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Interventional Radiology in the Combat Environment

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Abstract
Purpose of Review The role of radiology in the combat environment has been redefined recently by the conflicts in the Middle East. The current situation of interventional radiology in the deployed setting is indeterminate. This paper seeks to advocate the use of interventional radiology as a deployable specialty.
Recent Findings The role of interventional radiology in the deployed setting is not yet fully outlined. To our knowledge, this is the first review of the role of interventional radiology in the combat environment in the US Army.
Summary The role of interventional radiology in the combat environment needs further exploration by the US military as it is often overlooked by military planners. In the future, interventional radiologists should be deployed in a manner that maximizes their skill sets.

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The views expressed are those of the author(s) and do not reflect the official policy of the Department of the Army, the Department of Defense, or the US Government.

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Introduction

As current and future military radiologists, we have Lieutenant Colonel (LTC) Giuseppe Alvaro to thank for paving the way for radiology to forever make its mark in military history. During the Abyssinian War in 1896, LTC Alvaro used radiographs to identify bullets and fractures when two wounded soldiers were brought back from the front lines. It was at that moment that radiology began to identify its role in military medical history through its use in combat casualty care. Historically, radiology had been confined to large military hospitals with fixed X-ray equipment. It was not until World War II when the British first utilized portable X-ray machines, the Watson MX2, that the role of the radiologist in the combat environment expanded [1].

Currently, radiologists have a more proactive and hands-on approach while deployed in the operational theater. The US Military adoption of the North Atlantic Treaty Organization (NATO) medical "role" system identifies five different echelons of care at which combat casualties are treated. These roles cover the full spectrum of care from point of injury to stateside military medical treatment facilities [2]. In the past, most military radiologists have been confined to a NATO role 3 level or higher, where they are responsible for creating imaging protocols as well as interpreting imaging studies which are typically limited to radiographs, computed tomography (CT), and ultrasound [3].

With the development of the "role 2-plus" as described by Lynn et al., military radiologists have seen their role in military medicine expand to even closer to the battlefront [4]. In

this expanded role 2 setting, radiologists, particularly the interventional radiologist, can explore opportunities to further care in the deployed environment and increase their role in acute and non-acute patient care settings. This expanded role provides both opportunities and challenges that accompany their utilization in this limited, and often austere, battlefield environment. Interventional radiology (IR), while usually associated with the latest technological advancements in the civilian setting, is a specialty that is innovative and fast adapting at its core, which allows a unique opportunity to take on the challenges of military medicine during combat operations. With this in mind, the deployed environment is a relatively unexplored frontier for interventional radiologists to establish themselves fully and become a staple alongside surgeons and internists alike. Their addition to the medical support arsenal of the US Army could have far reaching effects on overall survival and vast improvements in the morbidity and mortality of our soldiers and civilians while in combat.

Radiologist Role in the Combat Environment

Radiology's Role in the Military Health System's Roles

The US military has adopted NATO's role system, identifying five echelons of combat casualty care which begin at the battle's front lines, progress through rear support areas, and end in higher tiered facilities (roles 4 and 5) located in Europe and the Continental USA (CONUS). The echelons increase in medical care complexity and versatility as numbers increase: role 1 consists of self-aid or buddy care; role 2 is mostly commonly associated with forward surgical teams (FST) which have basic surgical and X-ray imaging capabilities with no on-site radiologist typically; role 3 facilities are known as combat support hospitals (CSH) and will be described in detail below; and roles 4 and 5 encompass major hospital systems outside of the combat area, such as Landstuhl Regional Medical Center in Germany and Walter Reed National Military Medical Center in the continental USA.

Radiologists historically have been assigned to facilities designated as a role 3 or higher, and each branch of the US military has a different role 3 design and structure. The US Army currently designates role 3 facilities as CSH, which can typically provide inpatient services for up to 248 patients. It has surgical capabilities, including six operating room (OR) tables for 96 operating table hours per day. Additional services provided by the CSH are as follows: pharmacy, psychiatry, physical therapy, clinical lab, blood bank, nutrition, and radiology. The CSH also has the capability of utilizing augmentation teams, such as FST, and other specialty care services, such as pathology and infectious diseases. The US Air Force role 3 medical facilities are either an Expeditionary Medical Support (EMEDS) Basic with 25 beds or an Air Force Theater Hospital. The Air Force Theater Hospital is the largest of the two, with critical care and surgical capabilities deployed into the combat environment. Finally, the US Navy role 3 expeditionary medical facility with 150 beds can be deployed with land-based units to support troop medical care away from maritime operations in a similar fashion as the CSH, or can utilize one of two hospital ships (USNS Comfort and Mercy), with much larger capacity including a standard setup of 999 beds, 12 ORs, and around 1216 medical staff [2].

Role 3 facilities classically have up to three dedicated radiologists, at least one CT scanner, basic plain radiography, and ultrasound [5•]. Additionally, portable C-arm fluoroscopy is generally deployed with the surgical suite as support for orthopedic, trauma, and general surgical procedures. The availability of these units provides the opportunity for radiologists to perform limited fluoroscopic studies such as esophagrams, arteriography, abscess drainage, and feeding tube placement [6] (Fig. 1). There are usually no angiography suites dedicated for either IR or vascular surgery, and as such, any angiography procedures are done in the OR with limited endovascular supplies, very basic catheters, and hand injection of contrast [7••]. More recently, in 2012, there were deployment and utilization of magnetic resonance imaging (MRI) units in Afghanistan for mild traumatic brain injuries, spinal trauma, and musculoskeletal injuries; however, this is rare in most combat environments.

Recently, there has been an argument for reducing the number of radiologists in the field given the technological advances in teleradiology and the potential to read exams remotely in real time. Although the US military has been at the forefront of technology with advances such as global Picture Archiving and Communication Systems (PACS), there was a lag in developing teleradiology communication systems in combat following the Vietnam War mostly due to lack of adequate telecommunications bandwidth [8]. The historic lack of adequate bandwidth, often unreliable communications, and uncertainty of being able to send images has necessitated a radiologist to be present in theater with combat units to provide on-site radiology support. Furthermore, the deployed radiologist's responsibilities go beyond that of just interpreting images: typically, they are tasked with overseeing radiation dose, formulating scanning protocols, and properly selecting scanning parameters based upon the indication of the exam, as well as assisting in trauma settings with real-time interpretation of CT and ultrasound imaging [9]. There are other factors that argue against total dependence on teleradiology, including providing input for non-standard cases, on-site supervision of technologists, triage of patients, and finally, perhaps most importantly, the opportunity to provide the best medical

Fig. 1 Deployed interventional radiologists in a hardened medical facility performing a nephrostomy tube placement using a portable C-arm in the operating suite

care for our troops given the radiologists physical presence within the department [6, 10].

The radiologist's presence in the combat environment has recently evolved into a more patient-centered role when compared to its civilian counterpart. In the deployed setting described by Long et al., there was an increased need for the radiologist to interact with the patient directly as opposed to the usual relationship between the radiologist and the referring physician commonly encountered stateside [11]. In many cases, the radiologist in the deployed setting presents and discusses imaging results directly with the patient, while also making the appropriate referrals based on the findings [11]. These interactions fuel a unique dynamic not typically seen among their colleagues stateside: the concept of the radiologist as a clinician.

Interventional Radiology—an Opportunity

There is currently no established role for IR as a unique subspecialty on the battlefield. In the Air Force role 3 facility described by Les Folio et al., IR skills were not a necessity for the deployed radiologists given the variety of surgical subspecialists available, such as vascular surgeons and neurosurgeons [5•]. However, in today's complex and often fragmented combat healthcare system which emphasizes increasingly subspecialty care within theater closer to the point of injury, this may not always be the case as the US Military moves towards deployment of increasing numbers of role 2 and role 2 plus facilities. For example, in the case report by Plackett et al., an intraabdominal abscess was percutaneously drained with the combined efforts of a surgeon and a diagnostic radiologist using CT guidance and an improvised use of a central venous catheter while at a role 2 facility [12•]. This report uniquely identifies the need for proper IR skills in the setting of austere environments, and argues for their utilization at lower echelons of care [12•]. Ferrara et al. also described the need for interventional radiology procedures that were lifesaving and/or limb-saving given the injuries encountered in the combat environment [7••]. These tended to be high velocity, penetrating injuries, highlighting the need for and superiority of minimally invasive angiography when evaluating patients with vascular injuries [7••]. The continually evolving practices in the combat environment provide unique challenges and opportunities for interventional radiologists to participate as a more common component of the deployed military medical team.

Opportunities in the Deployed Environment

Despite the logistical challenges often presented to the deployed interventional radiologist, the inherent innovative and resourceful nature of this subspecialty perfectly suits itself to the combat environment. The lifesaving potential for IR in the deployed setting is vast, and this becomes increasingly clear to the authors with every deployment experience. Procedures which are frequently performed in today's IR suite may seem as if they require state-of-the-art fluoroscopy, ultrasound, and CT units. However, as discussed previously, with imaging equipment typically available within the CSH, along with basic catheters, access needles, and drains, deployed interventional radiologists are poised to provide great care to patients using the same minimally invasive, image-guided procedures they perform everyday back home. Having basic IR capability in the forward-deployed environment has the potential to make a significant difference in mitigating morbidity and mortality for the injured or ill patient across the spectrum of casualty care, similar to that seen in the stateside setting.

A CT scanner, portable C-arm, ultrasound, and fluoroscopy compatible operating table are the basic tools that a deployed interventional radiologist requires in order to provide quality care. The possibility of performing procedures is limited by the interventional radiologist's thoughtfulness, versatility, and the tools available on hand at the treatment facility or within theater. In addition to the well-known endovascular capabilities of the interventional radiologist which have clear implications for combat injuries as described by Ferrara et al., the non-vascular procedural aspect of care that the interventional radiologist offers can most certainly be a force multiplier, providing minimally invasive care of traumatic and non-traumatic injuries commonly encountered in the combat environment [7••].

Patients wounded during military operations will frequently undergo exploratory laparotomy in the setting of traumatic hollow viscous or solid organ injury. Following traumatic injury, patients are most commonly evacuated out of theater from the FST or CSH at the earliest opportunity, allowing for definitive care at role 4 hospital settings. Unfortunately, poor weather, combat engagements, or limited aeromedical evacuation resources may preclude prompt evacuation, and casualties must remain at lower levels of care until the evacuation system "catches up" with demand. This often leaves patients at facilities longer than originally intended, sometimes days or even weeks, and the capability of an interventional radiologist to place a CT- or ultrasound-guided abscess or fluid collection drain into a postoperative patient is tantamount to avoid the potential morbidity of a return to the OR for surgical evacuation. In addition to the risk for traumatic injury, deployed military personnel, civilian contractors, and the local populace are subject to the same illnesses as those seen at home or abroad, e.g., appendiceal rupture and ensuing periappendiceal abscess formation, cholecystitis not amenable to surgery, parasitic infection, or pyogenic abscess. The ability to place a percutaneous abscess drain under either ultrasound or CT guidance would allow for non-surgical management of cases that would have otherwise required surgical treatment in the limited logistical environment of the combat setting. Furthermore, drainage can provide a temporizing measure to stabilize the patient to facilitate evacuation to a role 4 facility. As previously mentioned, Plackett et al. in fact described placing a percutaneous abscess drain in a combat environment [12•]. The surgeon performed the procedure because "no interventional radiologist or catheters were available," leaving the authors to wonder how this situation could have been different if the radiologist assigned to the CSH was an interventional radiologist who could perform both roles [12•].

The use of a simple drainage catheter is not unique to the role of managing fluid collections alone, as these same catheters, techniques, and imaging equipment offer the potential to treat pneumothorax in the setting of penetrating chest injury, barotrauma, and blast injury. In addition to pneumothorax, the treatment of hemothorax or management of pleural effusions is readily accomplished with these minimally invasive techniques, and may be of particular benefit to those patients who may be less critically ill (as in the case of a patient with pneumonia, empyema, etc.), preventing placement of a large bore surgical chest tube. Also, the drainage catheter can be readily utilized for cholecystostomy tube placement in the critically ill intensive care unit patient, or as more commonly seen in the author's experience, in the setting of nephrostomy tube placement for patients with obstructing kidney stones. As previously discussed, the deployment of subspecialists such as vascular and cardiovascular surgeons is inherent to the combat environment; however, many surgical subspecialties such as urology and gynecology are under-represented in the operational theater, and as such, the interventional radiologist can many times "bridge the gap" in caring for patients with urologic injury such as ureteral transection, obstruction, or fistula until definitive subspecialty care is reached (Fig. 2). In fact, performance of urologic diagnostic and therapeutic procedures such as pyelography, nephrostomy tube placement, and ureteral stent placement and retrieval by the interventional radiologist can often prevent patients from having more invasive surgery, thus affording early return to duty and reducing the loss of manpower in front line units.

Given the increasing use of improvised explosive devices (IEDs) in the Middle East and Afghanistan over the past two decades, the US Military has seen an increase in penetrating trauma to the extremities which is attributed to improved functionality and effectiveness of our body armor systems. As such, imbedded foreign objects are commonly encountered in patients within the deployed setting, accounting for a significant amount of morbidity in patients who might otherwise return to duty. Foreign body retrieval using imaging guidance (most commonly via ultrasound) could be a major part of the interventional radiologist's role. With the knowledge of different materials' appearance under ultrasound, removal of metal shards, glass, wood, and other debris could be easily and deftly performed, ultimately returning soldiers and civilians to duty in an efficient fashion while minimizing the effects of injuries these objects produce (Fig. 3).

Finally, interventional radiologists are keenly adept at using ultrasound in ways that make them perfectly qualified to perform Focused Assessment with Sonography in Trauma (FAST) exams and as needed diagnostic paracentesis to rule out hemoperitoneum when the clinical scenario is unclear. The presence of a radiologist who is comfortable and well versed in the diagnostic and clinical use of ultrasound in a trauma bay allows other providers, such as emergency physicians, surgeons, and anesthesiologists, to focus on triage, trauma, and airway management rather than focusing on purely diagnostic portions of the assessment. The interventional radiologist provides an exceptional substitute in these settings for both venous and arterial central line placements, prior to transfer to the surgical suite for further supportive care.

The ability to perform even the most basic interventional procedures could help to stabilize patients prior to transfer and possibly reduce the need for the patient to be evacuated at all. Interventional radiologists are often thought of as the "MacGyvers" in medicine. They are asked to perform procedures for patients when no other treatment options are feasible. Given this role, they are comfortable improvising with available materials and devices, which make them a perfect fit for the deployed setting. Interventional radiologists are in a unique position to augment the CSH capabilities by providing

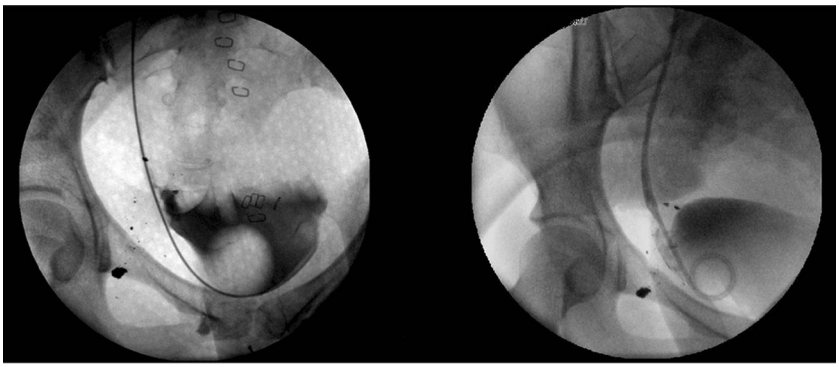

Fig. 2 Non-combatant patient with a left ureteral injury secondary to a gunshot wound during Operation Enduring Freedom. *Left* fluoroscopic image taken after obtaining wire access across a transected ureter, with surrounding shrapnel. *Right* fluoroscopic image taken after placement of a double J ureteral stent across the ureteral transection

the dual role of diagnostic and interventional radiologist. They offer the opportunity to perform lifesaving, minimally invasive, image-guided procedures that could significantly reduce morbidity and mortality in combat.

Challenges of the Deployed Interventional Radiologist

Despite the interventional radiologist's pivotal and often critical role as both a clinical provider and a diagnostician while in the deployed environment, several unique challenges exist in the operational theater which prevents full realization of the interventional radiologist's capabilities. These challenges include providing care within austere medical facilities, limitations of imaging equipment and logistical support, and working within the confines of a medical evacuation (MEDEVAC) system while in theater which can lead to difficulty with patient evacuation to higher levels of care. These factors, although often overlooked, can preclude the interventional radiologist from reaching his or her full potential while operating in a deployed environment.

Fig. 3 Intraoperative ultrasound guided removal of glass particles by an interventional radiologist following an IED blast injury

As mentioned previously in this article, the radiologist's role in the care of patients within the combat theater is well recognized; however, the diverse spectrum of facilities at which a radiologist may be located can range significantly from a mobile, tent-based CSH to fixed and hardened facilities often acquired from the host country (i.e., local hospitals). Initially, as described by Statler et al., the radiologist's role was questioned by some in the forward theater of operations due to sporadic availability of forward deployed advanced medical imaging [13]. During Operation Desert Storm and Operation Enduring Freedom, the radiologist's role within the CSH was fully recognized following the regular deployment and utilization of CT capability at role 3 and more recently at some role 2-plus settings [14]. Oftentimes, CT scanners were deployed to the mobile CSH environment through the use of International Standards Organization (ISO) shelters, therefore improving their ability to be transported across the battlefield as units advance. Over the course of operations, fixed facilities are constructed in rear support areas, or alternatively, shelters and buildings are acquired by forward forces during their advance, providing opportunities for hardened medical treatment facilities to be utilized to treat injured patients in addition to using the native medical infrastructure of the host country. This wide range of facilities potentially provides an opportunity for interventional radiologic work if proper equipment becomes available for use, but intrinsic limitations of the facility can prohibit the interventional radiologist's full utilization. For example, in the mobile CSH environment, the radiology section is usually limited to a portable X-ray unit and the aforementioned CT scanner in an attached ISO shelter. These mobile shelters have poor temperature regulation and minimal space, which means little room for support devices. These restrictions may limit

the capability of the interventional radiologist to perform otherwise straightforward procedures, such as CT-guided fluid collection drainage and chest tube placement, if appropriate monitoring devices and support personnel cannot be safely situated within the shelter.

Also, the natural environment of current operations in the Middle East and Afghanistan (i.e., high temperature, dust, and sand) is a common problem, often rendering the delicate electronics of the CT scanner useless due to poor temperature regulation, particulate contamination, and difficulty maintaining proper air filtration within the ISO shelters. Although hospitals within the host country or those built by allied forces provide a great opportunity for IR care since they have advanced medical imaging available, these facilities often have equipment aged beyond its normal life cycle or poorly maintained due to logistical difficulty of fielding specialty biomedical support. This scenario leaves the interventional radiologist with equipment which is either suboptimal for imaging or potentially useless due to years of neglect.

Additional equipment that is utilized stateside by the interventional radiologist includes ultrasound and even more commonly fluoroscopy. Although these modalities are typically available in the combat environment, their regular use and standardization between facilities are uncommon, potentially leaving the interventional radiologist with inadequate imaging equipment. Ultrasound is common in the austere environment and is mainly limited to battery operated, portable units with a relatively small footprint. Depending upon the location, the Diagnostic Radiology Department may or may not be assigned one of these ultrasound units, which, in the author's experience, subsequently requires coordination among different providers to utilize this modality in a shared fashion. Given the basic functionality and limitations of portable ultrasound units in the deployed environment, many older units lack adequate imaging power or the full array of sonographic probes offered in facilities stateside, which limit the potential opportunities for interventions to patients with adequate imaging windows and those which can be performed safely with probes made available to providers in the facility.

Similarly, though portable fluoroscopy units are not standard equipment for the CSH, they are typically deployed for use in CSH surgical suites, much like CT scanners are deployed for use today within the CSH Diagnostic Radiology Department. These portable C-arms provide an exceptional opportunity to multiply an interventional radiologist's capability while deployed, not only offering their use for therapeutic interventional and surgical procedures but also broadening the spectrum of diagnostic procedures afforded to referring providers. Much like portable fluoroscopy units seen stateside within operating suites, these units offer the interventional radiologist opportunities for additional procedures, including placement of nephrostomy and cystostomy tubes, ureteral stents, and cholecystostomy tubes, as well as providing basic angiography capability. Unfortunately, these units can be limited by their imaging capability (i.e., penetration), field of view, sporadic digital subtraction capability, and compatibility with surgical or procedural tables. These units are typically quite large for the small footprint of the CSH operating room, which limits their deployment to some facilities due to the logistics of storage.

Routine supply of catheters, wires, and interventional medical supplies within the forward operating theater is likely one of the greatest challenges for deployment of IR capabilities into the combat environment. Catheters, wires, and the vast array of specialty equipment utilized by today's interventional radiologists within the US and Europe significantly limit their capability in theater due to the relatively small supply footprint allowed by any one specialty in the CSH. Typically, the deployed interventional radiologist is limited to basic drainage procedure "kits," including a pigtail-style drainage catheter, associated dilators, basic J-wires, and an access needle in addition to local anesthetic and several syringes (Fig. 4). These kits are usually available through military medical logistics from several large biomedical supply manufacturers; however, these drainage kits are not routinely included in the initial supply pack during deployment of a CSH. This requires the interventional radiologist to have the foresight to request this equipment prior to their deployment or upon arrival in theater, which often takes weeks to months for delivery depending upon location. Remaining supplies, such as catheters, wires, snares, and specialty drains or stents (e.g., ureteral stents), are "piece-mealed" together from surgical supplies found throughout the facility, borrowed from NATO partners, or sent

Fig. 4 Typical table set up for an IR procedure in the deployed setting. Note the very basic catheter and wire selection as well as tray materials

individually from stateside as logistics allow. These additional supplies can multiply the capability and spectrum of procedures available to the deployed interventional radiologist, but given their limited use, cost, and availability downrange, they are usually reserved for non-emergent cases where the logistical supply chain can provide adequate support in the time required for the patient. Ultimately, this is where the interventional radiologist shines due to his or her capability to make good use of the supplies on hand as well as ability to adapt to what is available for the patient (one of the authors often found himself spending hours searching through his facility's medical logistics store room and surgical supply to see what he could utilize given his limited logistical support).

One of the final challenges to the interventional radiologist within the deployed environment, much like many other specialties, is the movement of patient into and out of the operating environment, or MEDEVAC system. IR provides a great opportunity to expand patient care in the combat zone; however, much like their surgical or medical counterparts, patient evacuation can limit what an interventional radiologist can or should do based on considerations for safety, cost, and capability. Patient evacuation can also be delayed for many patients due to their lower evacuation priority following stabilization, often with concerns voiced by military and civilian aviators about safety, pressure changes, and effects of altitude on drainage and chest tubes during evacuation. Given that these patients typically respond quite well to minimally invasive therapy, their departure from the combat zone can often be delayed by higher priority, more critically ill patients, leaving a service member who is unable to return to their unit due to their medical condition sitting in a hospital bed for days, sometimes even weeks, until they can be properly evacuated to a higher level of care within Europe or CONUS. Additionally, civilian contractors are often afforded the opportunity through contractual agreements to have healthcare provided for by US medical providers and their allies. Performing minimally invasive procedures on these individuals within the combat zone leads to issues with their evacuation from the war zone due to their non-emergent, non-combatant status. Oftentimes this is due to their host country's lack of regular MEDEVAC operations or lack of funding by the contractor's employer to provide prompt civilian MEDEVAC from the area of operation. This, unfortunately, leads to patient backlog within medical facilities and strains the already limited logistics of the interventional radiologist's supply required to keep these patients well-stocked with drainage bags and bulbs, for example. In summary, one of the biggest challenges for the deployed interventional radiologist is not the performance of a procedure, but properly and safely evacuating a patient out of theater following stabilization.

Despite the significant challenges posed to an interventional radiologist working within a combat zone which include providing care within an austere medical facility, working with limited imaging equipment and medical supply, and a complex MEDEVAC system, the authors agree unanimously that these challenges can be overcome with a flexible mindset, proper logistical planning prior to deployment, and open communication with US and allied medical partners. Ultimately, these challenges are but a "speed bump" for the interventional radiologist who is willing to go beyond his or her role as a diagnostic radiologist in the combat setting, offering patients minimally invasive care with maximal benefit where it otherwise would not be available.

Conclusions

Throughout the various conflicts the US military has experienced, the role of radiology has expanded and redefined its place in the combat environment. CT scanners are getting closer to the frontlines and thus placing the diagnostic radiologist closer to the warfront than ever before. However, IR has yet to define its place in the deployed setting. From simple to complex procedures, IR has a vast array of skills to offer regardless of the technology available.

Compliance with Ethical Standards

Conflict of Interest Drs. Kitley, Mallari-Ramos, and Thoren and Mr. Mendoza declare no conflicts of interest relevant to this manuscript.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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