History of emergency and critical care ultrasound: The evolution of a new imaging paradigm

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The tradition of clinical ultrasound in the hands of physicians who provide critical care to the most acutely ill patients stretches back into the 1980s and is rich with experiences from surgical, emergency medicine, and other practices. Now, as critical care ultrasound explodes around the world, it is important to realize the path its development has taken and learn from trials and tribulations of early practitioners in the field. The development and battles for the right to use ultrasound at the patient’s bedside for >20 yrs is described in relation to its emergency medicine and surgical origins. Approaches to education, scanning, documentation, and organization at the national and regional levels are described. (Crit Care Med 2007; 35[Suppl.]:S126–S130)

KEY WORDS: emergency ultrasound; history; development

The chronology of emergency ultrasound is a confluence of many factors, including input from many specialties, improvements in technology, and a clinical imperative to provide the best possible care to patients with emergency and critical conditions. The history of emergency ultrasound is best communicated by describing the factors that brought about the need for emergency physicians and trauma surgeons to perform ultrasound examinations, the characteristics of examinations they perform, the factors that have contributed to the growth of these examinations, and finally, how the emergency ultrasound examination defines a new paradigm in imaging that can be applied to many different settings.

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Background

The first ultrasound instrument was introduced in the early 1950s; although it was not until the 1960s that similar units became available for limited, primarily experimental use. Barriers to more widespread use included the complexity and size of the early machines, the need to immerse scanning subjects in water, images that were difficult to interpret, and the limited anatomic regions that could be imaged. By the 1970s, ultrasound was being adopted in diverse settings by a variety of clinical specialties. In the early 1980s, there had been significant improvement in the technology to the extent that real-time ultrasound was being developed, which allowed users to view sonographic images without an appreciable delay between signal generation and display of the image. In addition, sufficient images were generated by real-time ultrasound to allow the visualization of continuous motion. Before the development of real-time ultrasound, the complexity of acquiring images prevented the practical application of ultrasound for most injured or emergency patients and was an absolute barrier to usage at the bedside. Real-time scanning was one of the most significant factors in determining how ultrasound would be used, who would use ultrasound, and where studies would be performed.

Significant time and effort was devoted to improving ultrasound devices throughout the 1980s and 1990s. This resulted in the units being smaller, faster, and more portable. Other technological advancements included the transvaginal transducer, multifrequency probes, and color Doppler. These improvements accelerated the movement of technology from the domain of a specific specialty to the bedside, where clinicians could use it for the immediate evaluation of their patients.

While technological advancements were occurring, a similar pattern of growth in clinical applications was being documented. As early as 1970, a radiologist in the United States evaluated the ability of ultrasound to detect instilled saline in the peritoneal cavity of cadavers (1). A year later, the first case report describing a positive ultrasound examination for hemoperitoneum in a patient who had sustained blunt abdominal trauma was published (2). In 1976, an American surgeon used ultrasound to describe and grade splenic injuries (3). The first publication by an emergency physician pertaining to ultrasound appeared in 1988 (4). From the late 1980s through the mid 1990s, significant investigations were conducted in Japan, Asia, the United States, and Germany to evaluate the utility of ultrasound in trauma patients, specifically for the detection of hemoperitoneum and hemopericardium. This research culminated in the description of the Focused Assessment with Sonography for Trauma, or the FAST examination (5–12).

In most trauma centers, the FAST examination has replaced diagnostic peritoneal lavage as the preferred method of initial evaluation and been fully integrated into Advanced Trauma Life Sup-
port teaching. The American College of Surgeons National Ultrasound Faculty has developed several hands-on courses to train surgeons to use ultrasound in many acute settings, including trauma. Consequently, the FAST examination is the initial ultrasound examination for trauma victims performed by trauma surgeons and emergency physicians and is the prototype of “emergency ultrasonography.”

The American College of Emergency Physicians (ACEP) offered its first course specifically dedicated to emergency applications of ultrasound in 1990. In 1991, both ACEP and the Society of Academic Emergency Medicine published position papers recognizing the utility of ultrasound for emergency patients (13, 14). These documents were noteworthy in that they endorsed not only the clinical use of ultrasound but also ongoing research and education. Shortly afterward, in 1994, the Society of Academic Emergency Medicine published “Model curriculum for physician training in emergency ultrasonography” (15). This document’s primary focus was to outline the spectrum and components of the emergency ultrasound examination as a guide for emergency medicine training programs. Shortly after the development of this curriculum, the first textbook dedicated to emergency ultrasound was published in 1995 (16).

In 2001, ACEP published the Emergency Ultrasound Guidelines, which pertain to the scope of practice and clinical indications for emergency ultrasonography (17). This policy statement was noteworthy in that it advanced recommendations for credentialing, quality assurance, and the documentation of emergency ultrasound examinations and that it represents current best practices and standards for ultrasound provided by emergency physicians.

The American College of Surgeons (ACS) has also assumed a leadership role in the use of ultrasound in acute critical care settings. In the mid 1990s, the ACS Ultrasound Users Group was formed. This group of surgical innovators established the concept of surgeon-performed ultrasound on a national basis. In 1995, the ACS Committee on Emerging Surgical Technology and Education established the ACS National Ultrasound Faculty, which was tasked with the development of surgical ultrasound courses, educational materials, and instructors. The National Ultrasound Faculty has developed a modular educational program that permits surgeons and surgical residents to gain ultrasound skills for a number of clinical applications, including the trauma bay and the intensive care unit (18). In 1997, the ACS Board of Regents published a statement regarding verification of a surgeon’s ultrasound qualifications (19).

During the past decade, results of studies regarding emergency ultrasound have been published pertaining to a wide spectrum of clinical conditions, including abdominal aortic aneurysm (20–22), ectopic pregnancy (23–27), thoracoabdominal trauma (5–12, 28), pericardial effusion (29, 30), determination of cardiac activity (31–35), biliary disease (36–39), renal tract disease (40, 41), and procedure guidance (42–44). Each of these is now considered a primary indication for emergency ultrasound (17). Ongoing research will likely establish the efficacy of additional emergency applications such as the assessment of undifferentiated hypotension (45–47), the bedside evaluation of deep venous thrombosis (48–50), and a variety of soft-tissue and musculoskeletal applications (51–54).

Characteristics of the Emergency Ultrasound Examination

Emergency ultrasound studies share a common set of characteristics that reflect their clinical utility and the practicality of performance in the emergency setting. They include the following:

1. Emergency ultrasound examinations should be done for a clearly defined emergency condition in which ultrasound has been shown to improve patient care. This includes life-threatening conditions such as ectopic pregnancy, abdominal and thoracic trauma, or abdominal aortic aneurysm; situations in which invasive procedures can be averted such as needle thoracostomy, pericardiocentesis, or culdocentesis; conditions in which ultrasound can significantly decrease the cost or time of patient evaluation such as blunt abdominal trauma or ectopic pregnancy; and indications in which ultrasound is the primary diagnostic modality such as ectopic pregnancy, gallbladder disease, or abdominal aortic aneurysm.

2. Emergency ultrasound examinations should be focused, limited examinations. Emergency ultrasound diagnostic studies are goal-directed and designed to answer specific questions that guide care. They frequently focus on the presence or absence of a single significant finding such as hemoperitoneum in the blunt trauma patient. These studies are quite different from the complete examinations typically performed by radiologists. Complete studies evaluate all structures and organs within an anatomic region. They are typically more expensive and time consuming because they may address findings unrelated to those necessary for immediate patient management.

3. An emergency ultrasound examination should be characterized by one or two easily recognizable findings. Carefully defined indications result in simple questions, straightforward examinations, and useful answers. For example, free intraperitoneal fluid, a gestational sac, absence of a heartbeat, and the presence of pericardial fluid are all easily recognizable and have clear and immediate clinical utility.

4. The emergency ultrasound examination should be easily learned. Some findings, such as the presence of hemoperitoneum, the absence of lung sliding in pneumothorax, an intrauterine pregnancy, or cardiac activity are relatively easy to learn. Other evaluations, such as evaluation for focal myocardial wall motion abnormalities in ischemic heart disease, are more difficult to assess and learn.

5. Emergency ultrasound examinations should be quickly performed. Emergency physicians and trauma surgeons have limited time with individual patients and may have responsibility for many patients at any given time. Ultrasound procedures in the acute setting should be completed in a reasonable amount of time. Selecting focused examinations that are more quickly performed does not diminish the value of the data, intensity of the service, or the positive effect on patient care. For example, an ultrasound examination performed in the presence of penetrating cardiac injury may be quickly performed, yet it provides potentially life-saving information that cannot be obtained by performing even the most comprehensive physical examination.

6. The emergency ultrasound examination should directly affect clinical de-
cision making and should provide the emergency ultrasound examination should provide valuable information that is used to determine subsequent care. Examinations that will not reasonably be expected to change clinical decision making should be performed on an elective basis.

7. Emergency ultrasound examinations should be done at the bedside. This entails having access to equipment to perform bedside examinations on an immediate basis for unstable patients and in a timely fashion for the stable patient. ACEP policy recommends that optimal patient care is provided when dedicated ultrasound equipment is located within the emergency department (13). The ACS Committee on Trauma’s “Resources for the Optimal Care of the Injured Patient 2006” recommends that an ultrasound machine be immediately available in the trauma resuscitation area.

**Growth of Emergency Ultrasound**

A number of factors contribute to current and future developments of emergency ultrasound. They include a growing recognition of the utility of ultrasound to provide vital information, a need for timely access to ultrasound imaging, declining access to consultative imaging services, improved ultrasound technology, and the endorsement of emergency ultrasound by several specialties for bedside ultrasound.

**Recognition of Ultrasound's Value.**

Key in contributing to the growth of emergency ultrasound is an increased recognition of ultrasound's clinical utility. The primary indications for diagnostic emergency ultrasound were established and endorsed in 2001 (17). Where immediate ultrasound is available, it has essentially replaced invasive techniques such as diagnostic peritoneal lavage and culdocentesis and has obviated the need for blind pericardiocentesis. The use of ultrasound for procedural guidance, such as central venous access, is an evolving standard of care. More recently, the management of patients in cardiac arrest (32, 33, 35) and the evaluation of patients with nontraumatic hypotension (34, 45–47) are examples of ultrasound usage that were not contemplated in the early stages of the evolution of emergency ultrasound but are increasingly becoming a standard of assessment, treatment, and care.

**Timely Access to Imaging.**

For many emergency and critical conditions, ultrasound as a diagnostic tool is needed on an immediate basis, within minutes of a patient’s presentation or deterioration. Examples may include central catheter placement using ultrasound guidance in hypotensive or hemodynamically unstable patients with suspected aortic aneurysm, trauma, or ectopic pregnancy. In addition, patients in cardiac arrest, with penetrating chest injuries, or with undifferentiated hypotension are all candidates for immediate bedside ultrasound. Examinations such as these are extremely time sensitive and typically cannot be performed by even the best-staffed radiology departments or echocardiography laboratories in a clinically useful time frame. For some of these conditions, both diagnostic ultrasound (e.g., abdominal) and echocardiography are required for the same patient, but in many hospitals, these studies are supplied by separate consulting services. It is the physician who is trained in the bedside applications of ultrasound who is in the best position to utilize ultrasound for immediate analysis and treatment of life-threatening conditions.

**Imaging Availability.**

Emergency department and trauma patients do not schedule appointments. Patients present at any time, and a certain percentage of them will require an ultrasound evaluation. Although the utility of ultrasound imaging in emergency patients has grown, radiology departments have become progressively less committed to emergency patients. This is especially true during nighttime hours and weekends. The reasons most often cited for this decreasing access include higher costs incurred by diagnostic imaging services for “off-hours” studies and the paucity of sonographers to perform examinations (55). Consequently, patients are asked frequently to wait until the next day for diagnostic testing. Common examples of this scenario include holding a patient with undifferentiated abdominal pain pending a right upper quadrant study, treating a patient with anticoagulants before a deep vein ultrasound examination, or sending a patient home with suspected ectopic pregnancy before pelvic imaging. Delays and decreased access to diagnostic imaging have the potential to increase risks to patients, worsen emergency department overcrowding, and increase medical liability for emergency physician and surgeons.

On the other hand, immediate bedside ultrasound imaging by clinicians can provide needed data, decrease requirements for studies performed by radiologists, and avoid associated delays in diagnosis and treatment (24, 26, 36, 56–58).

**Improving Technology.**

Technological improvements to ultrasound devices have contributed substantially to the growth and maturation of emergency ultrasound. The stationary, complex devices historically associated with ultrasound imaging have been replaced with a variety of highly portable and more intuitive devices. Hardware improvements have been accompanied by software enhancements, resulting in increased speed, flexibility, image quality, and ease of use. These technological advancements have increased the practical utility of ultrasound and have allowed the movement of this technology from the purview of imaging specialists to the bedside and into the clinician’s hands.

**Specialty Endorsement.**

The use of emergency ultrasound has been endorsed by professional societies such as ACEP, the Society of Academic Emergency Medicine, and the ACS (13, 14, 18, 19). Assumptions underlying these endorsements are that physicians and surgeons in a particular specialty are in the best position to recognize the needs of their patients and, in addition, have an obligation to utilize available technologies that have been demonstrated to improve patient care. Finally, because ultrasound is widely taught in general surgery and emergency medicine training programs (18, 19, 28, 59–67), specialists now enter practice with the expectation of utilizing ultrasound in emergency situations.

**Paradigm of Emergency Ultrasound**

The approach to ultrasound performed by the clinician at the bedside differs significantly from that embraced by radiologists. Specific components, such as who performs the study, where the examination is conducted, how quickly it is accomplished, and how study results are communicated, all differ. In addition, the scope of the examination and study goals are typically quite different. Physician work associated with the examination, the expense of test performance, and how data are integrated into patient care are also unique to each of these approaches.
The paradigm of emergency ultrasound is reflected in the ACEP policy, “Use of ultrasound imaging by emergency physicians” (13).

Ultrasound imaging enhances the physician’s ability to evaluate, diagnose, and treat emergency department patients. Because ultrasound imaging is often time-dependent in the acutely ill or injured patient, the emergency physician is in an ideal position to use this technology. Focused ultrasound examinations provide immediate information and can answer specific questions about the patient’s physical condition. Such bedside ultrasound imaging is within the scope of practice of emergency physicians.

The paradigm of emergency ultrasound has at its origins the study being performed by the treating physician at the patient’s bedside. It is done contemporaneously with patient care, and it is performed on an immediate basis. In this context, “immediate” means within seconds or minutes of the clinician identifying a need. Interpretation of images is done by the treating physician and occurs simultaneously with the generation and display of images. In this approach, permanent images serve to document what has already been interpreted by the treating physician rather than becoming a work product for delayed interpretation by a radiologist. Finally, the scope of the examination is focused, or limited, in nature. The treating physician is seeking to immediately answer a specific question that will drive a clinical decision or be utilized to guide a difficult or high-risk procedure. In the paradigm of emergency ultrasound, the work product is improved patient care by using ultrasound technology. It should be emphasized that the focused examinations performed in this paradigm meet the medical needs of the patient without providing unnecessary services.

The paradigm of consultative ultrasound imaging begins when a treating physician requests a study. The patient is usually transported to an ultrasound suite where a sonographer images the patient. The completed study is presented, or transmitted, to a radiologist who documents the study results and communicates these results to the treating physician. The treating physician then incorporates the reported data into clinical decision making. Real-time ultrasound guidance of emergency procedures is impossible under this paradigm. Diagnostic studies are stored as hard copies in file rooms or in a digital format. The radiologist’s work product is an image and a report that may not appear in the medical record for hours or days.

The paradigm of emergency ultrasound has historically been a difficult concept for traditional providers of ultrasound to understand or accept. Emergency ultrasound is not an inferior imitation of comprehensive consulting imaging services, but rather, it is a focused, appropriate application of technology that provides essential diagnostic information and guidance of high-risk procedures. Unfortunately, the development of clinician-performed emergency ultrasound has been accompanied by a great deal of misunderstanding. Issues of physician credentialing, ownership of technology, exclusive contracts, reimbursement, and specialty society advocacy positions have overshadowed clinical evidence and the practical experience of improved patient care (68). Not only does the paradigm of emergency ultrasound offer tangible benefits in patient care, but it also represents a technology that emergency physicians, surgeons, and others will continue to utilize and refine.

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