A comprehensive five-step surgical management approach to penetrating liver injuries that require complex repair

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BACKGROUND: The objective of this study was to describe a comprehensive five-step surgical management approach for patients with penetrating liver trauma based on our collective institutional experience.

METHODS: A prospective consecutive study of all penetrating liver traumas from January 2003 to December 2011 at a regional Level I trauma center in Cali, Colombia, was conducted.

RESULTS: A total of 538 patients with penetrating thoracoabdominal trauma were operated on at our institution. Of these, 146 had penetrating liver injuries that satisfied the inclusion criteria for surgical intervention to manage their hepatic and/or associated injuries. Eighty-eight patients (60%) had an American Association for the Surgery of Trauma–Organ Injury Scale (AAST-OIS) of Grade III (54 patients, 37%), Grade IV (24 patients, 16%), and Grade V (10 patients, 7%). This group of patients required advanced "complex" techniques of hemostasis such as the Pringle maneuver (PM), perihepatic liver packing (PHLP), and/or hepatotomy with selective vessel ligation (SVL). The focus of our study was this subgroup of patients, which we further divided into two as follows: those who required only PM + PHLP (55 patients, 63%) to obtain control of their liver hemorrhage and those who required PM + PHLP + SVL (33 patients, 37%). Of the patients who required PM + PHLP + SVL, 10 (27%) required ligation of major intrahepatic branches, which included suprahepatic veins (n = 4), portal vein (n = 4), retrohepatic vena cava (n = 1), and hepatic artery (n = 1). The remaining 23 patients (73%) required direct vessel ligation of smaller intraparenchymal vessels. The overall mortality was 15.9% (14 of 88), with 71.4% (10 of 14) related to coagulopathy. Mortality rates for Grade III was 3.7% (2 of 54), for Grade IV was 20.8% (5 of 24), and for Grade V was 70% (7 of 10). The mortality in the PM + PHLP + SVL group was higher compared with the PM + PHLP group (12 [36.4%] vs. 2 [3.6%], $p = 0.001$).

CONCLUSION: For those patients who fail to respond to PM + PHLP and/or those who have AAST-OIS penetrating liver injuries, Grades IV and V would benefit from immediate intraparenchymal exploration and SVL. (*J Trauma Acute Care Surg*. 2013;75: 207–211. Copyright © 2013 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Therapeutic study, level V.

KEY WORDS: Damage-control surgery; penetrating liver injuries; complex repair; Pringle maneuver.

In the course of the 21st century, much progress has been made in achieving hepatic injury hemostasis. However, the progress has not always been linear. Some lessons have been learned, set aside, and then reconsidered in light of changing circumstances. Fortunately, most liver injuries (70–90%) require minor therapy.[1] In contrast, the mortality of complex hepatic injuries remains very high (54%) despite improvements in resuscitation, anesthesia, and intensive care facilities.[2] Similarly, their surgical management poses a formidable challenge to even the most experienced trauma surgeon. This is because uncontrolled hemorrhage leading to exsanguination remains the leading cause of hepatic mortality.[3]

The management of parenchymal injuries has continued to evolve since the early descriptions of compression of the hepatoduodenal ligament, use of mattress sutures, and insertion of gauze packing into hepatic lacerations 80 years ago. Certain forms of treatment that have been popular in the past are now used infrequently. Included among these are the use of deep mattress sutures, intrahepatic packing, lobectomy, and hepatic artery ligation. In contrast, techniques such as hepatotomy with selective vascular ligation, limited resectional debridement, and perihepatic packing have gained favor.[4] Based on our experience, we set forth to describe a comprehensive five-step surgical approach that deals with severe penetrating liver injuries and attempts to include all of these concepts.

PATIENTS AND METHODS

From January 2003 to December 2011, all patients with liver injury admitted to our regional Level I trauma center in Cali, Colombia, following penetrating trauma were evaluated prospectively. All initial data were captured using a Web-based

Submitted: February 20, 2013, Revised: April 25, 2013, Accepted: April 26, 2013.

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This study was presented as a poster at the 71st Annual Meeting of the American Association for the Surgery of Trauma and Clinical Congress of Acute Care Surgery, September 12–15, 2012, in Kauai, Hawaii.

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DOI: 10.1097/TA.0b013e31829de5d1

MySQL platform (Hughes Technologies, Queensland, Australia) and subsequently transferred to a STATA 11.0 software program (Stata Corp., College Station, TX). All penetrating trauma to the torso inferior to the nipple line and superior to the inguinal creases were included in our study. The data collected on these patients included demographics, such as sex, age, mechanism of injury, Revised Trauma Score (RTS), Injury Severity Score (ISS), New Injury Severity Score (NISS) and abdominal Abbreviated Injury Scale (AIS) score, associated injuries, intraoperative blood loss, blood product requirements, and overall outcome. Outcome was measured by calculating the overall mortality, which was also stratified according to hepatic causes and by injury grade. Resuscitation and treatment of all patients with hepatic injuries during this time interval were similar among four attending trauma surgeons. All patients with peritoneal signs, persistent hemodynamic instability after initial trauma bay resuscitation, and/or any penetrating injury trajectory that had crossed the abdominal cavity were taken immediately to the operating room for exploratory laparotomy. Asymptomatic hemodynamically stable patients with no obvious peritoneal traversement on initial examination were evaluated by a contrast-enhanced computed tomography scan of the abdomen. Of those who underwent computed tomography scan, the presence of radiologic signs of hollow viscous perforation, evolving hemodynamic instability, and/or peritonitis were taken to the operating room for immediate exploratory laparotomy. Those who did not require laparotomy were admitted for serial abdominal examinations and observation. In patients who were near death with a massively distended abdomen secondary to hemoperitoneum underwent an anterolateral thoracotomy for cross-clamping of the descending thoracic aorta before or concurrent with laparotomy. Our institutional approach to operative management of penetrating liver injuries is as follows: an initial midline laparotomy incision is performed, the falciform ligament is divided, and all four quadrants of the abdomen are packed. If gross hemorrhage without fecal contamination is present, a cell saver device is used. Time is then given to the anesthesiologist to "catch up" on damage-control resuscitation at a 1:1:1 ratio following our preestablished institutional massive transfusion protocol. The packs are then removed in a systematic fashion starting with the two lower quadrants with prompt control of any fecal contamination. Then, the packs of the left upper quadrant are removed, followed by splenectomy if required for hemorrhage control. The anterior hepatic packs are then removed, and the liver is inspected. The severity of the liver injury is graded intraoperatively by the trauma surgeon according to the American Association for the Surgery of Trauma–Organ Injury Scale (AAST-OIS). If upon removal of the liver packs hemorrhage ensues, then the porta hepatis is compressed with a soft clamp or Rummel tourniquet (Pringle maneuver [PM]). If minor hepatic lacerations are present, hemostasis is generally obtained by the use of compression, application of topical thrombotic agents, and/or suture hepatorraphy. With major hepatic lacerations, hepatotomy by finger fracture with selective vessel ligation (SVL) or clipping, as described by Pachter et al.,[5] is performed. Hepatotomy is also performed to connect missile entrance and exit sites when active hemorrhage is noticed from either. When large peripheral sections of the liver are devitalized by blast injury, resectional debridement with SVL or clipping is performed.

Liver injuries Grades I and II that required "simple" repairs, defined as suture hepatorraphy, high current electrocautery, and/or application of topical thrombotic agents, were not included in our final statistical analysis. Only major liver injuries Grades III, IV, and V that required advance "complex" techniques of hemostasis such as the PM, perihepatic liver packing (PHLP), and/or hepatotomy with SVL were included. We further divided these patients into two subgroups as follows: those who required only PM + PHLP to obtain control of their liver hemorrhage and those who required PM + PHLP + SVL. All categorical variables are described in absolutes and relative frequencies. All continuous variables as median and interquartile range (IQR). Comparisons between subgroups for categorical data were performed using χ^2 or Fisher's exact test; Mann-Whitney U-test was used for continuous variables. A $p < 0.05$ was considered significant.

RESULTS

From January 2003 to December 2011, a total of 538 patients with penetrating thoracoabdominal trauma were operated on at our institution. Of these, 146 had penetrating liver injuries that satisfied the inclusion criteria for surgical intervention to manage their hepatic and/or associated injuries. Fifty eight (40%) had minor AAST-OIS Grades I and II. These injuries required "simple" repairs, defined as suture hepatorraphy, high current electrocautery, and/or application of topical thrombotic agents. Eighty-eight patients (60%) had an AAST-OIS of Grade III (54 patients, 37%), Grade IV (24 patients, 16%), and Grade V (10 patients, 7%). This group of patients required advance "complex" techniques of hemostasis such as the PM, PHLP, and/or hepatotomy with SVL. The focus of our study was this subgroup of patients, which we further divided into two as follows: those who required only PM + PHLP (55 patients, 63%) to obtain control of their liver hemorrhage and those who required PM + PHLP + SVL (33 patients, 37%). The most common mechanism of injury in both groups was gunshot wounds in 78 patients (88.64%), followed by stab wounds

TABLE 1. Penetrating Liver Injuries AAST-OIS Grades III, IV, and V

	Median (n = 88)	IQR
Age, y	30	15–64
Sex (male)*	83	94.3
Gunshot wounds*	78	88.6
Stab wounds*	10	11.3
Estimated prehospital time, min	30	8–75
Trauma bay time, min	68	40–120
Systolic blood pressure, mm Hg	100	70–120
Heart rate, beats/min	99	86–118
RTS	7.5	5.9–7.8
APACHE II	16	9–21
ISS	25	18–34
NISS	34	27–50
Abdominal AIS score	4	3–4

*n (%).
APACHE, Acute Physiology and Chronic Health Evaluation.

in 10 patients (11.36%). Median age was 30 years (IQR, 15–64 years), and the median severe injury burden scores were 7.5 for RTS (IQR, 5.9–7.8), 16 for Acute Physiology and Chronic Health Evaluation II (IQR, 9–21), 25 for ISS (IQR, 18–34), 34 for NISS (IQR, 27–50), and 4 for abdominal AIS score (IQR, 3–4) (Table 1).

Definitive single-stage surgery was performed in 20 patients (23%) and damage-control surgery in 68 patients (77%). Median operative time was 90 minutes (IQR, 60–130 minutes). The median volume of hemoperitoneum upon laparotomy was 1,100 mL (IQR, 500–2,500 mL). Of the patients who required PM + PHLP + SVL, 10 (27%) required ligation of major intrahepatic branches, which included suprahepatic veins (n = 4), portal vein (n = 4), retrohepatic vena cava (n = 1), and hepatic artery (n = 1). In this subgroup, a total of three patients (right portal vein [n = 1], middle suprahepatic vein [n = 1], and a hepatic artery ligation [n = 1]) survived with no significant short- or long-term complications. The remaining 23 patients (73%) required direct vessel ligation of smaller intraparenchymal vessels (Fig. 1).

Overall, the right lobe of the liver was involved in 109 patients (70.7%) and the left lobe in 45 patients (29.2%). The PM + PHLP + SVL group had a right lobe predominance and had an associated higher volume of hemoperitoneum upon laparotomy (PM + PHLP + SVL, 2,500 mL [1,500–4,000 mL] vs. PM + PHLP, 1,500 mL [1,000–2,500 mL]; $p = 0.006$). The PM + PHLP + SVL group had more patients with higher abdominal AIS scores of 4 and 5 (abdominal AIS score = 4: PM + PHLP, 15 [27.3%] vs. PM + PHLP + SVL, 22 [66.7%] [$p < 0.0001$]; abdominal AIS score = 5: PM + PHLP, 4 [7.2%] vs. PM + PHLP + SVL, 8 [24.2%] [$p = 0.0250$]). The mean intraoperative transfusion requirements during the initial surgical procedure for both groups were as follows: 5 U (IQR, 3–7 U) of packed red blood cells, 6 U (IQR, 4–7 U) of fresh frozen plasma, 6 U (IQR, 5–12 U) of platelets, and 6 U (IQR, 4–9 U) of cryoprecipitates. This translated in average to an intraoperative transfusion ratio of 1:1.4:1.4:1.4. The average total autotransfusion volume was 913 mL (IQR, 600–1,200 mL) (Table 2).

TABLE 2. Penetrating Liver Trauma Requiring ''Complex'' Repair

	PM + PHLP (n = 55)	PM + PHLP + SVL (n = 33)	p
ISS*	25 (17.5–34)	20 (16–34)	0.8679
RTS*	7.6 (6.0–7.8)	7.6 (5.5–7.8)	0.8322
NISS*	34 (27–50)	34 (27–50)	0.9341
Abdominal AIS score			
Abdominal AIS score = 3	36 (65.4)	3 (9.0)	<0.0001
Abdominal AIS score = 4	15 (27.3)	22 (66.7)	<0.0001
Abdominal AIS score = 5	4 (7.2)	8 (24.2)	0.050
Packed red blood cells transfused, U*			
Intraoperative, U	4 (2–6)	6 (4–8)	0.2063
Intensive care unit, U	4 (2–9)	8 (3–14)	0.059
Intensive care unit stay, (days)*	5 (0–10)	4 (1–9)	0.9964
Hospital stay, (days)*	10.5 (4–19)	7 (2–16)	0.1165

*Median (IQR).

Associated injuries were similar in both groups, and the most common organs injured were the colon (34%), stomach and duodenum (30%), small bowel (25%), and lung (16%) (Table 3). Fifty patients developed postoperative nonfatal complications. The most common were infectious in origin (20%), which consisted of either peritonitis (14%) or intra-abdominal abscess formation (6%). There were nine instances of intestinal fistula and six instances of biliary fistula (Table 4).

The overall mortality was 15.9% (14 of 88), with 71.4% (10 of 14) related to coagulopathy. Mortality rates for Grade III was 3.7% (2 of 54), for Grade IV was 20.8% (5 of 24), and for

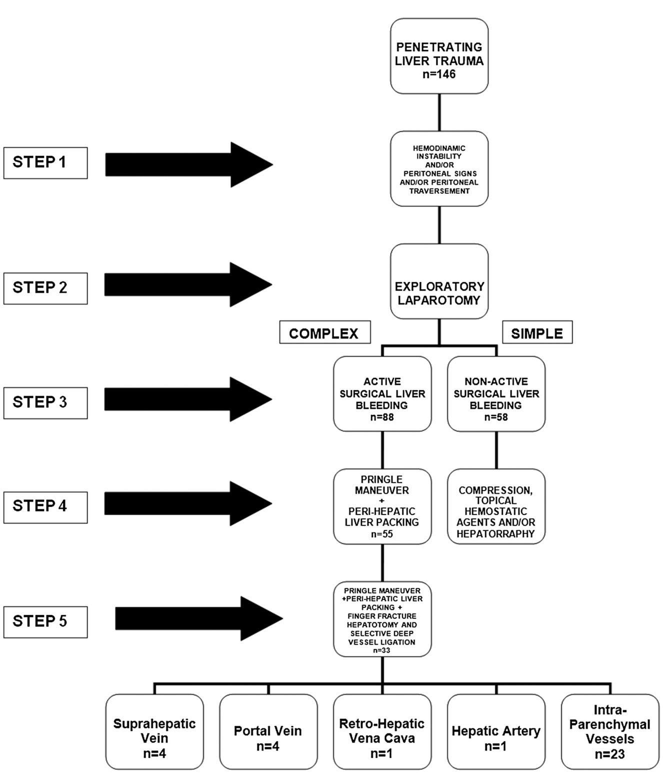

Figure 1. Comprehensive stepwise surgical approach.

TABLE 3. Associated Injuries with ''Complex'' Penetrating Liver Trauma

	PM + PHLP (n = 55)	PM + PHLP + SVL (n = 33)	p
Hemoperitoneum,* L	1.5 (1.0–2.5)	2.5 (1.5–4.0)	0.006
Lung	6 (10.9)	8 (24.2)	0.098
Heart	4 (7.3)	1 (3.0)	0.646
Thoracic great vessels	3 (5.4)	0 (0.0)	0.289
Colon	18 (32.7)	12 (36.6)	0.728
Stomach and duodenum	18 (32.7)	9 (27.3)	0.591
Small bowel	17 (30.9)	5 (15.2)	0.098
Pancreas	7 (12.7)	4 (12.1)	1
Spleen	6 (10.9)	4 (12.1)	1
Abdominal great vessels	9 (16.4)	3 (9.0)	0.523

*Median (IQR).

TABLE 4. Postoperative Complications and Mortality

	PM + PHLP (n = 55)	PM + PHLP + SVL (n = 33)	*p*
Postoperative complications			
Peritonitis	16 (64.0)	6 (31.6)	0.033
Abdominal compartment syndrome	8 (14.8)	5 (15.1)	1
Adult respiratory distress syndrome	7 (28.0)	5 (26.32)	0.757
Intestinal fistula	7 (13.0)	2 (6.0)	0.474
Evisceration	2 (3.7)	0 (0.0)	0.526
Cause of death			
Coagulopathy	2 (100)	8 (66.7)	1
Sepsis	0 (0.0)	2 (16.7)	1
Multisystem organ failure	0 (0.0)	2 (16.7)	1
Overall mortality	2 (3.6)	12 (36.4)	0.000
Intraoperative mortality	1 (50.0)	5 (45.4)	1
Mortality per liver injury grade			
Grade III	2 (100)	0 (0)	0.526
Grade IV	0 (0)	5 (41.7)	0.006
Grade V	0 (0)	7 (58.3)	0.001

Grade V was 70% (7 of 10). The mortality in the PM + PHLP + SVL group was higher compared with the PM + PHLP group (12 [36.4%] vs. 2 [3.6%], $p = 0.001$) (Table 4).

DISCUSSION

Our study reports a very select patient population, consisting exclusively of penetrating liver injuries AAST-OIS Grades I to V that required operative management for control of life-threatening hemorrhage and/or associated intra-abdominal injuries. With many techniques available for major liver injury management, it is obvious that the surgeon must tailor the surgical approach to the individual injury.[6] Death from penetrating liver wounds is generally secondary to hemorrhage and hypovolemic shock from either the liver or associated major vascular injuries.[7] When hemodynamic stability cannot be achieved, we advocate immediate laparotomy with hemorrhage control by means such as packing or direct injury repair.[8] Penetrating liver trauma does not usually occur in isolation, and a total of 152 associated injuries were found in our study group.

It has been the practice of trauma surgeons for years to avoid entering the liver to suture vascular injuries, opting instead for reapproximating the liver with large deep sutures, hoping that the subsequent pressure would tamponade the bleeding. While this may work in many situations and at times be lifesaving, this is not ideal. Mattress sutures passed deeply through lobar lacerations or around missile tracts are accompanied by two problems. The first is the frequent failure of the sutures to control hemorrhage, while the second is the extensive amount of hepatic necrosis that occurs underneath the tied sutures.[4] These large liver sutures close the surface over what is often deep substantial hepatic injury, which can lead to late bleeding, abscess formation, intrahepatic hematomas/bilomas, or late biliary complications. The preferred method for deep injury is either liver resection or deepening the fracture and directly and precisely suturing the bleeding. With a PM in place, hepatotomy can be performed to expose deep intraparenchymal bleeding. Tractotomy may be required to expose missile tract bleeding, and selective vascular ligation can then be performed with anatomic precision.[4,9] Following these principles, our approach to the surgical management of penetrating liver trauma is systematic and logical (Fig. 1).

Step I

Patients presenting hemodynamically unstable, with peritoneal signs and/or with peritoneal cavity traversement, require immediate surgical intervention.[10,11]

Step 2

An initial midline laparotomy incision is performed, the falciform ligament is divided, and all four quadrants of the abdomen are packed. If gross hemorrhage without fecal contamination is present, a cell saver device is used. Time is then given to the anesthesiologist to "catch up" on damage-control resuscitation at a 1:1:1 ratio following a preestablished institutional massive transfusion protocol. The packs are then removed in a systematic fashion starting with the two lower quadrants with prompt control of any fecal contamination. Then, the packs of the left upper quadrant are removed, followed by splenectomy if required for hemorrhage control.

Step 3

The anterior hepatic packs are then removed, and the liver is inspected. The severity of the liver injury is graded intraoperatively by the trauma surgeon according to the AAST-OIS.

Step 4

If minor hepatic lacerations are present, hemostasis is generally obtained by the use of compression, application of topical agents, and/or suture hepatorraphy. If simple maneuvers control the bleeding liver in the unstable patient, pack the liver and truncate the operation.[12–14] If packing fails to control the bleeding parenchyma, the next step is the PM; this is both diagnostic and therapeutic. When the bleeding continues despite the clamp on the porta hepatis, this represents back-bleeding from the main hepatic veins and/or the retrohepatic vena cava. Thus, response to the PM—control or lack of control of bleeding—defines the anatomic injury (portal triad vs. hepatic veins/vena cava).[15]

Step 5

With the PM in place, the origin of the bleeding must quickly be determined for expeditious exposure and control of hemorrhage.[16] This is performed through the laceration in the liver, often extending the injury for adequate control of hemorrhage. This can be accomplished by the finger fracture technique or even more rapidly with the stapling devices.[15] The only goal at the first operation is control of hemorrhage.[17] Once surgical bleeding has been controlled, the operation is truncated, the abdomen is packed with temporary abdominal closure, and the patient is transferred to the intensive care unit for further resuscitation.[18] It is critical that the operation be terminated only when control of "surgical bleeding" is clearly accomplished, and what remains is oozing (medical bleeding) caused by hypothermia and coagulopathy.[15]

Cogbill et al.[19] in a 5 year multi-institutional study consisting of 1,335 patients reported 59 Grade IV and V injuries with mortality rates of 46% for Grade IV injuries and 80% for Grade V injuries. Asensio et al.[3] reported a mortality rate of 19% for Grade IV injuries and 57% for Grade V injuries, although it is important to note that early postoperative angiography and angioembolization were used in this study.[20,21] Our overall mortality was 15.9% (14 of 88 patients). In our study, the mortality and morbidity rates of patients with penetrating liver injuries increased with severity of the liver injury. When mortalities were stratified by injury grade, they yielded a mortality rate of 3.7% for Grade III, 20.8% for Grade IV, and 70% for Grade V (Table 4). Right-lobe liver injuries were more frequent and required more often SVL for hemorrhage control as compared with the left-lobe liver injuries. This is probably caused by the need of a wider and deeper hepatotomy to reach and control intraparenchymal vessels. Based on our experience, we believe that our comprehensive stepwise surgical approach to the management of these injuries is helpful in decreasing mortality. We strongly advocate early surgical intervention to control life-threatening liver hemorrhage, which quickly moves toward intraparenchymal SVL.

CONCLUSION

Thirty percent of patients with penetrating liver injuries require emergent laparotomy caused by hemodynamic instability, peritonitis, or peritoneal traversement, and the majority of these patients require surgical intervention for concomitant injuries. The traditional PM associated with PHLP (PM + PHLP) is an effective first-line surgical therapy for hemorrhage control for most patients with severe penetrating liver trauma. For those patients who fail to respond to PM + PHLP and/or those who have AAST-OIS penetrating liver injuries, Grades IV and V would benefit from immediate intrahepatic exploration and SVL. It is our institutional experience and recommendation that hepatotomy with SVL rather than the insertion of mattress sutures is preferable for hemorrhage control for deep lacerations from penetrating liver injuries.

AUTHORSHIP

C.A.O., J.C.P., and M.W.P. contributed in the study conception and design. C.A.O. and M.B. were responsible for the collection, assembly, and quality of data. J.C.S., W.B., D.S., L.F.P., and M.M. performed the acquisition of data. M.B. and J.S. performed the statistical analysis. C.A.O., M.B., J.C.P., M.W.P., and J.C.S. performed the analysis and interpretation of data. C.A.O., M.W.P., M.B., J.C.P., L.F.P., and J.C.S drafted the manuscript. C.A.O., M.W.P., J.C.S., M.B., J.C.P., and R.F. provided critical revision of the manuscript for important intellectual content. C.A.O. and M.B. provided study supervision and administrative, technical, or logistic support. C.A.O. and M.B. obtained funding.

ACKNOWLEDGMENTS

We thank to Dr. Magda Cepeda and statistician John Loaiza for their invaluable assistance with the data management.

DISCLOSURE

This study was funded by Fundación Valle del Lili.

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