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Tips and tricks for the trauma patient.

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ABSTRACT

Interventions on the trauma patient are an essential component of the complete scope of care that is provided to the multiply injured patient today. The active participation by the interventional radiologist along the entire spectrum of clinical care is very important to optimize patient outcomes. Suggestions on how to establish a clinical presence are presented. A few of the newer concepts and terminology applicable to trauma care are reviewed. Tips useful in the trauma room, in the interventional radiology suite, and during the postprocedural period are discussed.

KEYWORDS: Clinical care, damage control laparotomy, damage control resuscitation, embolization, prophylactic inferior vena cava filter, superior vena cava filter

Objectives: Upon completion of this article, the reader (1) should be able to state how the interventional radiologist can become more involved along the entire spectrum of clinical care that is provided to the trauma patient today and (2) should be able to explain some of the newer concepts and terminology, as well as a few useful tips applicable to trauma care.

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> "It was on the wards, interacting with the surgeons and house officers that the Radiologists earned respect for what they were doing clinically. The benefits of clinical rounds were combined with clinical interests by the radiologists, their availability, and their new contribution taking care of the patient. These aspects of Interventional Radiology were clearly as important as the success of the procedure itself."[1]
>
> –Peter Mueller

The purpose of this article is to discuss concepts, suggestions for practice, as well as a handful of tips and tricks that may be useful when caring for the trauma patient. It is important to acknowledge that some of the ideas discussed may not be practical or applicable for some readers. The ideas expressed herein are presented with the hope that, to whatever extent they may be useful for each individual, they will help that interventionalist to provide excellent care for the trauma patient within the system that he or she practices.

Interventional radiology has been at a crossroads for some time now, and there has been increased emphasis on the need for all practicing interventional radiologists (IRs) to develop a greater clinical practice.[2,3]

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It is no longer sufficient to only be technically competent to perform a wide variety of procedures. All IRs are encouraged to manage patients before and after a procedure is performed. The ability to care for patients more like a clinician, as opposed to functioning only as a technician, will translate into improved outcomes. It will also allow the IR to remain competitive in the current health care environment. The words above were written by Peter Mueller, who described the history of percutaneous abscess drainage. As he noted, the willingness to care for patients proved to be a very valuable practice when draining abscesses.

In a similar manner, the active participation by the IR along the entire spectrum of care for the trauma patient can be beneficial to the patient and the trauma surgeon, as well as the IR (Fig. 1). For this reason, it is important for the IR to become clinically involved in the care of the trauma patient to the fullest extent possible. This can be achieved by four means: (1) establishing a clinical presence; (2) evaluating patients in a dedicated clinical setting; (3) providing timely service; and (4) attending multidisciplinary trauma meetings.

ESTABLISHING A CLINICAL PRESENCE

Establishing a clinical presence can be accomplished in several ways. One useful practice is to attend the general surgery/trauma surgery morning report that occurs at the start of the day in most teaching medical centers. During this session, the chief residents of the various surgery teams present a brief update on the progress of their critically ill patients in the intensive care unit (ICU; Fig. 2). Similarly, the on-call team presents all the admissions and consults from the previous 24 hours. Each case is usually discussed by both residents and attending surgeons for teaching purposes as well as to discuss management issues. By being present at morning report, the IR can become familiar with all the ICU patients as well as all the trauma and nontrauma surgery admissions from the previous day. It provides a valuable opportunity for the IR to offer immediate and informal consultation for patients as the need arises.

A consultation often results in an intervention that may need to be done that same day. Once the working day has started, the IR may become very involved with regularly scheduled interventions. By discussing a case during morning report, the IR avoids being interrupted later in the day with such a consultation. The IR may also avoid a situation where a midday consult subsequently results in a late intervention—a procedure that perhaps could have been done earlier during the day. By having visibility early in the day, the interventional radiology service can better integrate add-on procedures into the overall interventional radiology schedule for the day. This increases efficiency and improves the day for everyone involved from the patient to the interventional radiology staff and everyone in between.

During morning report, various imaging studies are usually presented, including plain films and computed tomography scans of trauma patients. The IR can serve as the subject matter expert on any of the imaging studies that are presented and answer questions that may arise regarding these studies. In a training center, the IR can provide teaching points on the interpretation of imaging studies that are useful for the young residents. Attendance at morning report may require 15 to 30 minutes of the IR's time, but it will often prove to be time well spent. It is likely that most general and trauma surgeons would welcome the presence of an IR at their morning report. In time, he or she will be looked upon as a valuable member of the patient care team.

A second way to establish a clinical presence is to make rounds in the ICU as time and schedule allows. This will not be practical for many IRs to do on a regular basis, but even if it is accomplished only once in a while, it remains beneficial to do so. Performing rounds in the ICU can be done on a formal basis as most ICU teams have morning rounds usually starting at 7:30 or 8:00 AM. By being present at such a time, the IR can help ensure good postprocedural care for the patient in the ICU who has had an intervention performed. For example, the patient with the percutaneous drain may require tissue plasminogen activator (TPA) to facilitate optimal drainage, and this topic can be discussed during rounds in the ICU. Alternatively, the IR can provide suggestions for a procedure that may be indicated but has not been considered in a patient. As an example, the trauma patient with a retained hemothorax can be treated with thrombolytics early in the course once the retained hemothorax has been identified. If TPA is successful in evacuating the clot, it would obviate the need for a video-assisted thoracoscopic procedure or a decortication to treat the clotted hemothorax. However, TPA is only successful when used early, and the presence of an IR in the ICU may facilitate initiating this process. Otherwise, there may be a delay in generating a referral to the interventional radiology service, which in turn will decrease the likelihood of a successful thrombolysis of a retained hemothorax.

A third way to establish a clinical presence is to round on the wards. This is already a routine procedure for many IRs. By evaluating patients after a procedure on the ward, the IR can facilitate excellent care while the patient continues to convalesce in the hospital. The IR can take note whether the patient's progress is as expected relative to the procedure performed. Follow-up interactions with the patient can help to ensure thorough patient education regarding the condition that is being treated. For example, the IR can remind a patient and the family of the importance of the eventual removal of a retrievable inferior vena cava (IVC) filter as

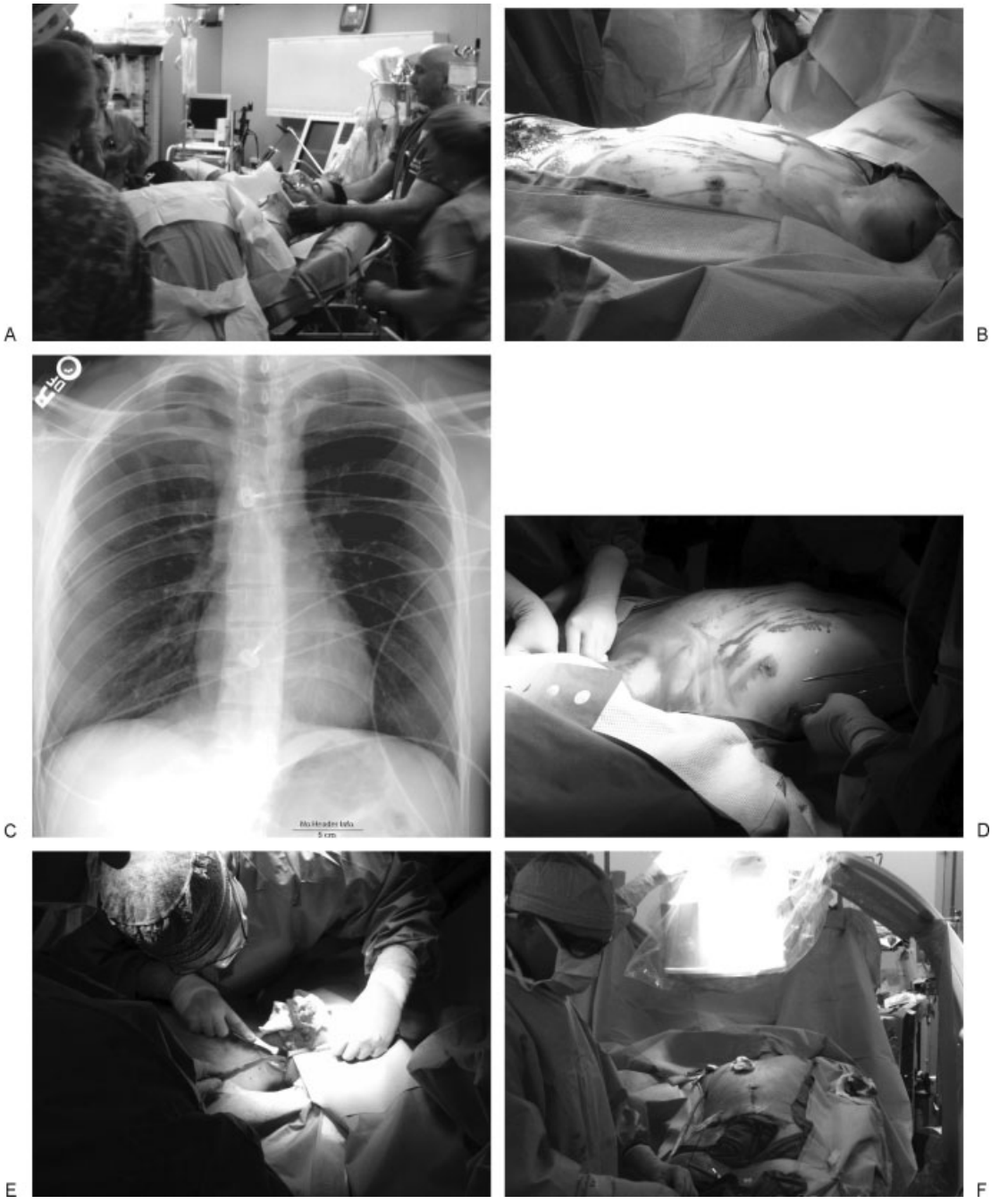

Figure 1 Providing care throughout the entire hospitalization. (A) A 24-year-old man was stabbed in the right upper quadrant, and in zone III of the left neck (above the angle of the mandible). Active bleeding from the neck was controlled with direct pressure. He was promptly transported to the operating room. (B) The interventional radiologist (IR) and trauma surgery attending discussed that it may be necessary to perform an arteriogram in the event of ongoing bleeding. In the operating room, the inguinal regions were prepped along with the abdomen, chest, and neck. (C) The chest radiograph was initially interpreted as normal, but the IR who was present in the trauma room was able to assist by identifying a right pneumothorax. (D) A right chest tube was placed at the start of the procedure. (E) Brisk bleeding was encountered when the neck wound was explored. (F) A cervical arteriogram was immediately performed using the right groin.

soon as it is clinically appropriate. Some trauma patients are transferred to a rehabilitation facility prior to that point being reached. Excellent patient education is critical in helping to ensure that the patient returns to the interventional radiology service for removal of the IVC filter. The topic of retrievable IVC filters is discussed in greater detail below.

Performing rounds in the ICU and on the wards increases the credibility of interventional radiology as a valuable clinical service. It will remind other physicians

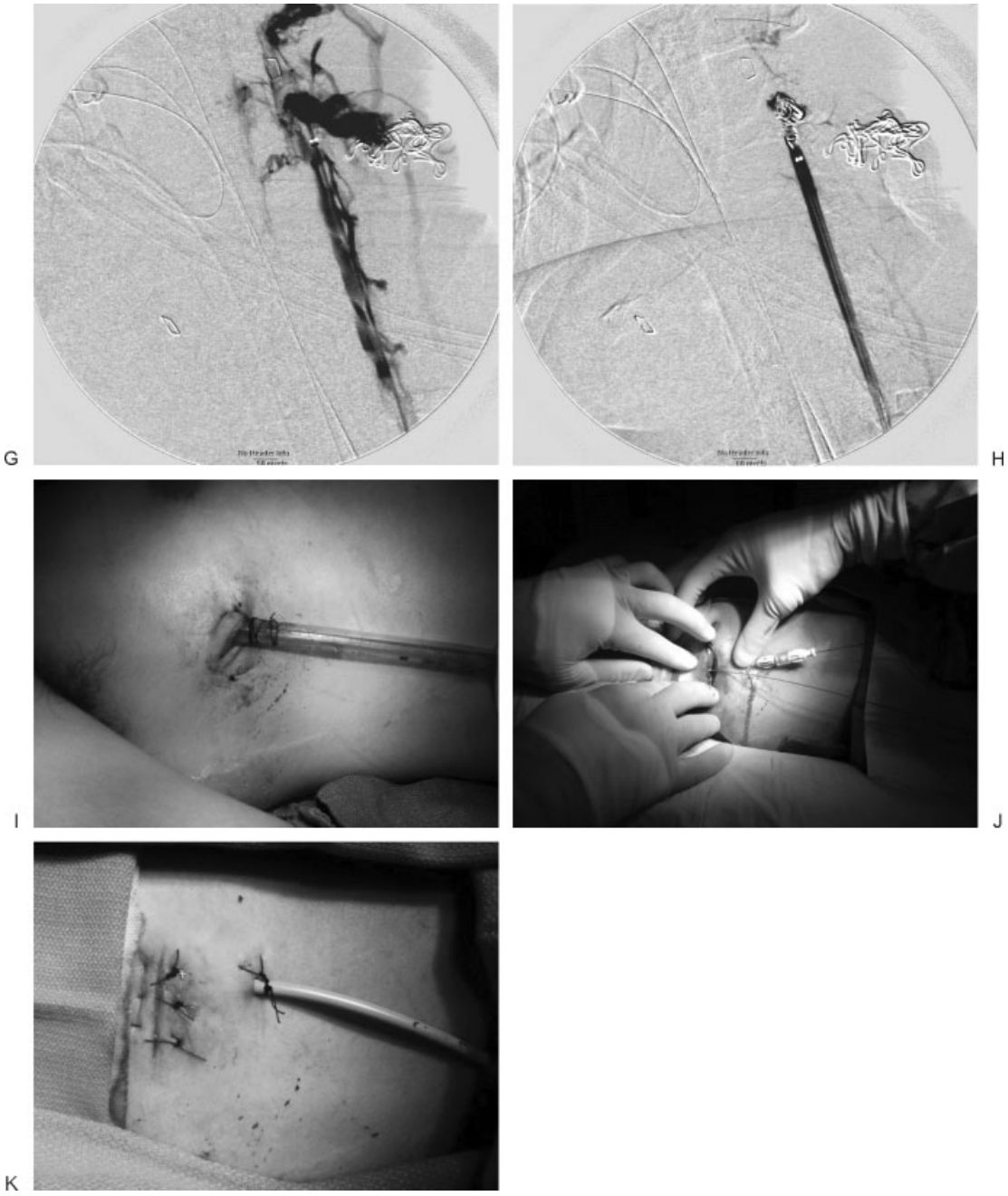

Figure 1 (*Continued*) (G) Active extravasation from the left vertebral artery was identified. Radiopaque packing within the wound is visible on the image. (H) The vessel was embolized using coils and Gelfoam (Ethicon, Somerville, NJ). Postembolization images (not shown) demonstrated complete resolution of the pseudoaneurysm and extravasation. (I) Postprocedural day 3, the right chest tube, which became occluded, was revised by the interventional radiology service. (J) A new tube was placed from a separate percutaneous site, but through the original tube tract through the chest wall. (K) Final image after new tube was in place and the old chest tube incision sutured. The patient did well. He was seen by the trauma surgeons and the IR in the surgery clinic 1 week after discharge.

and the nursing staff that there is an interventional radiology service available for consultation as needed. It will also facilitate improvement of communication with both medicine and surgery teams, as well as the nursing services. It is not uncommon that many of the house staff and nurses are unfamiliar with the variety of interventional radiology procedures that are performed today. The IR can provide a valuable service by educating these individuals, in turn, they will be better prepared to anticipate the needs of the IR patient during the postprocedural period. For these reasons, the IR who spends time on the wards can contribute significantly toward ensuring good patient care as the patient recovers from a procedure.

Figure 2 Surgery morning report is a time when all trauma admissions are discussed. It provides an interventional radiologist the opportunity to offer input on the interpretation of imaging studies and immediate consultation regarding potential interventions.

Figure 3 The interventional radiology clinic is a dedicated setting where patients referred to the interventional radiology service can be evaluated. After the procedure, patients can also be seen in follow-up to ensure continuing progress until completion of care.

A fourth way to establish a clinical presence is to provide formal lectures to the surgery and ICU staff. In teaching institutions, this is an excellent way to express a commitment to education and improving health care by teaching residents and fellows. Didactic sessions allow others to become familiar with the particular scope of practice of the IR within a facility. For example, if appropriate, the IR can announce that he or she is willing to perform trauma embolization in the operating room with a C-arm if needed for patients who cannot be transported from the operating room to the interventional radiology suite. The opportunity to provide dedicated lectures will also familiarize the trauma surgeons and the critical care staff regarding the specifics of how interventional radiology deals with certain types of patients or procedures. As an example, the IR can discuss how he or she performs a splenic embolization in contrast to what the published literature written by other IRs describe how that procedure is done elsewhere. This effort will facilitate improved patient care by ensuring that everyone at the facility is on "the same sheet of music," with regard to certain procedures.

DEDICATED CLINICAL SETTINGS

A second means to become more clinically involved with trauma patients is for the IR to evaluate patients in a dedicated clinical setting, as opposed the interventional radiology holding area. Many interventionalists today have a dedicated interventional radiology clinic, which is staffed and offers patients scheduled appointments on a regular basis (Fig. 3). The interventional radiology clinic is an ideal setting in which to evaluate new patients prior to and following an intervention. A dedicated interventional radiology clinic is also an excellent place to see trauma patients following their discharge from the hospital. Many of these individuals require close follow-up, similar to patients who have had an oncological intervention such as a transarterial chemoembolization. In the patient who had an abscess treated percutaneously, the drain can be removed at the appropriate time. For the trauma patient with a prophylactic IVC filter (PIVCF), an evaluation in the interventional radiology clinic may facilitate planning for a follow-up procedure such as the retrieval of the IVC filter.

In addition to an interventional radiology clinic, it may be appropriate and advantageous to evaluate a patient in the surgery clinic. Many trauma patients will follow up with the surgery team in the surgery clinic. If time allows, the IR should be willing to evaluate the patient at the same time in that clinic along with the patient's other providers. This effort will ensure that there is excellent communication between the trauma service and the interventional radiology service. It is understandable that time constraints may not allow the busy IR to see patients in the surgery clinic. However, whenever possible, this should be done, and is usually very much appreciated by the patient and the trauma surgery service. It will contribute significantly toward fostering an excellent collegial relationship between the two services.

PROVIDING TIMELY SERVICE

A third and important way to become more clinically involved with trauma patients is to provide timely service in various locations as clinically indicated. Although it is not common, in a busy trauma center, it may be necessary for a member of the interventional radiology team to evaluate a trauma patient in the trauma room. A classic scenario is the hypotensive trauma patient with a pelvic fracture who has no significant amount of free fluid in the chest or abdomen. This patient is unstable

and will likely require an emergent procedure to address the hemorrhage from the pelvic fracture. The options include placement of an external fixation device to stabilize the pelvis and/or a pelvic angiogram. These patients will often proceed from the emergency department directly to the operating room or the interventional radiology suite depending on clinical factors. If such a patient will require an interventional radiology procedure, it is helpful and important for the IR to evaluate the patient in the emergency department as soon as possible. This will be discussed in greater detail below.

On rare occasions, it may be necessary for the IR to evaluate a patient who is already in the operating room. For example, the unstable abdominal trauma patient who has undergone a damage control laparotomy (DCL) may remain unstable despite the control of obvious vascular injuries. Alternatively, the pelvic fracture patient may remain hypotensive despite external fixation and appropriate resuscitation. These scenarios suggest the presence of ongoing bleeding and the need for an immediate arteriogram. In such situations, it will be necessary and beneficial for the IR to evaluate the patient in the operating room to facilitate a smooth transition to the interventional radiology suite.

It may also be necessary for the IR to evaluate a patient in the ICU. Occasionally, the initially unstable trauma patient who is aggressively resuscitated will temporarily stabilize and be transferred to the ICU. However, recurrent hypotension may develop if there is persistent bleeding. This patient will require either an urgent laparotomy or possibly an arteriogram. By evaluating the patient in the ICU, the IR can ensure that if there is a need for an arteriogram, this could be performed expeditiously and as smoothly as possible.

Providing timely service also means that a mechanism is set in place to evaluate outpatient referrals as soon as reasonably possible. If the interventional radiology service offers routine clinic appointments once or twice a week only, it is helpful to have a mechanism to evaluate any urgent outpatient consult on nonclinic days in a dedicated clinical setting. The ability to evaluate a patient the same day the referral is generated, and to perform a necessary procedure within the next day or two, is usually greatly appreciated by both the patient and the referring clinician. It is an excellent example of practicing good medicine, and also a great way to ensure continuing referrals from that clinician.

It is important for the IR to perform procedures on patients within an appropriate period of time. In addition to evaluating patients in the clinical settings described above, it may also be necessary for the IR to evaluate the patient in the surgery clinic, as has been previously mentioned. This is particularly useful if an acute problem is discovered when the trauma team evaluates a patient following discharge from the hospital. Two common scenarios are that a percutaneous drain has become occluded or partially dislodged. Depending on the availability and the willingness of the IR, it may be helpful for the IR to quickly evaluate the patient in the surgery clinic. It is possible that the problem with the drain can be corrected easily. If that is not the case, arrangements can be made for an appropriate intervention to be done expeditiously. Like most patients, the trauma patient often benefits greatly from prompt interventions. It is important not to put off until tomorrow what can be done today, particularly when there may be another trauma patient to treat the next day.

Last, but not least, providing timely service should involve discussing the results of an intervention with the trauma service shortly following completion of a procedure. A simple call to a member of the trauma team is usually appreciated, facilitates excellent communication, and improves patient care. After all, patient care does not end when an interventional radiology procedure is completed. At times, the postprocedural care is more important than the procedure itself. That care begins with a simple discussion on how the procedure went and what the postprocedural care should include. It is worthwhile to leave little room for errors due to miscommunication or incorrect expectations on the part of the referring clinician.

MULTIDISCIPLINARY TRAUMA MEETING

A final way for the IR to become more clinically involved with trauma patients is to become a regular attendant at the multidisciplinary trauma meeting that usually occurs in most level 1 trauma centers on a regular basis. Interventions on the trauma patient have become an essential part of the complete scope of care that is provided. In some facilities, the IR is present in these multidisciplinary meetings where discussions on optimizing trauma care are conducted. The meetings usually occur once a month, and although they do require time away from the interventional radiology suite, they are often worthwhile to attend.

Ideally, it is important for the IR to become an integral member of the trauma team. By becoming clinically involved as described above and establishing themselves as a valuable consultant to the trauma service, the IR becomes a key element of the system that cares for trauma patients. In many tertiary centers, the interventional radiology service is more likely to be involved in the care of trauma and other surgery patients than patients on other services. When viewed as a legitimate and involved member of the trauma team, any recommendation that is made by the IR is more likely to be accepted by the surgeons. Conversely, if the IR suggests that a requested procedure is not indicated, surgeons are more likely to accept that suggestion if the IR is perceived as a valued member of the trauma team—when he or she is viewed as a colleague, and not just a

consultant. A final advantage of becoming an integral member of the trauma team is that the IR may learn a great deal about trauma care and therefore become a better interventionalist in the process.

NEW CONCEPTS AND TERMINOLOGY

The trauma literature is replete with new concepts and terminology with which the interventional radiology physician should become familiar. One example is the term "MVC," or motor vehicle collision or crash, which is more commonly used today than the older term "MVA," or motor vehicle accident. It is now felt that when a traumatic injury occurs, it is usually not an accident. Most often there is an inciting factor. When a drunk driver crashes his vehicle into a tree, it is because he chose to drive impaired and it was not an accident. By using the term "MVC" instead of "MVA," the IR will demonstrate that he or she is up-to-date with the current terminology used by trauma surgeons.

DAMAGE CONTROL LAPAROTOMY (DCL)

The concept of performing a DCL is also a relatively recent and important concept. In the past, performing extensive surgery on a multitrauma patient would cause generally poor outcomes due to the development of hypothermia, acidosis, and coagulopathy—the so-called "lethal triad." The traditional approach of attempting to definitively treat all identified injuries in one setting would often result in a long procedure during which the abdomen was open and the patient required multiple transfusions of blood products. Such a laparotomy would uniformly lead to the onset of the lethal triad. Patients would do very poorly, and may even have expired in the operating room from severe coagulopathy and persistent bleeding. For this reason, it is more common today for a trauma patient to undergo an emergent trauma laparotomy with the primary goal of stopping hemorrhage and controlling spillage only. Hemorrhage control involves rapid repair or ligation of vessels, or strategically placing packs to tamponade a bleeding source such as the liver, spleen, or pelvis. Any injured bowel is resected, usually with a stapling device, and anastomosis of bowel is not performed. The DCL is completed as quickly as possible, and the abdominal fascia and skin are not closed. The abdomen is temporarily "closed" using a variety of devices such as a wound vac (Fig. 4).

DCL allows the vascular and bowel injuries to be expeditiously controlled in some manner, and the patient is then transported to the ICU to be resuscitated further to correct any hypothermia, acidosis, and coagulopathy. The patient who undergoes a DCL may require the involvement of the IR if there is evidence of persistent bleeding despite abdominal packing or repair of vascular injuries. Following stabilization, the removal of packs and the definitive repair of bowel injuries such as anastomosis of discontinuous loops of bowel are performed after the patient has been physiologically optimized within the next 24 to 48 hours. This method of treating the multitrauma patient has yielded significantly improved outcomes and is currently practiced by most trauma surgeons when dealing with the severely injured, multitrauma patient. The IR should have a good understanding of his or her role in this process.

ACUTE COAGULOPATHY OF TRAUMA SHOCK

In civilian trauma populations, several authors have described a significant coagulopathy already present on the patients' admission.[4–7] Furthermore, this coagulopathy is associated with an increase in mortality. This very early coagulopathy demonstrated in the civilian arena is also present in those injured in combat.[8] The data that are available overwhelmingly suggests that in the injured patient, an acute coagulopathy of trauma shock (ACoTS) is present in ~25% of patients, it occurs very early (regardless of resuscitation), and it is lethal.[4–10] The military and civilian data have prompted the increased focus on the role ACoTS has in the early management of the exsanguinating patient. ACoTS is not a simple dilutional coagulopathy that occurs in injured patients but a complex problem with multiple factors whose mechanisms overlap with one another.[7] The main driving force for this early coagulopathy is shock.[11] Because of this known early coagulopathy, the current state of the art involves damage control resuscitation (DCR) in the management of the exsanguinating patient.[12,13]

DAMAGE CONTROL RESUSCITATION (DCR) AND THE ''RATIOS''

An increasing number of institutions have demonstrated that a small portion of the trauma population will require a massive transfusion (MT) of blood products in a rapid fashion.[9,13–15] In light of this, it is essential that trauma centers have an established mechanism to deliver these products quickly and in the correct amounts to these critically injured patients. Several institutions have shown that a trauma exsanguination protocol can be successfully implemented and have a significant positive impact on trauma outcomes.[12,16–18]

The concept of DCR evolved from the damage control surgery paradigm advocated by Stone et al and Rotondo.[19,20] DCR is composed of three basic components: (1) permissive hypotension-palpable distal pulses in an awake patient, (2) minimizing crystalloid-based resuscitation strategies (prevention of hypothermia), and (3) the immediate release and administration of predefined blood products (packed red blood cells, plasma, and platelets) in ratios (1:1:1) similar to that of whole

Figure 4 Open abdomens following damage control laparotomy (DCL). (A) A patient suffered multiple penetrating injuries to the aorta, vena cava, liver, small bowel, and colon. A DCL was performed, a clamp was left on the aorta, and the abdomen was closed with a wound vac. He was resuscitated further, but expired 6 hours later in the intensive care unit. (B) A different patient with blunt trauma to the abdomen who underwent a DCL 48 hours previously was taken back to the operating room with a wound vac in place. (C) This is the appearance of the abdomen after the wound vac was removed. After the abdominal packs were removed, the abdomen was closed primarily.

blood.[9,11,21] This aggressive delivery of blood products begins prior to any laboratory-defined anemia or coagulopathy.[11,22,23] Damage control hematology defines the process of delivering large amounts of blood products (third component of DCR) in an efficient manner in patients who have been identified as having life-threatening hemorrhage.[12,24,25] This aggressive approach directly attacks the entire lethal triad of hypothermia, coagulopathy, and acidosis, which is often present in this small group of patients who are seriously wounded. It is better to start with an aggressive hemostatic resuscitation and then shut it off early, as opposed to waiting until it is certain that a patient will require an MT and starting the hemostatic resuscitation late. The philosophy of DCR is "stay out of trouble as opposed to getting out of trouble."[11]

WHAT IS THE OPTIMAL RATIO?

To date, there are no prospective data informing clinicians of the optimal ratio of blood products for the MT trauma patient. The available literature demonstrates no class 1 data (and little class 2 evidence) describing the ideal ratio to transfuse to the trauma patient with exsanguinating hemorrhage.[15,16,21,26–32] Based on what is available, however, ratios of at least 2:3 for fresh frozen plasma:red blood cells and 1:5 for platelets: red blood cells seemed justifiable and have been routinely implemented.[12] These ratios were evaluated by Gunter et al in an attempt to describe the impact of blood component ratios within such a protocol.[33] The authors found that patients receiving fresh frozen plasma:red blood cells at a ratio of 2:3 or greater and platelets:red blood cells at a ratio of 1:5 or greater had lower 30-day mortality when compared with patients receiving less than these ratios. Surprisingly, achieving ratios of 1:1 did not reduce mortality any further than that observed for 2:3.[33] This was similar to what Kashuk et al showed in a 5-year retrospective review of 133 patients.[34] However, it is worth noting that only 45 patients in the Gunter study and 11 patients in the Kashuk study achieved plasma:red blood cell ratio of 1:1 and their findings may represent a

type II error. In summary, transfusing fresh frozen plasma:red blood cells at a ratio of 2:3 and transfusing platelets: red blood cells at a ratio of 1:5 is an advisable goal during the course of DCR. This is a new concept that is worthwhile for the IR to become familiar with.

THE TRAUMA ROOM

The IR who has an interest in trauma care should be present in the trauma room, if time allows, for the resuscitation of a severely injured patient who is likely to need an intervention to control bleeding. One example is the injured patient with a pelvic fracture who presents with hypotension. The IR can help with the interpretation of a focused abdominal sonogram for trauma (FAST) examination. This ultrasound examination of the abdomen is routinely performed in most trauma centers on trauma patients. It can identify free fluid in the abdomen. The FAST has evolved to include views of the chest and the heart as ultrasound can identify a pneumothorax as well as a pericardial effusion. As the resuscitation of the hypotensive trauma patient evolves, the IR can discuss with the trauma team the possible procedures or interventions that are being considered. This allows for real-time planning for surgery and/or an interventional radiology procedure as indicated. If a decision is made to perform an intervention in the interventional radiology suite, by being present in the trauma room, the IR can facilitate communication with the remainder of the interventional radiology service: one can communicate directly that a patient will be transported from the trauma room to the interventional radiology suite within a defined period of time, be it 5 or 15 minutes.

The trauma room can be a tense environment, and it may be difficult to obtain an adequate history from a trauma patient. Despite the challenges, this process will need to be completed quickly and efficiently during a trauma resuscitation. A helpful guide is the mnemonic AMPLE. It is useful in obtaining the patient's list of allergies, medications, past medical history, last meal, and events prior to the injury. By keeping in mind this short list of necessary information, one is less likely to overlook obtaining these important components of the patient's history.

PLANNING FOR PROCEDURES IN THE INTERVENTIONAL RADIOLOGY SUITE

Trauma patients may be referred to IR for a specific emergent procedure, such as embolization to treat hemorrhage, but the patient may benefit from other procedures that could be performed during the same visit to interventional radiology. A patient treated with embolization for pelvic fractures may also need a PIVCF based on institutional practice. With the groin already prepped for the arterial embolization, an IVC filter can be placed with little additional time and potentially save the patient a repeat trip to interventional radiology in the next days. For patients specifically referred for an IVC filter, a peripherally inserted central catheter (PICC) line or central line can be placed with a simple wire exchange at the end of the procedure depending on the venous access chosen. Patients who have emergently placed central lines may have the lines in suboptimal position. In a stable patient, the line can be repositioned or upsized. Arterial access used for arteriography can be left in place for pressure monitoring in the ICU with no additional time or work in the interventional radiology room. Patients with a pneumothorax or hemothorax may also benefit from the rapid, image-guided placement of a chest tube after their more urgent interventional radiology procedure. For patients who are bleeding from pelvic fractures and who also have bladder and/or urethral injuries, an ultrasound-guided suprapubic bladder drain can be placed after a pelvic embolization. Male patients with suspected urethral injury can have a retrograde urethrogram performed, and fluoroscopic wire-guided placement of a Foley catheter into the bladder (Fig. 5). For each of the additional procedures, there is a cost of additional time and work for the IR, but for the patient the benefit is large. It facilitates having rapid, image-guided care to treat the acute problem, and it also addresses other important interventions that may save one or more trips out of the ICU within a day or two.

Some additional procedures may be needed, but it will be better if they are performed at a later time. Discussion with the trauma surgeon at the time of initial consultation will allow the additional procedures to be scheduled promptly. Some procedures, such as vertebral augmentation, may be initially unfamiliar to the trauma surgeon and can present an opportunity for an open discussion of the many interventional radiology procedures that may benefit a trauma patient.

TIPS FOR THE INTERVENTIONAL RADIOLOGY SUITE

Once a patient arrives in the interventional radiology suite, it is important to move efficiently to start, perform, and complete the procedure as quickly as possible to avoid the development of the lethal triad of hypothermia, acidosis, and coagulopathy. Severely traumatized and unstable patients will usually require the assistance of the anesthesia service to manage the airway and conduct the ongoing resuscitation of the patient. In a busy trauma center, it is possible that the anesthesia service may already be committed to other ongoing procedures. In the event anesthesia is not readily available to assist with a procedure that must be done expeditiously, it may be possible to recruit the assistance of the trauma fellow or senior surgery residents in the management of the patient. They can work with the interventional radiology

Figure 5 Performing multiple procedures at one setting in the interventional radiology suite. (A) A patient presented with an open book pelvic fracture. (B) He was referred for a pelvic arteriogram and embolization. (C) The embolization was successfully performed. (D) A prophylactic inferior vena cava filter was inserted via a right IJ access. (E) A right internal jugular (IJ) triple lumen was left in place. (F) A retrograde urethrogram was performed that demonstrated a stretched but intact urethra. (G) A Foley catheter was safely inserted.

nurse to resuscitate the patient so that the IR can focus on completing the procedure.

It is vitally important to ensure that all patients are kept as warm as possible to avoid hypothermia. This is particularly critical in patients receiving transfusions of cold blood products and also in pediatric patients. By increasing the ambient temperature of the interventional radiology suite, loss of heat to the environment can be decreased. It will be helpful to administer IV fluids using a rapid infuser, a device that has the ability to warm the fluid. It is also possible to heat IV fluids in a microwave oven. A warming blanket appropriately placed on the patient can be very useful. One type of device employs warm air that is generated by a floor-based device and circulated within the blanket. A Bair Hugger (Arizant, Eden Prairie, MN) is one example of such as device. Alternatively, it is possible to use a specially designed disposable blanket that becomes warm due to the chemical reaction of materials placed within its layers. Whatever means is chosen, the goal is to keep the patient warm.

MODIFIED AUTOLOGOUS CLOT

Patients with severe trauma may present with acute coagulopathy of trauma shock or may develop coagulopathy associated with multiple transfusions. The triad of depletion of clotting factors, hypothermia, and acidosis that often develops in these situations leads to

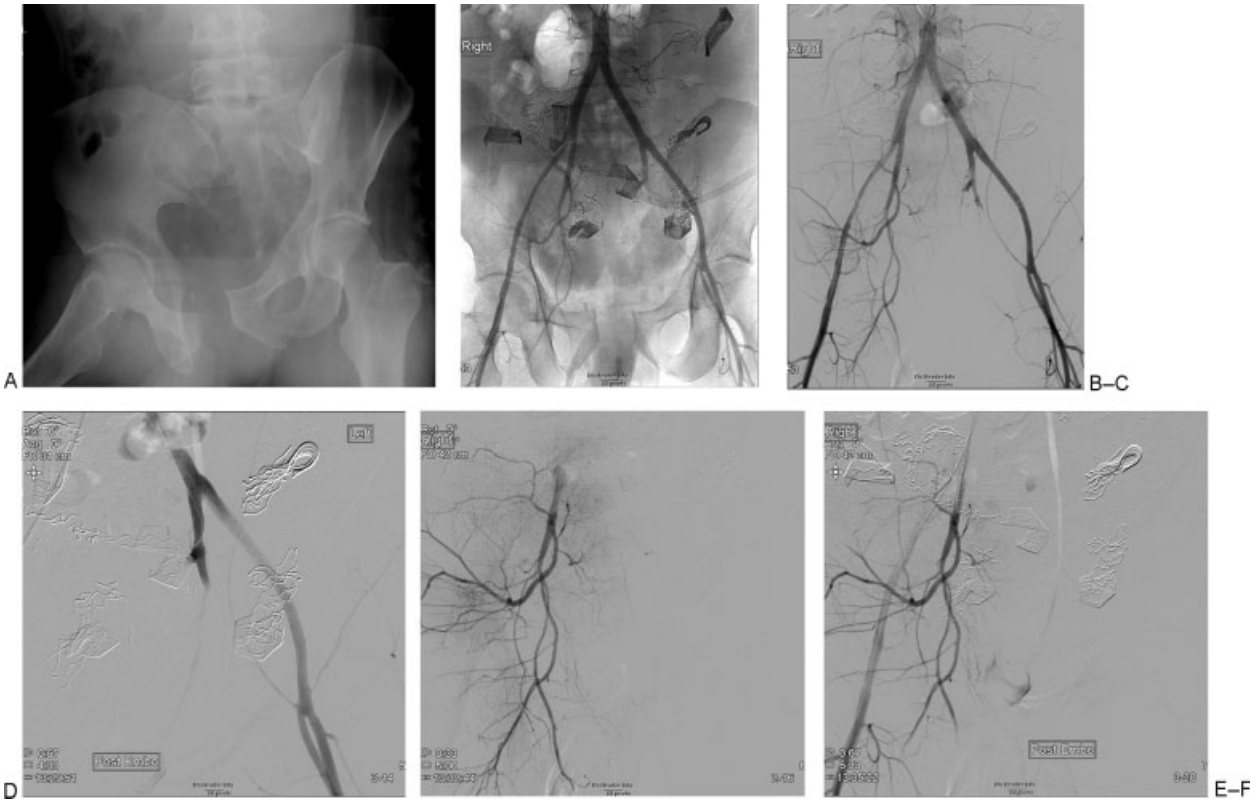

Figure 6 Bilateral internal iliac artery (IIA) embolization. (A) A 40-year-old man was severely injured when an 18-wheeler ran over his torso. (B) He remained persistently hypotensive despite undergoing a damage control laparotomy, during which pelvic packs were placed. A pelvic arteriogram was immediately performed. (C) Initial pelvic arteriogram demonstrates abrupt cutoff of the anterior and posterior divisions of the left IIA. (D) Postembolization images following Gelfoam (Ethicon, Somerville, NJ) embolization of the left IIA. (E) Preembolization angiogram of the right IIA without evidence of active bleeding. The decision was made to proceed with embolization, which is safe to perform. (F) Postembolization of the right IIA with pruning of the vessels. The patient subsequently became hemodynamically stable.

malfunction of the endogenous coagulation mechanism. Most embolic agents only work properly when a relatively normal coagulation cascade is present. Modified autologous clot, which is clot stabilized with thrombin and Amicar Xanodyne® Pharmaceuticals Inc., Newport, KY), can overcome this problem. Combining autologous clot with other embolic agents can decrease flow significantly, giving these other agents more time to achieve a more permanent occlusion.

Modified autologous clot is produced by withdrawing 20 to 50 mL of the patient's blood, to which 0.5 to 1 mL of thrombin (1000 U/mL) and Amicar (250 to 500 mg) are added. Amicar (e-aminocaproic acid) is 6-aminohexanoic acid, which acts as an inhibitor of fibrinolysis.[35] Amicar is useful in enhancing hemostasis when fibrinolysis contributes to bleeding. Amicar promotes cross-linking of fibrin precipitate and formation of a more stable thrombus. Once the blood is mixed with thrombin and Amicar, the supernatant is discarded and the clot is injected through the catheter. This can achieve a very rapid occlusion, which can then be supplemented with other embolic agents such as Gelfoam (Ethicon, Somerville, NJ) or coils.

Autologous clot and thrombin without Amicar will cause vessel occlusion for 24 to 48 hours, with clot lysis occurring at 3 to 24 hours. This is delayed by the Amicar.[36] Although autologous clot is rarely utilized today, modified autologous clot can be beneficial in the extremely coagulopathic patient when rapid and immediate stasis is needed.

PELVIC EMBOLIZATION

Pelvic injury secondary to blunt trauma can be life-threatening. Arterial hemorrhage is one of the most urgent problems associated with pelvic fracture.[37] Hemorrhage from pelvic trauma with associated fracture can carry up to a 50% mortality rate. Spontaneous hemostasis can develop secondary to a tamponade effect in a stable pelvic fracture. However, when bleeding is brisk, a dilutional coagulopathy may occur that increases the risk of persistent hemorrhage. Selective angiographic embolization has been shown to be an effective treatment in posttraumatic patients with severe pelvic bleeding and offers a better alternative to surgery in managing retroperitoneal bleeding.[38] The aim of transcatheter

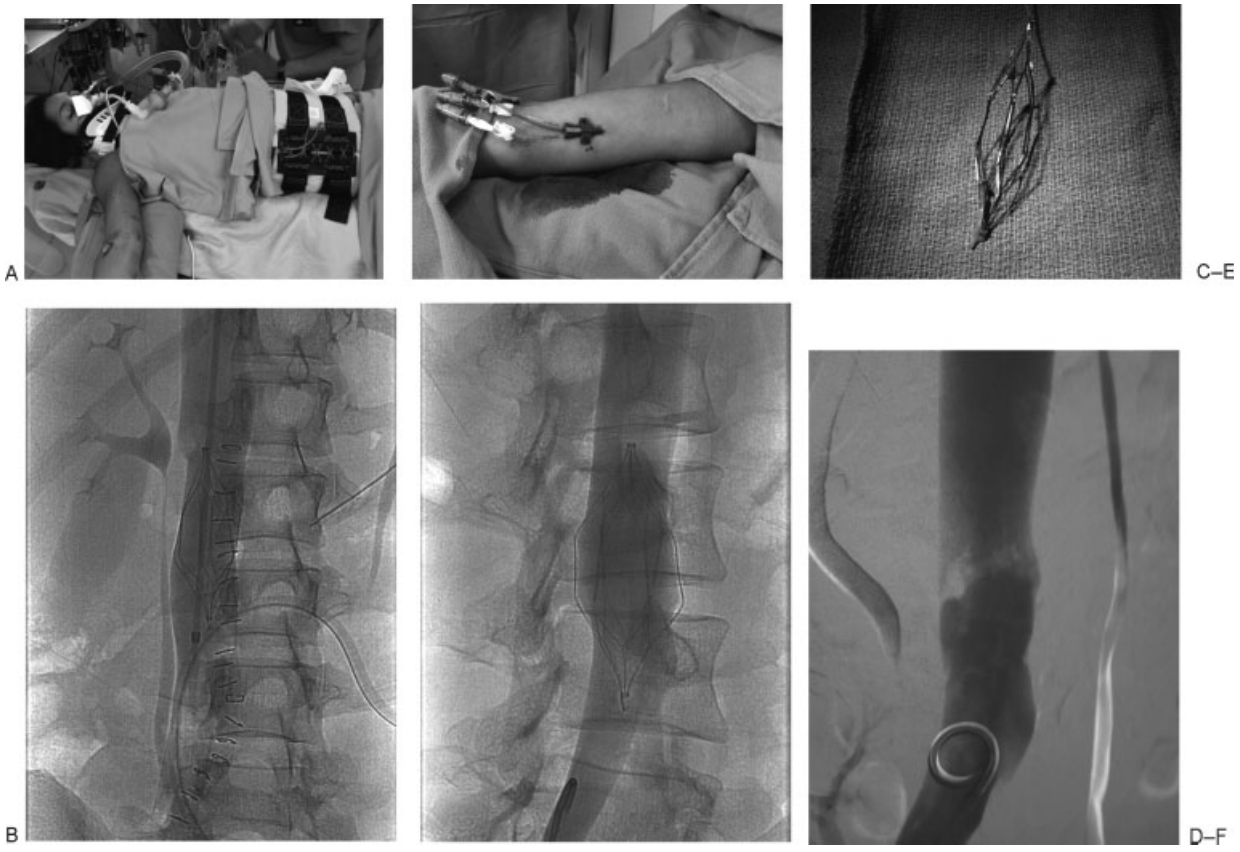

Figure 7 The filter-peripherally inserted central catheter (PICC). (A) This 17-year-old woman was involved in a head-on collision and suffered a closed head injury and spleen laceration, along with pelvic and lower-extremity fractures. A prophylactic inferior vena cava filter was requested. (B) An OptEase (Cordis Corp., Miami Lakes, FL) filter was inserted from a right basilic vein access. (C) A 6-French triple-lumen PICC was left at the conclusion of the procedure. (D) Inferior vena cavagram obtained 6 weeks later, prior to retrieval of the filter. (E) OptEase filter that was removed. (F) Postretrieval inferior vena cavagram with evidence of an acute thrombus in along the caval wall. The patient was placed on short-term anticoagulation.

embolization is to reduce pulse pressure and blood flow to the bleeding sites, allowing the body's hemostatic mechanisms to become effective.[39]

Percutaneous transcatheter Gelfoam embolization has been shown to be safe and efficacious when used to treat pelvic hemorrhage.[39] Endovascular management of hemorrhage following pelvic fracture has been described since the 1970s.[40] Technical success rates of up to 91% have been reported.[38] A Gelfoam slurry can be readily made by cutting a sheet of Gelfoam into small 2-mm cubes. These pieces are then added to 50% dilute nonionic contrast. This is then agitated between two 10-mL syringes connected with a three-way stopcock. A thicker slurry can be made by adding more Gelfoam and a thinner slurry by adding more dilute contrast. The slurry can be delivered through 5-French or 2.7-French catheters. The end point of embolization is when stagnant flow is reached with pruning of distal branch vessels.

Gelfoam is typically classified as a temporary embolization agent. However, densely packed Gelfoam can be a permanent occlusion agent.[39] Complications of emergent internal iliac artery (IIA) embolization include buttock, thigh, and perineal paresthesia.[41] Bilateral IIA embolization has been shown to be safe and effective (Fig. 6).[38] However, gluteal muscle necrosis after aggressive IIA embolization has been reported in a small percentage of patients.[41,42] For this reason, selective embolization of the anterior division of the IIA, when possible, is favored to avoid buttock claudication symptoms. Bilateral IIA embolization does not cause sexual dysfunction. Sexual dysfunction frequently occurs after traumatic pelvic fracture, and the injury itself is the likely etiology of dysfunction as opposed to embolization.[43] It is important to perform BIIA embolization even if no active extravasation is noted on an arteriogram. It is also important to perform bilateral embolization due to the rich collateral circulation that is present in the pelvis. Embolizing only one side often leads to persistent bleeding from collateral flow from the opposite side.[38]

PROPHYLACTIC IVC FILTERS (PIVCFS)

PIVCFs should be considered in appropriate trauma patients. This topic is discussed in greater detail

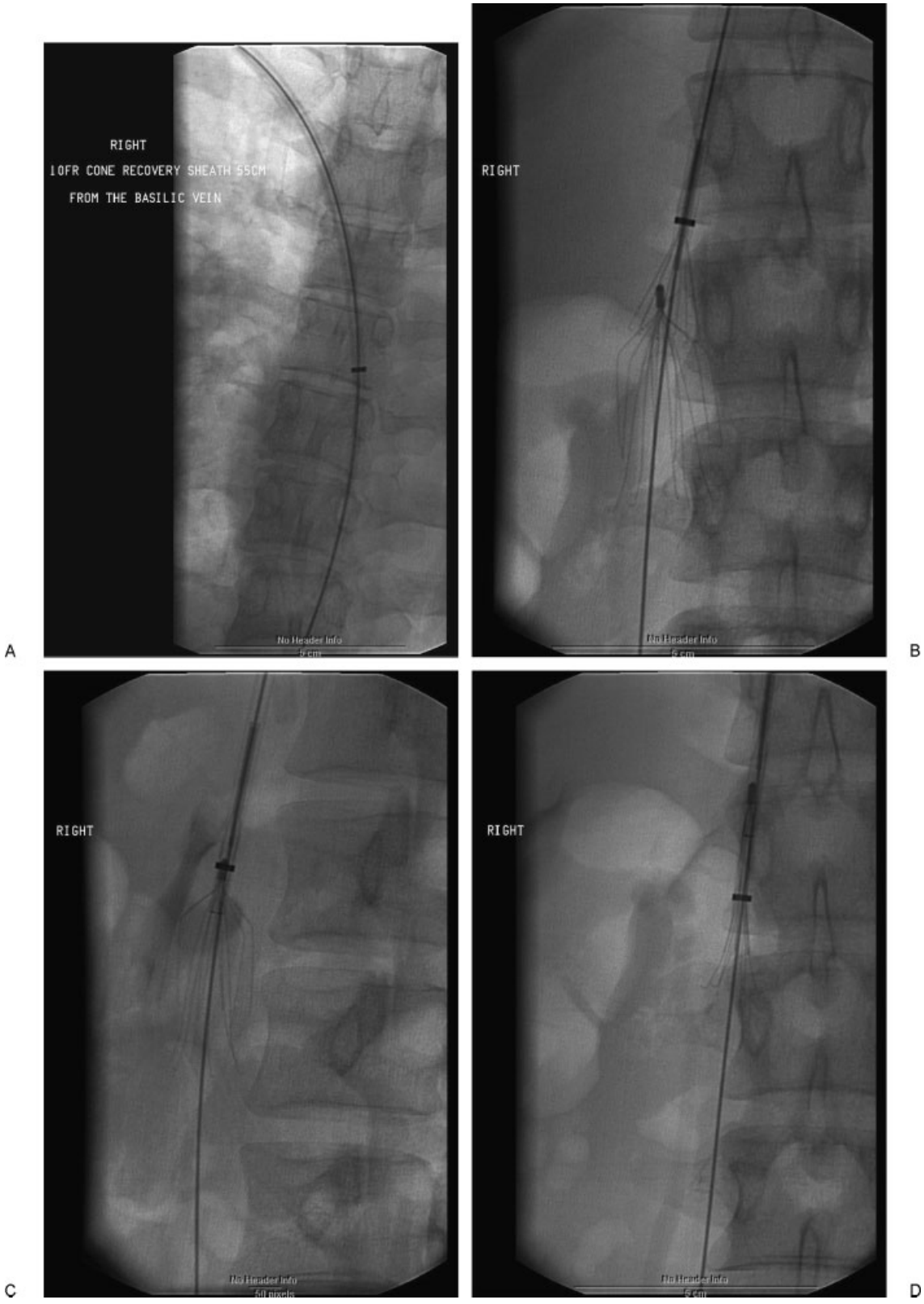

Figure 8 Retrieval of G2 (Bard Peripheral Vascular, Tempe, AZ) filter from brachial access. (A) A 20-year-old female trauma patient had a prophylactic G2 filter that required removal. The retrieval sheath was inserted via the right basilic vein. (B–D) The G2 filter was retrieved.

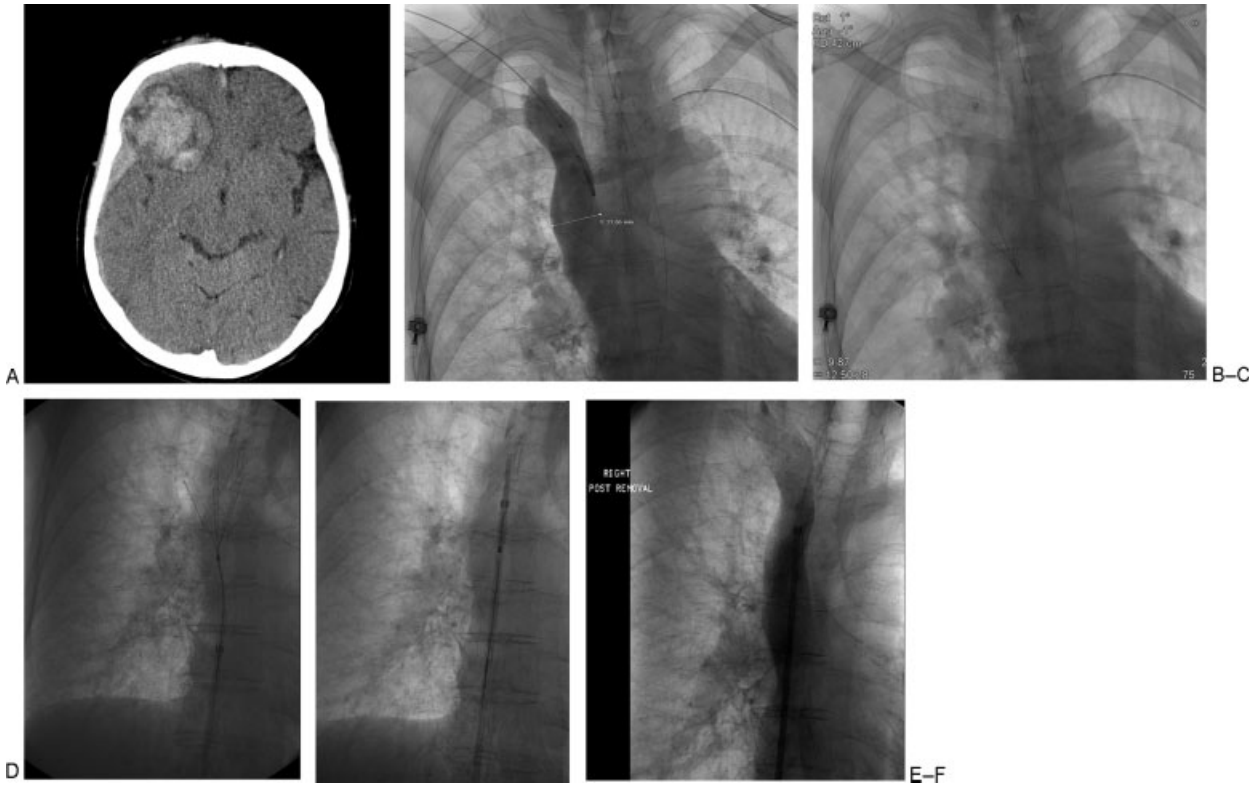

Figure 9 Gunther Tulip (Cook Inc., Bloomington, IN) filter in superior vena cava (SVC). (A) A 77-year-old woman with multitrauma, including an intracranial hematoma, developed an upper-extremity deep vein thrombosis and required an SVC filter. (B) A superior vena cavagram obtained from a jugular approach. (C) A Gunther Tulip filter was placed. (D–F) Six weeks later, when she could be anticoagulated, the filter was retrieved.

elsewhere in this issue in the article by Drs. Kinney and Aryafar. The indications for a PIVCF include the multitrauma patient with a severe head injury, spinal injury, or pelvic and long-bone fractures. The currently available retrievable IVC filters include the Gunther Tulip (Cook Inc., Bloomington, IN), Celect (Cook Inc.), G2/G2X (Bard Peripheral Vascular, Tempe, AZ), OptEase (Cordis Corp., Miami Lakes, FL), ALN (Implants Chirurgicaux, Chisonaccia, France), and Option (Angiotech Pharmaceuticals, Vancouver, BC, Canada) filters. When placing retrievable filters, one should consider inserting the device from the basilic or brachial vein, which will allow placement of a PICC at the end of the procedure (Fig. 7). This will require some planning, but it can be done successfully even using the Celect, G2/G2X, and Option filter systems, which do not have dedicated brachial delivery systems. Retrieval of filters is also possible from the arm even with larger retrieval systems such as the Gunther Tulip retrieval system (Fig. 8).

RETRIEVING PICVFS

It is important to maximize the retrieval rate of PIVCFs. This begins even before the insertion of the PIVCF by informing the patient and the family of the possibility of retrieving the filter as soon as it is appropriate to do so. This can be accomplished by improving the education of the medical staff, as well as patients. Postprocedural visits to educate the patient and the family on the ward, as discussed previously, can be very helpful. At such a visit, it is also worthwhile to provide a business card as well as handouts for the patients and their families that will be helpful to serve as a reminder. Establishing a system for monitoring filter patients including utilizing a tracking database, as well as contacting the patient at a predetermined time to check progress, will be very helpful. Ideally, the service responsible for inserting the PIVCF should also be the one responsible for following the patient. Alternatively, a trauma nurse can track the patient's progress and initiate a referral to the interventional radiology service as needed.

It is also important to establish a point of contact to arrange for the eventual retrieval of the PIVCF. The patient should be given a phone number that will be answered by a person such as a resident, a fellow, or an attending. If someone in the interventional radiology service has an interest in and responsibility for the entire process, the tracking and eventual removal of PIVCF is

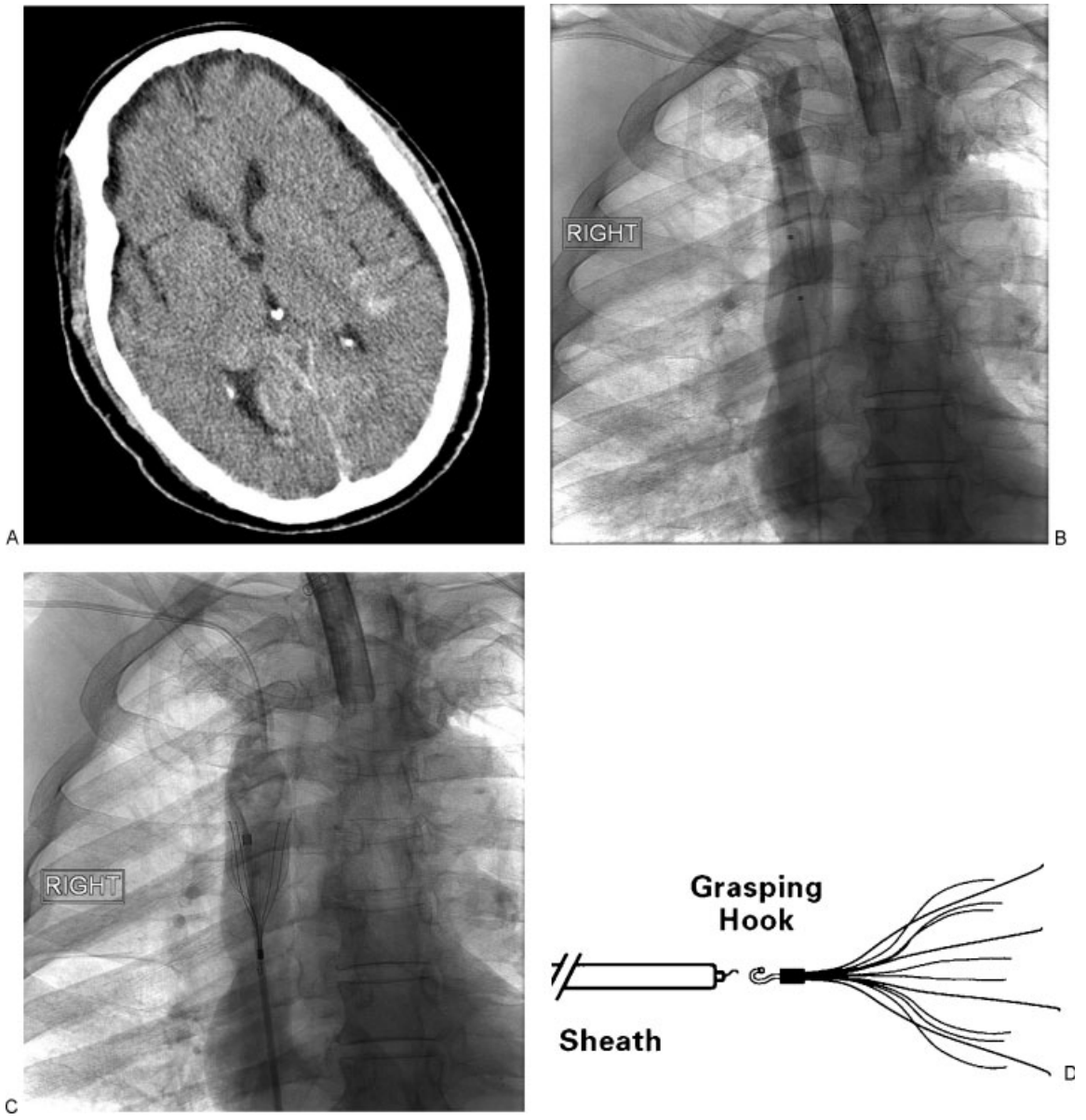

Figure 10 Celect (Cook Inc., Bloomington, IN) filter in superior vena cava (SVC). (A) A 70-year-old trauma patient with paraplegia and bilateral upper-extremity deep vein thromboses developed an acute intracranial hemorrhage while on heparin. (B) A superior vena cavagram obtained from a femoral approach. (C) A Celect filter was placed. (D) The jugular Celect filter deployed from a femoral approach allows the device to be unsheathed and positioned optimally in the SVC prior to releasing the grasping hook.

likely to be successful. If retrieval of PIVCFs is made a priority, it is likely that the retrieval rate will increase.

SUPERIOR VENA CAVA FILTERS

It is worth noting that superior vena cava (SVC) filters are safe and can also be retrieved at the appropriate time. According to the American College of Chest Physicians Evidence-Based Clinical Practice Guidelines (8th Edition) regarding the management of venous thromboembolic disease, upper-extremity deep vein thromboses (UEDVTs) should be treated because they can cause a pulmonary embolus in up to one third of patients.[44] UEDVTs can also cause postthrombotic syndrome. For these reasons, UEDVTs should initially be treated in a manner similar to lower-extremity deep vein thromboses with anticoagulation. In the event of a contraindication to anticoagulation, and if there is clear evidence of deep vein thrombosis progression or clinically significant pulmonary embolus, placement of an SVC filter is suggested.[44] In some centers, SVC filters are placed for these indications (Fig. 9).

In the course of inserting an SVC filter, the Celect filter may be the most ideal filter to deploy.

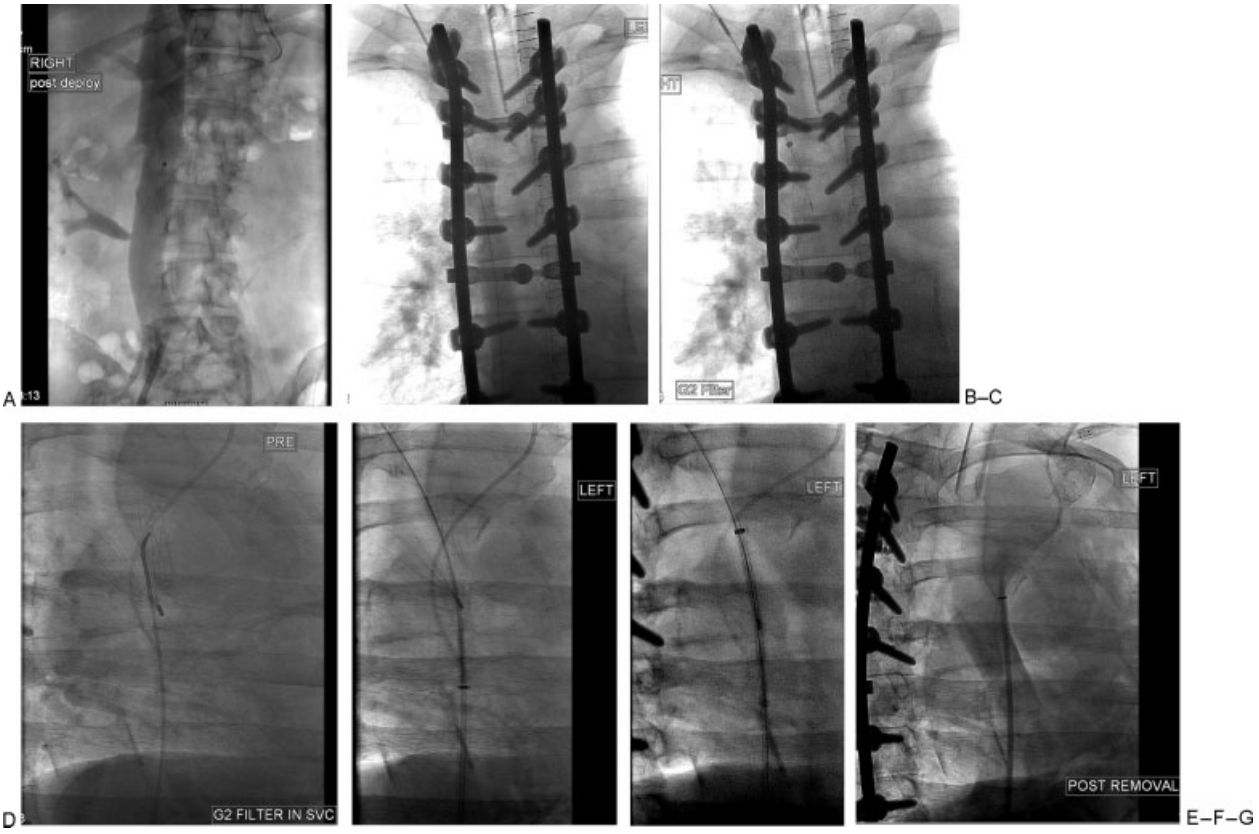

Figure 11 G2 (Bard Peripheral Vascular, Tempe, AZ) filter in superior vena cava (SVC). (A) A 62-year-old male multitrauma patient with a lower-extremity deep vein thrombosis developed heparin-induced thrombocytopenia and had a Greenfield (Boston Scientific, Natick, MA) inferior vena cava filter placed. Patient then developed a large pulmonary embolus (PE), and an SVC filter was requested because ''he could not tolerate another PE.'' (B) Superior vena cavagram obtained from a jugular approach. (C) Frontal view of G2 filter deployed in SVC. (D) Oblique view of the filter 17 days later, when his cardiopulmonary status was improved, prior to removal. (E–G) The G2 filter was retrieved.

One approach uses the jugular set, and the filter is deployed within the SVC from a femoral approach. The advantage of this filter is that it can be unsheathed and positioned, and resheathed and repositioned, as needed, prior to being released from the delivery catheter (Fig. 10). The G2/G2X is an alternative to the Celect, but it is more likely to migrate than other filters. Similar to an IVC filter, it is important to retrieve an SVC filter whenever the patient is eligible for retrieval, and as soon as possible. This occurs whenever the patient can be anticoagulated or once the duration of treatment of the UEDVT has been exceeded (Fig. 11).

CONCLUSION

In many tertiary centers today, interventional radiology has become a key and essential component of the system that cares that the multitrauma patient. By becoming clinically oriented and very familiar with some of the newer concepts currently employed by trauma specialists, the IR can become an invaluable member of the team. It is worth reiterating that some of the suggestions for practice that have been outlined may not be applicable or practical for many individuals reading this article. They are nevertheless potentially valuable for many and perhaps can be incorporated by each individual to some extent, particularly based on his or her unique interest in interventions on the trauma patient.

DISCLOSURE

The views expressed in this report are those of the authors and do not reflect the official policy of the Department of Defense or other departments of the U.S. Government.

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