Narrative Review Article

Vol. 1, No. 1; 2017; pp 28–33
DOI: 10.26676/jevtm.v1i1.3

Trauma Pan-Scan in Resuscitative Endovascular Occlusion: A Novel Strategy for Hemodynamically Unstable Polytrauma Patients

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The trauma pan-scan (TPS) offers particular benefits in trauma care. Resuscitative endovascular balloon occlusion of the aorta (REBOA) may provide an opportunity to scan hemodynamically unstable (HU) polytrauma patients; however, the benefits and risks of REBOA-TPS remain unknown. The rationale for TPS in HU patients is to choose the best intervention and to quickly achieve hemostasis rather than directly initiating surgery without scanning. TPS would most greatly benefit geriatric trauma patients and those with coagulopathies with unidentified bleeding sources, particularly noncavitary hemorrhage in blunt trauma and accompanying brain injury, because TPS may predict unexpected physiological collapse via anatomical imaging. Computed tomography (CT) is a common cause of flow disruption, but specific trauma team training was shown to reduce the time spent in the CT room from 16.8 to 7.3 minutes ($P < 0.001$). While REBOA-TPS cannot be utilized widely or indiscriminately, its appropriate use may increase the number of salvageable trauma patients.

Keywords: *Resuscitative Endovascular Balloon Occlusion of the Aorta; REBOA; Trauma Pan-Scan; Computed Tomography; Multidisciplinary Training; Hemorrhagic Shock*

Received: 21 February 2017; Accepted: 28 July 2017

INTRODUCTION

Hemorrhagic shock is the leading cause of preventable trauma death [1,2]. The Advanced Trauma Life Support (ATLS) guidelines emphasize the importance of the initial assessment of shock and resuscitation. Chest and pelvic plain X-rays and focused assessment with sonography for trauma (FAST) are recommended during the initial assessment to identify the source(s) of bleeding [3].

Improvements in technology have altered the use of computed tomography (CT) in medicine. A survival benefit of whole-body CT, also called trauma pan-scan (TPS), has been reported [4-6], but the results have been inconsistent [7,8]. The ATLS guidelines also clearly note that definitive hemostasis should be started immediately, which indicates that surgery should be performed without scanning in hemodynamically unstable patients [3].

However, resuscitative endovascular balloon occlusion of the aorta (REBOA) [9] is increasingly accepted as a less invasive resuscitation procedure that offers several benefits [10]. REBOA effectively bridges definitive hemostatic care in exsanguinating patients [11]. Additionally, it elevates the blood pressure and provides an opportunity to scan hemodynamically unstable patients. In designated trauma centers, interventional radiology (IR) should be available early on, but arrival to angiography time has been reported as three to five hours even in high-volume trauma centers [12,13]. Currently, 24/7 in-house IR physicians are not common; therefore,

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Conflict of interest: None
Funding: None.

REBOA in Zone III occlusion in life-threatening pelvic fracture is useful to salvage refractory hemorrhagic shock [14]. Moreover, TPS under REBOA (TPS-REBOA) while waiting for IR physicians may be acceptable for a certain duration, because infra-renal aortic clamping is preferable to supravisceral aortic clamping [15,16]. However, the benefits and risks of REBOA-TPS in Zone I occlusion have not yet been investigated or analyzed.

The use of REBOA to scan Zone I occlusion patients seems contraindicated according to the classical trauma dogma. Although we realize that REBOA-TPS cannot be used without clear purpose and preparation, we discuss this novel and aggressive strategy from the viewpoint of the radical use of diagnostic and interventional radiology in trauma settings, which focuses on prompt diagnostic imaging and rapid IR [17].

What is the Rationale for the Use of REBOA-TPS?

TPS should not be performed simply to obtain anatomical information for reassurance before surgery. There is no room for discussion in early hemostasis. The "golden hour" theory proposed by Cowley has been widely accepted and states that trauma patients have better outcomes if they are provided definitive care within 60 minutes of the occurrence of their injuries [18]. In the pre-endovascular era, starting definitive care meant surgery, and early operation enabled early hemostasis. Cavitary hemorrhage, such as splenic injury, can be identified by FAST without CT imaging, and splenectomy can be performed very quickly. However, in the present day, we have more hemostasis options, including surgical, endovascular, or hybrid approaches. Undoubtedly, to "complete" hemostasis is more meaningful than to "start" procedures. TPS allows for the precise identification of the bleeding site and severity of the main or associated injuries that may not have been recognized in the primary survey. The first rationale is to choose the most appropriate strategy: the OR, IR, a hybrid intervention, or craniotomy. TPS may enable the selection of trauma patients for possible embolization. Secondly, because TPS elucidates the vascular anatomy for IR and may help identify the bleeding source, it may contribute to the earlier completion of hemostasis by reducing the procedure time. Subsequent arterial embolization of the hepatic artery after perihepatic packing helps to complete hemostasis. Most intercostal artery injuries do not require hemostatic procedures, though some do require surgery or embolization. Effective utilization of TPS data may contribute to the embolization of intercostal injuries even quicker than by performing surgery.

Who Benefits from the REBOA-TPS?

Geriatric trauma and coagulopathies

Japan has the longest life expectancy in the world (83.7 years) [19] and is currently the only country with a proportion of the population aged 60 years or older that exceeds 30% [20]. The process of aging brings inevitable physiological and anatomical changes, and associated comorbidities and medication use may affect the response to injury. Old populations typically have vulnerable loose tissue, which easily expands to form hematomas. Likewise, geriatric individuals often take anti-thrombotic agents, which may induce unexpected bleeding in unexpected sites, such as subcutaneous or intramuscular hematomas in the chest or abdominal walls or in the thighs without femur fracture. Additionally, individuals in this population often deteriorate and collapse unexpectedly due to slow but prolonged exsanguination when physicians underestimate the presence of compensated shock upon their arrival in the hospital. TPS may predict unexpected physiological collapse by way of rigorous anatomical imaging. While coagulopathy is measured by various laboratory tests or viscoelastic coagulation monitoring, many trauma patients are not recognized as having coagulopathy using these tests. Thus, REBOA-TPS is indicated in the context of not only abnormal coagulopathy tests but also anamnesis of anticoagulants administration or any suspicion of trauma-induced coagulopathy.

Unidentified bleeding sources and unknown mechanisms of injury

In non-compressible blunt polytrauma patients, physicians need to prioritize the main bleeding source. Chest X-ray and FAST can reveal cavitary hemorrhage, while the pelvic X-ray shows pelvic fractures, which can be identified in the ED. However, noncavitary hemorrhage, including extra-pelvic retroperitoneal hemorrhage due to kidney injury, paravertebral hematoma, and lumbar artery injury, is often difficult to identify during the primary survey. Not all retroperitoneal bleedings are lethal, but some do require surgery or IR, particularly in elderly patients and/or those in a coagulopathic state. TPS may help arrive at a more precise interventional strategy.

Accompanying traumatic brain injury (TBI)

Patients with mild TBI may not show a significantly altered mental status at initial presentation. Small brain contusions or subdural hematomas may grow rapidly, particularly in the context of coagulopathy [21,22]. TPS including brain CT provides a red flag for possible neurological deterioration that may result in earlier or simultaneous neurosurgical intervention. However, REBOA may induce hypertension above the balloon, resulting in increased intracranial bleeding, deteriorated brain edema, and elevated intracranial pressure. Partial occlusion may be required to avoid unnecessary hypertension.

Table 1 Tips and tricks for 'sub-5' scans by multidisciplinary trauma teams.

Profession	*Tips and Tricks*
Physician	Early decision
	Clear declaration
Nurse	Choose the injection line and extend with a pressure resistance tube
	Arrange the tubes and lines
	Remove metal material upon exposure
	Connect to the oxygen cylinder during the initial assessment
	Avoid using a standalone IV pole
Radiology Technician	Ensure to remove any metal
	Confirm the oxygen supply flow
	Fix the upper extremities in the emergency department
	Pre-mark the backboard position
	Remove the contrast injection after the arterial phase (while wearing a lead protector)

How Can TPS Data be Utilized to Shorten the Procedure Duration?

TPS provides valuable information of the vascular anatomy. We have previously proposed the creation of virtual fluoroscopic images from the volume data of the arterial phase to guide the catheter to the target site on a 3D workstation, a method termed "pre-procedural planning" (PPP) [17]. PPP aids in elucidating the target injury and arterial route, as well as the best oblique angle. This method can reduce the need for mapping injection and blind cannulation. For example, pelvic angiography is usually performed in most elective cases to obtain the angiographic anatomy and diagnose the target vessels. However, pelvic fracture cases often require immediate hemostasis of the main injury, and PPP reveals the injured region and target vessels (usually internal iliac artery and its branch). Thus, we are able to omit the pelvic angiography and cannulate internal iliac artery directly. Intercostal or lumbar arteries are branched from the aorta directly. PPP allows the exact level and direction of the root of vessels to be determined, eliminating the need to search for the branch root by aortography. The "conductor" doctor can then indicate the exact vessel position, and the operator can aim for the target vessels directly. Although the procedure time is highly dependent on both the catheter manipulation skills of the operator and the patient's particular vascular anatomy, the single artery embolization time (total embolization time divided by number of embolized arteries) was reduced to as little as five to seven minutes in hemodynamically unstable trauma patients in the authors' institution. Consequently, the use of TPS may permit the earlier completion of hemostasis.

TPS data can be utilized with experts or supervisors to educate young or inexperienced operators, which would contribute to the standardization of these procedures.

How to Achieve Safe and Quick Scans?

Recently developed CT instruments can scan the whole body within minutes, and yet scanning of patients is still considered to be a dangerous procedure. CT is a common cause of flow disruption in trauma care [23,24] and patients spend approximately 30 minutes in the CT scan room [25]. This duration may cause a critical delay in treatment in a location with poor monitoring and lack of resuscitative capability, which may place patients at risk of sudden deterioration or cardiac arrest.

Multidisciplinary trauma team training: practice makes perfect

Although the benefits of TPS have been reported [4–6], no reports have specifically focused on trauma team training for the minimization of time spent in the CT room. To achieve safe and quick scans, the trauma team must include multidisciplinary professionals such as physicians (emergency medicine, trauma surgeons, and anesthesiologists), nurses, and radiology technicians (RT). When CT is ordered, nurses and RTs often play key roles in reducing transfer times and CT stay durations. However, the journey starts in the emergency department (ED) rather than in the CT scan room. Our trauma team introduced a "TPS transfer protocol" to shorten the overall process of TPS. Preparation in the ED is key to complete scans in less than five minutes ("sub-5" scans) (Table 1). The attending physician should make a prompt decision to scan the patient and declare it clearly to the team. Nurses then choose the IV line and extend it with a pressure resistance tube for contrast injection. Prior to leaving the ED, all of the tubes and lines are arranged and any metal materials have to be removed by the nurses and radiology technicians. The patient's upper extremities are also fixed in the ED, and the backboard position is pre-marked to set the scan range immediately. The trauma team practiced this transfer protocol using a mannequin to share the concept with their team members, with each one practicing at least once.

To verify the effectiveness of the multidisciplinary protocol, we analyzed the CT room duration (time from arrival at the CT room to discharge from it) before

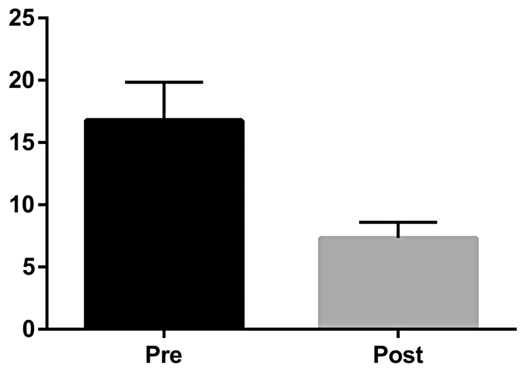

Figure 1 Duration of time spent in the CT room.

Changes in the duration of time spent in the CT room by polytrauma patients. The CT room duration shortened from 16.8 ± 3.1 to 7.3 ± 1.3 minutes after the introduction of the trauma pan-scan protocol.

and after the training. The CT room durations of patients undergoing TPS were measured consecutively at St. Marianna University Hospital from September 2011 to September 2014 (pre-training period) and from October 2015 to March 2016 (post-training period). The inclusion criteria were adult trauma patients who underwent TPS (non-enhanced brain, arterial phase of the neck to the pelvis, and then delayed phase of the chest to the pelvis) after the trauma code was announced and for whom the TPS was ordered by the attending physician following the initial survey. In the study hospital, the trauma code is typically announced to the emergency medicine physicians, radiologists, and surgeons to request their attendance for suspected hemorrhagic shock prior to patient arrival. Although the CT scanner is shared among elective cases, emergency patients, and in-hospital patients, emergency patients are usually prioritized according to the level of urgency. The CT room is located next to the ED, but not within the ED area, and a multidisciplinary trauma team (physician, nurse, and RT) is available 24/7. Forty-four patients were enrolled (pre-training, $n = 23$; post-training, $n = 21$) and compared. The mean (standard deviation) CT room duration significantly decreased from 16.8 (3.1) to 7.3 (1.3) minutes after the training ($P < 0.001$, unpaired *t*-test). Our results suggest that the CT room stay duration may be shortened by approximately 10 minutes with the use of the multidisciplinary transfer protocol and training (Figure 1). We continue to aim for the "sub-5" scan.

After scanning the patient, the question of how much time and who is needed to interpret the results has an impact on the trauma care strategy. Accordingly, the authors have developed a three-step reading of the TPS images. The first step should be focused on the findings and has been named "Focused assessment with CT for trauma (FACT)". FACT orients the treatment approach; evaluation of intracranial area (midline shift, hematoma), left pulmonary artery region (aortic injury and mediastinal hematoma), base of lungs and pericardium (hemopneumothorax, pericardial hematoma), pelvic floor (peritoneal hematoma), pelvis and spine, peritoneal and retroperitoneal organs (liver, spleen, kidney, pancreas, mesentery) occurs within two to three minutes on the CT console screen. The second step immediately follows the first step. It evaluates active bleeding (extravasation or pseudoaneurysm), intestinal perforation, and spinal injuries. The third step may be confirmed by radiologists or other readers after some time has elapsed in order to prevent missed injuries.

How Should the REBOA-TPS be Performed?

A 47-year-old male had been injured in a motor vehicle crash. He presented with a systolic blood pressure (SBP) of 70 mmHg and a heart rate of 110 beats/min upon arrival. His SBP increased to 125 mmHg after complete inflation of a 7 Fr sheath-compatible REBOA catheter that was advanced over the wire (Rescue Balloon, Tokai Medical Products, Aichi, Japan). With a completely inflated REBOA, the contrast agent does not enhance the vessel and organs. Thus, partial occlusion must be performed during TPS with REBOA (Figure 2*a*, *b*), which permits distal perfusion; this is frequently observed in Japanese REBOA settings [26]. In the present case, TPS revealed small bowel mesentery and liver injury with partial REBOA. In general, the balloon should be titrated carefully by 1–3 mL and the target proximal systolic blood pressure is usually around 90 mmHg. Because the arterial flow is inhibited by REBOA, the contrast enhancement may be delayed; the arterial phase may seem non-enhanced and the portal venous phase may seem similar to the arterial phase. RTs and physicians need to closely watch the scanning on the CT console in order to judge the timing of the enhancement.

Limitations and Possible Negative Consequences of REBOA-TPS

REBOA carries the potential risk of organ dysfunction and leg ischemia. TPS often provides useful information, but it is not a hemostasis technique. These risks should be carefully evaluated when using this approach. In addition, the use of REBOA-TPS becomes more equivocal in the following circumstances.

Hemothorax with multiple rib fractures

Hemothorax is a critical thoracic injury. Although thoracotomy and ligation of the artery to the rib is the classical approach, arterial bleeding from the intercostal arteries is treated more rapidly by IR [27,28]. TPS may accelerate the decision-making process or may prevent unnecessary thoracotomy. High Zone I REBOA may control the intercostal flow, but low Zone I REBOA may deteriorate proximal intercostal bleeding. The balance

(a) (b)

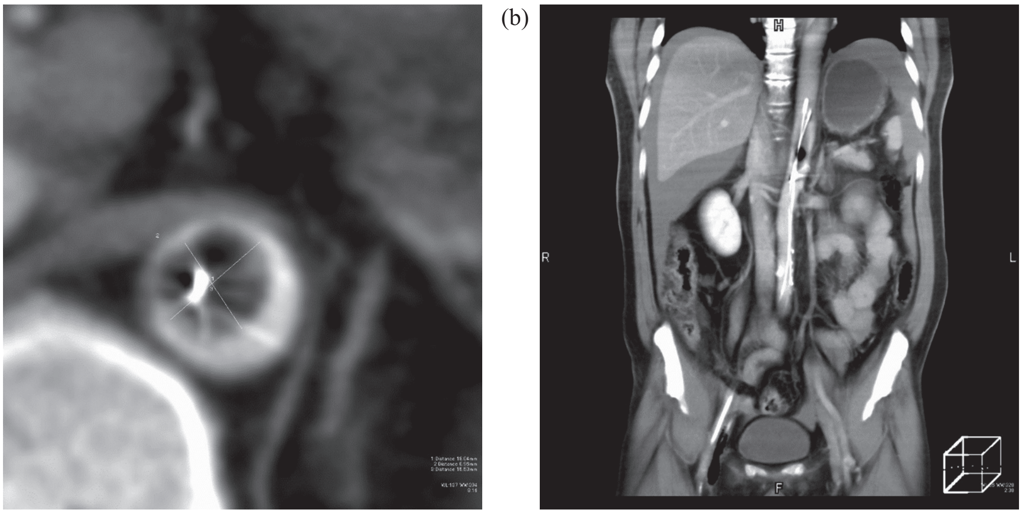

Figure 2 CT image of REBOA-TPS.

A 47-year-old male had been injured in a motor vehicle crash. He presented with a systolic blood pressure (SBP) of 70 mmHg and a heart rate of 110 beats/min upon arrival. His SBP increased to 125 mmHg after complete REBOA inflation. TPS revealed small bowel mesentery and liver injury with partial REBOA, with a target SBP of 90 mmHg. He was taken to the operation room, where he underwent perihepatic packing and resection of the mesentery. (**a**) The balloon was partially inflated in the aorta. (**b**) Partial occlusion allows for the enhancement of the CT images.

between the risks and benefits in these situations requires further evaluation.

Multiple penetrating injuries, uncertain trajectories

The choice of treatment strategy in hemodynamically unstable penetrating trauma with an apparent trajectory is simple: Call the operating room and grab a scalpel. Meanwhile, in cases of multiple stab wounds or gunshot wounds with unclear trajectories, TPS may provide crucial injury-related information, enabling a determination of the presence or absence of the bullet within the body, the location of the bullet (great vessel, spine), and the existence of unexpected injuries without an apparent trajectory.

CONCLUSION

The rationale for REBOA-TPS is to choose an optimal treatment strategy with the earlier completion of hemostasis. Blunt polytrauma involving noncavitary hemorrhage with coagulopathy in geriatric populations is the most appropriate context for REBOA-TPS. TPS data can be utilized to shorten the hemostasis procedure and may lead to the earlier completion of hemostasis. Multidisciplinary trauma team training and pre-marking of the backboard resulted in a seven-minute CT room stay, which may be acceptable even in cases of refractory hemorrhagic shock. While REBOA-TPS cannot be utilized widely or indiscriminately, its appropriate implementation may increase the salvageable trauma population.

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