

19. Endovascular Therapy in Trauma

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Introduction

The use of interventional procedures in trauma has increased steadily over the past 10 years. An analysis of the National Trauma Data Bank (NTDB) reported that 8.1 % of acute arterial injuries in 2003 were treated with endovascular therapy, compared to only 2.1 % in 1994. Nearly an equal number of blunt (55 %) and penetrating (45 %) injuries were treated with endovascular therapy [1]. A more recent study, also using NTDB data, reported that 16 % of traumatic vascular injuries were treated with endovascular therapy, including 20 % who were hypotensive at the time of intervention. The authors report decreased mortality with the increased use of endovascular intervention [2]. With advancements in both imaging and device technology, the use of endovascular techniques has become part of the treatment algorithm for the injury.

Endovascular therapy in trauma involves a minimally invasive, catheter-based approach. Sheaths, catheters, and guidewires are universal instruments, regardless of procedure. Devices passed over guidewires form the basis of diagnosis and treatment.

Thoracic Aortic Injury

History of Care

Prior to the endovascular era, care of thoracic aortic injury had been open repair. Early aortic stent grafting was based on treatment of thoracic aortic disease. These devices were not tailored to the younger, disease-free aorta of most trauma patients. As a result, many device-related complications occurred in the early stages of the endovascular era.

Assessment and Operative Technique

Immediate assessment of the patient with suspected blunt thoracic aortic injury (BTAI) includes imaging studies if hemodynamics allow. Once the diagnosis is confirmed, aggressive beta-blockade is highly recommended in the absence of contraindications. The decision regarding endovascular versus open repair is made largely on the position of the lesion relative to arch vessels. Traditionally, a proximal landing zone of 2 cm was considered acceptable, although newer devices have been used successfully with a proximal neck length of 1.5 cm. Aortic injuries are usually shorter than lesions due to aortic disease, negating the need for a preoperative spinal drain.

Injuries to the thoracic aorta that are within proximity to the major branch vessels present a challenge when the proximal or distal landing zones for the device include the take-off of major branch vessels. Coverage of the left subclavian artery (LSCA) has been routinely performed with minimal morbidity. Close observation is usually sufficient; in the event that symptoms develop and progress, a carotid-subclavian bypass is required. Other situations, such as prior cardiac surgery, may necessitate a bypass procedure prior to stent-graft placement. Careful preoperative assessment of vertebral artery patency, dominance, and flow direction must be performed in the event that the LSCA origin needs to be covered. Intraoperative neuromonitoring can provide immediate information regarding cerebral flow after coverage of the LSCA. Cerebral angiography may also be performed if absolutely needed.

Bilateral femoral artery cutdown or percutaneous cannulation is obtained. Access sheaths for wires, catheters, and sheaths are advanced under fluoroscopy. Pre-procedural planning can significantly decrease the amount of contrast used, particularly in patients with concomitant injuries. If uncertainties regarding the lesion exist with angiography, the intravascular ultrasound (IVUS) is used to more accurately assess the injury, as well as to confirm the proximal landing zone and stent apposition and rule out endoleak.

Outcomes

Thoracic endovascular aortic repair (TEVAR) is currently the most studied endovascular intervention in trauma. The short-term data suggests that aortic stent grafting is comparable to open repair, citing lower rates of paraplegia, blood loss, and complications and shorter hospital

stays [3–5]. While many have embraced its use, it suffers from a lack of long-term data. The relationship of the aging stent graft to the aging aorta is unknown.

Complications

Complications of TEVAR include stent collapse and “bird beaking” (the proximal portion of the stent graft does not oppose to the aortic wall) due to size mismatching and/or a small arch radius and may ultimately require additional endovascular or open repair. The American Association for the Surgery of Trauma (AAST) multi-institutional trials have documented the complication rates of TEVAR [3]. Many industry-sponsored multi-institutional trials are currently investigating devices with improved deployment systems and conformability, particularly suitable for small arch radius aortas seen in younger patients. Ongoing trials for branched and fenestrated grafts (Fig. 19.1) will allow devices suitable for coverage across arch vessels to be available if proven safe and effective.

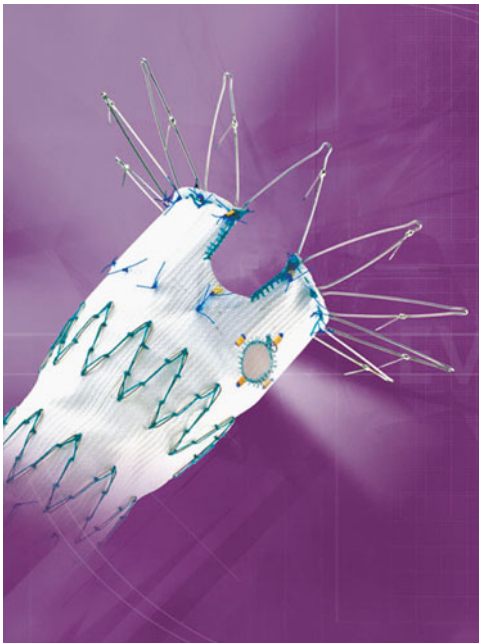


Fig. 19.1. Fenestrated aortic stent graft. For use only in approved trials in the USA.

Abdominal Aorta

Introduction

Abdominal aortic injury (BAAI) occurs from the biomechanical direct and indirect forces applied to the aorta while it is tethered between the spinal column, the peritoneum, and the abdominal viscera. The most frequent force causing abdominal aorta injury is compressive, associated with deceleration [6]. Indirect forces occur when the aortic wall is directly stretched and compressed against a high-pressure column of blood leading to intimal tears, pseudoaneurysm, rupture, or thrombosis. Atherosclerotic changes of the aorta have been associated with a weakening of the intima in addition to the loss of elasticity and compliance and thus thought to increase the risk of aortic injury [7, 8]. These forces can occur during motor vehicle collisions when the aorta is compressed by the seat belt thus termed “seat belt aorta” [6]. Other mechanisms include long-distance falls from heights, direct compression of the aorta, and penetrating injuries.

The underlying pathologic lesion of BAAI is the disruption of the intima. Depending on the magnitude of force, BAAI presents as a spectrum of disease ranging from a minimal aortic injury (MAI) to free rupture of the aorta. With increasing use of computed tomography angiography (CTA) for diagnosis of BAAI, there have been increasing numbers of MAI diagnosed [9]. Traumatic intimal tears can occur and manifest as intimal flaps or dissection. Furthermore, these can be complicated by thrombosis [10] and acute arterial insufficiency [11–13]. Injuries involving the adventitia lead to pseudoaneurysm formation (Fig. 19.2) or even rupture of the aortic wall. Rupture of the aortic wall can also be due to branch vessel avulsion.

The majority of BAAI occur inferior to the renal arteries. They are classified based on the presence of aortic contour abnormality and presence of free rupture [14]. This classification is based on experience with BTAI [15]. Intimal tears/flaps are not associated with external aortic contour abnormality. A pseudoaneurysm presents as a contained rupture and is clearly associated with an aortic contour abnormality. The most common associated injuries are small bowel injuries (38 %) and thoracolumbar spine injuries (25 %). The most common reported BAAI are intimal tears/flaps (41 %) followed by pseudoaneurysms (29 %) [14].

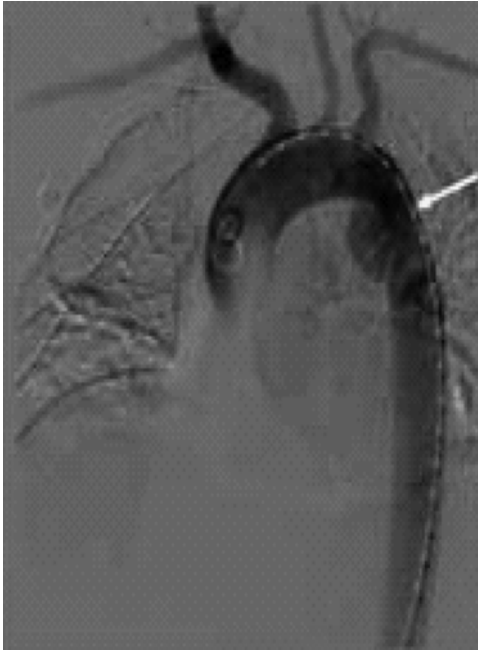


Fig. 19.2. Traumatic aortic pseudoaneurysm.

Assessment

The initial presentation is dependent on the presence or absence of free rupture of the abdominal aorta, branch vessel avulsion, or concomitant inferior vena cava injury [16]. Those typically present with hemorrhagic shock. In a recent series, all such patients were hemodynamically unstable, and 75 % had cardiac arrest in the emergency department with 38 % receiving an ED thoracotomy [14].

Tamponade is usually associated with retroperitoneal hematoma and allows a temporary period of hemodynamic stability increasing survival [17]. Abdominal wall ecchymosis (seat belt sign) is seen in one-third of the cases of BAAI and should raise suspicion for hollow viscus and aortic injuries [14].

Initial Management

Management of aortic injury varies and risk of mortality rises with the severity of the pathologic lesion. In a recent review of the NTDB of 436 patients with BAAI from 180 centers between 2007 and 2009, 90 % were managed nonoperatively. Of those who underwent operative repair, 69 % underwent endovascular repair, with the remainder undergoing open aortic repair and two extra-anatomic bypasses [18]. In general, cases of BAAI with uncomplicated intimal flaps are managed nonoperatively with beta-blockers and antiplatelet (aspirin) therapy and close follow-up. The natural history in these cases is a decrease in size and complete resolution [19]. Cases of aortic pseudoaneurysm require operative repair to prevent rupture, but this can be managed on a semi-elective basis during the initial hospitalization. Cases complicated by thrombosis, acute arterial insufficiency, and free ruptures require repair. The timing of repair also depends on associated injuries. Patients with pulse and neurologic deficits, an expanding hematoma, and concomitant intra-abdominal injuries require emergent repair. Otherwise, treatment can be individualized in the hemodynamically stable multisystem trauma patient.

Operative Techniques

Endovascular stent placement for BAAI is an attractive alternative for patients with both isolated BAAI and multisystem trauma in a manner similar to that of BTAI (Fig. 19.3). Most of the literature is limited to case reports and small case series where endovascular stents, aortic extension cuffs, and limb extensions have all been used. Indications include cases with associated gross contamination from hollow viscus injury that can jeopardize aortic grafts due to risk of infection or management of injuries difficult to expose by open exploration. Endovascular interventions can be used as a stabilizing measure for critically ill patients and a bridge to open definitive repair.

Abdominal aorta zones of injury can be classified [14] based on feasibility of endovascular approach as follows: Zone I injuries from diaphragmatic hiatus to the superior mesenteric artery (SMA). Zone II injuries are between the SMA and renal arteries. Zone III injuries are inferior to the renal arteries to the aortic bifurcation. Zone I and III injuries are amenable to endovascular repair, whereas Zone II lesions are not

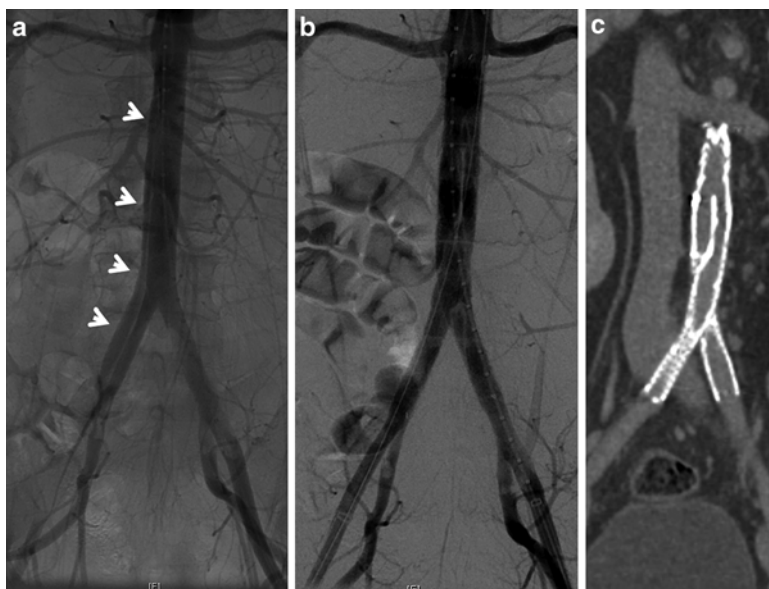


Fig. 19.3. Infrarenal blunt abdominal aortic dissection. (a) An intraoperative arteriogram showing the dissection flap (*arrows*) in the infrarenal aorta and extending to the right common iliac artery. (b) Arteriogram post-endovascular stent graft placement. (c) Coronal view of CT angiography 6 weeks post repair.

without fenestration for the SMA and renal arteries. The timing of the repair is dependent on the patient's hemodynamic status and the presence of acute limb ischemia.

In the abdominal aorta, major injuries near the visceral and renal vessels are not amenable to stent placement. Technologic advancements such as fenestrated (Fig. 19.1) or branched grafts are only used in the USA in trials for elective aortic surgery, but have been used with success in other countries. They may be available in the future for off-label use in the injured aorta. Additionally, the chimney technique, in which the branch vessels are stented along with the aorta, may be an option for select patients. Unfortunately, this technique is time consuming and requires a high degree of experience. Rarely, an aortic injury occurs where the proximal and distal landing zones do not place branch vessels at risk, and a stent is an excellent and minimally invasive treatment option (Fig. 19.4) [20].

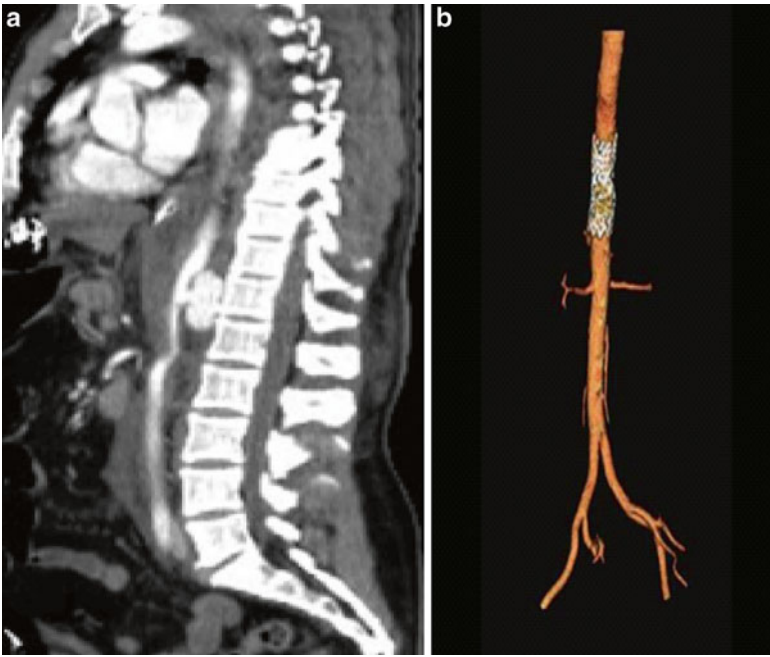


Fig. 19.4. Distal thoracic aortic injury (a) repaired with aortic stent graft seen on postoperative CTA with reconstruction (b).

Outcomes

BAAI is highly lethal. Among those who survive the transport to the hospital mortality rates range from 32 to 78 % with hemorrhagic shock being the most common cause of mortality [16, 21, 22]. Outcomes in cases requiring a resuscitative thoracotomy remain poor [23, 24]. In BAAI, mortality varies by the type of aortic injury. When minimal aortic injuries, dissections of the aorta, and pseudoaneurysms are included, aggregate mortality is 11 % [14]. In cases treated by endovascular repair, the long-term durability of aortic endografts for abdominal aortic trauma has not been well described. Clearly long-term follow-up will be required in these cases. The ongoing AAST multi-institutional PROOVIT and AORTA trials will provide some answers in the near future.

Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA)

History

The most common cause of death from aortic trauma remains hemorrhagic shock compounded by ongoing coagulopathy; thus, early proximal control of the aorta is a life-saving maneuver [14, 16, 21, 22]. The intra-aortic occlusive balloon placed through an open approach was first described for controlling major aortic hemorrhage in the Korean War [25]. Reports of use for control of bleeding during pelvic surgery [26, 27], hepatobiliary surgery [28], orthopedic surgery [29], postpartum hemorrhage [30], and repair of ruptured AAA [31, 32] suggest that resuscitative endovascular balloon occlusion of the aorta (REBOA) is a life-saving measure. Physiologic parameters such as serum lactate, pH, $p\text{CO}_2$, and central, cerebral, and coronary perfusion in animal models of hemorrhagic shock have been shown to improve with the REBOA [33–36]. Descriptions of its use for trauma are few [14, 37–39], but indications include control of noncompressible torso hemorrhage in the abdomen and pelvis.

Operative Technique

The use of REBOA to obtain proximal control at the level of the diaphragm prior to entering the abdomen may have a role in early control of hemorrhage from the injured aorta. Placement of the REBOA can be done expeditiously and would not delay the laparotomy as demonstrated in proximal control of the aorta in cases of ruptured abdominal aortic aneurysms [40]. Currently, indications for REBOA in our institution include persistent hypotension with hemorrhage below the diaphragm and severe pelvic hemorrhage (Fig. 19.5). Contraindications for REBOA include suspected vascular injury above the diaphragm. The technique of REBOA begins with standard cannulation of the common femoral artery approximately 2 cm below the inguinal ligament. Ultrasound utilization is ideal, but landmarks, fluoroscopy, blind placement, or cut-down on the common femoral artery can be utilized. An Amplatz wire is advanced into the catheter to the level approximating the second rib space (measured externally prior to insertion). In the absence of fluoroscopy, an X-ray demonstrating wire position must be obtained to confirm

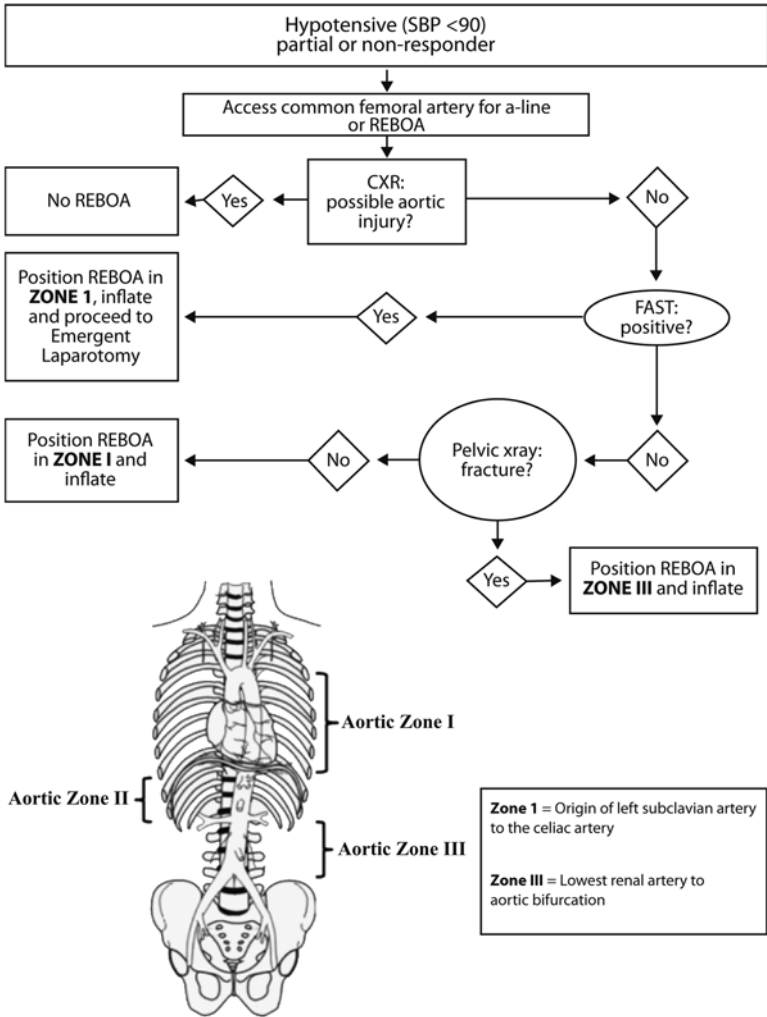


Fig. 19.5. STC clinical algorithm for REBOA.

placement. Marking of the wire at its end point on a draped end table helps to keep wire position during the procedure. The catheter is removed after enlarging the skin incision, and the 12 Fr sheath is inserted to a level approximating the proximal iliac artery (measured externally to the umbilicus). The dilator is removed, and the CODA 32 mm balloon catheter is advanced over the wire to Zone I (external

landmark: xiphoid) or to Zone 3 (external landmark: above the umbilicus). A 30 cc syringe filled with 10 cc of contrast and 20 cc of normal saline is used to inflate the balloon quickly to a point not beyond high resistance. An X-ray may be obtained to confirm balloon placement. An immediate increase in SBP should be noticed if the REBOA technique is successful. Transportation to definitive treatment can occur with the REBOA in place. Once aortic occlusion is no longer necessary, open repair of the common femoral artery is required. Careful attention should be paid to distal pulses, as any deficit may be due to prolonged cannulation and/or thromboembolism.

Our earliest experience with REBOA in the clinical setting demonstrates this procedure to be a potentially life-saving technique [39]. Currently the procedure uses US Food and Drug Administration (FDA)-approved devices not well suited for the trauma population. Lower-profile devices are in development (Pryor Medical) and will be available in the near future.

Endovascular Ultrasound

The intravascular ultrasound (IVUS) takes the concept of ultrasound and applies it to a “view from the inside” approach. The miniature ultrasound transducer is mounted on a catheter tip, and the ultrasound beam rotates around the axis of the catheter to give a 360° axial view of the vessel. The IVUS is the most sophisticated diagnostic tool available as it is able to visualize all three vessel layers simultaneously. It can measure lumen diameter to accurately size stent grafts and examine wall thickness, lesion shape, size, and type, as well as the position of the lesion within the vessel lumen. The IVUS can distinguish intimal flaps, dissections, pseudoaneurysms, and transections as well as visualizing blood flow with the color-flow mode (Fig. 19.6). There are no additional risks of using the IVUS if performed as part of angiography, and risks of use without angiography include contrast exposure and access site complications. Several reports in the literature have solidified the utility of IVUS in the diagnosis of vascular trauma by both changing the diagnosis and ruling out injuries previously equivocal on angiogram [41]. Furthermore, a comparison of CT, angiography, and IVUS studies in BTAI reported an unmatched sensitivity and specificity (100 %) of the IVUS compared to all other modalities [9]. The IVUS has been used to place IVC filters at the bedside when IV contrast and/or traveling outside the intensive care unit is unsafe.

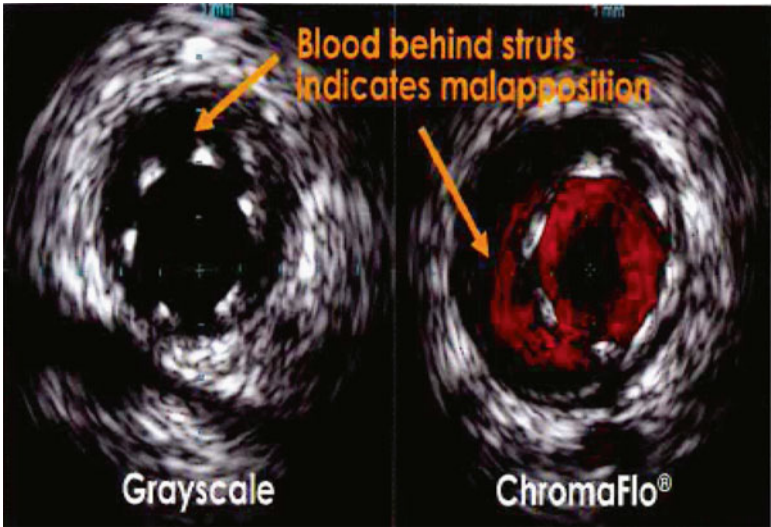


Fig. 19.6. Intravascular ultrasound (IVUS, Volcano Corp) can be used for both diagnosis and treatment, as well as confirmation of stent apposition post deployment.

The IVUS can differentiate chronic from acute injuries, rule out injuries deemed indeterminate by other modalities, and determine candidates for endovascular therapy. The IVUS may be used as a screening tool, for follow-up of minor injuries, or in lieu of CTA or angiogram when contrast is contraindicated.

Endovascular Damage Control

Hemodynamic instability should not itself necessitate an open operation. The REBOA can be advanced quickly up a guidewire to the aorta or branch vessel to provide proximal vascular control (Fig. 19.7). This can remain in place throughout the operation regardless of whether the repair is performed open or not. The balloon can be deflated, readjusted, and reinflated for optimal positioning, which may change throughout the procedure. A recently published case series from our own institution [39] suggests the life-saving role of REBOA for noncompressible truncal hemorrhage.

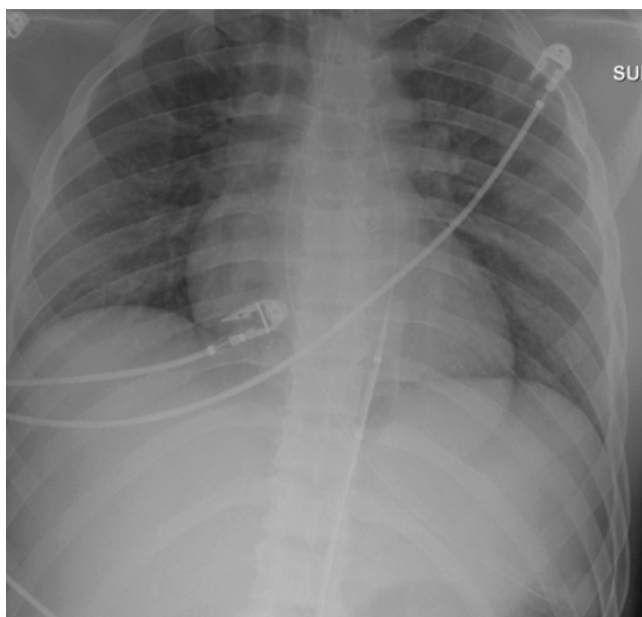


Fig. 19.7. Chest X-ray confirmation of placement of REBOA at Zone I. The CODA balloon is seen inflated at the level of the diaphragm providing proximal aortic control of exsanguinating intra-abdominal hemorrhage.

Angiography may also be used for diagnostic purposes, particularly in the multi-trauma patient whose body habitus or hemodynamic instability prevents travel to the CT scanner. Endovascular control of splenic, hepatic, pelvic, carotid, and intercostal artery injuries has occurred for decades. Technology has advanced from simple coils to gelfoam and plug devices that can be used to stop hemorrhage in these locations. Angiographic embolization has gained tremendous success in the control of hemorrhage in locations such as the pelvis where direct access is problematic.

Endovascular therapy as damage control can also be used as a bridge to open repair. Stent grafts may be used temporarily or permanently to cover partial- or full-thickness injuries, particularly in major vascular injury that cannot be easily or rapidly accessed with surgical exposure. Placing a stent across a full-thickness injury may save the physiologically devastated patient from prolonged illness by decreasing blood loss and ensuing coagulopathy.

Hybrid Trauma OR

A hybrid trauma operating and angiography suite—where the table itself is amenable to fluoroscopy and the available equipment, devices, and experienced staff are available within minutes and are located only a few feet from the trauma admitting area—allows the team to perform multiple procedures almost simultaneously (e.g., a laparotomy and an extremity angiogram) without change in location or time delay.

A fluoroscopy table, C-arm, monitors, lights, as well as anesthesia, surgical, and endovascular supplies form the basis of the hybrid trauma suite (Fig. 19.8). Additional instruments such as a TEE, RISS, IVUS, as well as bypass and dialysis pumps may be needed. Advancements in c-arm technology have led to the production of a CT/C-arm hybrid machine, the Artis Zeego by Siemens, which combines high-resolution angiography with CT fluoroscopy. This “CT” is not as sensitive as the 64-slice helical CT but can give excellent quality three-dimensional



Fig. 19.8. Trauma hybrid operating room at RA Cowley Shock Trauma Center. Angiography capability is provided by Siemens Artis Zeego system whose C-arm is advanced into the operating field when needed and returns to its stored position away from the table during open procedures.

views to supplement two-dimensional angiography. This allows the team to obtain CT images without travel and additional contrast use and acquires sensitive information such as endoleaks, which are not seen or poorly visualized on angiography.

The technology for a hybrid OR is costly, approximately \$3–9 million total for the room and \$1.5–5 million for just the fluoroscopic equipment. In addition, the OR staff need to be comfortable with the acquisition, preparation, use, and billing of devices. A competent radiation technologist is essential to help provide images critical to decision making and treatment. Radiation safety should also be practiced with vigilance.

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