Bringing Radiology And X-ray Imaging To The Wounded Warrior

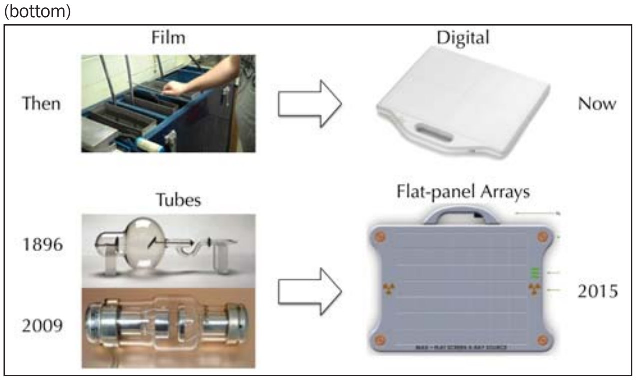
The evolution of X-ray imaging

by Mark Evans, Tom Carrell, Kristin Schmiedehausen, and Gil Travish

The simple 2D X-ray remains the staple of medical diagnostic imaging, even after over a century of technical and clinical development. While more advanced imaging modalities such as computer tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET) can offer the clinician enhanced diagnostic insights, these 3D imaging methods come at the expense of increased size and weight, preparation and acquisition time, complexity, and (often) radiation dose. So, planar radiology still offers the most rapid and simplest means of diagnosing a wide range of medical conditions and is often the first-line imaging technique in any type of emergency situation.

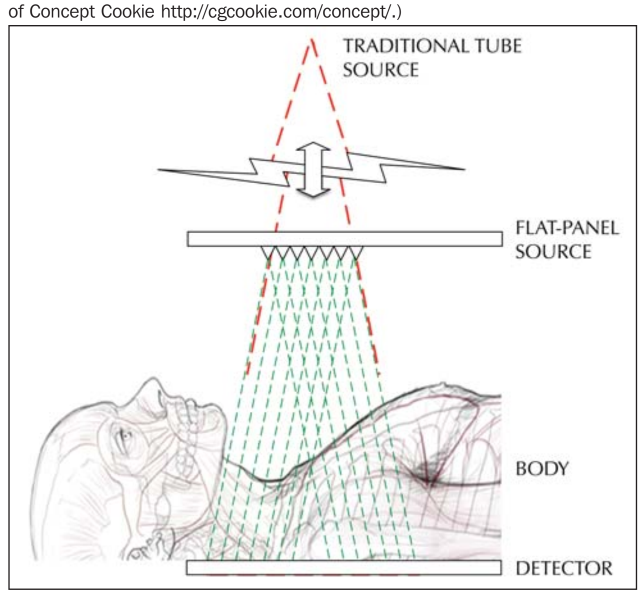
In a typical planar radiology system, X-rays are generated in a vacuum tube powered by a high voltage generator, which produces a cone of X-rays; it is effectively a point source. The X-ray source is typically big, heavy, and fragile. The X-rays traverse the patient, and the resulting attenuated beams are intercepted by a detector positioned directly behind the body part to be imaged. The transformation from the traditional X-ray film to digital detectors has occurred within the last two decades, which led to the elimination of process chemicals, time delays for developing, and to the arrival of nearly instantaneous image viewing, transmission, and storage. Now a similar transformation is set to occur for the X-ray source (Figure 1).

Figure 1: From film to digital radiography (top); from tube to flat-panel source (bottom)



A transition from the traditional X-ray tube to an innovative flat panel source could have enormous impact on the mobility and versatility of radiology and has the potential to revolutionize emergency field medicine outside a hospital setting (Figure 2). The lightweight flat-panel source would allow for the creation of a truly portable X-ray device that could be used in-field for military settings. Emergency situations often require fast treatment and triage decisions — currently based on clinical assessment alone — and many would benefit tremendously from complementary imaging information. A portable X-ray device could provide an immediate diagnosis — a potentially instrumental capability for further treatment and the survival of the patient. This is especially applicable to military medical units, such as Role 1 and Role 2 support units and Forward Surgical Teams (US DoD, 2011) (Nato, 1997), as well as to disaster relief teams, and others.

Figure 2: Traditional vs. flat-panel X-ray source geometries: Traditional sources employ a single cone with a narrow angle of emission and a long distance to the body in order to avoid geometric distortion and to provide sufficient coverage area, while flat-panel sources use arrays of emitters to cover large areas with relatively small "stand-off" distances. (Anatomical drawing used with permission of Concept Cookie http://cgcookie.com/concept/.)



Current Mobile Planar Imaging Options

The current generation of mobile X-ray sources relies on compact packaging of conventional X-ray sources. Increasingly portable X-ray sources are also used in hospital settings in an attempt to provide superior in-patient care, and represent ~15 percent (and growing) of the market for planar radiology. These devices typically weigh from 200 to 300 kg, have a footprint of approximately one square meter, and cost up to $250,000 (list price to the hospital). The size and weight are largely a function of the X-ray source, attendant high voltage power supply, and thermal management equipment — for example, of the 285 kg weight of a Siemens Mobilett, 4.8 kg is the detector, another few kg is the weight of the laptop computer used as an acquisition workstation, and the remainder (>270 kg) is the source. Most of the weight comprises the battery and power supply.

In military and field applications, weight and robustness are paramount. An example of currently available X-ray imaging systems is the MinXray MXRSLW Military X-Ray System that weighs (system and stand) 43.8 kg with a shipping weight (complete system weight in case) of 100.6 kg.

Beyond the critical demands on image quality, there are a number of factors that determine the clinical utility of an X-ray imaging system. However, the current generation of devices offers only a limited range of options due to the inherent size, weight, and profile of the X-ray source.

Benefits Of Portability For The Warfighter

A lightweight and portable X-ray device would enable injured soldiers to be directly imaged at a forward operating base (FOB) or at the site they are wounded in the case of critically wounded soldiers, which would translate into the following benefits:

1. Critically injured soldiers can have the correct placement of artificial breathing tubes (intubation) to ensure that the airway will sustain life until the casualty arrives at a field hospital.
2. Severely injured soldiers can have injuries imaged such that radiologists can read the scans using teleradiology before the casualty arrives at the field hospital, potentially compressing clinical workflow by allowing correct equipment and personnel to be waiting for the wounded soldier on arrival at the field hospital.
3. Disease nonbattle injuries (DNBI) could be imaged by generalist military medical staff in the FOBs and read remotely using teleradiology or locally, to achieve the following outcomes:
   - Soldiers who have minor open wounds could be imaged to ensure that there are no foreign bodies, allowing the wound to be managed without evacuation — saving helicopter hours, weight, and the risks associated with helicopter travel in combat zones.
   - Soldiers who sustain musculoskeletal nonbattle injuries (e.g., lower leg injuries were prevalent in Afghanistan due to the combination of equipment, weight, and terrain) can be assessed in the FOB to identify if the injury requires them to be withdrawn from operations or simply left at the FOB to rest. This will reduce either time waiting to be ruled out of service or the alternative costs and risks of helicopter transfer to a field hospital for imaging and subsequent return if the soldier is declared fit. It also means that appropriate treatment can commence earlier. The key benefit of the use of this technology in DNBI is to act as a force multiplier by reducing unnecessary helicopter hours and increasing operational availability of soldiers. Potentially, X-ray imaging could assist in triage decisions that affect whether helicopter assets are placed at risk.

As indicated above, one key benefit of the use of this technology in DNBI is to act as a force multiplier by reducing unnecessary helicopter hours and increasing operational availability of soldiers. Cargo weight for combat health support (CHS) radiological operations can be nearly 1,000 pounds and is of considerable importance. The overall breadbox size and weight of a fully digital imaging system using the flat-panel technology (less than one cubic foot and under 20 kg) are an order of magnitude smaller than any comparable high-energy X-ray device.

An overview of the most important applicable military emergency situations for which portable imaging could provide useful and instrumental information for the medical team before transportation

Table 1: Types of X-ray imaging relevant in a field setting (includes both trauma and medical emergencies).

Acquisition	Clinical rationale / indications
Chest (patient lying on back)	To diagnose air trapped next to the lung (pneumothorax) and blood trapped next to the lung (hemothorax)
All extremities	To identify long bone fracture
Pelvis (patient lying on back)	To diagnose unstable pelvic fracture
Abdomen (patient lying on back)	To aid diagnosis of acute abdomen
Chest (patient lying on back)	To identify correct breathing tube (endotracheal tube) or central venous catheter positions

and hospitalization of the patient(s) can be found in Table 1. The techniques utilized do not differ significantly from those used for routine X-ray exams and could be executed by a technologist, an emergency medicine physician, or any other appropriately trained medical emergency personnel in the field (Figure 3).

Crossover To Nonmedical Imaging

In addition, X-ray imaging finds uses in other military applications including nondestructive evaluation and testing (NDE/NDT) and security screening (packages and personnel). The ability to carry out these functions in the field, under concealment and with greatly reduced logistics requirements, makes for a compelling case for the "fully digital" radiographic solution.

The Next Generation Of Planar Imaging Options

A flat-panel imaging system, while potentially useful in any medical context, is particularly suited to the demands of military field use by virtue of its extreme portability, low power requirements, and simplicity of use and maintenance. As it has only a few components, is lightweight, and has a small footprint, such a fully digital radiology system can be transported easily and set up quickly. This new class of X-ray system has the potential to deliver advanced imaging options (unavailable from current commercial X-ray systems) in areas far from advanced hospitals.

Because these new flat-panel sources dispense with the tube and consist of large arrays of independent X-ray sources, past problems such as fragility of the glass tube and thermal management are reduced. New capabilities such as 3D imaging also become possible, since these distributed sources give more than one angle of view on a body part.

Various approaches are being taken to produce these flat-panel, addressable arrays of X-ray sources. Technologies such as field-enhanced emitters — familiar from plasma TVs — are being adapted for use in X-ray generation. Field generators such as triboelectrics — related to the effect of rubbing fur on an amber rod — and ferroelectrics — similar to the gas stove-top igniters — are desirable for their compact source of high voltage. Ongoing technological challenges include how to address (turn on and off) the emitters, image reconstruction, and fabrication of these technologies into robust medical devices. These challenges are being addressed by multiple research groups and companies.

Future Prospects

Planar X-ray imaging is still the workhorse of medical imaging. Technological advancements have brought planar radiology from simple film radiographs to computer-enhanced digital imaging and made sophisticated 3D imaging possible. Now, there is an opportunity to simultaneously advance general radiology and enable its deployment in the field. Flat-panel X-ray sources will change how and where X-rays are produced. This new class of X-ray source can bring radiology to the point of injury, to the battlefield, and to the warfighter. The hope is that bringing radiology to the patient, in all settings, will improve outcomes and reduce costs much as portable ultrasound has already done (Zaghrini, 2013). ■

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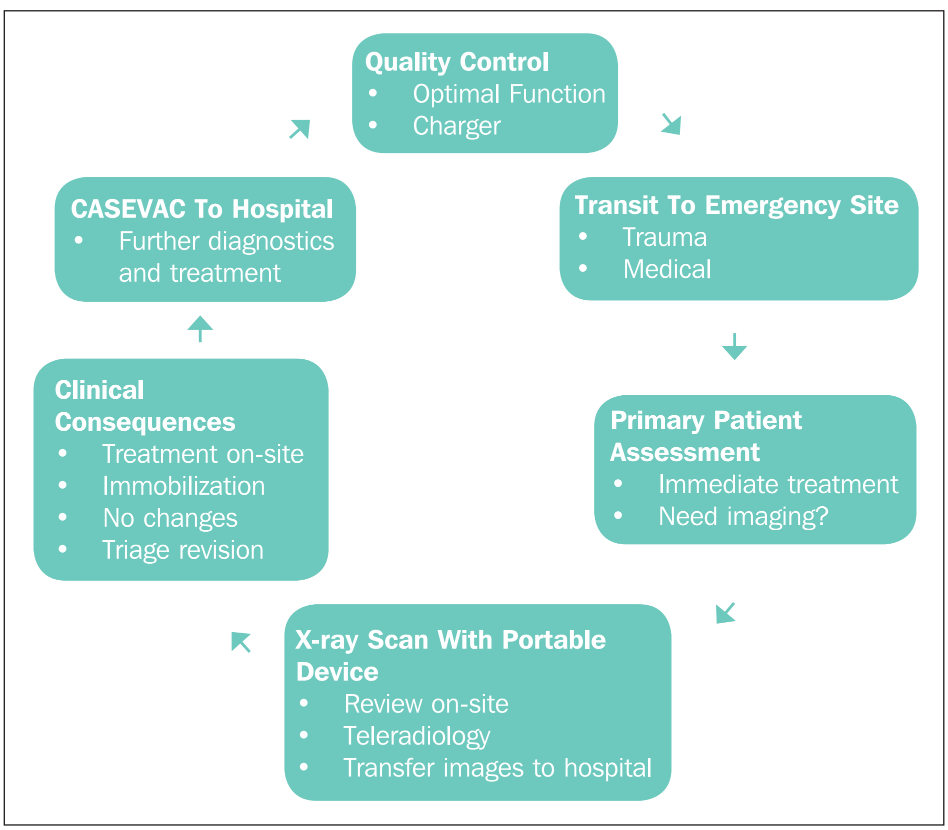
Figure 3: Flow diagram of the use case for a portable X-ray device in a field setting.



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