Development of a Field-Expedient Vascular Trauma Simulator

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ABSTRACT

The past few years have noted significant declines in combat casualty exposure over the course of a deployment. As a result, overall confidence and comfort in performing potentially life-saving therapies may wane during a deployment. Development of training simulators provides a method for bridging this gap. Herein, a field-expedient vascular trauma trainer for noncompressible torso hemorrhage is described. A low-fidelity simulator was created using a Penrose drain, intravenous tubing, suture, and a cardboard box. A higher-fidelity simulator was created using an aortobifemoral bypass graft, double-lumen endotracheal tube, suture, and an upper torso mannequin. The two trainers were successfully used to train for peripheral shunt placement and definitive vascular repair. The trainer makes use of supplies readily found at most Role 2 and 3 facilities and that are obtainable for Role 1 facilities providing damage control surgery. It provides a just-in-time way to develop and sustain confidence in the damage control principles applicable to vascular injuries.

Keywords: *noncompressible torso hemorrhage; training simulator; vascular trauma trainer*

Introduction

There has been a shift in the epidemiology of combat trauma over the past decade. Whereas during the height of the previous operations in Iraq and Afghanistan, medical teams were exposed to a robust variety and volume of severe traumatic injuries, this exposure has dwindled over the past 5 to 7 years.[1] Case volumes have shifted from Role 2 facilities performing care for hundreds of patients and Role 3 facilities caring for thousands of patients over a 9- to 12-month deployment[2–6] to more recent experiences where the provision of care is much less and unequally distributed among the various medical elements.[7–9] Teams can now go an entire deployment with caring for fewer than a dozen combat-injured patients.

A potential consequence of this decreased exposure to trauma patients is a degradation of clinical skills. Not surprisingly, during times of peak combat casualties, military providers have self-reported an increased confidence in trauma management skills over the course of a deployment.[10] The underlying presumption is that the continual exposure fostered this skill development. However, more recent surveys from these relatively slower deployments suggest lower levels of confidence in managing these critical injuries.[11]

Procedural simulation provides a means to limit or reverse skill erosion and decreasing confidence associated with a slower operative tempo. When patient exposure is more limited, simulation offers a mechanism to focus on clinical skills and team dynamics. Although there are numerous high-fidelity commercial products available for this type of training, their financial cost and the inherent restrictions of a resource-limited environment questions their practicality. Instead, field-expedient solutions making use of available supplies are needed. We describe the development of a practical multi-use vascular injury trainer made from commonly found medical supplies.

Trainer Construction

The initial vascular trainer was constructed using expired medical equipment and a medium-size cardboard box (Figure 1). A vascular structure was simulated using a Penrose drain (Figure 2). Intravenous tubing was sutured to the proximal and distal ends of the drain, thereby permitting the infusion of expired units of packed red blood cells. This was later refined to infusion of normal saline that had been dyed red. Bags of saline were placed within the box to simulate the presence of small and large intestine overlying the blood vessel. The trainer was successful used for several iterations and allowed for individual and team training on placement of intravascular shunts (Figure 3).

Over time, a higher-fidelity trainer was also constructed (Figure 4). The exterior of the patient was constructed using an upper body mannequin with a U-shaped mold constructed out of fiberglass casting material to create a retroperitoneum and flank. Moleskin was circumferentially applied to create skin and affix the fiberglass molding to the mannequin (Figure 5). The internal vascular anatomy was recreated using an expired

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FIGURE 1 *Initial simulator using a box to represent the torso of a patient.*

FIGURE 2 *Initial lower-fidelity simulator using Penrose drains to represent an injured vessel (arrows). A temporary vascular shunt in place spans across the injury and is secured in place with a silk suture. Bags of saline were used to replicate small bowel.*

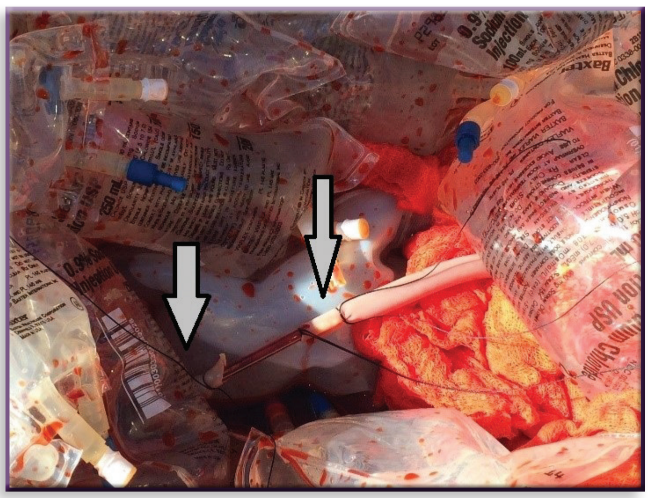

FIGURE 3 *Initial simulator being used to train 18Ds on temporary vascular shunt placement.*

FIGURE 4 *Higher-fidelity simulator using a mannequin upper torso and self-made lower torso.*

aortobifemoral bypass graft (Figure 6). The graft was tied down to rubber tubing proximally and distally. This allowed for infusion of "blood" proximally and collection distally (for reuse as needed). A surgical glove filled with saline was placed in the right upper quadrant to simulate the liver (Figure 4). A series of red balloons were filled with saline and tied together to simulate small intestine overlying the vascular structures. The trainer was successfully used for several iterations and allowed for individual and team training on placement of intravascular shunts and vascular repairs.

Experience

Both trainers were highly successful at achieving their education goals. The medics and entire team reported increased comfort with shunt placement after the training iterations. Likewise, the surgeons found it helpful to practice vascular repairs on the simulator. Most importantly, it provided an opportunity to work on team dynamics and communication skills when faced with life- and/or limb-threatening injury where time is of the essence. Shortly after the initial iterations of the training, the team was confronted with an injury requiring shunting and this training was of direct benefit to the patient. Specifically, team members reported increased confidence and comfort with placement of the shunt into the injured patient. In addition, the surgeons reported quicker placement of the shunt, resulting in decreased blood loss and less ischemia time for the distal limb.

FIGURE 5 *External appearance of the higher-fidelity simulator with moleskin applied.*

FIGURE 6 *Minimal internal components for the higher-fidelity simulator included a dual-lumen endotracheal tube and bifurcated aortobifemoral graft secured together using suture.*

A few key lessons are noteworthy. First, the Penrose drain is a ubiquitous piece of surgical equipment and is often used in vascular simulations.[12] Although a Penrose drain does a good job of approximating the characteristics of a vein, it is less successful at mimicking an artery. In particular, it lacks the rigid structure of an artery. As such, it can be unwieldy to work with and adds an extra layer of difficulty if the trainee is at the low end of their learning curve.

The aortobifemoral bypass graft better approximates an arterial injury. However, this is a more expensive product and are usually less abundant in a deployed environment. In this particular case, large quantities of equipment were being returned stateside as part of an overall theater drawdown, thereby making it easier to justify the use of this product. For the surgeons, it provided a better substrate upon which to practice their vascular-suturing skills.

As with any simulator, there is a suspension of reality that is required of the trainee. Although a higher-fidelity trainer is often thought to enhance the learning opportunity, this is not always the case.[13] Both trainers appeared to be equally effective for teaching vascular shunt placement and working on team dynamics. The higher-fidelity mannequin worked better for the surgeons to practice suturing.

Discussion

Major vascular injuries account for 10% to 12% of modern battlefield injuries.[1,14] When such injuries occur in the distal extremity, tourniquet is a mainstay of initial management and its adoption has improved overall survival from these injuries.[14] However, as the injuries become more proximal, external compression becomes difficult to achieve and as a result, there has been less improvement in survival despite the promotion of junctional and abdominal aortic tourniquets. Internal occlusion through the use of resuscitative endovascular balloon occlusion of the aorta (REBOA) is a potential solution to the limitations inherent with external compression of truncal and junctional hemorrhage.[15,16] It has shown some potential promise in treating combat casualties, but more robust data and clear understanding of when to use it are lacking.[17,18]

Although cessation of hemorrhage is paramount to save the injured patient's life, all the strategies discussed do so by making everything distal to the tourniquet or balloon ischemic. To preserve the limb, vascular flow needs to be restored as soon as reasonably possible. The use of a temporary intraluminal shunt is a key adjunct in damage control surgery because such a shunt eliminates hemorrhage, restores flow, and provides additional time to transport or resuscitate the patient while awaiting definitive repair.[19,20] Single unit experiences from Iraq and Afghanistan suggest that 25% to 50% of wartime vascular injuries were initially temporized with a vascular shunt.[21–23] As such, insertion of vascular shunts should be viewed as a critical skill for a deployed medical provider. The field-expedient box trainer demonstrated herein provides a simple tool for teaching and maintaining this skill.

The trainer also provides a platform for maintaining vascular surgery skills. Surveys of military surgeons with prior combat deployments have shown that although the need for surgeons to perform vascular repair is ubiquitous to combat surgery, there is a gap in their level of comfort and confidence.[11] During a period of disuse, there is a potential for skill erosion. Thus, in the less-busy environment, a surgeon who is already lacking comfort with vascular surgery may have a well-founded reason for their concern. The trainer provides a modality to sustain the surgeon's skill level and enable added confidence in the surgeon's capacity to perform vascular repairs.

The potential dual uses described herein demonstrate the versatility of this training tool. Although this model makes use of a standard aortobifemoral graft, it reasonable to conceive how additional segments of graft material to the aorta or femoral limbs can greatly expand its uses to include peripheral procedures and potentially even serve as a makeshift REBOA trainer.

Conclusion

The described vascular trauma simulator provides a field-expedient method for teaching and training temporizing and definitive treatment methods for life-threatening noncompressible torso hemorrhage. By using readily available supplies already found in the deployment environment, it eliminates the necessity to carry extra supplies in a resource-limited environment.

Disclaimer

The views expressed herein are those of the authors and do not reflect the official policy or position of the US Army Medical Department, Department of the Army, Department of Defense, or the US Government.

Disclosures

The authors have indicated they have no financial relationships relevant to this article to disclose.

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