

Open Balloon Tamponade and Hepatic Angiography for Hemorrhage Control of Transhepatic Gunshot Wounds in a Hybrid Trauma Operating Room Environment

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The management of high-grade liver trauma is challenging and mortality rates are high. Balloon tamponade is a valuable tool for control of transhepatic penetrating injuries. We report three cases of hybrid management of penetrating liver trauma with balloon tamponade and hepatic angiography in a hybrid operating room environment. The combination of balloon tamponade with hepatic angioembolization provides an enhanced approach for the management of these injuries.

Keywords: *Penetrating Liver Trauma; Balloon Tamponade; Hybrid Techniques; Endovascular Intervention*

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The optimal management of liver trauma continues to evolve. The development of endovascular adjuncts has afforded an increasing range of hemorrhage control capabilities that can be utilized in primary or supportive roles in appropriate patients. Even among patients requiring initial emergent damage-control laparotomy with open control of the liver hemorrhage, angiography and angioembolization can be effectively employed in a hybrid intra-operative fashion or postoperatively in order to improve the outcome and reduce mortality [1,2].

Despite the ready availability of open and endovascular capabilities, however, gunshot wounds (GSWs) to the liver can represent a particularly problematic form of hepatic injury. In particular, the optimal management of bleeding GSW tracts that traverse deep through the central aspect of the liver remain a clinical challenge. Although fortunately uncommon, these deep bleeding

tracts require dexterous clinical thinking and tailored approaches to optimize the outcome.

For a select pattern of GSW tracts through the central liver, balloon tamponade may prove a useful tool for initial hemorrhage control in the context of damage control. A quite effective improvised tamponade balloon to accomplish this can be fashioned from a simple red rubber or Foley catheter inserted into a Penrose drain that is closed with a tie on each end, as initially described by Poggetti and Moore [3]. A pictorial representation is shown in Figure 1. After the infusion end of the catheter is brought out through the abdominal wall, the end with the Penrose drain is passed through the liver injury and saline (or contrast dye) is instilled into the Penrose drain, inflating it until an effective diameter to achieve tamponade of bleeding from the hepatic wound tract is reached. The external portion of the infusion catheter is then clamped to prevent fluid escape and to maintain tamponade. Care should be taken to avoid accidental dislodgement of the clamp. If possible, at least 2–4 cm of the balloon should be protruding from each end of the tract to prevent underfilling of the balloon, kinking, or dislodgement. The created tamponade balloon is kept in place for 24–48 hours to allow time for hemostasis while minimizing the risk of intra-abdominal sepsis. It is subsequently removed intra-operatively at the time of re-exploration with or without endovascular embolization.

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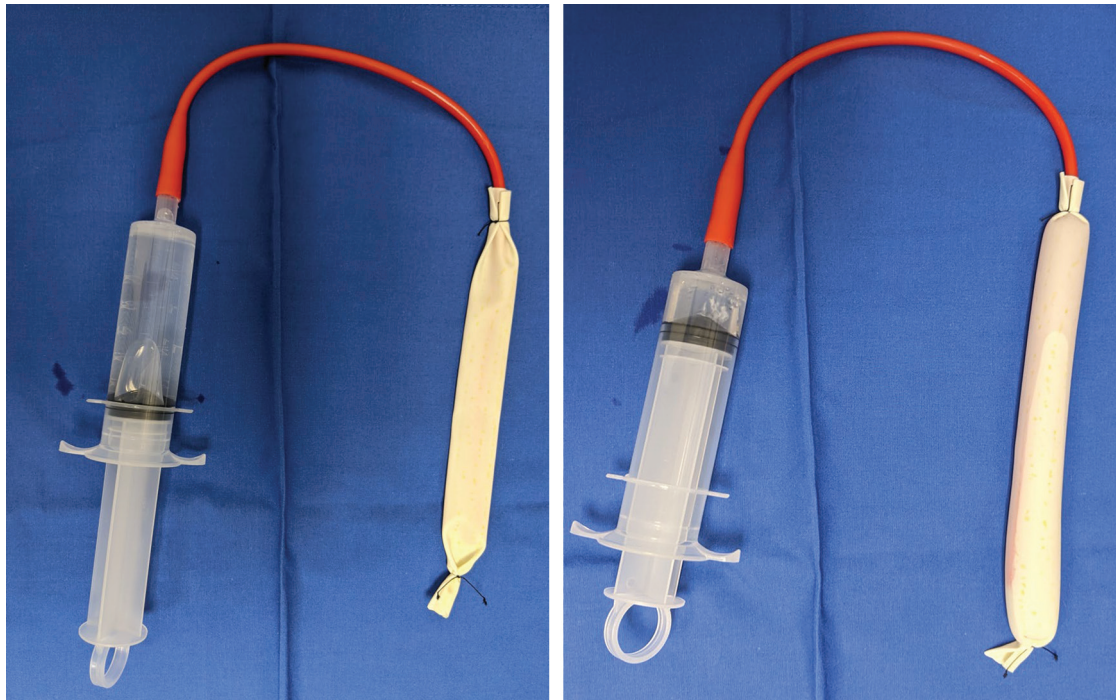


Figure 1 Demonstration of the Poggetti balloon pre- (left) and post-inflation (right).

Our present report demonstrates a successful case series of collaborative employment of the open damage-control Poggetti balloon followed by angiography or angioembolization for bleeding deep-hepatic GSW tracts. All procedures were conducted in a hybrid operating room (OR) environment specifically designed for trauma care by a cohesive team of trauma surgeons and dual-trained endovascular trauma specialists.

Case 1

A 37-year-old woman presented to the trauma resuscitation unit (TRU) having sustained one GSW to her right axilla. She had a systolic blood pressure of 70 mmHg, a heart rate of 115 beats per minute (bpm), and had severe tenderness and guarding throughout her abdomen. A foreign body series demonstrated a bullet in the right mid-abdomen (Figure 2). Decreased breath sounds were identified in the right chest and a large-bore chest tube was placed. A Focused Assessment with Sonography in Trauma (FAST) exam demonstrated free fluid in the right upper quadrant. After blood-product resuscitation, she was taken emergently to the hybrid OR for an exploratory laparotomy and hepatic angiography. A through-and-through injury through the right lobe of the liver, a right diaphragm injury, and a right renal hilar injury were identified. A diaphragm repair and nephrectomy were performed. Control of the liver injury was obtained with balloon tamponade by placing a red rubber catheter through a Penrose drain tied off at each end, passing it through the bullet tract and inflating it

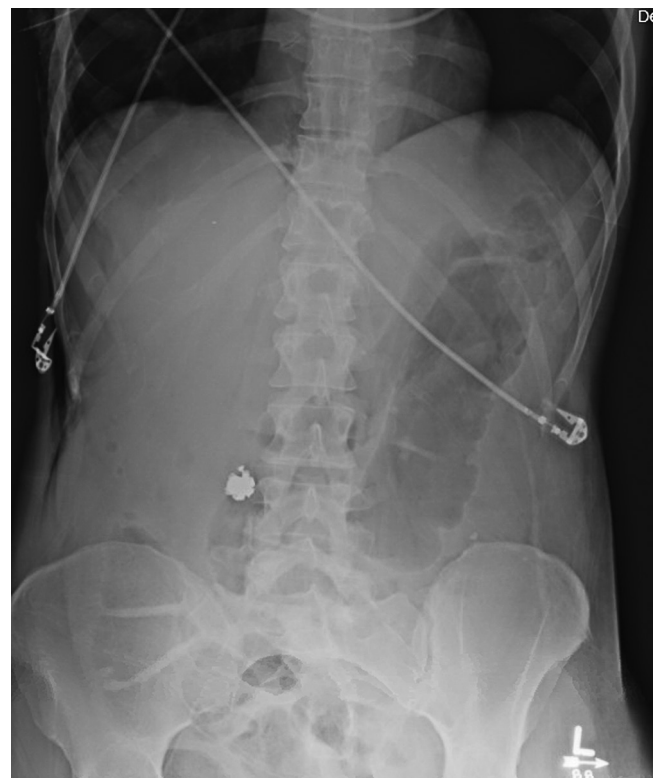


Figure 2 Foreign body series demonstrating the retained bullet in the right mid-abdomen.

with saline (Figure 3). There was some arterial bleeding from around the balloon. The balloon was then deflated and hepatic angiography was performed. This showed

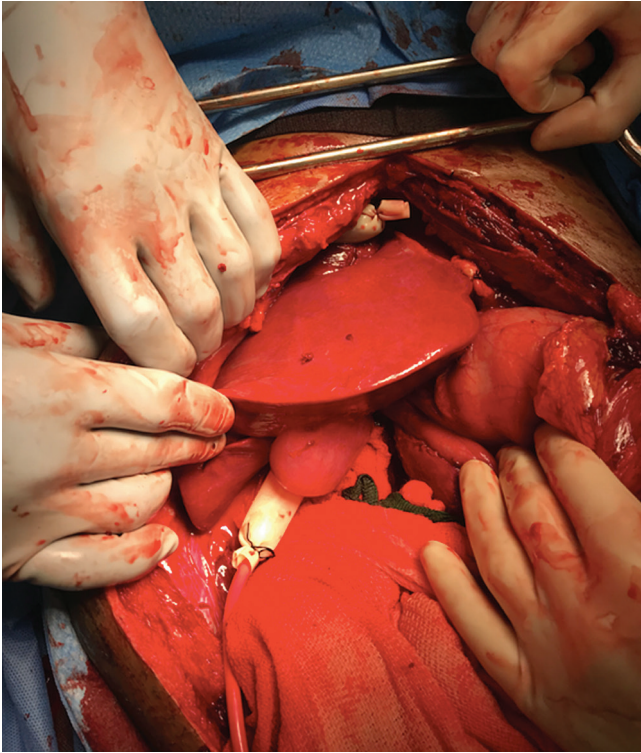


Figure 3 Intra-operative picture demonstrating balloon tamponade through the bullet tract.

active extravasation from a branch of the right hepatic artery. This was coil embolized (Figure 4). After reinflation of the balloon, complete hemostasis was apparent. Several packs were placed above and below the liver and a temporary closure of the abdomen was fashioned. An immediate postoperative computed tomography (CT) scan of her abdomen did not demonstrate evidence of ongoing bleeding from the liver injury (Figure 5). Then, 72 hours later, she was taken back to the OR, during which the balloon was deflated and the packs were removed. There was no evidence of ongoing bleeding. An omental plug into the bullet tract was performed and the fascia was closed. Her postoperative course was complicated by a hepatic abscess that was managed with antibiotics and percutaneous drainage. She otherwise had an uneventful recovery and was discharged home.

Case 2

A 22-year-old man presented to the TRU with two GSWs – one to the right of the sternum and another to the right posterior thoracolumbar region. He had thready pulses, was diaphoretic, and had a systolic blood pressure of 60 mmHg. Decreased breath sounds on the right necessitated placement of a chest tube. Large-bore access was obtained and he was given blood product resuscitation. A FAST exam was positive in the right upper quadrant. The chest tube drained 1,500 ml and he was taken emergently to the OR. A right anterolateral

thoracotomy identified several lung lacerations which were managed with tractotomy and wedge resection. An exploratory laparotomy identified a diaphragm injury and a through-and-through injury to the midportion of the right lobe of the liver. Packing followed by the Pringle maneuver did not control the hemorrhage, which was presumed to be coming from hepatic venous branches. Balloon tamponade, as described previously, was created in the bullet tract. This controlled the hemorrhage. The liver was packed above and below the injury, temporary closure was performed of the chest and abdomen, and the patient was transported to the intensive care unit for resuscitation. Two days later he was taken to the hybrid OR, at which point the balloon was deflated and a hepatic arteriogram was performed. There was no evidence of bleeding. The balloon and packs were removed, two drains were placed above and below the bullet tracts, and the chest and abdominal fascia were closed. The patient had an uneventful recovery and was discharged home 1 week after presentation.

Case 3

A 28-year-old man presented to the TRU having sustained a single GSW to the right upper quadrant. He had a blood pressure of 150/78, a heart rate of 110 bpm, and was complaining of severe abdominal pain. His abdomen was distended and firm. An abdominal x-ray showed a retained bullet in the right upper quadrant at the level of the eleventh intercostal space (Figure 6). He was taken to the OR for an exploratory laparotomy. A trans-lobar GSW was identified through the right hepatic lobe that was actively bleeding. The Pringle maneuver was performed but the bleeding persisted. Balloon tamponade was then applied to the bullet tract which effectively controlled the bleeding. The liver was packed, the abdomen was temporarily closed, and the patient was taken for a postoperative CT scan of the abdomen and pelvis (Figure 7). There was no evidence of ongoing bleeding from the liver. Then, 36 hours later, the patient was taken to the hybrid OR and an on-table hepatic angiogram was performed after deflation of the balloon (Figure 8). There was no further evidence bleeding. An omental plug was placed into the bullet tract, two drains were placed above and below the injury, and the fascia was closed. The patient had an uneventful recovery and was discharged home several days later.

DISCUSSION

The use of endovascular techniques in traumatic injury have undergone significant transformations over the past several decades. Endovascular diagnostic and therapeutic adjuncts are now employed across a broad spectrum of vascular injuries and other hemorrhagic sources. Increasingly, endovascular approaches for the management of non-compressible torso hemorrhage are being

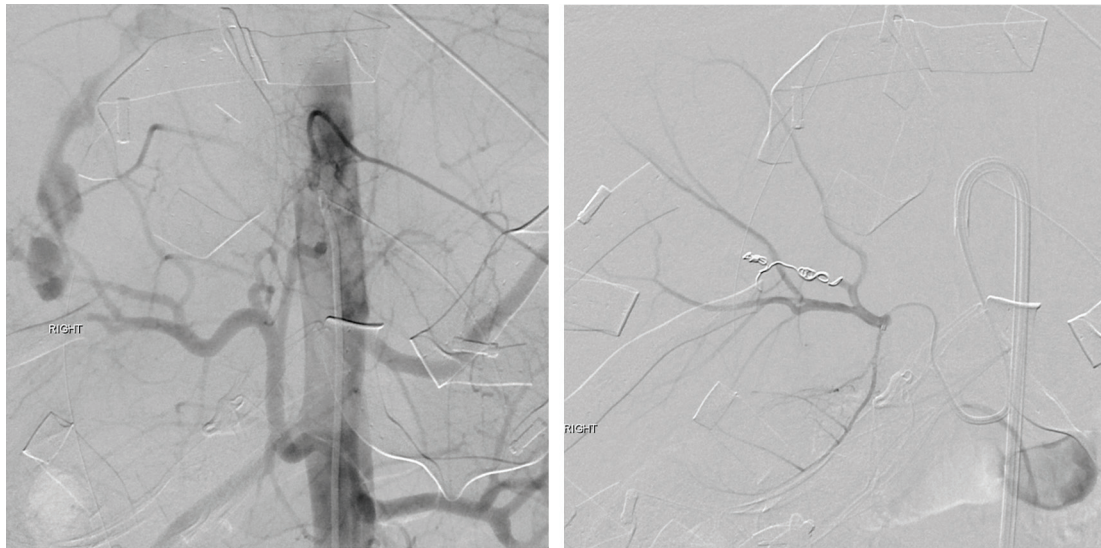


Figure 4 Aberrant right hepatic arterial takeoff from the superior mesenteric artery with active extravasation from a branch (left). Postembolization arteriogram demonstrates control of bleeding (right).

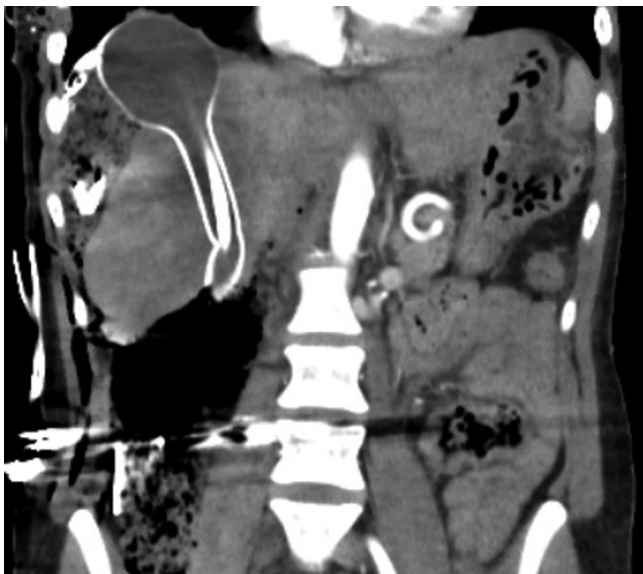


Figure 5 Coronal view CT demonstrating placement of the balloon catheter.

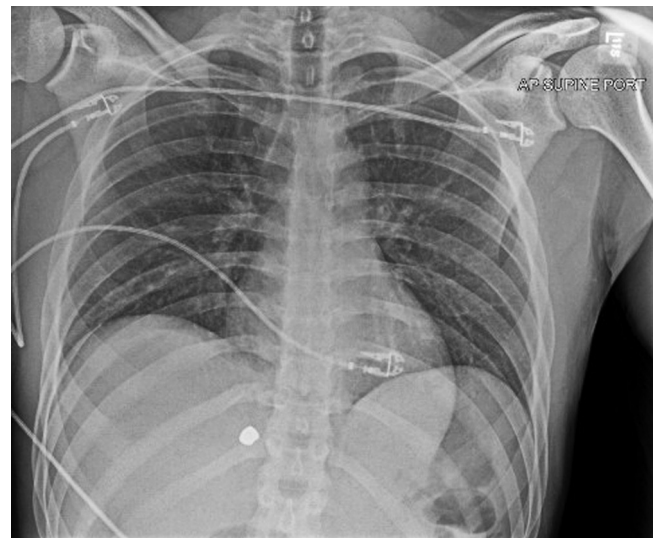


Figure 6 Foreign body series demonstrating the retained bullet in the right upper quadrant.

adopted in conjunction with open techniques or as a substitute for open surgery [4,5]. Several investigations have shown that these approaches can lead to a reduction in mortality and complication rates for specific injuries [6].

Despite these advancements, some specific injuries remain significant clinical challenges. Among them, major penetrating liver injury continues to be associated with high morbidity and mortality. Data suggest that among grade IV and V hepatic injuries, mortality rates can be as high as 80% [7], primarily due to initial hemorrhage and major complications specific to liver injury. Among these, bile leak, hepatic necrosis, and abscess

formation complicate management in 80–100% of cases [5]. While better outcomes in the contemporary era have been observed in stable patients appropriate for non-operative management [8], emergent operative intervention remains a requirement for patients presenting with indications for surgery such as refractory hypotension and peritonitis.

Operative management of liver injury varies based on the location and type of injury as well as the physiology of the patient. Simple injuries can be managed with finger fracture, direct suture ligation, and hemostatic agents, whereas more complex injuries may require packing, the Pringle maneuver, and/or resectional debridement. These

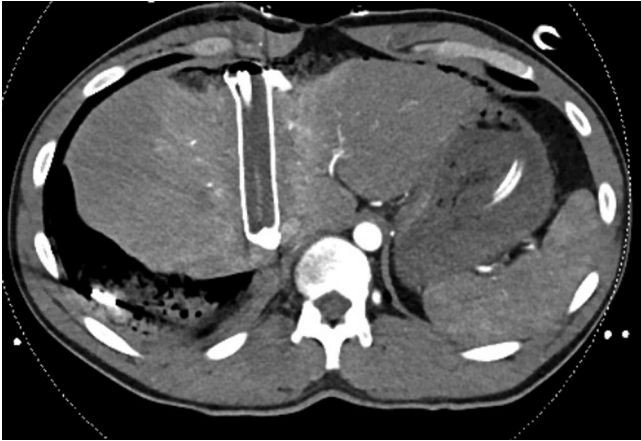


Figure 7 CT scan of the abdomen demonstrating adequate control of bleeding with balloon tamponade.

interventions are successful in most cases [9]. Major retrohepatic venous injuries or retrohepatic caval injuries are often considered a more problematic category of liver trauma and may be best temporized with packing, as last-ditch efforts such as total vascular exclusion and the Schrock shunt are associated with mortality rates of 90% or higher [7].

Balloon tamponade as a method for the management of liver injury was first described in Denver in 1992 by Poggetti and Moore [3]. This approach was described for the treatment of trans-hepatic GSWs that are difficult to control due to their extension deep into the liver parenchyma. The Poggetti balloon controls hemorrhage by tamponade of low-pressure portal and hepatic venous bleeding that can then thrombose over time. The classic description utilized a 12F red rubber catheter inflated inside a 30 cm Penrose drain which was tied off at each end. To this day, balloon tamponade continues to be a valuable tool in the management of central, penetrating liver trauma [10,11].

Following Poggetti balloon utilization and resuscitation, hepatic arteriography and potential embolization may serve as useful adjuncts to both identify and more selectively control unresolved sources of arterial hemorrhage from within the hepatic GSW tract. Depending upon patient condition and the operative scenario, these procedures can be undertaken at the index operation or at the time of balloon deflation at re-exploration. At our institution, this decision is made on a case-by-case basis. Although not without its complications [2,12,13], hepatic angioembolization (HAE) at the time of damage control laparotomy is a valuable adjunct to arrest bleeding from areas of the liver that are difficult to control surgically [12]. Some low-velocity penetrating liver injuries can even potentially be managed with HAE alone [14,15], although reported success rates with this adjunct are higher for injuries due to blunt trauma [16].



Figure 8 Hepatic arteriogram after balloon deflation demonstrating no arterial extravasation.

Traditionally, endovascular procedures for the management of liver trauma were performed by interventional radiologists in a separate procedural suite located in another wing, or even building, of the hospital. However, the need for the rapid control of bleeding in conjunction with endovascular adjuncts for non-compressible torso hemorrhage has led to the development of hybrid OR suites that have advanced open and endovascular capabilities [17]. These hybrid ORs allow for ongoing resuscitation by trauma anesthesiologists while a dedicated team of surgeons use open and endovascular techniques to gain expedient and definitive hemorrhage control. At our institution, an endovascular trauma service (ETS) staffed by dual-trained trauma and vascular surgeons is available 24/7 for this purpose [18]. The decision to transfer a patient to the hybrid OR is made jointly by the trauma and ETS attending. The availability of the hybrid OR allows for flexibility in intra-operative decision-making regarding the use of endovascular adjuncts.

This is the first series to date describing a combined approach of balloon tamponade with hepatic arteriography for penetrating liver injuries. In our series, all patients underwent angiogram in a hybrid OR at the time of re-exploration and Poggetti balloon deflation. One patient required selective angioembolization for subsequent arterial bleeding. The combination of location and expertise afforded by this hybrid approach provides optimal versatility in intervention strategies and complements the technique of balloon tamponade for penetrating liver trauma.

Ethics Statement

- (1) All the authors mentioned in the manuscript have agreed to authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.
- (2) The authors declare that they have read and abided by the JEVTM statement of ethical standards including rules of informed consent and ethical committee approval as stated in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Author Contributions

All authors have contributed to the writing and editing of this manuscript.

REFERENCES

- [1] Matsumoto S, Cantrell E, Jung K, Smith A, Coimbra R. Influence of postoperative hepatic angiography on mortality after laparotomy in Grade IV/V hepatic injuries. *J Trauma Acute Care Surg.* 2018;85(2):290–7.
- [2] Green CS, Bulger EM, Kwan SW. Outcomes and complications of angioembolization for hepatic trauma: a systematic review of the literature. *J Trauma Acute Care Surg.* 2016;80(3):529–37.
- [3] Poggetti RS, Moore EE. Balloon tamponade for bilobar transfixing hepatic gunshot wounds. *J Trauma.* 1992;33(5):694–7.
- [4] Faulconer ER, Branco BC, Loja MN, et al. Use of open and endovascular surgical techniques to manage vascular injuries in the trauma setting: a review of the American Association for the Surgery of Trauma PROspective Observational Vascular Injury Trial registry. *J Trauma Acute Care Surg.* 2018;84(3):411–7.
- [5] Mohr AM, Lavery RF, Barone A, et al. Angiographic embolization for liver injuries: low mortality, high morbidity. *J Trauma.* 2003;55(6):1077–82.
- [6] Branco BC, DuBose JJ, Zhan LX, et al. Trends and outcomes of endovascular therapy in the management of civilian vascular injuries. *J Vasc Surg.* 2014;60(5):1297–307.e1.
- [7] Cogbill TH, Moore EE, Jurkovich GJ, Feliciano DV, Morris JA, Mucha P. Severe hepatic trauma: a multi-center experience with 1,335 liver injuries. *J Trauma.* 1988;28(10):1433–8.
- [8] Schellenberg M, Benjamin E, Piccinini A, Inaba K, Demetriades D. Gunshot wounds to the liver: no longer a mandatory operation. *J Trauma Acute Care Surg.* 2019;87(2):350–5.
- [9] Trunkey DD. Hepatic trauma: contemporary management. *Surg Clin North Am.* 2004;84(2):437–50.
- [10] Ball CG, Wyrzykowski AD, Nicholas JM, Rozycki GS, Feliciano DV. A decade's experience with balloon catheter tamponade for the emergency control of hemorrhage. *J Trauma.* 2011;70(2):330–3.
- [11] Kodadek LM, Efron DT, Haut ER. Intrahepatic balloon tamponade for penetrating liver injury: rarely needed but highly effective. *World J Surg.* 2019;43(2):486–9.
- [12] Misselbeck TS, Teicher EJ, Cipolle MD, et al. Hepatic angioembolization in trauma patients: indications and complications. *J Trauma.* 2009;67(4):769–73.
- [13] Dabbs DN, Stein DM, Scalea TM. Major hepatic necrosis: a common complication after angioembolization for treatment of high-grade liver injuries. *J Trauma.* 2009;66(3):621–9.
- [14] Demetriades D, Rabinowitz B, Sofianos C. Non-operative management of penetrating liver injuries: a prospective study. *BJs Br J Surg.* 1986;73(9):736–7.
- [15] MacGoey P, Navarro A, Beckingham IJ, Cameron IC, Brooks AJ. Selective non-operative management of penetrating liver injuries at a UK tertiary referral centre. *Ann R Coll Surg Engl.* 2014;96(6):423–6.
- [16] Stassen NA, Bhullar I, Cheng JD, et al. Nonoperative management of blunt hepatic injury: an Eastern Association for the Surgery of Trauma practice management guideline. *J Trauma Acute Care Surg.* 2012;73(5):S288–93.
- [17] Kirkpatrick AW, Vis C, Dubé M, et al. The evolution of a purpose designed hybrid trauma operating room from the trauma service perspective: the RAPTOR (resuscitation with angiography percutaneous treatments and operative resuscitations). *Injury.* 2014;45(9):1413–21.
- [18] Morrison JJ, Madurska MJ, Romagnoli A, et al. A surgical endovascular trauma service increases case volume and decreases time to hemostasis. *Ann Surg.* 2019;270(4):612–9.