound infection rate.¹²⁰ The optimal timing of stoma closure also remains a point of discussion. A recent prospective randomized study of same-admission colostomy closure versus delayed closure involving 60 patients revealed similar complication rates of 23% and 27% ($p = 0.83$).¹²¹ Although the exact timing of closure that will minimize morbidity still needs further elucidation, clearly some patients benefit from early closure versus the traditional wide variation of 3 to 12 months. At this time, without adequate studies, it must be left up to the surgeon's judgment and experience.

Conclusion

Colon trauma management has evolved dramatically over the past century. The mere fact that what was once a near universally fatal injury has now transitioned to a debate of whether surgeons should perform a primary anastomoses or stoma says a lot about how far we have come in dealing with this difficult situation. Through advancements in perioperative care and surgical techniques, studies are now focusing on reducing the risk for anastomotic complications and maximizing the number of patients that can safely have up-front continuity restoration. Concepts such as early focused antibiotic use, appropriate resuscitation, and damage control techniques are now a mainstay of care for colonic injuries. Yet, although significant progression has been made, there are many areas that still lack adequate data. With continued

progress, we will see steady advancements that will ultimately result in minimizing morbidity and mortality in patients with colonic injuries.

Disclaimer

The opinions and assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of Defense. Use of commercial products in this project does not imply endorsement by the U.S. Government.

References

- 1 New International Version. *Bible*.
- 2 Welling DR, Duncan JE. Stomas and trauma. *Clin Colon Rectal Surg* 2008;21(1):45–52
- 3 Fraser J, Drummond H. A clinical and experimental study of three hundred perforating wounds of the abdomen. *BMJ* 1917;1(2932):321–330
- 4 Imes PR. War surgery of the abdomen. *Surg Gynecol Obstet* 1945;81(21005308):608–616
- 5 Miller PR, Fabian TC, Croce MA, et al. Improving outcomes following penetrating colon wounds: application of a clinical pathway. *Ann Surg* 2002;235(6):775–781
- 6 Ogilvie WH. Surgical lessons of war applied to civil practice. *BMJ* 1945;1(4400):619–623
- 7 Edwards DP, Galbraith KA. Colostomy in conflict: military colonic surgery. *Ann R Coll Surg Engl* 1997;79(4):243–244
- 8 Woodhall JP, Ochsner A. The management of perforating injuries of the colon and rectum in civilian practice. *Surgery* 1951;29(2):305–320
- 9 Stone HH, Fabian TC. Management of perforating colon trauma: randomization between primary closure and exteriorization. *Ann Surg* 1979;190(4):430–436
- 10 Burch JM, Feliciano DV, Mattox KL. Colostomy and drainage for civilian rectal injuries: is that all? *Ann Surg* 1989;209(5):600–610, discussion 610–611
- 11 al-Qasabi QO, Katugampola W, Singh ND. Management of colon injuries. *Injury* 1991;22(1):32–34
- 12 Demetriades D. Penetrating injuries of the colon—changing perspectives. *S Afr J Surg* 1991;29(1):25–25
- 13 Pachter HL, Hoballah JJ, Corcoran TA, Hofstetter SR. The morbidity and financial impact of colostomy closure in trauma patients. *J Trauma* 1990;30(12):1510–1513
- 14 Strada G, Raad L, Belloni G, Setti Carraro P. Large bowel perforations in war surgery: one-stage treatment in a field hospital. *Int J Colorectal Dis* 1993;8(4):213–216
- 15 George SM Jr, Fabian TC, Voeller GR, Kudsk KA, Mangiante EC, Britt LG. Primary repair of colon wounds. A prospective trial in nonselected patients. *Ann Surg* 1989;209(6):728–733, 733–734
- 16 Curran TJ, Borzotta AP. Complications of primary repair of colon injury: literature review of 2,964 cases. *Am J Surg* 1999;177(1):42–47
- 17 Brady RR, O'Neill S, Berry O, Kerssens JJ, Yalamarthi S, Parks RW. Traumatic injury to the colon and rectum in Scotland: demographics and outcome. *Colorectal Dis* 2012;14(1):e16–e22
- 18 Hudolin T, Hudolin I. The role of primary repair for colonic injuries in wartime. *Br J Surg* 2005;92(5):643–647
- 19 Uravić M. Colorectal war injuries. *Mil Med* 2000;165(3):186–188
- 20 Steele SR, Wolcott KE, Mullen PS, et al. Colon and rectal injuries during Operation Iraqi Freedom: are there any changing trends in management or outcome? *Dis Colon Rectum* 2007;50(6):870–877
- 21 Cho SD, Kiraly LN, Flaherty SF, Herzig DO, Lu KC, Schreiber MA. Management of colonic injuries in the combat theater. *Dis Colon Rectum* 2010;53(5):728–734
- 22 Steel M, Danne P, Jones I. Colon trauma: Royal Melbourne Hospital experience. *ANZ J Surg* 2002;72(5):357–359
- 23 Slim MS, Makaroun M, Shammá AR. Primary repair of colorectal injuries in childhood. *J Pediatr Surg* 1981;16(6):1008–1011
- 24 Williams MD, Watts D, Fakhry S. Colon injury after blunt abdominal trauma: results of the EAST Multi-Institutional Hollow Viscus Injury Study. *J Trauma* 2003;55(5):906–912
- 25 Ng AKT, Simons RK, Torreggiani WC, Ho SGF, Kirkpatrick AW, Brown DRG. Intra-abdominal free fluid without solid organ injury in blunt abdominal trauma: an indication for laparotomy. *J Trauma* 2002;52(6):1134–1140
- 26 Govender M, Madiba TE. Current management of large bowel injuries and factors influencing outcome. *Injury* 2010;41(1):58–63
- 27 Talton DS, Craig MH, Hauser CJ, Poole GV. Major gastrointestinal injuries from blunt trauma. *Am Surg* 1995;61(1):69–73
- 28 Chanson C, Nassiopoulou K, Kiesler P, Petropoulos P. [Trauma to the colon in civilian surgery]. *Swiss Surg* 1998;(5):244–248
- 29 Towne JB, Coe JD. Seat belt trauma of the colon. *Am J Surg* 1971;122(5):683–685
- 30 Halvorsen JF, Vagn Nielsen O, Bugge-Asperheim B. Injuries of the colon and rectum. *Ann Chir Gynaecol* 1981;70(5):287–291
- 31 Welling DR, Hutton JE, Minken SL, Place RJ, Burris DG. Diversion defecated—military colon trauma. *J Trauma* 2008;64(4):1119–1122
- 32 Vannix RS, Carter R, Hinshaw DB, Joergenson EJ. Surgical management of colon trauma in civilian practice. *Am J Surg* 1963;106:364–371
- 33 Ogilvie I, Wilkens S, Rodgers AJ, Aggeler R, Capaldi RA. The second stalk: the delta-b subunit connection in ECF1F0. *Acta Physiol Scand Suppl* 1998;643:169–175
- 34 Eshraghi N, Mullins RJ, Mayberry JC, Brand DM, Crass RA, Trunkey DD. Surveyed opinion of American trauma surgeons in management of colon injuries. *J Trauma* 1998;44(1):93–97
- 35 American College of Surgeons. Advanced trauma lifesupport. Chicago, IL : American College of Surgeons; 2008
- 36 Udobi KF, Rodriguez A, Chiu WC, Scalea TM. Role of ultrasonography in penetrating abdominal trauma: a prospective clinical study. *J Trauma* 2001;50(3):475–479
- 37 Martin MM, Willardson BM, Burton GF, et al. Human angiotensin II type 1 receptor isoforms encoded by messenger RNA splice variants are functionally distinct. *Mol Endocrinol* 2001;15(2):281–293
- 38 Johnson EK, Judge T, Lundy J, Meyermann M. Diagnostic pelvic computed tomography in the rectal-injured combat casualty. *Mil Med* 2008;173(3):293–299
- 39 Shanmuganathan K, Mirvis SE, Chiu WC, Killeen KL, Scalea TM. Triple-contrast helical CT in penetrating torso trauma: a prospective study to determine peritoneal violation and the need for laparotomy. *AJR Am J Roentgenol* 2001;177(6):1247–1256
- 40 Shanmuganathan K, Mirvis SE, Chiu WC, Killeen KL, Hogan GJF, Scalea TM. Penetrating torso trauma: triple-contrast helical CT in peritoneal violation and organ injury—a prospective study in 200 patients. *Radiology* 2004;231(3):775–784
- 41 Otomo Y, Henmi H, Mashiko K, et al. New diagnostic peritoneal lavage criteria for diagnosis of intestinal injury. *J Trauma* 1998;44(6):991–997, discussion 997–999
- 42 Hennehan PL, Marx JA, Moore EE, Cantrill SV, Ammons LA. Diagnostic peritoneal lavage: accuracy in predicting necessary laparotomy following blunt and penetrating trauma. *J Trauma* 1990;30(11):1345–1355
- 43 García JJ, Ogilvie I, Robinson BH, Capaldi RA. Structure, functioning, and assembly of the ATP synthase in cells from patients with the T8993G mitochondrial DNA mutation. Comparison with the

- enzyme in Rho(0) cells completely lacking MTDNA. *J Biol Chem* 2000;275(15):11075–11081
- 44 Islam NC, Wood KB, Transfeldt EE, et al. Extension of fusions to the pelvis in idiopathic scoliosis. *Spine* 2001;26(2):166–173
 - 45 Ogilvie CM, Kasten P, Rovinsky D, Workman KL, Johnston JO. Cysticercosis of the triceps—an unusual pseudotumor: case report and review. *Clin Orthop Relat Res* 2001;(382):217–221
 - 46 Leibman NF, Lana SE, Hansen RA, et al. Identification of matrix metalloproteinases in canine cutaneous mast cell tumors. *J Vet Intern Med* 2000;14(6):583–586
 - 47 Abcarian H. Rectal trauma. *Gastroenterol Clin North Am* 1987;16(1):115–123
 - 48 Baako BN, Badoe EA. Gallstone impaction in the duodenal bulb: an uncommon cause of gastric outlet obstruction associated with gallstone emesis. *West Afr J Med* 1998;17(2):124–127
 - 49 Morris DS, Sugrue WJ. Abdominal injuries in the war wounded of Afghanistan: a report from the International Committee of the Red Cross Hospital in Kabul. *Br J Surg* 1991;78(11):1301–1304
 - 50 Chappuis CW, Frey DJ, Dietzen CD, Panetta TP, Buechter KJ, Cohn I Jr. Management of penetrating colon injuries. A prospective randomized trial. *Ann Surg* 1991;213(5):492–497, discussion 497–498
 - 51 Berne JD, Velmahos GC, Chan LS, Asensio JA, Demetriades D. The high morbidity of colostomy closure after trauma: further support for the primary repair of colon injuries. *Surgery* 1998;123(2):157–164
 - 52 Jacobson LE, Gomez GA, Broadie TA. Primary repair of 58 consecutive penetrating injuries of the colon: should colostomy be abandoned? *Am Surg* 1997;63(2):170–177
 - 53 Sasaki LS, Allaben RD, Golwala R, Mittal VK. Primary repair of colon injuries: a prospective randomized study. *J Trauma* 1995;39(5):895–901
 - 54 Gonzalez RP, Merlotti GJ, Holevar MR. Colostomy in penetrating colon injury: is it necessary? *J Trauma* 1996;41(2):271–275
 - 55 Durham RM, Pruitt C, Moran J, Longo WE. Civilian colon trauma: factors that predict success by primary repair. *Dis Colon Rectum* 1997;40(6):685–692
 - 56 Miller BJ, Schache DJ. Colorectal injury: where do we stand with repair? *Aust N Z J Surg* 1996;66(6):348–352
 - 57 Pasquale M, Fabian TC. Practice management guidelines for trauma from the Eastern Association for the Surgery of Trauma. *J Trauma* 1998;44(6):941–956, discussion 956–957
 - 58 Mickevicius A, Klizaitė J, Tamelis A, Saladzinskas Z, Pavalkis D. [Penetrating colorectal trauma: index of severity and results of treatment]. *Medicina (Kaunas)* 2003;39(6):562–569
 - 59 Stewart RM, Fabian TC, Croce MA, Pritchard FE, Minard G, Kudsk KA. Is resection with primary anastomosis following destructive colon wounds always safe? *Am J Surg* 1994;168(4):316–319
 - 60 Maxwell RA, Fabian TC. Current management of colon trauma. *World J Surg* 2003;27(6):632–639
 - 61 Kamwendo NY, Modiba MCM, Matlala NS, Becker PJ. Randomized clinical trial to determine if delay from time of penetrating colonic injury precludes primary repair. *Br J Surg* 2002;89(8):993–998
 - 62 Payravi H, Mortaz SS, Fazel I. Surgical treatment results of Iranian abdominal trauma casualties in the Iran and Iraq war. *Mil Med* 2001;166(11):952–954
 - 63 Saghafeinia M, Nafissi N, Motamedi MRK, et al. Assessment and outcome of 496 penetrating gastrointestinal warfare injuries. *J R Army Med Corps* 2010;156(1):25–27
 - 64 Duncan JE, Corwin CH, Sweeney WB, et al. Management of colorectal injuries during Operation Iraqi Freedom: patterns of stoma usage. *J Trauma* 2008;64(4):1043–1047
 - 65 Vertrees A, Wakefield M, Pickett C, et al. Outcomes of primary repair and primary anastomosis in war-related colon injuries. *J Trauma* 2009;66(5):1286–1291, discussion 1291–1293
 - 66 Stankovic N, Petrovic M, Drinkovic N, Bjelovic M, Jevtic M, Mirkovic D. Colon and rectal war injuries. *J Trauma* 1996;40(3, Suppl):S183–S188
 - 67 Demetriades D, Murray JA, Chan L, et al; Committee on Multicenter Clinical Trials. American Association for the Surgery of Trauma. Penetrating colon injuries requiring resection: diversion or primary anastomosis? An AAST prospective multicenter study. *J Trauma* 2001;50(5):765–775
 - 68 Cleary RK, Pomerantz RA, Lampman RM. Colon and rectal injuries. *Dis Colon Rectum* 2006;49(8):1203–1222
 - 69 Demetriades D, Murray JA, Chan LS, et al. Handsewn versus stapled anastomosis in penetrating colon injuries requiring resection: a multicenter study. *J Trauma* 2002;52(1):117–121
 - 70 Adesanya AA, Ekanem EE. A ten-year study of penetrating injuries of the colon. *Dis Colon Rectum* 2004;47(12):2169–2177
 - 71 Singer MA, Nelson RL. Primary repair of penetrating colon injuries: a systematic review. *Dis Colon Rectum* 2002;45(12):1579–1587
 - 72 Nelson R, Singer M. Primary repair for penetrating colon injuries. *Cochrane Database Syst Rev* 2003;(3):CD002247
 - 73 Ogilvie GK. Dolasetron: a new option for nausea and vomiting. *J Am Anim Hosp Assoc* 2000;36(6):481–483
 - 74 Fontes RA Jr, Ogilvie CM, Miclau T. Necrotizing soft-tissue infections. *J Am Acad Orthop Surg* 2000;8(3):151–158
 - 75 DuBoise J. Colonic trauma: indications for diversion vs. repair. *J Gastrointest Surg* 2009;13(3):403–404
 - 76 Thompson JS, Moore EE, Moore JB. Comparison of penetrating injuries of the right and left colon. *Ann Surg* 1981;193(4):414–418
 - 77 Eshraghi N, Mullins RJ, Mayberry JC, Brand DM, Crass RA, Trunkey DD. Surveyed opinion of American trauma surgeons in management of colon injuries. *J Trauma* 1998;44(1):93–97
 - 78 Murray JA, Demetriades D, Colson M, et al. Colonic resection in trauma: colostomy versus anastomosis. *J Trauma* 1999;46(2):250–254
 - 79 Fealk M, Osipov R, Foster K, Caruso D, Kassir A. The conundrum of traumatic colon injury. *Am J Surg* 2004;188(6):663–670
 - 80 Ogilvie KM, Held Hales K, Roberts ME, Hales DB, Rivier C. The inhibitory effect of intracerebroventricularly injected interleukin 1beta on testosterone secretion in the rat: role of steroidogenic acute regulatory protein. *Biol Reprod* 1999;60(2):527–533
 - 81 Zacharias SR, Offner P, Moore EE, Burch J. Damage control surgery. *AACN Clin Issues* 1999;10(1):95–103, quiz 141–142
 - 82 Adams JM, Hauser CJ, Livingston DH, et al. The immunomodulatory effects of damage control abdominal packing on local and systemic neutrophil activity. *J Trauma* 2001;50(5):792–800
 - 83 Cotton BA, Reddy N, Hatch QM, et al. Damage control resuscitation is associated with a reduction in resuscitation volumes and improvement in survival in 390 damage control laparotomy patients. *Ann Surg* 2011;254(4):598–605
 - 84 Valerius KD, Ogilvie GK, Feltman MJ, et al. Comparison of the effects of asparaginase administered subcutaneously versus intramuscularly for treatment of multicentric lymphoma in dogs receiving doxorubicin. *J Am Vet Med Assoc* 1999;214(3):353–356
 - 85 Ogilvie MD, Hilton CE, Ogilvie CD. Lumbar anomalies in the Shanidar 3 Neandertal. *J Hum Evol* 1998;35(6):597–610
 - 86 McPartland KJ, Hyman NH. Damage control: what is its role in colorectal surgery? *Dis Colon Rectum* 2003;46(7):981–986
 - 87 Miller PR, Chang MC, Hoth JJ, Holmes JH IV, Meredith JW. Colonic resection in the setting of damage control laparotomy: is delayed anastomosis safe? *Am Surg* 2007;73(6):606–609, discussion 609–610
 - 88 Weinberg JA, Griffin RL, Vandromme MJ, et al. Management of colon wounds in the setting of damage control laparotomy: a cautionary tale. *J Trauma* 2009;67(5):929–935

- 89 Ott MM, Norris PR, Diaz JJ, et al. Colon anastomosis after damage control laparotomy: recommendations from 174 trauma colectomies. *J Trauma* 2011;70(3):595–602
- 90 Smallman-Raynor MR, Cliff AD. Impact of infectious diseases on war. *Infect Dis Clin North Am* 2004;18(2):341–368
- 91 Kirton OC, O'Neill PA, Kestner M, Tortella BJ. Perioperative antibiotic use in high-risk penetrating hollow viscus injury: a prospective randomized, double-blind, placebo-control trial of 24 hours versus 5 days. *J Trauma* 2000;49(5):822–832
- 92 Bozorgzadeh A, Pizzi WF, Barie PS, et al. The duration of antibiotic administration in penetrating abdominal trauma. *Am J Surg* 1999;177(2):125–131
- 93 Fabian TC, Croce MA, Payne LW, Minard G, Pritchard FE, Kudsk KA. Duration of antibiotic therapy for penetrating abdominal trauma: a prospective trial. *Surgery* 1992;112(4):788–794, discussion 794–795
- 94 Luchette FA, Borzotta AP, Croce MA, et al. Practice management guidelines for prophylactic antibiotic use in penetrating abdominal trauma: the EAST Practice Management Guidelines Work Group. *J Trauma* 2000;48(3):508–518
- 95 Fullen WD, Hunt J, Altemeier WA. The clinical spectrum of penetrating injury to the superior mesenteric arterial circulation. *J Trauma* 1972;12(8):656–664
- 96 Thadepalli H, Gorbach SL, Broido PW, Norsen J, Nyhus L. Abdominal trauma, anaerobes, and antibiotics. *Surg Gynecol Obstet* 1973;137(2):270–276
- 97 Hospenhal DR, Murray CK, Andersen RC, et al. Guidelines for the prevention of infection after combat-related injuries. *J Trauma* 2008;64(18316965):211–220
- 98 Ogilvie TH. Deans respond to task force report “opportunity for renewal.”. *Can Vet J* 1999;40(2):89–93
- 99 Schnüriger B, Inaba K, Wu T, Eberle BM, Belzberg H, Demetriades D. Crystalloids after primary colon resection and anastomosis at initial trauma laparotomy: excessive volumes are associated with anastomotic leakage. *J Trauma* 2011;70(3):603–610
- 100 Renz BM, Feliciano DV. Unnecessary laparotomies for trauma: a prospective study of morbidity. *J Trauma* 1995;38(3):350–356
- 101 Hollinshead WH. Embryology and surgical anatomy of the colon. *Dis Colon Rectum* 1962;5:23–27
- 102 Ogilvie K, Rivier C. The intracerebroventricular injection of interleukin-1beta blunts the testosterone response to human chorionic gonadotropin: role of prostaglandin- and adrenergic-dependent pathways. *Endocrinology* 1998;139(7):3088–3095
- 103 Risdon C, Ogilvie G. A fellowship in the population-centered clinical method. *Acad Med* 1998;73(5):600–601
- 104 Agaba EA, Zaidi RM, Ramzy P, et al. Laparoscopic Hartmann's procedure: a viable option for treatment of acutely perforated diverticulitis. *Surg Endosc* 2009;23(7):1483–1486
- 105 Causey MW, Oguntoye M, Steele SR. Incidence of complications following colectomy with mesenteric closure versus no mesenteric closure: does it really matter? *J Surg Res* 2011;171(2):571–575
- 106 Voyles CR, Flint LM Jr. Wound management after trauma to the colon. *South Med J* 1977;70(9):1067–1069
- 107 Yang HT, Ogilvie RW, Terjung RL. Exercise training enhances basic fibroblast growth factor-induced collateral blood flow. *Am J Physiol* 1998;274(6 Pt 2):H2053–H2061
- 108 Ogilvie GK. Chemotherapy and the surgery patient: principles and recent advances. *Clin Tech Small Anim Pract* 1998;13(1):22–32
- 109 Dente CJ, Tyburski J, Wilson RF, Collinge J, Steffes C, Carlin A. Ostomy as a risk factor for posttraumatic infection in penetrating colonic injuries: univariate and multivariate analyses. *J Trauma* 2000;49(4):628–634, discussion 634–637
- 110 Orsay CP, Merlotti G, Abcarian H, Pearl RK, Nanda M, Barrett J. Colorectal trauma. *Dis Colon Rectum* 1989;32(3):188–190
- 111 Kaiser AM, Israelit S, Klaristenfeld D, et al. Morbidity of ostomy takedown. *J Gastrointest Surg* 2008;12(3):437–441
- 112 Vermeulen J, Coene PP, Van Hout NM, et al. Restoration of bowel continuity after surgery for acute perforated diverticulitis: should Hartmann's procedure be considered a one-stage procedure? *Colorectal Dis* 2009;11(6):619–624
- 113 Mileski WJ, Rege RV, Joehl RJ, Nahrwold DL. Rates of morbidity and mortality after closure of loop and end colostomy. *Surg Gynecol Obstet* 1990;171(1):17–21
- 114 Pachter HL, Hoballah JJ, Corcoran TA, Hofstetter SR. The morbidity and financial impact of colostomy closure in trauma patients. *J Trauma* 1990;30(12):1510–1513
- 115 Bell C, Asolati M, Hamilton E, et al. A comparison of complications associated with colostomy reversal versus ileostomy reversal. *Am J Surg* 2005;190(5):717–720
- 116 Ogilvie G, Walsh A, Rice S. The problem-based medical audit program: influence on family practice residents' knowledge and skills. *Fam Med* 1998;30(6):417–420
- 117 Thal ER, Yeary EC. Morbidity of colostomy closure following colon trauma. *J Trauma* 1980;20(4):287–291
- 118 Bulger EM, McMahon K, Jurkovich GJ. The morbidity of penetrating colon injury. *Injury* 2003;34(1):41–46
- 119 Crass RA, Salbi F, Trunkey DD. Colostomy closure after colon injury: a low-morbidity procedure. *J Trauma* 1987;27(11):1237–1239
- 120 Taheri PA, Ferrara JJ, Johnson CE, Lamberson KA, Flint LM. A convincing case for primary repair of penetrating colon injuries. *Am J Surg* 1993;166(1):39–44
- 121 Khalid MS, Moeen S, Khan AW, Arshad R, Khan AFA. Same admission colostomy closure: a prospective, randomised study in selected patient groups. *Surgeon* 2005;3(1):11–14