Interventional Radiology in the Austere Environment

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ABSTRACT

Natural disasters, political turmoil, economic strife, and armed conflicts abound throughout the world. In efforts to ease human suffering and care for wounded soldiers, there is a significant demand for the delivery of high-quality medical care in environmentally challenging situations. Humanitarian assistance, disaster relief, and combat operations present three unique settings for the practice of modern medicine. As a subspecialty that has become integral to the delivery of high-quality health care, it is incumbent on interventional radiologists to seek ways to adapt their specialty to the austere environment. Advances in technology coupled with cognitive ingenuity have enabled interventional radiologists to move out of the medical center and into tents, ships, and battlefields.

KEYWORDS: Interventional radiology, humanitarian assistance, disaster relief, combat

Objective: Upon completion of this article, the reader should be able to list the differences between humanitarian assistance, disaster relief, and combat operations and explain the role interventional radiology can play in each.

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Interventional radiology (IR) is a subspecialty of medicine generally defined by cutting-edge technology. What enables interventional radiologists to do complex, minimally invasive procedures is the vast armamentarium of specialized and costly devices and catheters, which are used in conjunction with state-of-the-art imaging equipment: angiography suites, computed tomography (CT) scanners, ultrasound (US) units, and magnetic resonance imaging scanners.

Given these seemingly immobile, technologically intensive hardware requirements, it may initially

appear that IR is not a specialty suited to being practiced in austere environments including humanitarian assistance (HA), disaster relief (DR), and military combat operations. As a result of the current worldwide political and economic milieu, as well as advances in transportation and communication technologies, there have been increasing efforts by industrialized nations to lend, among other things, medical support to underserved or environmentally ravaged communities. Because IR has become so integral to the practice of modern medicine, it is germane

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Figure 1 Sailors assigned to *USNS Mercy* refurbish a school during Operation Unified Assistance (File 050424-N-1485H-06).

to look at ways the specialty can assist primary care providers and patients in these challenging environments.

HA

HA is generally used to refer to elective missions in regions lacking medical infrastructure. When performed by governmental bodies, such as the military, it is important to remember that it is largely a vehicle of diplomacy. The medical mission is often done in conjunction with civil action projects such as construction or renovation of schools and clinics, implementation of water purification measures, and disease vector control. In the HA setting, the populace has *not* recently suffered a sentinel event such as a natural disaster or political/military action that has undermined the existing medical infrastructure. The scope and complexity of medical care that can be offered during the HA mission is largely predicated on the amount of time available to spend in the location. Although both civilian and military organizations conduct HA operations, most HA missions are performed by nongovernmental organizations, which frequently rely on private funding and are thus often limited in their technological capabilities. Traditionally, the U.S. military, particularly the U.S. Navy, will embed HA operations into an already-existing operational deployment. Because of the nature of the global security deployment objectives, HA initiatives will be completed on an abbreviated timeline and will usually consist of only basic health care offerings. Examples included primary care, immunizations, and educational health programs. Additionally, military medical assets may be deployed to nearby locales where goodwill can be

fostered through medical diplomacy and civil action/community relation projects (Fig. 1).

DR

DR is fundamentally different from HA. DR involves infusion of medical and civil reconstruction assets into a populated area devastated by either a natural disaster or civil or military unrest. The degree of medical infrastructure in DR missions varies and depends on the scope of the disaster and how the preexisting health assets in the community were affected.

The medical mission in DR is therefore significantly different from HA and involves at least three categories of patients:

1. Casualties that are a direct result of the disaster
2. Patients requiring treatment of acute medical and surgical diseases that arise postdisaster but cannot be managed by the local medical community due to destruction of the preexisting infrastructure
3. Patients requiring care for preexisting medical conditions

HA versus DR

A common but critical pitfall in the approach to HA and DR is to conceptually bind the two entities. Each should be recognized for its distinct qualities and treated as such. HA missions deal with a population in status quo. Although the community health condition seems dire from our perspective, the population is relatively stable. Therefore, the medical mission should address long-term issues from a primary care and preventive medicine

Figure 2 (A) USNS Mercy and USS Abraham Lincoln off the coast of Banda Aceh, Sumatra, Indonesia February 3, 2005. (B) USNS Mercy relieves Lincoln to begin Operation Unified Assistance I.

approach. The complexity of the medical services will thus be dictated by factors such as time on station, number of personnel, equipment, cost, and professional expertise. The HA providers must also respect the local medical community to not undermine local health care providers' credibility with the population once the HA team vacates the region. The mantra of HA is to provide "the greatest good for the greatest number."

DR deals with a community or region in a state of turmoil. There are typically many traumatic casualties and often a great number of deaths. The infrastructure may be devastated, undermining basic services such as utilities and civil security. Transportation may also be a fundamental problem impeding the ability to deliver health care and disrupting the overall logistical chain. DR missions must operate in a state of triage, mindful of the requisite need for continuous retriage of patients. As in any triage environment, prioritization is a function of resources. Clearly defined capabilities, goals, objectives, and end points must be defined *in advance* to appropriately categorize patients. Similar to HA, these priorities will be driven by factors including time, personnel, equipment, cost, and expertise.

IR IN THE HA AND DR ENVIRONMENT

Because the HA and DR medical environments present such uniquely challenging obstacles to the delivery of any level of health care, is it possible to integrate IR into these settings? On the surface, the hallmark of IR is its technological innovation. Although the technological innovation is a prominent feature of image-guided procedures, it is the creativity that is inherent to the field that has driven its technological innovation. The ingenuity that permeates the IR mind-set is what makes it a viable specialty in the austere environment. As skilled clinicians who are experts in their craft, interventional radiologists routinely solve complex problems by thinking outside of the box. By integrating their understanding of medicine with the application of their tools, they are able to formulate novel solutions to clinical and/or logistical obstacles.

IR Afloat

Following the massive 2004 Asian tsunami, the United States deployed one of its two hospital ships, the USNS Mercy, in her first of its kind mission to deliver massive HA and DR (Fig. 2). The mission was conceived to initially provide DR to the most heavily affected area—Banda Aceh, Indonesia—and to follow with "island-hopping" HA missions throughout the Pacific. The geopolitical success of these missions has inspired policy makers to not only continue, but increase the military's role in global HA. Since 2006, the U.S. Navy has utilized both of its hospital ships, *Mercy* and *Comfort*, in annual dedicated HA deployments throughout Central and South America as well as the Pacific Rim.

Specifications of USNS Mercy

IR played a vital role in the DR missions in post-tsunami Banda Aceh [Operation Unified Assistance (OUA) I] and subsequently in earthquake-ravaged Nias Island, Indonesia (OUA II). The employment of IR was certainly facilitated by the substantial equipment that the *Mercy* brought to bear on the mission (Table 1). A full range of procedures were successfully performed in these devastated regions due to the presence of a dedicated shipboard angiography suite, CT scanner, C-arm capabilities, and US, in addition to pediatric and adult anesthesiologists, postanesthesia care unit, and intensive care unit (ICU) support. Due to obliteration of the local infrastructure, patient transport presented a substantial challenge. This was overcome by using helicopters in Banda Aceh and helicopters and small boats in Nias (Fig. 3). An unforeseen difficulty, ship motion, arose that uniquely affected the performance of interventional procedures. In the often unpredictable waters of the Indian Ocean, heavily pitching seas presented a unique and previously unexperienced dimension to complex cases such as neuroembolization (Fig. 4). Technical challenges such as these were mitigated through coordination with the ship's captain who would either redirect the ship into calmer seas or in a more favorable

Table 1 Specifications of USNS Mercy

Commissioned: November 8, 1986, San Diego, CA
Length: 894 feet
Beam: 106 feet
Draft: 33 feet
Displacement: 69,360 tons
Range: 13,420 nautical miles
Speed: 17.5 knots (20.13 miles per hour)
Aircraft: helicopter platform
Bed capacity: 1000/80 intensive care unit/20 PACU postanesthesia care unit
Operating rooms: 12 (including angio suite)
Auxiliary services: radiology, laboratory/blood bank/ histopathology, burn unit, pharmacy, dental, physical therapy, optometry/lens fabrication, central sterile receiving, biomedical repair, engineering services medical gas production, laundry services
Water production: 300,000 gallons per day

direction to minimize roll, thereby easing the tasks of catheter and guide wire manipulation.

What role can IR play in DR? In sophisticated environments such as aboard the *Mercy* or *Comfort*, a traditional trauma/inpatient setting practice can be expected, which includes performance of procedures such as embolization, optional inferior vena cava (IVC) filter placement, abscess drainage, chest tube placement, and venous access, among many others (Fig. 5). Approximately 300 minimally invasive, image-guided procedures were done aboard *Mercy* during her 2005 deployment. However, it is noteworthy that only ~85 of these procedures required use of the angiography suite, and ~20 additional procedures were done in the CT suite. Thus, nearly two-thirds of the procedures were done utilizing US and/or fluoroscopy—modalities, particularly US, which are generally easily available in even the most primitive of environments.

Advancements in US technology make it an inexpensive, portable, and nearly ubiquitous imaging modality. In concert with newly available portable digital radiography units (Fig. 6), a wide array of lifesaving and morbidity-sparing procedures can be performed with relative ease and little expense, and can be done in nearly any environment—including tent facilities. US can be used to diagnose and subsequently treat entities such as intra-abdominal (including commonly encountered solid organs, for example, the liver) abscess, empyema, pyonephrosis, and cholecystitis (Fig. 7). Placement of pigtail drainage catheters is a safe and effective treatment for illnesses with potentially high morbidity and mortality. Their use is particularly well suited to the austere environment because the care of the drain can easily be handed off to the local medical community for long-term management and removal. This provides a vital service to the patient while promoting cross-cultural

Figure 3 (A,B) Crew from *USNS Mercy* perform helo-borne ship-to-shore patient transport during Operation Unified Assistance (File 050212-N-0357S-114).

alliances and fulfilling the coexistent goal of medical diplomacy. Central venous access in the form of percutaneously inserted central catheters (PICCs) is also easily done with minimal supplies and equipment and can provide a vital lifeline through which to deliver long-term antibiotics for treatment of posttraumatic illnesses such as osteomyelitis and abscess.

Special Considerations

One of the inherent complexities in delivery of medical care in the austere environment is consideration of the “exit plan.” In other words, what procedures or therapies can, *or should*, be initiated given the abilities

Figure 4 (A) Large, heterogeneous right neck mass with areas of avid contrast enhancement. Ultrasound-guided biopsy confirmed this to be a papillary thyroid carcinoma. (B) Selective external carotid arteriogram prior to preoperative embolization. (C) Postembolization arteriogram.

and limitations of the local community to provide any ongoing care that will be required. For example, there is a stark difference between the long-term care plan when performing DR following a hurricane in Louisiana

versus a massive earthquake in the remote mountain ranges of Pakistan. Situations arise where evidence-based medicine cannot be applied because no study has been (or ever will be) performed evaluating the efficacy

Figure 5 (A) Optional inferior vena cava filter placement in polytrauma victim (Operation Unified Assistance II). (B,C) Selective preembolization left uterine arteriogram prior to hysterectomy in patient with massive fibroid uterus (B), computed tomography (C). (D,E) Contrast-enhanced computed tomography images reveal left-sided xanthogranulomatous pyelonephritis complicated by large retroperitoneal abscess formation. (F) Spot fluoroscopic image following placement of two percutaneous drainage catheters; biliary drains were used to provide additional side holes. (G,H) Chest radiograph reveals massive left-sided empyema associated with aspiration pneumonia, treated by percutaneous tube thoracostomy placement (Operation Unified Assistance I).

Figure 6 Portable digital radiography unit being utilized ashore for tuberculosis screening prior to patient movement to *USNS Mercy* (Operation Pacific Partnership, 2006).

of such deviations from the Western standard of care. For example, during OUA II, many crush injury victims were treated who had complex orthopedic trauma, including pelvic and/or multiple long-bone trauma. Although it is well supported in the literature that these patients are at high risk for venous thromboembolic events,¹⁻³ an added confounder in this environment is the difficulty providing continuous systemic anticoagulation once the ship has left and the patient is returned to his local community. This presents a dilemma as to how best to reduce the risk of pulmonary embolism. A multidisciplinary team aboard the *Mercy* confronted this and many other comparable dilemmas throughout the deployment. The pros and cons of the situation were discussed until a solution could be formulated, which was based on agreed-upon *most likely* long-term outcomes. In this example, it was concluded that the risk of

optional IVC filter placement (albeit with probable lifelong implantation, as the means to remove an optional filter was nonexistent locally) was a superior strategy for reducing the risk of significant pulmonary embolism compared with providing a markedly abbreviated course of anticoagulation. However, the real take-away lesson is that unique scenarios arise during these operations, which compel the clinicians on site to weigh the pros and cons of the available options and determine the best, although often unorthodox, solution for their patients.

An equally challenging clinical dilemma may arise during HA missions or be embedded into the third facet of DR: caring for the chronically ill (often in response to local officials' request). During the Asian tsunami experience, a vast number of patients were evaluated and treated for massive head and neck malignancies, the etiology of which is likely multifactorial and beyond the scope of this discussion. Because a pathologist was available (a luxury seldom enjoyed during HA/DR), biopsies were performed using basic US guidance and accurate cytological diagnoses were made (Fig. 8). Many of the tumors, although widely disseminated throughout the neck, were nonanaplastic thyroid carcinomas. Two major shortcomings to treatment existed, which presented a challenging dilemma: (1) the absence of I-131, and (2) the lack of availability of levothyroxine for the average Indonesian citizen. These factors essentially excluded standard therapeutic options for these patients. Despite being a vast deviation from Western practice, it was decided that the best option for these patients was to do a subtotal thyroidectomy utilizing perioperative US to identify the "most normal" appearing portion of the thyroid gland and leave that

Figure 7 (A) Computed tomography image reveals massive bilateral hydronephrosis on the basis of congenital ureteropelvic obstruction in 15-year-old female with fever and elevated serum creatinine. (B) Fluoroscopic image (prone) following left-sided percutaneous nephrostomy tube placement. Right-sided nephrectomy was performed.

Figure 8 Contrast-enhanced computed tomography image of large, heterogeneous neck mass. Partial resection was performed, which revealed thyroid carcinoma.

tissue unresected, preventing the patient from becoming profoundly hypothyroid. With unsubstantiated long-term outcomes available even anecdotally (due to the inability to have any meaningful follow-up) and clearly a controversial treatment option, this illustrates another example of the inventive mind-set that is requisite to all aspects of HA/DR.

Angiography Suites within the Combat Theater

Coalition forces have been involved in at least two major conflicts in Central and Southwest Asia for nearly a decade. These wars have created a fervent demand for strategies and techniques to mitigate the morbidity and mortality of combat wounded. From the introduction of modern forms of anesthesia, to penicillin, to utilization of helicopters for medical evacuation of casualties (MEDEVAC), armed conflicts have been a flash point for advancements in the delivery of medical care.⁴ Operation Iraqi Freedom and Operation Enduring Freedom have continued the tradition of wartime contributions to medical science. The combination of improvements in body armor and armored vehicles has been a significant factor in the reduction in combat deaths compared with past conflicts; however, the enemy's introduction and refinement of the improvised explosive device has resulted in high numbers of extremity injuries, which often require amputation. This has led to an unprecedented advancement in prosthesis technology, vastly reducing disability and improving the quality of life for thousands of wounded veterans.⁵ Another major advancement that has saved lives and reduced morbidity and disability is the continuous improvement in the MEDEVAC system. These improvements

Figure 9 Utilization of ultra-portable sonography machine during humanitarian assistance operation in Alor, Indonesia (Sono-Site, Bethell, WA).

include transportation and communication methods to pinpoint localization of casualties through the universal employment of global positioning systems and implementation of forward, advanced, highly mobile, yet highly capable, medical treatment facilities. This has resulted in progressive reduction in the time from battlefield injury to definitive surgical treatment.

Improved casualty outcomes have also been facilitated by improvements in medical technology. These advancements have created opportunities to deliver modern health care on the battlefield utilizing smaller, more durable, and more environmentally tolerant equipment. IR is one of the many medical specialties that has benefited from these technological gains.

Portable rechargeable US units are available that are durable, easy to operate, and inexpensive. Most importantly, they produce high-quality images, enabling operators to perform a vast array of percutaneous procedures with minimal infrastructure. These US units can be easily transported in a backpack and taken directly into a field environment where tent hospitals (or less) are employed to treat combat casualties (Fig. 9).

High-quality fluoroscopy has also become readily available in the combat hospital. Most modern C-arms have excellent image quality and can be readily purchased with digital subtraction software, enabling a wide range of vascular and nonvascular procedures to be performed. Although military planners may not equip field hospitals with the intent of doing interventional radiological procedures, they do prepare for orthopedic and other surgical procedures that require fluoroscopy. This presents a readily available opportunity for radiologists and other specialists trained in minimally invasive image-guided procedures, such as vascular surgeons (who are commonly assigned to combat hospitals), to apply their skills to save lives and minimize disability.

The combat environment creates a unique need for IR procedures, particularly angiography. Although IR has become an accepted mainstay in the management of civilian trauma, it is even more critical on the

Figure 10 Diagnostic angiography in the combat environment. (A) Soldier with gunshot wound through ankle with absent pedal pulses. (B) Lower-extremity arteriography reveals injury to tibial arteries requiring short-segment bypass surgery. (C) Popliteal arteriography following high-velocity gunshot wound to knee with associated tibial plateau fracture. Arteriogram reveals extrinsic hematoma without intimal disruption. Hematoma easily evacuated prior to medical evacuation to Landstuhl Regional Medical Center, Germany, without need for arterial repair or bypass procedure. (D–F) U.S. Marine with devastating chest injury following improvised explosive device blast. Angiography of great vessels confirmed venous source of bleeding, assisting surgical planning by obviating need for massive thoracic exploration.

battlefield. This is due to important distinctions between battlefield and civilian trauma that arise from their major mechanisms of injury. Combat wounds tend to result from high-velocity, penetrating injuries, which are fre-

quently accompanied by blast effect. This is in contrast to civilian trauma, which typically results from blunt or low-velocity projectile mechanisms. The tissue cavitation and projectile tumbling resulting from high-velocity

Figure 11 (A,B) Makeshift drainage bag following placement of chest tube for empyema in local national Afghani citizen. (C) Left (prone) nephrostomy tube placement in child with ureteral disruption following penetrating blast injury. (D) Spot fluoroscopic image following right basilic vein percutaneously inserted central catheter line placement in pediatric patient.

missiles, and the cavitation associated with blast injuries results in vascular injuries, which may be remote from the actual projectile tract and also frequently result in endoluminal vascular injuries. These patients are better evaluated angiographically than surgically for at least two reasons: (1) angiography can evaluate large regional territories in a single procedure with minimal invasion, and (2) angiography provides superior evaluation of endoluminal injuries, such as arterial dissection, compared with direct surgical observation (Fig. 10).

In the 8-year history of Operation Enduring Freedom, the summer of 2009 was the bloodiest to date. An international team of trauma surgeons, orthopedists, vascular surgeons, intensivists, and an interventional radiologist collaborated at the Role 3 Multi-National Medical Unit (Role 3), Kandahar Airfield, Afghanistan to select patients who would benefit from IR procedures in their mobile field hospital. Procedures that were uniformly deemed to be lifesaving and/or limb-saving, or would alter surgical management, were

successfully performed in this forward combat environment. These included, among many others: arterial embolization; optional IVC filter placement in patients with complex orthopedic and/or neurological trauma; diagnostic angiography for evaluation of extremity as well as head and neck (particularly zone I) wounds, resulting in modification or obviation of surgical explorations and bypasses; percutaneous abscess drainage; nephrostomy and nephroureterostomy placement; percutaneous chest tube placement for empyema; pediatric central venous access; and PICC line access (Fig. 11).

Procedures requiring fluoroscopy were performed in the operating room and, not surprisingly based on the procedure description, required very basic angiography supplies (Fig. 12). Given the luxury of excellent logistical support, the interventionalist at the Role 3 was able to perform more advanced procedures such as stent-graft placement and embolization. The two greatest technical challenges of the Afghanistan experience were the lack

Figure 12 (A,B) Typical mobile field hospital operating theater being utilized to perform C-arm angiography in a combat casualty (OEC 9800, GE Medical Systems, Milwaukee, WI).

of a proper operating room table for fluoroscopic procedures and the absence of a power injector. The Role 3 had three operating suites, two of which could accommodate the C-arm (one could not based on its low ceiling height). None of the rooms had radiolucent tables. Although this required creative patient positioning and tube angulation to visualize the area of interest, it was always possible to obtain the needed views (Fig. 13). And as in any process, the operating room team quickly became proficient on repeat procedures at maneuvering the patient and the fluoroscopy unit to achieve the necessary field of view. Although procedure times were sometimes slightly increased due to the cumbersome positioning, the benefit for the patient was substantial. The lack of a power injector, while

suboptimal, was also not prohibitive. The on-site presence of a 16-slice CT scanner precluded the need for diagnostic aortography, leaving the remaining angiograms able to be satisfactorily performed using selective hand-injection technique.

The benefit of angiography was so readily apparent that both shortcomings were rapidly addressed. Within the first 3 months of introducing angiography to the combat zone, a radiolucent Jackson table and a power injector were purchased. With a relatively small outlay of capital, an elevated standard of care was facilitated without the need of additional infrastructure.

CONCLUSION

IR is one of the most comprehensive fields of 21st-century medicine. Procedures involve all organ systems and range from elegantly simple to intricately complex. The unifying theme is that regardless of the level of complexity, each procedure helps optimize patient care, in any environment. It should be defined not by its reliance on technology, but rather on its inherent adaptability.

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