Surgical Treatment of Injuries to the Solid Abdominal Organs: A 50-Year Perspective From the Journal of Trauma

Andrew B. Peitzman, MD, and J. David Richardson, MD

During its 50 years of publication, the Journal of Trauma (JOT) has chronicled virtually all the issues in the surgical management of solid organ injuries. This review highlights many of the sentinel articles published in the Journal that have impacted the management of injuries to the liver, spleen, kidney, and pancreas.

HEPATIC TRAUMA

When the Journal began publication in 1961, it consisted of bimonthly issues. The second issue had two small case series on injuries to the extrahepatic bile ducts. The initial article devoted exclusively to liver injuries appeared in the sixth issue at the end of the first year’s efforts. The article from Detroit Receiving Hospital reported 20 cases of blunt injuries treated by operation from 1954 to 1959 and emphasized portal triad compression, the dangers of prolonged packing, and the value of thoracoabdominal extension of the midline incision. The mortality rate was 35%. Two years later, the second article published on liver injuries reported a 55% mortality in 38 patients with blunt injury and a 12% death rate among the 73 who sustained penetrating trauma. This report carefully outlined the impact of multiple factors on outcome including the impact of race (which would certainly not be published today in the manner presented nearly 50 years ago!).

THE DECADES OF AGGRESSIVE OPERATIVE TREATMENT

Most of the publications on liver injuries that appeared in the Journal over the next two decades could be characterized (particularly in retrospect) as advocating extremely aggressive operative treatment. In 1964, the Parkland Group presented a series of 259 patients, of which 9.6% underwent anatomic liver resection. This article beautifully illustrated lobar anatomy and outlined the techniques of resection, and the authors were generally pleased with the 20% mortality rate for the 25 patients who underwent resection. Glenn et al. presented an experimental study at the American Association for the Surgery of Trauma (AAST) in 1965 in which they dropped normal human livers from measured heights onto a concrete floor as well as onto 25-pound sandbags on the livers of anesthetized canines! The damage to bile ducts was then assessed by cholangiography and potential bleeding by angiography. These essayists noted little vascular damage from this model but evidence of significant bile duct disruption on the biliary contrast studies. Their conclusion was that bile leak—not bleeding—was the primary cause of mortality with blunt injury and that this problem could be managed by universal drainage. These findings confirmed the observations of Madding and Kennedy that were originally made in World War II on the value of universal drainage for all liver wounds. Thus, the primary lesson on liver injury management from the first 5 years of the Journal’s existence was on the value of major hepatic resection and universal drainage of all wounds.

From the inception of the JOT until 1978, there were only about 20 articles on the management of liver injury and virtually all espoused some form of aggressive surgical therapy. A report from Harbor General Hospital noted that 28 consecutive patients were treated operatively without a mortality: 7 had a hepatic lobectomy, all injuries were drained, and 10 had a T-tube choledochostomy to facilitate bile drainage. These results were notably different from a report from Detroit appearing in the same issue that noted a 32% mortality rate with blunt injuries. However, the authors of the latter article were among the first to report a liver-related mortality rate when noting only 9.6% died related to the hepatic injury itself (Table 1).

The use of resectional therapy for wounds not controlled by suture alone continued despite reports of mortality in the range of 25% to 65%.

Submitted for publication August 5, 2010.
Accepted for publication August 27, 2010.
Copyright © 2010 by Lippincott Williams & Wilkins
From the Department of Surgery (A.B.P.), University of Pittsburgh, Pittsburgh, Pennsylvania; and Department of Surgery (J.D.R.), University of Louisville, Louisville, Kentucky.
Address for reprints: Andrew B. Peitzman, Professor of Surgery, F-1281, UPMC-Presbyterian, Pittsburgh, PA 15213.
DOI: 10.1097/TA.0b013e3181f9e216
Lucas and Ledgerwood\textsuperscript{18} focused on hemorrhage rather than injury remained high. Frey et al.\textsuperscript{15} reported a progressive decrease in mortality, despite improvements in mortality, the death rate from liver-related mortality was compelling in one report\textsuperscript{16} where comparing outcomes. The correlation of anatomic injury to injuries and physiologic grading of shock as important factors in determining mortality from such procedures and often questioned its use. Second, in contrast to earlier reports on the use of selective hepatic angiography to treat hepatic arterial bleeding. The use of atriocaval shunts was advocated by lesser means had a 5.4% death rate. Flint and Polk\textsuperscript{22} resected had a 52% mortality while those able to be treated “surgical restraint” in treating liver trauma; they noted that resection had a 52% mortality while those able to be treated by lesser means had a 5.4% death rate. Flint and Polk\textsuperscript{22} placed the aggressive use of hepatic artery ligation into perspective, and Scalfani et al.\textsuperscript{23} published one of the initial reports on the use of selective hepatic angiography to treat hepatic arterial bleeding. The use of atriocaval shunts was reviewed by surgeons from San Francisco,\textsuperscript{24} which likely had the best results ever reported but still noted only 4 of 13 survivors; later a Miami experience\textsuperscript{25} with 20 cases of retrohepatic vein injuries noted 90% mortality with the use of a shunt while 60% died with direct repair. These authors suggested portal triad occlusion with attempted direct repair was preferable to atriocaval shunt use.

### TABLE 1. Mortality From Hepatic Trauma, 1960–1975—The Years of Aggressive Surgical Therapy

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year of Report</th>
<th>No. Cases</th>
<th>Mechanism</th>
<th>Comments</th>
<th>Mortality Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robb et al.\textsuperscript{1}</td>
<td>1960</td>
<td>20</td>
<td>Blunt</td>
<td>Hepatorrhaphy, drainage</td>
<td>35%</td>
</tr>
<tr>
<td>Shaftan et al.\textsuperscript{2}</td>
<td>1963</td>
<td>111</td>
<td>Blunt/penetrating</td>
<td>Stressed deleterious effects of inadequate drainage</td>
<td>27%</td>
</tr>
<tr>
<td>McClellan et al.\textsuperscript{3}</td>
<td>1964</td>
<td>259</td>
<td>Blunt/penetrating</td>
<td>Universal drainage, 60% hepatorrhaphy, 10% anatomic reaction</td>
<td>Not stated; 20% for resections</td>
</tr>
<tr>
<td>Nemhauser et al.\textsuperscript{4}</td>
<td>1969</td>
<td>28</td>
<td>Blunt/penetrating</td>
<td>Aggressive use of hepatic resection, T-tube drainage</td>
<td>0</td>
</tr>
<tr>
<td>Kindling et al.\textsuperscript{5}</td>
<td>1969</td>
<td>303</td>
<td>Blunt/penetrating</td>
<td>Suture and cholecystostomy for bile drainage liberally used</td>
<td>10% overall mortality; 32% for blunt, 20% for GSW</td>
</tr>
<tr>
<td>Fischer et al.\textsuperscript{8}</td>
<td>1971</td>
<td>19</td>
<td>Penetrating, Military, Vietnam</td>
<td>Emphasized portal triad occlusion and rapid hepatectomy with improved results over complex anatomic dissection</td>
<td>42%</td>
</tr>
<tr>
<td>Mays\textsuperscript{9}</td>
<td>1972</td>
<td>38</td>
<td>Blunt/penetrating</td>
<td>All had resection, many with hepatic artery ligation</td>
<td>50%</td>
</tr>
<tr>
<td>Faris et al.\textsuperscript{10}</td>
<td>1971</td>
<td>91</td>
<td>Combined civilian and military</td>
<td>Questioned the use of aggressive treatments</td>
<td>10.1% overall; 65% with formal resection</td>
</tr>
</tbody>
</table>

persistent arterial bleeding requiring hepatic artery ligation,\textsuperscript{13} and hepatostomy for central hematomas of the liver.\textsuperscript{14} However, in the mid-1970s, four publications\textsuperscript{15–18} reiterated that despite improvements in mortality, the death rate from liver injury remained high. Frey et al.\textsuperscript{17} reported a progressive decrease in mortality during 5-year increments from 50% to 27% to 16%, but the death and complications rate was high in patients requiring aggressive hepatic resection and/or hepatic artery ligation. Carica and Powers\textsuperscript{16} noted a 40% mortality in burst injuries, whereas a large series from Malaysia\textsuperscript{17} had a 16% overall mortality. In a classic report of 637 patients, Lucas and Ledgerwood\textsuperscript{18} focused on hemorrhage rather than sepsis as the primary driver of lethality and evaluated the efficacy of various techniques that they had used to control liver bleeding. They reported an overall mortality of 22.1% in bleeding patients with 48% mortality in those having anatomic resections. These articles as a group had several similar characteristics and altered the discussion compared with previous reports. First, the reported mortality was relatively similar in these articles ranging from 16% to 22%, and hemorrhage was a much more important contribution to mortality than was infection. Second, in contrast to earlier enthusiastic reports on the value of aggressive anatomic resection for trauma, these reports documented nearly 50% mortality from such procedures and often questioned its use. Third, these reports began to use anatomic classifications of injuries and physiologic grading of shock as important factors in comparing outcomes. The correlation of anatomic injury to liver-related mortality was compelling in one report\textsuperscript{16} where the mortality caused by liver injury was 4.4% in those without a “bursting” injury but was 42.9% in those with severe anatomic injury. The emphasis on hemorrhage as the major determinant of mortality rather than sepsis coupled with two articles on biliary drainage\textsuperscript{19,20} lead to several major changes in management in the 1970s. A number of earlier articles had stressed the value of the aggressive drainage of bile in patients with hepatic trauma. The use of cholecystostomy tubes or T-tube choledochostomies or both was advocated by several authors as previously noted. In 1972, a report\textsuperscript{19} from the Detroit General Hospital presented data on the randomization of patients into three groups, vis-à-vis, biliary drainage: standard alone, standard plus cholecystostomy, and standard plus T-tube choledochostomy. This large study of 189 patients showed markedly increased morbidity in those with aggressive drainage with no apparent benefit. A later study\textsuperscript{20} demonstrated the lack of the effectiveness of peritoneal drains for bile leaks and particularly questioned their use in minor liver injuries.

### REAPPRAISAL OF MANAGEMENT TECHNIQUES

If the first roughly 20 years of JOT articles on liver trauma focused on aggressive treatment, the next decade was characterized by calls for restraint, a reappraisal of previously espoused techniques and detailed analyses of large series in an attempt to improve mortality, particularly from bleeding. Levin et al.\textsuperscript{21} from the Charity Hospital in New Orleans urged “surgical restraint” in treating liver trauma; they noted that resection had a 52% mortality while those able to be treated by lesser means had a 5.4% death rate. Flint and Polk\textsuperscript{22} placed the aggressive use of hepatic artery ligation into perspective, and Scalfani et al.\textsuperscript{23} published one of the initial reports on the use of selective hepatic angiography to treat hepatic arterial bleeding. The use of atriocaval shunts was reviewed by surgeons from San Francisco,\textsuperscript{24} which likely had the best results ever reported but still noted only 4 of 13 survivors; later a Miami experience\textsuperscript{25} with 20 cases of retrohepatic vein injuries noted 90% mortality with the use of a shunt while 60% died with direct repair. These authors suggested portal triad occlusion with attempted direct repair was preferable to atriocaval shunt use.

Numerous reports over the first two decades of the Journal’s existence decried the use of perihepatic packing, although there were few, if any, reports that focused on its use. The large Detroit series\textsuperscript{18} of >600 patients used packing only three times, but all those patients survived. In 1981, a sentinel article\textsuperscript{26} from Ben Taub Hospital in Houston reported...
10 patients treated for coagulopathic bleeding after liver injury treated by perihepatic packing. The authors stated that the packing was added as a “last desperate maneuver” and noted that nine patients survived. This article from one of the country’s largest trauma units with its excellent results in patients who would, heretofore, have likely died, lead to a complete reappraisal on the use of perihepatic packing. Over the next several years, many additional articles27–31 on packing appeared in the JOT and generally offered validation of the merits of this technique as well as refinements in its use. Only one report29 did not find packing to be efficacious. These articles as a group served as the experiential backbone, which allowed perihepatic packing to become a mainstream practice for the treatment of bleeding patients; this maneuver, unlike several earlier techniques, appears to have withstood the test of time for the treatment of the subset of severely injured patients whose hepatic bleeding cannot be controlled by other means.

One of the significant advances promulgated by the JOT has been the work on the AAST Organ Injury Scaling System. The 1989 report32 on grading of injuries to the liver, spleen, and kidney provided a method to categorize injuries anatomically that remains in use to the present and has permitted a framework for the consistent categorization of injuries (with an update on liver and spleen in 1995; Table 2). In the period nearing the end of the decade of the 1980s, most reports focused on the evaluation of large series of liver injuries in an attempt to solve the continuing problems these difficult wounds offered. Cogbill et al.34 presented a multicenter experience on 1,335 severe injuries treated at six centers at the 1988 meeting of the Western Trauma Association (WTA). This report outlined the treatments used and results encountered in a large contemporaneous series, which served as a benchmark for subsequent studies. Large multicenter experiences from members of the WTA continue to be reported in JOT with regularity.

### TABLE 2. Liver Injury Scale (1994 Revision)33

<table>
<thead>
<tr>
<th>Grade</th>
<th>Type of Injury</th>
<th>Description of Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Hematoma</td>
<td>Subcapsular, &lt;10% surface area</td>
</tr>
<tr>
<td>II</td>
<td>Laceration</td>
<td>Capsular tear, &lt;1 cm parenchymal depth</td>
</tr>
<tr>
<td></td>
<td>Hematoma</td>
<td>Subcapsular, 10%–50% surface area</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>Capsular tear 1–3 parenchymal depth, &lt;10 cm in length</td>
</tr>
<tr>
<td>III</td>
<td>Hematoma</td>
<td>Subcapsular, &gt;50% surface area of ruptured subcapsular or parenchymal hematoma; intraparenchymal hematoma &gt;10 cm or expanding</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>&gt;3 cm parenchymal depth</td>
</tr>
<tr>
<td>IV</td>
<td>Laceration</td>
<td>Parenchymal disruption involving 25% to 75% hepatic lobe or 1–3 Couinaud’s segments</td>
</tr>
<tr>
<td>V</td>
<td>Laceration</td>
<td>Parenchymal disruption involving &gt;75% of hepatic lobe or &gt;3 Couinaud’s segments within a single lobe</td>
</tr>
<tr>
<td>V</td>
<td>Vascular</td>
<td>Juxtahepatic venous injuries; i.e., retrohepatic vena cava/central major hepatic veins</td>
</tr>
<tr>
<td>VI</td>
<td>Vascular</td>
<td>Hepatic avulsion</td>
</tr>
</tbody>
</table>

* Advance one grade for multiple injuries up to grade III.

Three reports published near the end of the third decade of JOT’s existence focused on the unresolved problems in liver trauma with detailed evaluation of large series of patients.35–37 Rivkind et al.35 carefully evaluated patterns of injury and detailed the importance of associated injuries on mortality, whereas a case series from Detroit36 reevaluated the impact of infection and sepsis from liver injury on mortality. Beal37 focused on the “unresolved problem of hemorrhage” in complex liver wounds and noted that 82% of fatalities were directly attributable to uncontrolled bleeding. Although there have been refinements in some aspects of the operative management of major liver injuries, there have been essentially no major technical innovations of note reported in the past two decades.

### THE ADVENT OF NONOPERATIVE MANAGEMENT

Interestingly, the first article38 published in the JOT focusing on nonoperative management (NOM) of liver injuries was written by pediatric surgeons and expressed concern about this approach for children and suggested caution until further data accrued. It was 6 years before an adult series appeared in the Journal describing 52 patients managed nonoperatively with good success. Four years later, two reports on NOM detailed expanded use of this protocol with roughly half of the patients who were treated without operation and with good results. The partial titles of these publications reflect some of the caution or ambivalence about this management strategy: “the need for continued surveillance”,39 “safe at any grade?”,40 and “the exception or the rule?”.41 In 1995, a multicenter experience42 presented to the aforementioned WTA noted good outcomes in 404 patients treated by NOM from 13 centers. This article concluded, “Nonoperative management of blunt hepatic injuries is clearly the treatment modality of choice in hemodynamically stable patients, irrespective of grade of injury or degree of hemoperitoneum.” Those recommendations remain the standard of care in trauma centers 15 years hence.

As the experiences increased with NOM, it became clear that some patients required other adjunctive techniques to manage complications encountered. In 1999, Carrillo and the Louisville group43 reviewed 32 patients who required adjunctive procedures after NOM and introduced the concept of laparoscopic evacuation of major collections of bile to treat patients who seemed to have systemic inflammatory response syndrome from undrained bile.

In the past decade, there have been relatively few articles on hepatic injury in the JOT. Of note, Polanco and the Pittsburgh group44 reviewed contemporary results with hepatic resection in 56 patients and noted only 9% mortality. This article demonstrated that skilled surgeons could accomplish excellent results in these complex wounds in the current environment.

### MANAGEMENT OF RENAL INJURIES

The first report45 on renal injuries, which appeared in JOT in 1962, was a textbook-style article without data in which the authors noted the importance of not allowing a patient to die while trying to save a kidney but emphasized...
that “conservation of renal tissue” is the main objective. A similar article without data were presented in 1970.46 Three articles on penetrating injuries to the kidney—two civilian reports47,48 from Ben Taub in Houston and a military experience from Vietnam49—were published in the first decade of JOT’s existence. These three reports stressed the high mortality caused by associated injuries and outlined strategies for renal salvage in appropriate patients with gunshot wounds (GSW).

In the early 1970s, three articles50–52 presented at the AAST focused on the controversies of managing renal trauma. In 1972, Cass and Ireland50 stressed the value of “aggressive radiologic evaluation and operation for renal injuries.” The aggressive diagnostic approach was by the use of high-dose contrast intravenous pyelography while renal exploration was often done after obtaining vascular control. The authors noted that in 32 patients in whom renal control was obtained before opening Gerota’s fascia, no nephrectomies were required. These authors advocated operation for any evidence of urine extravasation; the aggressive operative approach mirrored the stance of vigorous surgical therapies espoused for the treatment of liver injuries.

The following year, two articles from the AAST meeting on nonpenetrating51 and penetrating injuries52 were presented. An article on blunt injury51 stressed the need for aggressive diagnostic studies including intravenous pyelography, retrograde pyelography, arteriography, and renal scanning to potentially diagnose occult renal artery injuries; in keeping with several other articles on renal injury from that era, no data were presented. Interestingly, an article on penetrating trauma52 noted, “If possible, renal exploration should be avoided.” In the published discussion that ensued, Cass was very critical of the authors for their “lack of aggression.” The use of arteriography was noted in passing in these articles, but its role was not clearly defined.

Within 3 years, a large series of renal injuries assessed by arteriogram was reported.53 Arteriography was performed in 176 patients who sustained both blunt and penetrating injuries, and the authors carefully illustrated findings that permitted patients to be managed either by surgical intervention or nonoperative care. Subsequently, for several years, articles on renal injury often stressed the value of arteriography in planning treatment. In the same year (1975), a classic article by Holcroft et al.54 from San Francisco General Hospital carefully examined the indications for exploration of renal injuries causing retroperitoneal hematomas and conducted a follow-up analysis that verified the safety of conservative management of many perirenal hematomas. Within 2 years, an article55 presented to the AAST reviewed the controversial aspects of renal trauma management including nonoperative treatment, the indications for operation, and the role of arteriography. These authors outlined the defined role of arteriography and noted it was not universally required and could not supplant clinical judgment.

In 1982, JOT published an article by McAninch et al.56 from San Francisco General Hospital demonstrating the excellent results obtained in preserving renal tissue if vascular control was obtained before opening Gerota’s fascia. Although this technique had been previously mentioned in other reports, this study firmly documented the validity of this approach in a large series of patients with superb results, and 11 years later, a larger series further confirmed these observations.57 The initial article represented an early report by the lead author who has continued to contribute to the field of genitourinary trauma for the past 30 years.

Although the concept of vascular control has been shown to be beneficial in several studies, there have been others who have challenged the necessity of this maneuver. Gonzales et al.58 randomized 56 patients into a group that had vascular control before entering Gerota’s fascia and a group that had such control done after opening the perirenal fascia as required. These authors demonstrated no difference in nephrectomy rates (9 of 29 in preliminary control group and 8 of 27 in the no control group).

In the past 20 years, several clinical series have been reported in JOT that reflect the state of the art in the management of renal injuries. Several of the precepts presented in these reports could be summarized as follows: aggressive diagnostic evaluation may not be indicated for minimal hematuria; computed tomographic scanning provided accurate preoperative assessment in most patients; blunt trauma patients who were hemodynamically stable rarely needed exploration of the kidney, even if it was severely injured; the overall nephrectomy rate for blunt renal trauma was low but was higher for penetrating injuries (particularly GSW); and NOM was offered to the majority of stable patients with blunt trauma and to some highly selected patients with penetrating wounds.

In the past decade, three reports from large databases have examined various aspects of the impact of renal trauma on nephrectomy rates. One such study validated the utility of the AAST Organ Injury Severity Score for the kidney59 (Table 3). An evaluation of 2,467 patients showed a progressive need for operative treatment for grade I and II injuries.

### TABLE 3. Kidney Injury Scale32

<table>
<thead>
<tr>
<th>Grade</th>
<th>Type of Injury</th>
<th>Description of Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Contusion</td>
<td>Microscopic or gross hematuria, urologic studies normal</td>
</tr>
<tr>
<td></td>
<td>Hematoma</td>
<td>Subcapsular, nonexpanding without parenchymal laceration</td>
</tr>
<tr>
<td>II</td>
<td>Hematoma</td>
<td>Nonexpanding perirenal hematoma confirmed to renal retroperitoneum</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>&lt;1.0 cm parenchymal depth of renal cortex without urinary extravasation</td>
</tr>
<tr>
<td>III</td>
<td>Laceration</td>
<td>&lt;1.0 cm parenchymal depth of renal cortex without collecting system rupture or urinary extravasation</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>Parenchymal laceration extending through renal cortex, medulla, and collecting system</td>
</tr>
<tr>
<td>IV</td>
<td>Vascular</td>
<td>Main renal artery or vein injury with contained hemorrhage</td>
</tr>
<tr>
<td>V</td>
<td>Laceration</td>
<td>Completely shattered kidney</td>
</tr>
<tr>
<td></td>
<td>Vascular</td>
<td>Avulsion of renal hilum which devascularizes kidney</td>
</tr>
</tbody>
</table>

* Advance one grade for bilateral injuries up to grade III.
and save the spleen operatively, and ultimately the review of over half-a-million hospitalized patients in 1997 or greater requirement for dialysis, and increased mortality. A grade of injury was associated with higher nephrectomy rates, Bank (NTDB) of 742,774 patients showed that increased injuries to 9% for grade IV and 86% for grade V injuries. A subsequent large study from the National Trauma Data Bank (NTDB) of 742,774 patients showed that increased grade of injury was associated with higher nephrectomy rates, greater requirement for dialysis, and increased mortality. A review of over half-a-million hospitalized patients in 1997 or 1998 disclosed 6,231 patients with renal injuries, of which 11% required operation on their kidneys and 7% underwent a nephrectomy.

Shattered renal units may result from either blunt or penetrating injury and the need for nephrectomy increased with higher injury severity score, hemodynamic instability, and increased transfusion requirements. Penetrating injuries were more likely to result in nephrectomy. Although these findings were not unexpected, they focused on the unsolved problem of requirement for nephrectomy in high-grade injuries, particularly GSW. However, a recent large study of 206 kidneys injured by GSW showed that by using a strategy of selective observation and a combination of operative techniques, renal salvage approximating 85% was able to be achieved, even in this difficult cohort of patients.

The parallels in the management of renal trauma over the past 50 years to that of liver and spleen injury are worth noting. As with the latter two solid organs, the initial management emphasis was on both aggressive diagnostic maneuvers and operative interventions. The management of blunt renal injuries, in particular, is currently largely nonoperative except in the most severe grade of injuries (similar to the liver and spleen). Many penetrating injuries confined to the kidney are managed without operation. It seems that the NOM approach has likely increased renal salvage.

**SPLENIC TRAUMA**

Early in the 20th century, splenectomy became the standard of care for any splenic injury. Operative mortality was low, and the bleeding was effectively stopped. This approach was also driven by four dogmas. First, the spleen had no purpose. Second, splenectomy had no consequences. Third, the spleen cannot heal. Fourth, any injured spleen would ultimately bleed with the demise of the patient. Publications in the JOT have been critical in correcting these misconceptions by providing evidence to show us the immunologic consequences of splenectomy, that we can repair and save the spleen operatively, and ultimately the revolution of NOM. In the mid-20th century, with reports of overwhelming postsplenectomy infection (OPSI), the importance of splenic preservation became clear. We spent the 1980s and early 1990s operating on the majority of splenic injuries. Multiple series reported splenic salvage by splenorrhaphy, applied in 29% to 63% of laparotomies for splenic injuries. Although these findings were not unexpected, they focused on the unsolved problem of requirement for nephrectomy in high-grade injuries, particularly GSW. However, a recent large study of 206 kidneys injured by GSW showed that by using a strategy of selective observation and a combination of operative techniques, renal salvage approximating 85% was able to be achieved, even in this difficult cohort of patients.

The parallels in the management of renal trauma over the past 50 years to that of liver and spleen injury are worth noting. As with the latter two solid organs, the initial management emphasis was on both aggressive diagnostic maneuvers and operative interventions. The management of blunt renal injuries, in particular, is currently largely nonoperative except in the most severe grade of injuries (similar to the liver and spleen). Many penetrating injuries confined to the kidney are managed without operation. It seems that the NOM approach has likely increased renal salvage.

The parallels in the management of renal trauma over the past 50 years to that of liver and spleen injury are worth noting. As with the latter two solid organs, the initial management emphasis was on both aggressive diagnostic maneuvers and operative interventions. The management of blunt renal injuries, in particular, is currently largely nonoperative except in the most severe grade of injuries (similar to the liver and spleen). Many penetrating injuries confined to the kidney are managed without operation. It seems that the NOM approach has likely increased renal salvage.

Shackford et al. in 1981 reported 85 patients with splenic injury, of which 77 had blunt trauma. Forty-three patients had grade I–IV injuries and underwent splenorrhaphy. The 42 patients with grade V injury underwent splenectomy. Splenorrhaphy took no longer than splenectomy in this series. The authors emphasized two technical points in performing a splenorrhaphy. First, the spleen needed to be fully mobilized into the operative field. Second, all clotted blood must be evacuated from the abdomen.

Several advances in operative technique have facilitated the technique of splenorrhaphy. Argon Beam Coagulation allowed rapid, dependable hemostasis in the laboratory. High intensity ultrasound, staplers, and hemostatic wrap in the management of splenic injury have also been reported.

The routine availability and accuracy of computed tomography (CT) allowed the promulgation of NOM of solid abdominal organ injury. The critical criterion for safe observation of blunt injury to the spleen is hemodynamic stability. Early articles in the Journal suggested that older age, inability to examination the patient (closed head injury), and concern for hollow viscus injury were contraindications to observation of blunt splenic injury. We know through the Eastern Association for the Surgery of Trauma (EAST) studies in the JOT that full-thickness intestinal injury after blunt trauma is more uncommon than once believed; only 0.3% in >250,000 trauma patients. This observation is a major factor in allowing NOM to be safe. Keller et al. demonstrated that head injury was not an absolute contraindication to NOM of blunt splenic injury. As mentioned, age >55 years has been suggested as a contraindication to NOM. Barone et al. and Cocanour et al. reported similar failure rates in older patients, 17%, compared with younger patients. The EAST multicenter study reported that patients older than 55 years had greater mortality for all forms of treatment and failed NOM more often than patients younger than 55 years, 19% versus 10%. The corollary is that NOM was successful 81% of the time in patients older than 55 years. However, failure of NOM in this group resulted in increased mortality and length of stay compared with younger patients.

The multicenter study from WTA in 1989 was a landmark article. Cogbill et al. reported 832 patients with blunt splenic injury over 5 years from six Level I trauma centers. Thirty-six percent of the patients were children, and 64% were adults. Eighty-six percent of patients underwent immediate laparotomy. Fifty percent of the total group underwent splenectomy and 36% had the spleen preserved by splenorrhaphy. One hundred twelve of the patients were admitted for NOM of the blunt splenic injury, which is only 14% of all patients with blunt splenic injury. Importantly, numbers of patients of the 832 total by splenic grade of injury admitted for observation were grade I, 28 patients; grade II, 51 patients; grade III, 31 patients; grade IV, 2 patients; and grade V, no patients. Observation failed in 17% of adults and 2% of children.

Blunt splenic injury in children clearly has a different natural history than in adults. The reports of OPSI in children and classic reports in the 1970s led to quick adoption of NOM of blunt splenic injury in children. This evolution is nicely reviewed in Dr. Roger Sherman’s 1979 EAST presidential address. However, he also stated “The incidence of overwhelming sepsis following splenectomy is difficult to establish from a review of the literature.” This statement remains true today.
Comparison of care for children with multiple injuries at adult versus pediatric trauma centers, including splenic injury, is thoroughly reviewed in the article by Ochoa et al.96 Multiple studies have shown that children with splenic injury are more likely to undergo splenectomy when cared for by adult surgeons when compared with pediatric trauma surgeons.96–99 Nationally, most pediatric trauma patients receive care at community hospitals or adult trauma centers. Largely because of urban concentration of Level I pediatric trauma centers, a small proportion of pediatric trauma patients receive their care at such centers. Mooney et al. reported that frequency of splenectomy for children with splenic injury was 3% at freestanding children’s hospitals, 9% at a pediatric unit within an adult hospital, and 15% at adult hospitals. Odds ratios for splenectomy were 2.8 at the adult hospital and 2.6 at the pediatric unit in the adult hospital versus a freestanding pediatric hospital.97,98

Hospital factors seem to influence the frequency of splenectomy versus continued observation in adults as well.100 Splenic injuries were more likely to be observed at urban teaching hospitals (60%) as opposed to urban non-teaching hospitals (54%) and rural hospitals (54%). As the authors stated, the differences are probably appropriate because of the differences in resources between the hospitals. Multiple reports have stated that grade of splenic injury and quantity of hemoperitoneum have no impact on success of NOM101 (Table 4). The majority of these studies were single institution, with small numbers of grade IV and V splenic injuries. Many studies also included children and adults. We know now that >90% to 95% of children do well with observation. Thus, inclusion of children in studies with adult splenic injury skewed the data.

The EAST addressed these conflicting recommendations with a multicenter study.79 Evolution toward increasing observation of blunt splenic injury in adults was documented. The percentage of adult patients with blunt splenic injury admitted for observation was 48% in 1993, 59% in 1995, and 61% in 1997. To eliminate the change in frequency of observation as a confounding variable, only patients from 1997 were reported in detail. Totally, 1,488 adults from 27 trauma centers in the year 1997 were included in the study. Of these, 38.5% of patients went directly to the operating room and 61.5% of patients were admitted for observation. Eleven percent of patients failed observation, the majority in the first 24 hours and 90% by 72 hours. This large study confirmed that the majority of patients stable enough to be observed has splenic injury grades I–III. Patients underwent immediate laparotomy in 74% of grade IV and 94% of grade V blunt splenic injury. The failure of observation increased with grade of splenic injury: grade I (5%), grade II (10%), grade III (20%), grade IV (33%), and grade V (75%). Thus, 83% of grade IV splenic injuries and 98.7% of grade V splenic injuries ultimately required laparotomy. This important observation has been corroborated by several studies using the NTDB.81,82 Watson et al.82 reported of 3,085 adults with grades IV and V blunt splenic injury, NOM was attempted in 40.5% but ultimately failed in 55% of these high-grade splenic injuries (splenectomy in 92% of group). Smith et al.81 evaluated 23,532 patients with blunt splenic injury from the NTDB. Immediate laparotomy was performed within 2 hours of arrival in only 10.3% of adults with blunt splenic injury, a dramatic change from the EAST multicenter study. Smith et al.81 reported failure of observation of 40% with grade III splenic injury and 53% of grades IV and V. Trauma surgeons are currently willing to attempt to observe higher grade splenic injuries, with the predictable increase in failure of observation. Thus, trauma surgeons are pushing the envelope toward observation of splenic injury in adults. The optimal set point for observation of blunt splenic injury and frequency of failure are not clear. All studies confirmed that patients who were hemodynamically unstable, and admitted for observation despite this, have high risk of failure.

Liberal use of angioembolization (AE) was reported to improve NOM of blunt splenic injury.84,102–104 However, multiple articles have shown no improvement in outcomes in evaluation of the efficacy of AE.105,106 A major difficulty with this literature is that all are retrospective studies and some cohort analyses. As the tendency toward observation has increased so much,79 historical reviews are difficult to assess. The WTA summarized their literature review in 2008. “There is considerable variability in the use of angiography across centers. Although more aggressive use of angiography is associated with the highest rates of NOM (80%) and the lowest rates of failure (2–5%), there is ongoing debate over the optimal use of this intervention because it is labor intensive and there have been several reports that document a surprisingly high rate of complications. In our WTA multi-institutional experience, we reported on 140 patients who underwent AE, of which 27 (20%) suffered major complications including 16 (11%) failure to control bleeding (requiring 9 splenectomies and 7 repeat AE), 4 (3%) missed injuries, 6 (4%) splenic abscesses, and 1 iatrogenic vascular injury.”80

The immunologic consequences of splenectomy were nicely reviewed by Dickerman70 in 1976 in JOT. He reviewed

### TABLE 4. Spleen Injury Scale (1994 Revision)13

<table>
<thead>
<tr>
<th>Grade*</th>
<th>Injury Type</th>
<th>Description of Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Hematoma</td>
<td>Subcapsular, &lt;10% surface area</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>Capsular tear, &lt;1 cm parenchymal depth</td>
</tr>
<tr>
<td>II</td>
<td>Hematoma</td>
<td>Subcapsular, 10%–50% surface area</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>Intraparenchymal, &lt;5 cm in diameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Capsular tear, 1–3cm parenchymal depth that does not involve a trabecular vessel</td>
</tr>
<tr>
<td>III</td>
<td>Hematoma</td>
<td>Subcapsular, &gt;50% surface area or expanding; ruptured subcapsular or parenchymal hematoma; intraparenchymal hematoma ≥5 cm or expanding</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>&gt;3 cm parenchymal depth or involving trabecular vessels</td>
</tr>
<tr>
<td></td>
<td>Vascular</td>
<td>Laceration involving segmental or hilar vessels producing major devascularization (&gt;25% of spleen)</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>Laceration</td>
</tr>
<tr>
<td></td>
<td>Vascular</td>
<td>Hilar vascular injury with devascularized spleen</td>
</tr>
</tbody>
</table>

* Advance one grade for multiple injuries up to grade III.
earlier articles reporting the incidence of postsplenectomy sepsis after trauma as 0.68%. He concluded earlier studies confirmed: “that the incidence of bacterial infection following splenectomy is (1) greatest in children splenectomized for serious underlying conditions such as thalassemia or reticuloendothelial disease and (2) greatest in young children or infants.”79 The article stated that OPSI carried a mortality of 50% to 75%. OPSI is generally caused by encapsulated bacteria: Pneumococcus (60% of cases of OPSI), H. influenza, and Meningococcus. Laboratory studies from JOT confirmed higher mortality and persistent bacteremia with bacterial challenge after splenectomy.74,107 Hebert69 reported the importance of splenic mass on immunocompetence. Preservation of splenic mass by hemisplenectomy in animals improved lung clearance of bacteria and resulted in fewer bacteria cultured from tracheobronchial lymph nodes. Currently, care of postsplenectomy patients includes vaccination with pneumococcal vaccine and H. influenza type B conjugate and meningococcal vaccine within 2 weeks of splenectomy. Obviously, vaccines should be given several weeks before elective splenectomy. In the trauma population, concern exists regarding efficacy of vaccines given to patients early in the postoperative period. Several studies have confirmed that pneumococcal vaccine can be given in the postoperative period.71,72 Conflicting data have recently been published in assessment of immunocompetence after splenic preservation, either by splenorrhaphy or AE.67,68

PANCREATIC TRAUMA

Pancreatic injury is relatively uncommon, occurring in 12% of abdominal trauma. Early deaths are from hemorrhage due to associated vascular, splenic, or hepatic trauma. Late deaths are from infection and sepsis, generally from pancreatic or hollow viscus injury. It is important to remember that shared blood supply and anatomic proximity commonly result in both pancreatic and duodenal injuries. Failure to recognize major ductal injury remains a key element in poor outcome from pancreatic injury. Articles from the early issues of the JOT described demographics and operative options.108 Interestingly, little has changed regarding key principles since these early articles.109–111

In 1965, Strum112 observed that “primary reconstruction of the pancreatic ducts does not appear to be a practical method of treatment, and sphincterotomy with the necessary duodenotomy presents an unnecessary hazard in an already ill patient.” Wilson et al.108 reported 84 patients with pancreatic injury in 1967, one-half from blunt and the other half from penetrating mechanisms. Mortality was 38% in blunt injury and 27% for penetrating (mortality of 8% stab, 45% gunshot, and 100% shotgun injuries). Associated injuries were present with 77% of blunt injury and 89% of penetrating injuries. Sixty percent of the pancreatic injuries were managed with simple drainage, at that time using Penrose drains. Indications for simple drainage were “mild-to-moderate laceration, penetration, or contusion or if the patient’s condition was too precarious to attempt more complex procedures.”112 Except for our use of closed suction drains, little has changed since 1967. They reported that amylase levels were somewhat helpful in the diagnosis of complications, elevated in half the patients with complications. Early deaths were from hemorrhage. The presence of shock was associated with 61% mortality. Of the 69 patients who survived >48 hours, 54% had complications. One-third of this group died. However, “isolated injuries to the pancreas were relatively benign and only 13% of these patients died.”108 Patients with two or more injuries had a 57% mortality. A table in the Wilson’s article summarizes data from 11 articles with 647 patients with pancreatic injury. Overall mortality was 26%, essentially the same for penetrating and blunt mechanisms. However, shotgun wounds carried a 68% mortality compared with 28% for GSW and 7% for stab wounds. Causes of death in this series were hemorrhage and shock (56%), renal failure (13%), abdominal sepsis (10%), pancreatic complications (6%), central nervous system injury (5%), and pulmonary complications (4%). They stated “The most difficult problems encountered in pancreatic trauma concern the management of severe injury to the head of the pancreas. These injuries have usually been treated by drainage alone.”108

In 1970, Sheldon et al.113 reported 59 patients with injury to the pancreas. The majority of patients had associated injury, 27% mortality overall, and 30% developed major postoperative complications. The authors again emphasized that with minor-to-moderate wounds, drainage was sufficient treatment, emphasizing the use of sump drains. With deep lacerations to the pancreas and the possibility of duct injury, a resection was preferred treatment. Injuries to the body and tail of the pancreas were managed by distal pancreatectomy with low morbidity and mortality. The authors described injuries to the head of the pancreas as relatively unusual and more difficult to manage.

In 1971, Smith et al.114 described 95 patients from Charity Hospital with pancreatic and duodenal injuries, of which 78% were penetrating. Eighty-six percent of patients had associated injuries, one-third of whom had vascular injury. Mortality was 17% for isolated pancreatic injury, 21% for duodenal injury alone, and 40% for combined injuries to the pancreas and duodenum. In the same issue of the JOT, Nance and DeLoach115 reported a series of five patients, combined with another 20 patients in the literature undergoing pancreateoduodenectomy for trauma. They reported >75% survival with extensive combined pancreatic and duodenal injuries. More than 80% of patients had major complications after pancreateoduodenectomy. However, long-term results in surviving patients were good. The authors asked, “What are the indications for pancreateoduodenectomy in trauma?”115 They emphasized that the majority of patients with injuries to the pancreas or duodenum can be treated with more conservative measures. Duodenal injuries can be treated by suture and drainage. Pancreatic injuries are managed with suture and drainage or resection of the tail of the pancreas. In the presence of combined severe injuries to the head of the pancreas, common duct and duodenum—particularly where tissue damage is extensive and the blood supply to surviving structures tenuous—the greatest hazard to the patient may be undertreatment. In 1977, Lowe et al.116 summarized data on 70 patients undergoing pancreateoduodenectomy and reported
serious and often lethal complications." The authors em-
to satisfy these tenets routinely leads to the development of
failure based on three essentials: (1) arrest of hemorrhage, (2) selective
drainage of the pancreas resulted in leak at the pancreaticoje-
junostomy in five of seven patients and bacterial pancreatitis
of the superior mesenteric vessels), and 87 were distal inju-
ies. All proximal injuries were managed by drainage without
resection. Distal injuries with high suspicion of ductal injury,
63% of distal injuries, underwent distal pancreatectomy and
drainage. The spleen was preserved in 64% of distal pancre-
atectomies. Thirty-seven percent of distal pancreatic injuries
were treated with closed suction drainage alone. Pancreatic
morbidity was 11% in the 37 proximal injuries treated with
drainage alone. In the subgroup of patients with distal pan-
cratic injury and indeterminate ductal status, the complica-
tion rate was similar whether drainage alone (27%) or distal
resection (33%) was used ($p = 0.60$). Overall, the incidence
of pancreatic fistula was 15%, nearly all of which closed
spontaneously. Conclusions from this article were that the
majority of proximal pancreatic injuries can be treated by
drainage alone. The rare, devitalizing combined proximal
pancreatic and duodenal injury may require pancreateoduode-
necotomy. For distal injuries, high suspicion for ductal injury
is treated with distal pancreatectomy; indeterminate distal
injuries may be managed by drainage alone.

Kao et al. attempted to validate AAST Organ Injury Scale grades for the pancreas in 2003 (Table 5). They re-
ported 193 patients with pancreatic injury over 14 years.
Mortality was 12%, morbidity was 50%, and pancreas related
complications occurred in 22%. Multivariate analysis re-
vealed that the grade of pancreatic injury was an independent
predictor of pancreatic complications (odds ratio, 4.4) and
mortality (odds ratio, 2.6).

During the development of total parenteral nutrition,
Dudrick et al. reported in 1970 the closure of traumatic
pancreaticoduodenal fistulae in three patients supported with
total parenteral nutrition. It is fascinating to read this article
now knowing the historical perspective. The authors discuss
the importance of adequate nutrition in patients with gastro-
intestinal fistulae.

Diagnosis of pancreatic ductal injury remains difficult.
As summarized in the EAST Guidelines, "Hyperamylasemia,
CT findings and leukocytosis have not been as reliable as in
pancreatitis of nontraumatic origin." In essence, amylase or
lipase levels are suggestive but not diagnostic for pancreatic
injury; they are neither sensitive nor specific. Unfortu-
nately, delays to operation of 24 hours for pancreatic injury
result in two to three times the morbidity. The most compelling
article assessing CT for pancreatic injury is the 2009
multicenter study from the AAST. Twenty centers enrolled
206 patients. The sensitivity of 16-slice CT for pancreatic
injury was 60%; sensitivity was only 47% for 64-slice CT.
For pancreatic ductal injury, sensitivities were 54% for 16-
slice CT and 52% for 64-slice CT.

Several studies have used endoscopic retrograde cholangiopancreatography (ERCP) in the management of

### Table 5. Pancreas Injury Scale

<table>
<thead>
<tr>
<th>Grade*</th>
<th>Type of Injury</th>
<th>Description of Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Hematoma</td>
<td>Minor contusion without duct injury</td>
</tr>
<tr>
<td>II</td>
<td>Laceration</td>
<td>Superficial laceration without duct injury</td>
</tr>
<tr>
<td>III</td>
<td>Laceration</td>
<td>Major laceration without duct injury or tissue loss</td>
</tr>
<tr>
<td>IV</td>
<td>Laceration</td>
<td>Distal transection or parenchymal injury involving ampulla</td>
</tr>
<tr>
<td>V</td>
<td>Laceration</td>
<td>Massive disruption of pancreatic head</td>
</tr>
</tbody>
</table>

* Advance one grade for multiple injuries up to grade III.

Proximal pancreas is to the patients' right of the superior mesenteric vein.
pancreatic injury.111,127–130 Duchesne et al.127 reported that ERCP was used to essentially stage patients in initial evaluation, with confirmed ductal injuries undergoing laparotomy and avoidance of laparotomy in those patients with intact ductal systems. ERCP was uncommonly used intraoperatively. Rogers et al.130 reported 26 patients undergoing ERCP, on average 19 days after injury. Nine patients underwent definitive endoscopic treatment of their pancreatic injuries, including pancreatic sphincterotomy or ductal stenting or both.

NOM has become the standard of care for blunt solid organ injury in children. Pancreatic injuries in children are commonly produced by handlebar or sports injuries. Observation has been suggested for blunt pancreatic injury in children as well. As Nadler et al. reported, with clear evidence of pancreatic transection, treatment with distal pancreatectomy resulted in shorter length of stay.131–133 Of the six children with pancreatic injuries, including pancreatic sphincterotomy or ductal stenting or both.

Our review of surgical management of solid organ injury published over 50 years in the JOT reveals remarkable contributions and metamorphosis. More than 85% of blunt injuries to the liver, kidney, and spleen are currently managed nonoperatively. The corollary is when we do operate on injuries to these solid organs, the injuries are high grade, the patient has multiple injuries, and the patient is often hemodynamically unstable. Particularly in the case of liver injuries, the injuries are complex and operations are challenging. Management of pancreatic injuries has changed little from our earliest publications that emphasized the importance of identification of pancreatic duct disruption, which is best managed by distal resection, and wide closed suction drainage with all pancreatic injuries.

REFERENCES


