Portable 3D X-Ray Diagnostic Imaging: Improving Patient Outcomes In Battlefield Emergency Settings

A portable diagnostic tool with localization and quantification capabilities could eliminate trips to medical facilities and improve patient survival outcomes in emergency settings.

By Nuruzzaman Noor, Zena Patel, Kristen Schmiedehausen, and Gil Travish

Diagnostic imaging in war zone battlefields and mass casualty events is uniquely characterized by unpredictable resource- and time-limited environments. This austerity impacts every diagnostic and treatment decision, from first-responder combat medics treating casualties under fire (Role 1: point of injury care) to physicians caring for critical patients in forward-operating field hospitals (Role 2: basic primary care), as well as the various critical care transport methods.

Additionally, terror attacks on civilian centers throughout the world mean that such restrictive and overwhelming conditions are also faced by civilian healthcare providers. For example, shrapnel injuries, once confined to the battlefield, are now frequently seen in non-combatants.

Explosions from high-velocity projectiles and blast weapons, fragmentations from IEDs, and shrapnel can cause tissue damage resulting in multi-system, life-threatening injuries — in multiple victims, simultaneously — and yield complex triage and diagnostic challenges for radiologists. Secondary blast injuries involve projectiles: Shrapnel, stone, and earth are the primary wounding agents.

Impacting fragments typically travel at lower velocity (<600 m/s) than bullets but undergo motion that dramatically increases the amount of tissue damage. Shrapnel usually affects the musculoskeletal system; approximately 60 to 70 percent of non-lethal injuries are orthopaedic in nature. Unique patterns of injury are found in all blast types but usually involve abrasion of soft tissue, bone fractures, and wounds prone to infection. To add further complication, civilian victims of suicidal and improvised bombings present with a wide range of injury patterns, which often differ from those incurred by military personnel in similar situations.

Effective disaster response begins with timely and accurate assessment of the situation, followed by a well-coordinated and appropriately resourced response to minimize the risk of negative outcomes. To this end, medical imaging techniques are used for diagnosis and triage, shrapnel localization, and determining the timing and extent of treatment and therapy guidance. However, pre-hospital diagnosis and care for blast injury casualties does not currently involve imaging for embedded shrapnel (Figure 1). Currently, prior to hospital admission, a handheld Geiger counter is often used to detect any potential radioactive material in/on the casualties; it also detects embedded radioactive shrapnel, as long as it is not located deep within the body.

The ability to detect shrapnel and localize its position...
with respect to critical organs before moving the patient (i.e., in the field) is likely to have a material impact on patient well-being, considering that shrapnel readily migrates within the body, potentially causing further damage. As such, aides in localizing structures and providing estimations of foreign object position and size are required in the field. The ability to view a comprehensive 3D image of any area before surgery also limits unexpected outcomes in the operating theater and increases the efficiency of treatment.\textsuperscript{15,16,17,18,19}

There are several diagnostic tools available for shrapnel detection, including general X-ray imaging, computed tomography imaging (CT), ultrasound, and angiography. These tools are used in a hospital setting before surgery for shrapnel removal or directly following a blast injury event. Ultrasound currently is the best imaging method to use in determining the relationship between the shrapnel and other structures in the body, such as tendons. The introduction of ruggedized, handheld ultrasound devices by SonoSite in 1999 transformed diagnostic capability on the modern battlefield.\textsuperscript{1}

Metal detectors have also been used and are the most portable device for shrapnel detection but, as with the Geiger counter, will not detect metal deep in the body or inform of the shrapnel’s relative anatomical position. Non-metallic shrapnel also would not be detectable. Magnetic resonance imaging (MRI), normally a critical tool for surgical planning, is unsuitable for imaging shrapnel, as the strong magnetic fields used may move the shrapnel inside the body, causing further injury. MRI equipment is bulky and difficult to deploy in field-forward hospitals.

X-rays, meanwhile, are the oldest and most commonly used form of non-invasive medical imaging and have recently shown promise for in-the-field use. X-ray radiation passes through the body to image a person’s internal structure, depending on the degree of interaction with the variable density organic material. Such methods allow the presence, size, and location of areas of interest to be imaged in detail.\textsuperscript{20} The importance of radiology in field medicine was first recognized in the Second Boer War (1899-1902), and it was subsequently used in World War I by army surgeons, who quickly became accustomed to working with radiologists in a team. Medical imaging techniques, such as X-ray imaging, are currently invaluable patient management methods within the golden hours of a combat emergency for first responders in combat casualty care, as well as civilian disaster medical support, helping to image the site and measure the extent of the injury, which feeds into surgical planning, is unsuitable for imaging shrapnel, as the strong magnetic fields used may move the shrapnel inside the body, causing further injury. MRI equipment is bulky and difficult to deploy in field-forward hospitals.

X-ray imaging in Role 1 battlefield imaging applications.\textsuperscript{24} Mobile healthcare technology, such as tomosynthesis and its 3D imaging capability, should allow faster processing and transport of patients, improved accuracy of triage, and better monitoring of the unattended at a disaster scene, improving scarce transportation and human resource allocation in high-risk arenas for improved patient care and survival outcomes.\textsuperscript{13,21,25}

X-ray tomosynthesis uses multiple projections acquired over a limited range of angles to image a stationary patient.\textsuperscript{26} As such, tomographic images can be rendered in 3D (similar to CT), with high in-plane spatial resolution, obtained at low dose and with scanning times of approximately 10 seconds, using a moving source.\textsuperscript{27} Tomography, combined with novel technologies for automated shrapnel localization and quantification, potentially adds to the arsenal of decision-making tools for enhancing patient care, especially where prompt diagnosis and treatment of medical and surgical conditions is required. Existing tomosynthesis systems rely on motorized tube-based X-ray sources, which reduce the systems’ ease of mobility.

However, it now is possible to realize a rugged, compact, lightweight, and portable X-ray-based diagnostic 3D imaging system, with wireless integration and versatility of power source, for use in the field for war zones, disasters, and emergency settings (Table 1 and Figure 3 compare various available technologies). Advancements in X-ray source technology allow motion-free tomosynthesis with lightweight distributed sources. The enhanced diagnostic 3D imaging capability will accurately localize shrapnel/foreign bodies in relation to anatomic structures to better determine the approach for their removal. Using innovative image reconstruction techniques, the field image will be of sufficient quality (high sharpness and signal-to-noise) to allow a go/no-go decision with respect to transporting the patient for further treatment or assessment across a diverse range of battlefield settings and mass casualty events.\textsuperscript{1,8,21}

For shrapnel detection, a panel X-ray source (either curved or flat), comprising an array of emitters across the
entire surface, is used to provide the minimum X-ray dose to the patient. Imaging in the field is a two-step process:

1. A set of emitters in the panel X-ray source, in conjunction with a detector, allows capture of an overall image of the patient. Any shrapnel in the body will appear as a dark spot on the patient image, as it absorbs X-rays which pass unmolested through tissue. This provides initial shrapnel localization in the x-y plane (top view of a patient lying down), displayed on an image of the patient's body.

2. Emitter clusters, localized above each of the detected shrapnel pieces, are switched on for more detailed imaging. Triangulation is employed in processing these signals by utilizing the overlapping X-ray cone beams provided by multiple emitters and located close together above the region of interest. The known distance from the source to the detector is used together with the spot length created by the shrapnel to determine the depth (z plane) and length of the shrapnel.

A panel X-ray source would be compact enough to be used in the field and will provide clearer and more objective imaging quality than ultrasound, such that smaller pieces of shrapnel may be detected. For this Role 1 application, a curved X-ray panel could be mounted on wheels and rolled over the patient. Further, this method of imaging may also be used in Role 2 hospital settings before surgery to identify the location and depth of the shrapnel inside the patient.

While portable X-ray exams may offer a lower quality than those performed in a radiology department, the usual imaging pathways are disrupted in emergency settings, due to staff and facilities being overwhelmed. Furthermore, improving convenience and eliminating trips to medical facilities is an accelerating trend in the commercial medical device space. Thus, a portable 3D X-ray diagnostic imaging tool with localization and quantification capability would have great potential to improve patient survival outcomes in battlefield and other emergency settings.

References

Figure 3: Images of various 3D flat panel X-ray source devices detailed in Table 1. Left: Xintek device. Middle: Stellarray device. Right: Tribogenics device.

Table 1: Comparison table of various new portable application X-ray source technologies.

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<tr>
<th>X-ray Source Application Focus</th>
<th>Adaptix Imaging</th>
<th>Xintek</th>
<th>Stellarray</th>
<th>Tribogenics</th>
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<td>High-power medical imaging</td>
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<td>Graphite based</td>
<td>Triboelectric polymer</td>
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