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AHC Media

Rhabdomyolysis: Review and Update

In the past few weeks, I have seen several patients with rhabdomyolysis. One of the more memorable patients was a person who had too much to drink at a party, and the guests restrained him with duct tape to keep him from driving. After a night of struggling to get free, he developed dark urine and was admitted to the hospital.

We have also seen rhabdomyolysis from self-poisoning and as a side effect of medication. Although the references suggest this disease is somewhat uncommon, it may be that we overlook some cases.

— Sandra M. Schneider, MD, Editor

Introduction

Rhabdomyolysis is a syndrome with far-reaching systemic sequelae. The release of intracellular components into the vascular space following striated muscle injury produces tissue necrosis, end-organ damage, and metabolic derangements. The incidence of rhabdomyolysis is approximately two cases per 10,000 person-years in North America.[1] The mortality rate is estimated to be 8%.[2]

Rhabdomyolysis was first described in the medical literature after the London bombings during World War II, and began to be fully recognized following studies on military recruits as early as the 1970s. Olerud published a study in 1976 detailing exertional rhabdomyolysis in Marine Corps recruits in 1976.[3] The syndrome has received much more attention in the last 30 years, and now we have a much better understanding of its pathophysiology.

Striated muscle injury is at the core of mechanisms producing vast systemic insults in rhabdomyolysis. Central to the development of the syndrome is intracellular ATP depletion.[4] This triggers a cascade of cellular disruptions, such as Na+ K+ ATPase pump dysfunction, impaired calcium transport, and release of free oxygen radicals.[5] Intracellular calcium levels increase in unregulated fashion, leading to persistent muscle contraction.[6] Eventually, there is cell death. Intracellular components such myoglobin, creatine kinase (CK), lactate dehydrogenase (LDH), uric acid, aldolase, and electrolytes (e.g., potassium) are released into the bloodstream.[4]

Rhabdomyolysis is a systemic event. It involves virtually every organ system. Disseminated intravascular coagulation (DIC), compartment syndrome, electrolyte abnormalities, cardiac arrhythmias, and acute renal failure form part of a large list of potentially life-threatening complications from rhabdomyolysis.[7]

The kidneys are exquisitely sensitive to myoglobin. Not only do the renal tubules sustain significant damage from tissue necrosis and obstruction, but there is also a direct toxic effect of ferrihemate, a byproduct of myoglobin breakdown. Hypovolemia and aciduria appear to compound the effect of myoglobin, resulting in acute renal failure. It is estimated that 30-50% of rhabdomyolysis patients develop acute renal failure.[8] Seven percent to 10% of all cases of acute kidney injury in the United States are due to rhabdomyolysis.[6]

Similar mechanisms may be responsible for the vascular insult and tissue

Executive Summary

- Rhabdomyolysis is caused by the breakdown of muscle tissue. Frequent causes include trauma (especially crush injuries), drugs (particularly statins), insect stings, and infections.
- While classically rhabdomyolysis presents with muscle tenderness, weakness, and dark urine, often patients present without all of the classic symptoms.
- Acute renal failure is the most common complication of rhabdomyolysis, but electrolyte abnormalities of hyperkalemia, hypocalcemia, and hyperuricemia are seen.
- The mainstay of treatment is aggressive fluid resuscitation with either normal saline or lactated Ringer's. Bicarbonate and mannitol have been used, but there are some data to suggest they may not be essential.

necrosis that affects the cardiovascular system and brain, leading to the cardiopulmonary and neurological findings associated with rhabdomyolysis.

There are many causes of rhabdomyolysis. Exercise has traditionally been considered the main culprit. Release of CK during strenuous exercise is a well-documented phenomenon.[9] However, it is important to remember that there are many other causes of muscle injury. Immobilization, medications, environmental exposures, infection, and work-related hazards (e.g., electrical injury) are well known to cause muscle injury, tissue ischemia, and necrosis. It is crucial to remember that rhabdomyolysis is often multifactorial, and each cause can compound the effects of the other.[8]

Table 1: Major Causes of Rhabdomyolysis

Exertional
• Genetic predisposition
Trauma
Drugs
Toxins/venoms
Infection
Environmental
• Heat or cold
Electrolyte abnormalities
Food

Clinical Presentation

The assessment of the patient with rhabdomyolysis must take into consideration the systemic nature of the syndrome. The patient with rhabdomyolysis may present with classic signs and symptoms, including myalgias, weakness, and dark-colored urine. However, only approximately 50% of patients with rhabdomyolysis experience myalgias or weakness. Emergency physicians should be aware that even an obtunded patient may have rhabdomyolysis.

Knowledge of the patient's activities, behavior, and environment prior to the ED visit should trigger the addition of rhabdomyolysis to the list of differential diagnoses. A history should include a thorough medication review looking for medications associated with rhabdomyolysis.

The physical examination may vary widely, and may even be normal. However, fever, tachycardia, hypertension, hypotension, tachypnea, evidence of immobilization, agitation, central nervous system (CNS) depression, seizure activity, edema, and increased muscle tone may be found. Patients with altered mental status and rhabdomyolysis may be particularly difficult to diagnose. The emergency physician should consider the diagnosis when the history is suggestive.

The laboratory workup is essential in determining optimal management of the patient suspected of having rhabdomyolysis. A CK level of 5000 IU/L, or five times the normal level, is considered by most to be rhabdomyolysis, although a definitive number varies in the published literature.[10] The CK should be monitored serially, as its rise may be evidence of ongoing muscle injury. An electrolyte panel, including renal function, magnesium, phosphorus, and calcium should be obtained. A bedside capillary blood glucose is extremely useful in ruling out hypoglycemia. An arterial blood gas is helpful in determining serum pH. Serum and urine myoglobin may be obtained as part of the workup. The patient's coagulation may be useful, as DIC is a severe complication of rhabdomyolysis. Obtain a complete blood cell count with differential, blood culture, and urine culture when infection is highly suspected as the cause of rhabdomyolysis. Chest radiography may help delineate the cause when a pulmonary source is suspected in patients with rhabdomyolysis. A lumbar puncture should be considered in the patient with rhabdomyolysis who have a clinical suspicion of bacterial meningitis.

Cardiac ischemia is a potential complication of rhabdomyolysis, particularly in patients with comorbidities or those known to abuse sympathomimetic drugs. An electrocardiogram and cardiac markers suffice as an initial cardiac workup. A toxicologic workup aids in delineating possible triggers for muscle injury, but a positive test should not stop the search for other possible causes. Panels testing for drugs of abuse are widely available, but other offending agents, such as salicylates,

alcohol, and opiate narcotics, must be considered. When altered mental status is present, a CT of the brain should be considered as an adjunct when intracranial pathology enters the differential diagnosis.

Causes of Rhabdomyolysis

Exertional. The most common causes of non-traumatic rhabdomyolysis are hypermetabolic exertional stress injury. Strenuous exercise will increase serum CK in normal humans. Exertional rhabdomyolysis, or "hyper-CK-emia" occurs in individuals who have a sudden increase in overall levels of physical activity and can demonstrate CK levels more than five times normal. There is an increased incidence in males, African-Americans, and individuals with high muscle mass.[9] The majority of these individuals do not have muscle soreness, weakness, and myoglobinuria, and have CK levels that rapidly return to normal. When hyperCK-emia and myoglobinuria occur in a patient with muscle soreness and weakness, the patient has exertional rhabdomyolysis. A common factor in exertional rhabdomyolysis cases is repetitive exercise or exertion beyond when fatigue would compel an individual to normally stop (for example, new military recruits and participants in long-distance running events). It is exacerbated by high ambient temperatures.

Exertional rhabdomyolysis occurs when exertional energy requirements exceed ATP production. Depletion of ATP within the myocyte during exertion causes a release of calcium into the cell and, therefore, cellular necrosis. The myocytes then become permeable, swollen with fluid, and leak their components into the intracellular matrix. This results in intravascular volume depletion from third spacing and lactic acidosis. There is a resultant rapid increase in serum creatinine. The prognosis for exertional rhabdomyolysis is better than for other forms of rhabdomyolysis and less often results in acute kidney injury. However, exertional rhabdomyolysis exacerbated by severe heat injury will increase risk of renal injury.

Anyone may develop exertional rhabdomyolysis when under enough mechanical and environmental stress. However, exertional rhabdomyolysis can also be triggered by genetic influences that predispose the individual to the development of exercise and heat-related illness. These genetic abnormalities cause abnormal intracellular skeletal muscle calcium regulation via disorders of carbohydrate metabolism, lipid metabolism, or mitochondrial disorders. Recognized genetic causes include McArdle's disease, CPT2 deficiency, and AMPD deficiency.[9] In McArdle's disease, the individual lacks the enzyme to break down muscle glycogen to continue to fuel cells after circulating ATP are spent. Carnitine palmitoyl transferase (CPT2) deficiency causes an increase in open-state probability of RYRI calcium channels, so there is a much lower threshold for high calcium levels within cells to cause cell breakdown. In adenosine monophosphate deaminase deficiency (AMPD), a critical enzyme for muscle energy metabolism is present in abnormally low levels, therefore decreasing exercise capacity and shortening the time to tissue ischemia. Polymorphic variations in angiotensin-converting enzyme, CK muscle isoform, and myosin light-chain kinase have also been associated with exertional rhabdomyolysis.[9] Hereditary causes are listed in Table 2.

Trauma. Traumatic injury is the most common cause of rhabdomyolysis.[11] Table 3 lists the common trauma causes of rhabdomyolysis. The two types of trauma that result in rhabdomyolysis include crush and electrical injuries. Physical beating has also been associated with rhabdomyolysis.[12] Electrical injuries may be caused by lightning or high-voltage electrical current. Due to the short duration of exposure, lightning injuries do not cause significant burns or muscle breakdown. In contrast, high-voltage electrical injuries

Table 2: Hereditary Conditions Associated with Rhabdomyolysis

Carnitine Metabolism Disorders
• Carnitine palmitoyl transferase (CPT2) deficiency
• VLCAD (very long chain acyl CoA deficiency)
Adenosine monophosphate deaminase deficiency (AMPD)
McArdle's disease (glycogen storage disease type 5)
Malignant hyperthermia
Phosphorylase kinase deficiency
Duchenne muscular dystrophy
11-hydroxylase deficiency
Phosphofructokinase deficiency

Table 3: Trauma Conditions Associated with Rhabdomyolysis

• Crush injury
• Compartment syndrome
• Physical torture and abuse
• Exercise
• Heat stroke
• High voltage electrical injury
• Lightning
• Elevated ambient temperature (heat exposure)
• Low ambient temperature (cold exposure)

commonly cause rhabdomyolysis in patients who survive the initial insult. In such cases, rhabdomyolysis cannot be predicted by the size of external wound or site of electrical current entry.[8,13] Up to 10% of patients with severe electrical injuries will develop rhabdomyolysis.[14]

Crush injury is the most common traumatic cause of rhabdomyolysis, as it is seen in natural disasters such as earthquakes and landslides, or in war zones, in which individuals are trapped under fallen buildings.[14] Epidemics of traumatic and crush injuries have been described following massive earthquakes.[15,16] Crush injuries occur when a patient is trapped or compressed under the weight of external forces. Due to external pressure compressing the affected limb, there is inadequate blood pressure to deliver blood and oxygen to the tissue. Intramuscular compartment pressure may rapidly exceed arterial blood pressure, resulting in muscle tamponade, compartment syndrome, and muscular necrosis within the first 30 minutes of injury.[14] Severe crush injury may result in transient flaccid paralysis without spinal cord injury secondary to an increase in compartment pressures and ischemia to peripheral nerves.

Decreased blood flow and lactic acidosis from tissue ischemia causes the release of vasodilatory nitric oxide in crushed muscle. As a result, there is rapid swelling within muscle compartments once the injured limb is released from entrapment. This massive third spacing often causes sudden hypotension, hypocalcemia, and hyperkalemia.[14] Pre-renal azotemia from hypotension, along with lactic acidosis and hyperCKemia, result in oliguria and acute kidney injury. Renal failure causes further sudden increases in potassium levels. The cardiotoxic effects of hyperkalemia are aggravated by hypocalcemia from muscle breakdown. Hypovolemic shock and arrhythmias are the most common early causes of death.[17]

Drug-related. The list of drugs associate with rhabdomyolysis is extensive, including more than 200 medications.[18] It is estimated that drugs and medications cause about one-third of the cases of adult rhabdomyolysis.[18]

There are some common mechanisms for drug-induced rhabdomyolysis:[19]

- Inadequate delivery of oxygen and nutrients to the tissue.[19] This can be due to pressure ischemia from prolonged immobilization that can occur with any central nervous system (CNS) depressant. Examples include the narcotics, general anesthetics, benzodiazepines (BDZ), tricyclic antidepressants (TCAD), antihistamines, ethanol, barbiturates, and carbon monoxide (CO). The syndrome can also be due to increased pressure within specific compartments, as when the person passes out in an awkward position.

Some drugs cause significant vasospasm or vasoconstriction that can restrict blood flow. One example is vasopressin. Other drugs result in a "functional anemia" due to the production of abnormal hemoglobins that cannot transport and/or deliver oxygen to the tissues. Carboxyhemoglobin and methemoglobin are examples of such drugs. Finally, drugs that cause hemodynamic shock have the potential to cause rhabdomyolysis.

- Excessive energy use by the muscle.[19] Any drug that results in excessive exertion, delirium, agitation, and seizures can cause rhabdomyolysis. This group of drugs is extensive and includes the sympathomimetics, LSD, and PCP. Isoniazid (INH), strychnine, theophylline, and lithium are some of the drugs known to result in seizures and status epilepticus. The withdrawal from ethanol, BDZ, and gamma hydroxybutyrate (GHB) can also cause both agitation and seizures.

Drugs that cause movement disorders like dystonias and choreoathetosis are also in this category, such as the phenothiazines and butyrophenones.

Depolarizing neuromuscular blockers like succinylcholine have been associated with rhabdomyolysis in children.

- Metabolic poisons, which are drugs that interfere with the production or use of ATP.[19] Drugs in this category include the inhibitors of the electron transport chain (cyanide [CN], hydrogen sulfide (HS), CO, and phosphine); the uncouplers of oxidative phosphorylation (salicylates and chlorophenoxy herbicides; and the inhibitors of glycolysis [sodium fluoroacetate]). Rarer agents in this group include the heavy metals like mercury, selenium, copper, and tetra ethyl lead.
- Potassium depletion.[19] Patients in this category include those taking diuretics or mineralocorticoids (like licorice), and toluene users. The mechanism for rhabdomyolysis in hypokalemia is thought to be due to inadequate cell release of potassium, which helps with vasodilation during exercise.
- Other miscellaneous mechanisms.[19] **Ethanol.** Ethanol is thought to account for about 20% of cases of myoglobinuria.[19] The mechanism for this is not clear, but could in part be behavioral and also due to a local toxic effect.

HMG-CoA reductase inhibitors (statins). Statins are the drug class most commonly associated with drug-induced rhabdomyolysis.[4] This is probably because they are one of the most widely prescribed drug classes.[20] The myopathies from statins are a spectrum of disease, ranging from isolated CK elevation with no symptoms, to pain or weakness with little CK elevation, to profound rhabdomyolysis.

Rhabdomyolysis due to statins is thought to be due to inhibition of HMG-CoA reductase, which leads to decreased levels of ubiquinone (Coenzyme Q).[20] Ubiquinone is a key player in electron transport chain, and is also an intracellular antioxidant.[21] However, the exact mechanism has not been elucidated.

Higher serum statin concentrations have been associated with a higher likelihood of rhabdomyolysis.[22] Statins undergo glucuronidation in the liver. Drugs like gemfibrozil, which have a similar metabolism, can increase serum statin levels.[20]

Subsequently, most statins are metabolized by cytochrome oxidase 3A4 (CYP 3A4), so co-administration of drugs such as macrolide antibiotics, non-dihydropyridine calcium channel blockers, and protease inhibitors may also increase blood concentrations of statins and precipitate rhabdomyolysis.[20]

There is no consensus on screening for rhabdomyolysis in patients taking statins, but patients taking other drugs that can result in elevated statin levels, or patients on high-dose simvastatin, should be recognized as at high risk for developing the syndrome.[20,22]

Propofol. Propofol is a widely used sedative and short-acting anesthetic due to its very favorable neurologic profile and its quick "on and off" properties.[23] Propofol is toxic to the mitochondria and elevates malonyl-carnitine levels, which results in inhibited fatty acid transport. It also uncouples oxidative phosphorylation and inhibits the respiratory chain.[4] The toxicity of propofol is also thought to be mediated to beta antagonism and catecholamine inhibition.[24]

The Propofol Infusion Syndrome (PRIS) was first termed by Bray in 1998. In this series, he described 18 children who developed bradycardia leading to asystole with at least one of the following: metabolic acidosis, rhabdomyolysis or myoglobinuria, lipemic plasma, and enlarged or fatty liver. Most patients had a respiratory illness. The mortality in this report was 83%.[25] In more recent reports, the mortality from PRIS has been 18%.[26] Between 1996-2000, the first adult cases were reported. In 2001, a report first showed a dose relationship in the development of PRIS in adult head-injured patients.[27] In this series, patients taking doses of less than 5 mg/kg/hr did not develop PRIS; those taking doses between 5-6 mg/kg/hr had a 17% incidence; and those taking doses greater than 6 mg/kg/hr had a 31% incidence.

Risk factors for the development of PRIS include: severe head injury; respiratory illness; young age; large total cumulative dose; high catecholamine and glucocorticoid levels; low carbohydrate/high fat intake; critical illness; and inborn errors of fatty oxidation.[27]

The proposed adult criteria for PRIS are:

- Age between 18-55 years;
- Progressive heart failure with arrhythmias;
- Two of the following: metabolic acidosis, hyperkalemia, or evidence of muscle cell destruction;
- Exclusion of other causes for symptoms.[23]

Cardiac dysfunction or a Brugada-like ECG may be the first clue of PRIS. This is thought to be due to NA channel blockade or unmasking of a genetic channel defect.[23]

A recently published report, the largest one to date, gives an incidence of 1.1% for PRIS. Most patients developed symptoms by the first 24 hours. In this study, most patients (91%) were receiving vasopressors. Interestingly, only 18% of patients were receiving propofol at a rate greater than 5 mg/kg/hr doses, demonstrating that PRIS can occur at low doses.[26]

To prevent the development of PRIS, when possible propofol infusions should be less than 4 mg/kg/hr and they should not be continued longer than 48 hours.[23] However, cases of PRIS have been reported even after propofol has been used for procedural sedation.[23] The propofol infusion should be stopped and the patient appropriately resuscitated. Case reports have shown some success with hemodialysis, hemoperfusion, and extracorporeal membrane oxygenation (ECMO).[4,23]

Drugs of Abuse. Virtually all the sympathomimetics have been associated with rhabdomyolysis. Most notably, cocaine has been reported to cause rhabdomyolysis in about 5% of all cocaine-related visits in one ED study.[28] As expected, the degree of agitation was the best predictor for the development of rhabdomyolysis. Patients with cocaine-induced rhabdomyolysis have been reported to have high mortality.[29] The mechanism for cocaine-induced rhabdomyolysis is thought to be multifactorial, including agitation, seizures, vasoconstriction, and other causes of skeletal muscle dysfunction like neuroleptic malignant syndrome (NMS), serotonin syndrome (SS), and malignant hyperthermia (MH).

The newer synthetic amphetamines like MDMA and N-benzylpiperazine have also been reported to result in rhabdomyolysis. Finally, the synthetic cathinone derivatives, such as "bath salts" (MDPV and mephedrone), have also been associated with rhabdomyolysis.[30,31]

Table 4 lists the drugs that have been associated with rhabdomyolysis.

Toxins/Venoms. Rare cases of rhabdomyolysis have been documented after red fire ant bites, massive stings from Africanized bees, wasp stings, and following snake bites.[32-35] The spread of Africanized honey bees across the southern United States has increased the incidence of massive stings. When the bee colony feels threatened by human activity, the bees swarm in defense. In contrast to anaphylaxis secondary to a bee or wasp sting with laryngeal constriction, bronchospasm, and hypotension, rhabdomyolysis occurs secondary to massive envenomation from hundreds of stings. Melittin, the pain-inducing compound in bee venom, in conjunction with phospholipase A2, compromise red blood cell membrane integrity. The mast-cell degranulating protein, hyaluronidase, and neurotoxic apamin allow bee venom to infiltrate tissues and propagate cell apoptosis, resulting in rhabdomyolysis and renal failure.[35]

Fire ant venom contains formic acid, which in large quantities acts as an inhibitor of the mitochondrial cytochrome oxidase complex.[33] Rhabdomyolysis may occur secondary to tissue ischemia from the formic acid. Severe scorpion stings from certain species (most notably the Centruroides species, known also as the "bark scorpion") are reported to result in elevated CK, but in patients who also suffered severe neurotoxic and cardiotoxic effects.[36] Bites from pit vipers with hemotoxic or myotoxic venom may

Table 4: Medication/Drug Causes of Rhabdomyolysis[19]

- Ethanol
- Cocaine and other sympathomimetics
- Anticholinergic agents
- Sedatives and hypnotics
- Metabolic poisons (cyanide, carbon monoxide)
- Colchicine
- Steroids
- Zidovudine
- Statins
- Propofol (infusion)
- Daptomycin
- Sunitinib and Imatinib
- Leflunomide
- Serotonin syndrome
- Neuroleptic malignant syndrome

also cause rhabdomyolysis, which in conjunction with disseminated intravascular coagulation (DIC), hypotension, and hemorrhage may result in renal failure.[32] Table 5 lists common envenomations associated with rhabdomyolysis.

Infection. Many infections have been related to the development of rhabdomyolysis. In adults, infections may represent only about 5% of total cases of rhabdomyolysis, but in the pediatric population, infection is the most common cause of rhabdomyolysis.[18] In at least one adult cohort study of patients with sepsis, the presence of rhabdomyolysis carried a mortality of 59%.[37] Table 6 summarizes infectious causes of rhabdomyolysis.

Other. There are many additional causes of rhabdomyolysis, including tumors, endocrine, electrolyte derangements, hereditary, and dietary. All are listed in Table 7.

Complications of Rhabdomyolysis

As rhabdomyolysis is a multi-organ disease, its complications are many. The most common and obvious complication is acute renal failure (ARF).[19,40] The association was first reported by Bywaters in 1941.[41] It is thought that rhabdomyolysis causes 5-8% of all cases of ARF in hospitals. Renal failure occurs when released myoglobin, which is partly bound to alpha-2 globulin, dissociates into ferrihemate and globin. This occurs predominantly at low serum pH. Ferrihemate results in direct toxicity to the kidney. Additionally, there is alteration of renal blood flow (RBF), and tubular obstruction due to precipitation of heme pigment casts and uric acid crystals.[18,19] Other aspects of rhabdomyolysis that contribute to ARF include: intravascular volume depletion with renal hypoperfusion and ischemia; oxidative stress to the kidney from iron-mediated free radical formation; myoglobin-induced nitric oxide scavenging; circulation of inflammatory mediators; and activation of innate immune system.[42] The ARF can be oliguric or non-oliguric.

Nearly half of patients with rhabdomyolysis develop hyperkalemia.[43] Potassium is released from damaged muscle, and its clearance is impaired from fall in glomerular filtration rate (GFR) and decreased renal function.[19,40] Profound hyperuricemia, as high as 36 mg/dL, has also been reported.[19,40] Purines released from injured muscle are converted to uric acid by the liver. Due to the falling renal function, uric acid levels may rise.[19] Other electrolytes are also deranged in rhabdomyolysis, including hypocalcemia, found in 63% of patients.[40] Both calcium and phosphorus are sequestered and deposited in injured muscle. Later, once ARF ensues, these low levels resolve, and hypercalcemia can develop.[19]

Disseminated intravascular coagulation (DIC) has been reported to be associated with rhabdomyolysis. It could result from temperature elevation or from systemic release of substances such as plasminogen activator or thromboplastin.[19,40] Metabolic (lactic) acidosis is also common and has many contributors, including hypocalcemia, renal failure, and strenuous exertion leading to anaerobic metabolism.[19,40]

Rarer complications include hepatic damage, cardiomyopathy, ECG changes, arrhythmias, and cardiogenic shock.[40] Respiratory failure, delayed compartment syndromes, and peripheral neuropathies have also been reported.[19]

Laboratory Evaluation

Creatine kinase (CK) is the most sensitive indicator of rhabdomyolysis. Most authors will use a CK greater than five times the upper limit of normal as a definition for rhabdomyolysis, but there is no absolute number that defines the syndrome.[10] The CK starts increasing within 12 hours from injury, peaks at 1-3 days, and declines 3-5 days after the insult ceases (declines by about 39% from the previous day's value).[10,11] It should be noted that these criteria and elevations are variable and poorly studied, especially in heat-related illness and drug-induced rhabdomyolysis. Once 100 grams of muscle are damaged, myoglobin is released into the circulation.

The renal threshold for myoglobin is 15 mg/dL. Once this threshold is reached, myoglobinuria ensues. Myoglobinuria can be detected using the orthotolidine reaction, in which myoglobin is detected as blood in urine. This test is very sensitive.[19] Visible urine discoloration occurs at myoglobin levels of more than 1,000 mg/L. At alkaline pHs, myoglobin is red or pink; at acidic pHs, it is dark red-brown (from ferrihemate). But, it is important to note that the discoloration also depends on urine flow and GFR and is therefore very variable.[19]

As discussed before, the electrolytes, particularly hyperkalemia, hypocalcemia, and hyperuricemia are

also clues to the presence of rhabdomyolysis. Both the creatinine and the BUN are elevated in rhabdomyolysis, but the normal ratio of 10:1 decreases to about 6:1.[11]

Management

Intravenous Crystalloid Fluid Resuscitation. The cornerstone for the successful treatment of rhabdomyolysis and the prevention of ARF is prompt and aggressive intravenous isotonic crystalloid resuscitation.[16,44] Fluid sequestration in injured skeletal muscles of rhabdomyolysis patients leads to intravascular volume depletion, and repletion of up to 10-12 liters per day is often needed to maintain adequate urine output.[6,45]

Numerous studies have confirmed an increased incidence of acute kidney injury (AKI) when fluid initiation is delayed or not aggressive.[14,45,46] Thus, prompt administration of large-volume crystalloid repletion is important. Aggressive fluid resuscitation can improve long-term patient outcomes and prevent progression to ARF. Similarly, prehospital EMS providers can assist by beginning the process while en route to the ED. Maintaining a high index of suspicion for the development of rhabdomyolysis in the appropriate setting of presumed skeletal muscle injury is key to early and effective treatment.

Following an initial fluid bolus of 20 cc/kg, intravenous fluids should be continued at a rate of approximately 400-500 cc/hr.[6,47] Placement of a urinary catheter is necessary to closely monitor urine output, which should be maintained at a target of 2-3 cc/kg/hr (or approximately 200-300 cc/hr).[6,45,47] Volume overload and pulmonary edema is infrequent, even after infusion of these large volumes. In older and more frail patients, however, volume overload can occur. It is important that these patients be monitored for signs of pulmonary edema.[45]

No large, randomized, controlled trials exist to demonstrate the superiority of 0.9% normal saline (NS) versus lactated Ringer's (LR) as the solution of choice for volume resuscitation in rhabdomyolysis patients. However, because large volumes of NS lead to the development of a metabolic acidosis, some authors advocate LR.[6,47] In a small study that randomized 28 patients to NS versus LR resuscitation for the treatment of rhabdomyolysis induced by doxylamine intoxication, Cho and colleagues found that in order to maintain an alkaline urine (pH > 6.5), the addition of sodium bicarbonate was required more frequently in the NS group as compared to the LR group. They thus concluded that LR is a superior crystalloid in this setting.[47] However, no patients in either group developed renal failure necessitating dialysis, and time to CK normalization (recovery) did not differ significantly between the two groups. Most case series of patients with crush injuries use normal saline as the fluid of choice.[45] Particularly in the early ED phase of volume resuscitation, the choice of NS versus LR is likely less important.

During the initiation of treatment

Table 5: Envenomations Associated with Rhabdomyolysis[19]

- Ants (fire ants in particular)
- Bees
- Centipedes
- Wasps
- Scorpions
- Snakes (hemotoxic and myotoxic snakes)

Table 6: Infections Associated with Rhabdomyolysis

Viral
- Influenza (H1N1; A; B)
- Coronavirus
- Herpesvirus
- HIV
- Dengue
- Parainfluenza
- Varicella
- West Nile encephalitis
- Mononucleosis (Epstein-Barr)
- Cytomegalovirus (CMV)
- Coxsackie

Bacterial
- *Staphylococcus aureus*
- *Salmonella typhi*
- *Pseudomonas aeruginosa*
- *Mycoplasma pneumoniae*
- *Bacillus cereus*
- *Clostridium tetani*
- *E. coli*
- *Listeria monocytogenes*
- *Legionella pneumophila*
- Tularemia
- Tetanus

Protozoan
- *P. vivax* (malaria)

Table 7: Miscellaneous Causes of Rhabdomyolysis

Electrolytes
• Hypokalemia
• Hypernatremia
• Hypocalcemia
• Hypophosphatemia
Food
• Quail ingestion (coturnism)[38]
• Mushrooms
• Licorice
• Red yeast rice (Monascus purpureus)[39]
Endocrine
• Thyrotoxicosis
• Hyperaldosteronism
• DKA
Other
• Status asthmaticus
• Massage
• Polymyositis
• Dermatomyositis
• Neurosarcoidosis
• Sjögren's syndrome

for significant rhabdomyolysis, patients should be placed on a cardiac monitor, and electrolytes checked frequently due to the risk of dysrhythmias relating to metabolic derangements, particularly hyperkalemia. Hemodynamic monitoring may also be required to avoid fluid overload in susceptible patients. Patients with significant rhabdomyolysis should be admitted to a monitored bed setting for these reasons. The rigorous treatment of hyperkalemia, which typically first begins early in the disease process, is paramount and may require dialysis if severe.

With the goal of preventing ARF, it is also important to minimize patient exposure to additional potential renal insults, including intravenous contrast material, nephrotoxic antibiotics, and other nephrotoxic medications such as ACE inhibitors and NSAIDs.[6] It is also imperative to search for and treat the underlying cause of rhabdomyolysis, and to exclude or treat compartment syndrome in affected injured muscle groups.

Urine Alkalization Using Sodium Bicarbonate and Mannitol Osmotic Diuresis. Despite the common practice of urine alkalinization to a pH greater than 6.5 using sodium bicarbonate and forced diuresis with mannitol, no randomized, controlled trials support their superiority to adequate fluid resuscitation alone for the treatment of rhabdomyolysis and prevention of ARF.[6,11] Most of the data to support their use come from the cardiothoracic and the renal transplant literature.[45]

Homsi and colleagues performed a retrospective review of rhabdomyolysis patients admitted to an ICU setting and found no difference in the rate of ARF in patients receiving saline, sodium bicarbonate, and mannitol versus those receiving saline alone.[46] Similarly, in a retrospective analysis of trauma ICU patients with rhabdomyolysis, Brown et al noted no difference in the rates of ARF as defined by a creatinine greater than 2.0 mg/dL (22% vs. 18%), need for dialysis (7% vs. 6%), or mortality (15% vs. 18%) among patients receiving fluid resuscitation with the addition of sodium bicarbonate and mannitol compared to those who received only volume replacement.[48] These authors concluded the standard practice of bicarbonate and mannitol therapy should be reconsidered for the treatment of rhabdomyolysis.

While the only clear disadvantage of urine alkalinization with sodium bicarbonate is exacerbation of the hypocalcemia associated with the initial phase of rhabdomyolysis, mannitol has been found to actually worsen renal failure if it is used without adequate fluid resuscitation or if used late in the course of rhabdomyolysis.[6,45] One possible additional benefit of sodium bicarbonate is the concomitant treatment of hyperkalemia and of metabolic acidosis.

Hemodialysis

Despite appropriate fluid therapy, approximately 10-50% of rhabdomyolysis patients progress to develop ARF.[11,14,44,48] In a retrospective review of 2,083 trauma ICU patients, CK levels of 5000 U/L and higher were found to be associated with an increased risk of developing of ARF.[48] In such cases of rhabdomyolysis-induced ARF complicated by oliguria, severe hyperkalemia, acidosis, or volume overload, hemodialysis (HD) is often required. Either daily HD or continuous hemofiltration can be used successfully to correct fluid and electrolyte abnormalities resulting from such processes as the release of excess potassium and urea from necrotic skeletal muscle. HD has also been shown to remove large amounts of myoglobin when used before ARF is established.[49] Continuous venovenous hemofiltration may be more advantageous in critically ill patients with hemodynamic instability, as it is not associated the hypotension and dysrhythmias caused by the rapid fluid shifts of HD.[14,44] The use of plasmapheresis for removal of myoglobin has been shown to be beneficial in a few case reports, but its routine use is not indicated.[50]

Experimental Therapies

Isolated case reports have documented the success of high-dose corticosteroids for rhabdomyolysis unresponsive to fluid resuscitation[2] and the possible benefit of rasburicase, a urate oxidase enzyme, for the treatment of hyperuricemia in patients with rhabdomyolysis and renal failure.[51] Small case series, case reports, and experimental models support the use of antioxidants and free-radical scavengers such as pentoxifylline and vitamins C and E, in addition to deferoxamine for the prevention of myoglobinuric renal failure.[6,11,14] Another animal model showed decreased CK release from muscle after exposure to ethanol, cocaine, and electricity with the use of dantrolene sodium.[52] However, none of these therapies is proven by controlled studies, and, thus, sufficient evidence of their efficacy is lacking.

In summary, early and aggressive crystalloid fluid resuscitation remains the mainstay of treatment of rhabdomyolysis and the prevention of rhabdomyolysis-associated renal failure. The addition of sodium bicarbonate should be considered in patients with crush injury and in those with severe metabolic acidosis, but its routine use is not supported by published evidence.

Conclusions

Rhabdomyolysis is a complex syndrome that has a multitude of causes. The classic description of muscle pain, muscle weakness, and dark urine is seldom completely present, so a high index of suspicion must be maintained for those at high risk of the syndrome: a history of heavy exertion, trauma (especially crush injuries), agitation, motor excitation, and seizures. However, other causes should also be considered, such as infections and drugs. In the ED, the insult should be identified if possible and promptly removed.

Aggressive, early isotonic crystalloid resuscitation is central to the prevention of ARF, the most common complication from rhabdomyolysis. In patients with metabolic acidosis and/or hyperkalemia, sodium bicarbonate can be used, although there is no definitive evidence showing its benefit.

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Physician CME Questions

1. Which of the following metabolic disturbances is *not* commonly seen with rhabdomyolysis?
   A. hyperuricemia
   B. disseminated intravascular coagulation
   C. hyponatremia
   D. hypocalcemia

2. Which of the following statements is true?
   A. Urine alkalization with sodium bicarbonate decreases progression to ARF.
   B. Forced diuresis with mannitol protects against progression to ARF.
   C. Lactated Ringer's solution is superior to normal saline in the treatment of rhabdomyolysis.
   D. Early and aggressive fluid resuscitation is associated with a decreased progression to ARF.

3. Creatine kinase levels most consistent with acute rhabdomyolysis are:
   A. greater than 2 times normal
   B. greater than 5 times normal
   C. greater than 10 times normal
   D. greater than 20 times normal

4. All of the following are known genetic influences that predispose the patient to exertional rhabdomyolysis *except*:
   A. McArdle's disease
   B. CPT2 deficiency
   C. AMPD deficiency
   D. beta thalassemia

5. Severe crush injury may result in transient flaccid paralysis of an isolated extremity secondary to:
   A. acute spinal cord injury
   B. direct trauma to peripheral nerves
   C. increased compartment pressures with resultant ischemia to peripheral nerves
   D. traumatic brain injury

6. Contributing causes of acute kidney injury resulting from crush injury include all of the following *except*:
   A. hypotension
   B. lactic acidosis
   C. hyper-CK-emia
   D. vasoconstriction by nitric oxide

7. Rhabdomyolysis has been associated with all of the following *except*:
   A. fire ant bites
   B. Africanized bee stings
   C. brown recluse spider bites
   D. pit viper envenomation

8. Rhabdomyolysis in Africanized bee stings occurs secondary to:
   A. anaphylaxis

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Upon completion of this educational activity, participants should be able to:

- recognize specific conditions in patients presenting to the emergency department;
- apply state-of-the-art diagnostic and therapeutic techniques to patients with the particular medical problems discussed in the publication;
- discuss the differential diagnosis of the particular medical problems discussed in the publication;
- explain both the likely and rare complications that may be associated with the particular medical problems discussed in the publication.

B. mast cell degranulation
C. formic acid release
D. disseminated intravascular coagulation

9. Acute kidney injury secondary to crush injury may cause the following concerning electrolyte abnormality:

A. hyperglycemia
B. hypoglycemia
C. hyperkalemia
D. hyponatremia

10. What percentage of patients with severe electrical injuries will develop acute rhabdomyolysis?

A. fewer than 1%
B. 3%
C. 10%
D. 30%

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Newer Anticoagulants in the ED

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Rhabdomyolysis: Review and Update

Major Causes of Rhabdomyolysis

- Exertional
  - Genetic predisposition
- Trauma
- Drugs
- Toxins/venoms
- Infection
- Environmental
  - Heat or cold
- Electrolyte abnormalities
- Food

Hereditary Conditions Associated with Rhabdomyolysis

- Carnitine Metabolism Disorders
  - Carnitine palmitoyl transferase (CPT2) deficiency
  - VLCAD (very long chain acyl CoA deficiency)
- Adenosine monophosphate deaminase deficiency (AMPD)
- McArdle's disease (glycogen storage disease type 5)
- Malignant hyperthermia
- Phosphorylase kinase deficiency
- Duchenne muscular dystrophy
- 11-hydroxylase deficiency
- Phosphofructokinase deficiency

Trauma Conditions Associated with Rhabdomyolysis

- Crush injury
- Compartment syndrome
- Physical torture and abuse
- Exercise
- Heat stroke
- High voltage electrical injury
- Lightning
- Elevated ambient temperature (heat exposure)
- Low ambient temperature (cold exposure)

Medication/Drug Causes of Rhabdomyolysis

- Ethanol
- Cocaine and other sympathomimetics
- Anticholinergic agents
- Sedatives and hypnotics
- Metabolic poisons (cyanide, carbon monoxide)
- Colchicine
- Steroids
- Zidovudine
- Statins
- Propofol (infusion)
- Daptomycin
- Sunitinib and Imatinib
- Leflunomide
- Serotonin syndrome
- Neuroleptic malignant syndrome

Envenomations Associated with Rhabdomyolysis

- Ants (fire ants in particular)
- Bees
- Centipedes
- Wasps
- Scorpions
- Snakes (hemotoxic and myotoxic snakes)

Infections Associated with Rhabdomyolysis

Viral

- Influenza (H1N1; A; B)
- Coronavirus
- Herpesvirus
- HIV
- Dengue
- Parainfluenza
- Varicella
- West Nile encephalitis
- Mononucleosis (Epstein-Barr)
- Cytomegalovirus (CMV)
- Coxsackie

Bacterial

- *Staphylococcus aureus*
- *Salmonella typhi*
- *Pseudomonas aeruginosa*
- *Mycoplasma pneumoniae*
- *Bacillus cereus*
- *Clostridium tetani*
- *E. coli*
- *Listeria monocytogenes*
- *Legionella pneumophila*
- Tularemia
- Tetanus

Protozoan

- P. vivax (malaria)

Miscellaneous Causes of Rhabdomyolysis

Electrolytes

- Hypokalemia
- Hypernatremia
- Hypocalcemia
- Hypophosphatemia

Food

- Quail ingestion (coturnism)
- Mushrooms
- Licorice
- Red yeast rice (Monascus purpureus)

Endocrine

- Thyrotoxicosis
- Hyperaldosteronism
- DKA

Other

- Status asthmaticus
- Massage
- Polymyositis
- Dermatomyositis
- Neurosarcoidosis
- Sjögren's syndrome

Supplement to *Emergency Medicine Reports*, September 10, 2012: "Rhabdomyolysis: Review and Update." *Authors:* **Larissa I. Velez, MD**, Assistant Professor of Emergency Medicine, University of Texas Southwestern, Dallas; **Melanie J. Lippmann, MD**, Department of Emergency Medicine, University of Texas Southwestern, Dallas; **Janna Welch, MD**, Assistant Residency Director, University of Texas Southwestern, Dallas; and **Gilberto A. Salazar, MD**, Department of Emergency Medicine, University of Texas Southwestern, Dallas.
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Trauma Reports

EVIDENCE-BASED MEDICINE FOR THE ED

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AHC Media

The Roles and Risks of Whole-Body Computed Tomography Scans in the Trauma Patient

Emergency departments in the United States are frequently confronted with trauma patients with varying degrees of injury. Clinically significant injuries may be missed, with devastating consequences for the patient. Concern for not missing any potentially serious injuries has led to an aggressive diagnostic approach with a goal of not missing any injuries. The CT scan has facilitated this approach, providing substantial information guiding management. However, CT scans have risks, especially when the pan-scan approach is used. The authors review the uses, advantages, and disadvantages of the pan-scan.

— Ann M. Dietrich, MD, Editor

Background

Emergency departments (EDs) in the United States received approximately 35 million trauma-related visits in 2007.[1] According to the Centers for Disease Control (CDC), unintentional injury accounted for 123,706 deaths in the same year, making it the fourth leading cause of death overall and the primary cause of death among people between 1 and 44 years of age.[2]

The trauma population constitutes a remarkably high-risk cohort for emergency care providers and trauma surgeons. The principles of Advanced Trauma Life Support (ATLS) aim to provide a simple and effective standardized approach for the assessment and care of injured patients. Between the patient with minor isolated trauma and the unstable patient with multi-trauma requiring immediate surgical intervention lies a complex group of various injury patterns that represents a significant gray area for any trauma care provider. Patients who are stable after initial clinical evaluation still might have serious injuries that require an expedient evaluation performed in an organized manner to avoid the significant morbidity and mortality associated with delays in localization and intervention.[3,4] Approximately 15% to 22.3% of trauma patients in whom injuries are missed have injuries that are clinically significant.[5] This prevalence of missed serious injury has led to an aggressive diagnostic approach with an emphasis on high sensitivity and early identification of all injuries. Initially, this aggressiveness was illustrated by the use of diagnostic peritoneal lavage (DPL), an invasive but highly sensitive diagnostic screening tool that decreased the number of missed intra-abdominal injuries. With the advent of computed tomography (CT), emergency care providers and trauma surgeons have increasingly relied upon this technology as an integral part of trauma evaluation and resuscitation.[6] The "traditional" imaging strategy includes plain radiographs of the chest, pelvis, and lateral cervical spine (C-spine), in accordance with ATLS guidelines; a Focused Assessment with Sonography for Trauma (FAST) exam; and selected CT scans as deemed necessary based on the physical examination, radiographs, or ultrasound assessment.[7]

The first generations of CT scanners suffered from a significant lack of

Executive Summary

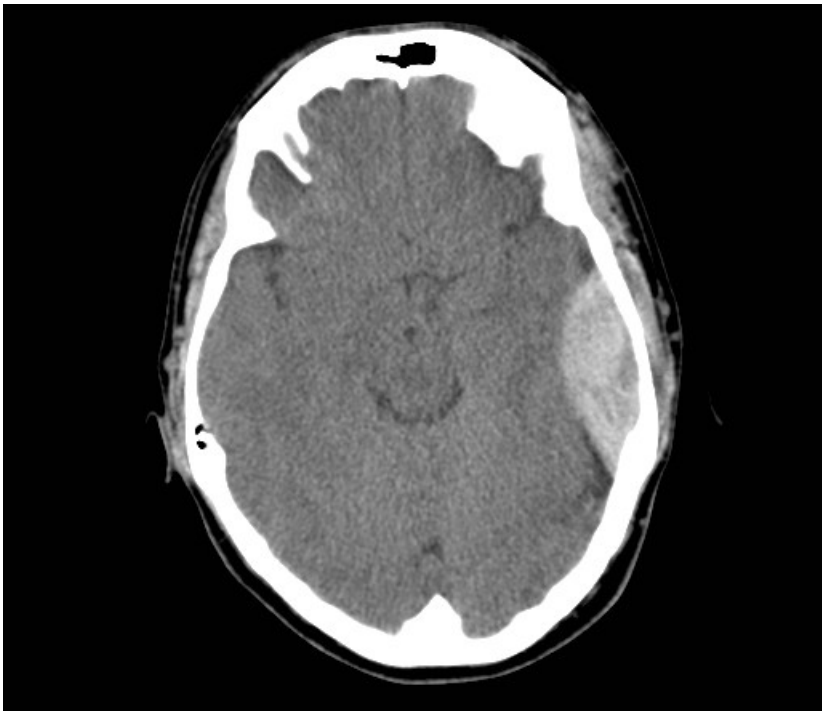
- Approximately 15% to 22.3% of trauma patients in whom injuries are missed have injuries that are clinically significant. This prevalence of missed serious injury has led to an aggressive diagnostic approach with an emphasis on high sensitivity and early identification of all injuries.
- Multiple studies have validated the hypothesis that CT is superior in accuracy and reliability compared with physical examination, laboratory screening, plain radiographs, and sonography alone in the evaluation of most serious traumatic injuries.
- A typical pan-scan involves a non-contrast CT scan of the head and contrast-enhanced scans of the neck, chest, abdomen, and pelvis.
- Recent studies have shown the single-pass pan-scan to be a viable, if not superior, alternative to conventional segmental whole-body protocols. The single-pass technique has been found to be accurate and timesaving, reducing acquisition time by as much as 42.5% and decreasing radiation dose.

sensitivity and specificity and were limited by the amount of time required for the scan (separating the patient from the monitoring of the trauma resuscitation bay). The introduction of multi-slice CT scanners has both improved diagnostic accuracy and reduced the time of scanning significantly.[8] Multiple studies have validated the hypothesis that CT is superior in accuracy and reliability compared with physical examination, laboratory screening, plain radiographs, and sonography alone in the evaluation of most serious traumatic injuries.[9-16]

The number of CTs performed in EDs for injury-related conditions nearly doubled between 1998 and 2007.[6] CT now has a well-established role in the secondary evaluation of trauma, and the concept of a whole-body CT scan, or "pan-scan," has become more accepted as an adjunct for definitive assessment of injuries during the early stages of trauma management.[6,17,18] A typical pan-scan involves a non-contrast CT scan of the head (*see Figure 1*) and contrast-enhanced scans of the neck, chest, abdomen, and pelvis. Some protocols also include dedicated reconstructed views of the rest of the spine or other osseous structures. (*See Figure 2.*) Modern multi-detector CT scanners have the ability to produce specialized studies such as fine cuts through the facial, orbital, and temporal bones, as well as CT angiography of the body and extremities (these are not included in most "standard" pan-scans).[19] Naturally, since departmental policies and CT manufacturers differ, institutions tend to have slightly different whole-body CT protocols. Strategies for reducing scan time, improving image quality, and decreasing radiation exposure are being investigated.[17,19,20]

Recent studies have shown the single-pass pan-scan to be a viable, if not superior, alternative to conventional segmental whole-body protocols. A single-pass CT scan captures the neck and body portions in a single scan, usually with multi-phased contrast injection. Conventional pan-scans usually incorporate pauses and multiple overlapping scans to

Figure 1. Epidural Hematoma



CT of a 26-year-old male on warfarin for a mechanical heart valve replacement. He fell from a ladder, sustaining an epidural hematoma. Image courtesy of University of Maryland School of Medicine Department of Emergency Medicine.

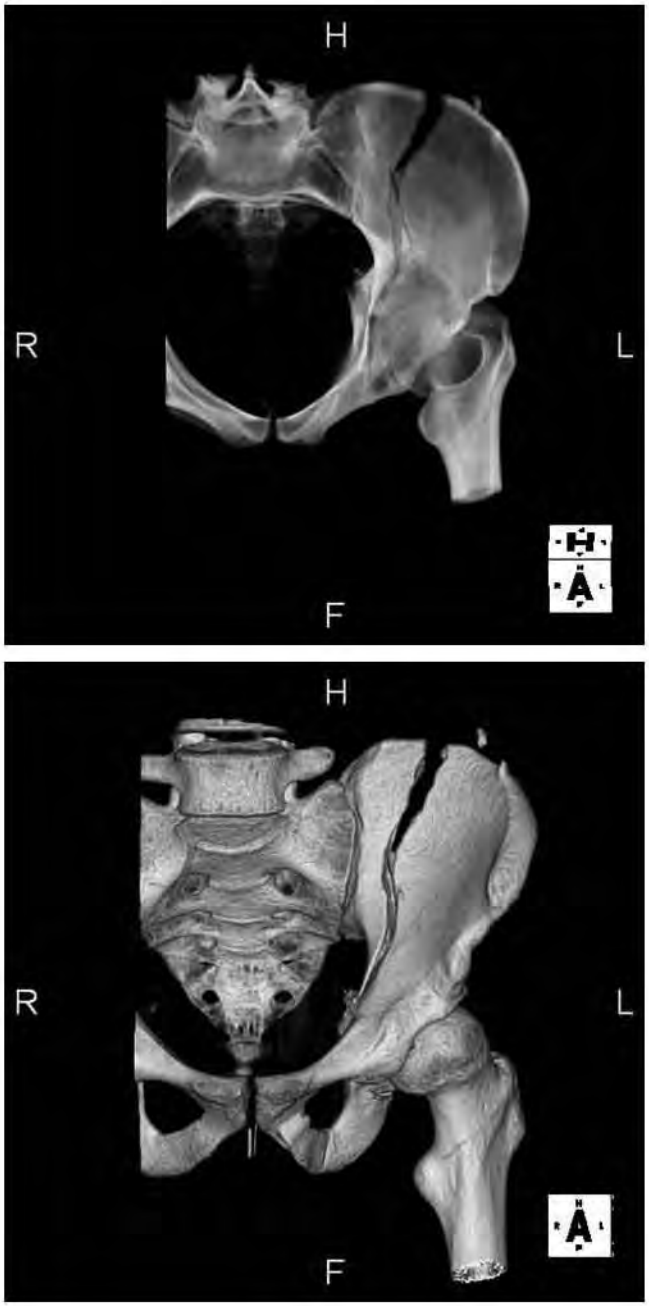
achieve separate portal and arterial phases. The single-pass technique has been found to be accurate and time-saving,[17,21] reducing acquisition time by as much as 42.5%[19] and decreasing radiation dose.[22]

The immediate benefits of CT are easy to recognize: A significant amount of clinical information can be gained in a short period of time in a noninvasive manner, which aids in triaging, surgical planning, and disposition. Multiple studies have suggested that the sensitivity of CT has progressed to the point that a negative study can effectively eliminate the possibility of significant traumatic injuries, allowing patients who otherwise might have required observation for hours or days to be discharged home earlier.[8,17,23-26] Few experts dispute the necessity of pan-scanning patients with significant physical evidence of multi-trauma (*see Figure 3*), those with massive blunt or penetrating injuries, and those in whom the physical examination is unreliable because of altered mental status, depressed level of consciousness, or significant distracting injuries.[27-29] However, an ongoing debate focuses on the utility of the pan-scan as a standard part of the evaluation of patients with moderate trauma and of those without clinically evident injuries who have normal laboratory values and plain radiographs.[30,31] The concerns are not without merit, as the pan-scan protocol poses several risks for the patient: radiation exposure, allergic reaction to contrast, contrast-induced nephropathy, and contrast extravasation.

Potential Benefits of Pan-Scan

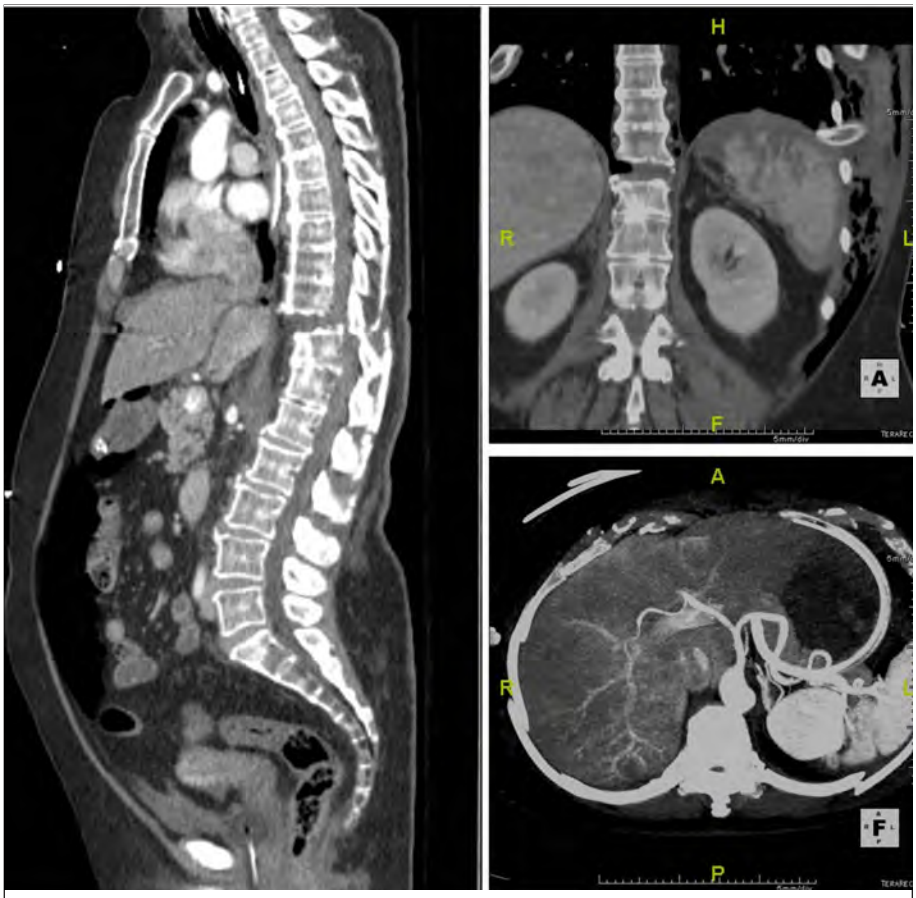
Diagnostic Yield. As discussed above, the initial management of trauma patients involves an aggressive attempt to identify all injuries early. The use of whole-body CT for this purpose has been supported by studies that suggest that a pan-scan identifies more injuries and leads to a change in management more often than following selective CT protocols.[18,32] In the study by Salim and colleagues,[18] 18.9% of patients had a change in management as a result of a finding on whole-body CT, including earlier discharge and procedural or surgical intervention. The study's data analysis focused on the abdominal portion of the pan-scan and found that 20.3% of patients who had a normal abdominal examination had a change in management after abdominal CT. Six of these patients required laparotomy. These

Figure 2. Iliac Wing Fracture



Two versions of 3D reconstructions of an iliac wing fracture in a 24-year-old male who was injured in a high-speed motor vehicle crash. Images courtesy of University of Maryland School of Medicine Department of Emergency Medicine.

Figure 3. Pan-scan of Serious Injuries



In this 64–year-old woman who was involved in a high-speed motor vehicle crash, pan-scan identified a number of serious injuries, including spinal fracture/dislocation, grade 3 splenic laceration, and grade 5 liver injury. Image courtesy of University of Maryland School of Medicine Department of Emergency Medicine.

results suggest that CT can identify injuries in patients with normal results on the physical examination. In another study, 18 emergency physicians' clinical judgment showed relatively high sensitivity (69.9% to 100%) in excluding injuries without a pan-scan if a patient's pretest probability of injury was "very low."[33] The sensitivity of excluding injuries in specific body regions steadily decreased with higher pretest probabilities of injury, supporting the idea that the accuracy of clinician judgment worsens in the assessment of severely injured patients.

Multiple studies have failed to develop a clinical decision rule that could completely exclude all types of intra-abdominal injuries after blunt trauma without performing CT.[15,25,34] In two of these studies, the presence of abdominal pain or tenderness achieved 100% sensitivity in detecting intra-abdominal injuries requiring surgical intervention,[25,30,34] even though it missed non-surgical injuries. Because the primary outcome of these studies was identifying all injuries, the clinical decision rules were viewed as failures. This illustrates two viewpoints as to what is the most important endpoint when evaluating the use of CT in trauma. Should the endpoint be finding any injury, or should it be finding only injuries that require surgical or medical intervention? Do clinicians really need to know about an injury that does not require treatment?

Gupta and colleagues presented a study that further illustrates this debate.[35] They polled emergency physicians and trauma surgeons about which components of the pan-scan obtained for individual trauma patients they thought were necessary. All scans were ordered at the discretion of the trauma surgeon. The ED physicians would have ordered 35% fewer scans, but in doing so would have missed 10% of injuries. However, only 0.3% of these injuries would have led to a predefined critical action. This suggests that although CT is superior in identifying objective injuries that the physical examination and clinical suspicion might miss, very few of these injuries prove to be emergently dangerous. Of note, the authors had difficulty agreeing on the true importance of the abnormal findings. The emergency medicine authors thought the projected miss rate of 0.3% (the number of missed injuries that would have required predefined critical actions) supported a more selective use of CT based on physician judgment. The trauma surgeon authors pointed to the projected missed injury rate of 10% (the number of all missed injuries, regardless of requiring a critical action or not) as justification for more liberal use of CT.

Survival/Mortality. Although most of these studies have used injuries identified on CT or change in management based on CT as the primary outcome, some studies have indicated a possible decrease in the mortality rate with a liberal CT approach. Hutter et al[36] studied the effect on survival before and after the institution of a liberal pan-scan policy at a major high-volume trauma center in Germany. The study included patients who did not undergo a pan-scan due to the unavailability of the method, patients who were eligible but were not pan-scanned due to physician discretion, and eligible patients who underwent a pan-scan. Patients who actually underwent a

pan-scan had a statistically significant reduction in overall mortality, with an odds ratio (OR) of 0.17 (95% CI, 0.1–0.28) and a total risk difference of 7%. The relative impact of a patient receiving a pan-scan on the mortality rate was small compared with the effect of Injury Severity Score (ISS) or neurologic function.

Huber-Wagner and associates[37] suggested that the use of whole-body CT in the management of trauma patients increased the probability of survival compared with the predicted mortality rate based on the Trauma Injury Severity Score (TRISS) and Revised Injury Severity Classification (RISC) scores. This study has been criticized because more patients in the whole-body CT group were treated at trauma centers, and it was acknowledged that the predicted mortality rate for the whole-body CT group was likely increased due to clinically insignificant findings that would in turn elevate the ISS.[38] Van Vugt et al[39] demonstrated that clinically insignificant findings found on CT do indeed elevate the ISS, artificially inflating mortality rate estimates beyond the true mortality rate, potentially altering the statistical importance of the pan-scan on survival. As overall survival in trauma generally continues to trend upward,[37] it is important to keep in mind that these observed effects are likely caused by complex systemic changes and that assigning a causal relationship to any one intervention is probably not appropriate.

Potential Pitfalls of Pan-Scan

Because the rates of CT use in EDs have skyrocketed in recent years, more attention is being directed toward the weaknesses of this diagnostic modality.[6]

Contrast-Induced Nephropathy (CIN). Published reports contain significant variability regarding the effect of intravenous (IV) contrast for CT on renal function. The incidence of CIN, most commonly defined as an increase in creatinine of 0.5 mg/dL or 25% from the baseline creatinine level, has been estimated to be anywhere from 0% to 12%, depending on the study and the underlying risk factors of the patients.[40-46] Importantly, it remains unclear whether IV contrast is the actual cause of the rise in creatinine. One literature review noted that in two studies in which control groups of patients did not receive IV contrast, no association was found between IV contrast and a rise in the serum creatinine level.[47-49]

Research into the true risks of IV contrast is ongoing. Mitchell and Kline found an incidence of CIN of 11% in a population of 633 general ED patients who underwent contrast-enhanced CT.[44] Of the 70 patients in whom CIN developed, renal failure developed in 7 (1% of the overall population), defined as an increase in serum creatinine of 3 mg/dL or more. Six of those seven patients died, and in four cases it was believed that renal failure significantly contributed to death.

Unfortunately, there is not a large body of literature investigating renal failure after contrast CT in the trauma patient. However, Matsushima and colleagues[50] did find an ISS of 16 or greater to be a risk factor for contrast-induced acute kidney injury, although the dose of contrast received was not associated with an increased risk, suggesting the possibility of an association rather than causality.

Overall, although there is still controversy about CIN and the exact risks associated with acute renal failure, especially in regard to the trauma population, the consensus seems to be that there is a small but very real risk of CIN following CT with IV contrast, a point all providers should consider when ordering CT scans.

Cancer Risk. CT is responsible for more than 70% of medical radiation exposure; 16.2 million scans were ordered for ED patients in 2007.[51,52] Brenner and Hall estimated that 1.5% to 2.0% of all cancers in the United States might be attributable to ionizing radiation from CT, including many types of scans other than those done during trauma assessments. The probable death rate is much lower, at about 0.1 to 0.35%.[38,53,54] These and other estimates are not universally accepted because they are based on a linear no-threshold relationship that assumes the incidence of cancer induction is proportional to

Table 1. Average Adult Effective Doses of Various Radiologic Studies

Radiograph	Average Effective Dose (mSv)
Single chest	0.02
Cervical spine	0.1
Thoracic spine	1.0
Lumbar spine	1.5
Pelvis	0.6
CT	**Average Effective Dose (mSv)**
Head	2
Neck	3
Chest	7
Abdomen	8
Pelvis	6
Spine	6

Adapted from Mettler FA Jr, Huda W, Yoshizumi TT, Mahesh M. Effective doses in radiology and diagnostic nuclear medicine: A catalog. *Radiology* 2008;248:254-263.

Table 2. Intermediate Level Trauma Patients (per MIEMSS* protocols)

Category B

- Glasgow Coma Scale (GCS) score 9-14
- Paralysis or vascular compromise of limb
- Amputation proximal to wrist or ankle
- Crushed, degloved, or mangled extremity
- Penetrating injuries to extremities proximal to elbow or knee
- Combination trauma with burns

Category C

- Age < 5 years or > 55 years
- Patient with bleeding disorder or patient on anticoagulants
- Dialysis patient
- Pregnancy > 20 weeks
- EMS provider judgment
- High-risk auto crash
  - Intrusion > 12 in. occupant site; > 18 in. any site
  - Ejection (partial or complete) from vehicle
  - Death in same passenger compartment
  - Vehicle telemetry data consistent with high risk of injury
- Exposure to blast or explosion
- Falls greater than 3 times patient's height

Intermediate trauma classifications based on the trauma decision tree protocols promulgated by the Maryland Institute for Emergency Medical Services Systems. Please refer to local trauma classifications and regulations for management in other jurisdictions. Adapted from The Maryland Medical Protocols for EMS Providers. Baltimore, Maryland: MIEMSS, 2011.

exposure, which some argue is not congruent with biological and animal data.[55] Most models are based on data extrapolated from atomic bomb survivors, but there has been debate about the level of radiation that leads to an increased cancer risk. A full explanation of this debate is beyond the scope of this article, but some have concluded that there is no significant carcinogenic risk with a dose up to 150 to 200 millisieverts (mSv) to normal tissues,[55,56] while others estimate that the safe dose is less than 100 mSv.[53] The sievert (Sv) is a measure of the effective dose of radiation on biological tissues based on the stochastic effect of ionizing radiation. The average underlying exposure from everyday background radiation is about 3 mSv per year.[54] Most patients receive an effective dose of about 20 to 50 mSv from a single pan-scan,[54,57] depending on the scanner power and scan technique. Table 1 includes a list of the average effective doses from individual radiologic studies.[58]

The risk of death from severe trauma has been estimated to be 50 to 100 times higher than the risk of a cancer death from CT-related radiation exposure.[59,60] In the trauma population, use of whole-body CT is usually not questioned because of the significant risk-benefit ratio. The population of particular interest and debate, however, has intermediate-level trauma, such as category B or C patients (*see Table 2*) or priority II patients; in other words, those who have potentially life-threatening, but not immediately life-endangering injuries. In this subset of patients, which has not been well-studied, trauma-related mortality is still a real concern, estimated between 0.6% and 2%,[38,57] but there is a larger proportion without serious injuries. In a recent study of 642 adult intermediate-level trauma patients, Laack and colleagues estimated that the risk of trauma-related mortality was six times greater than the cancer risk.[38] Trauma-related mortality was highest in older patients, and the risk of cancer death was inversely proportional to age; therefore, the youngest patients have the most potential danger from radiation — patients younger than 20 years have four times the estimated risk of those older than 60 years. (*See Figure 4.*) It is notable that no one younger than 80 died in Laack's study, and all deaths were caused by head injuries. The mortality rate and median ISS were relatively low compared with the findings in a smaller study by Winslow and associates, who examined the amount of radiation to which intermediate trauma patients were exposed.[57]

Pediatrics. Because children are more susceptible to the carcinogenic effects of ionizing radiation, efforts to reduce unnecessary radiation exposure are paramount. CT remains the diagnostic test of choice for evaluation of blunt trauma in children, but the risk of inducible cancer is much higher than in adults. Mueller et al[61] showed that the effective radiation dose during CT is on par with adults, but doses to organs such as the thyroid gland fell within the range of radiation doses historically correlated with increased cancer risk. Based on a model by Berrington de Gonzalez and associates, the mean lifetime cancer risk after whole-body CT in 3-year-old boys and girls is 1 in 133 and 1 in 166, respectively.[62] At 15 years of age, the risks were estimated at 1 in 250 for girls and 1 in 500 for boys.

Although the FAST exam is well-established in adult trauma, its utility as a screening exam in pediatric trauma is not universally supported.[7,26,63] CT has been shown to be sensitive for identification of injuries in children, similar to adults. An important consideration for pediatric

trauma, however, is that solid organ injuries in children are being treated increasingly non-operatively,[64,65] so discovery of these injuries in hemodynamically stable children does not automatically lead to surgical intervention.[66] On the other hand, a review of three prospective studies looking at intra-abdominal injury determined that the negative predictive value (NPV) of abdominal CT was 99.8%, suggesting that routine admission and serial exams after a normal abdominal CT and a normal physical exam may not be necessary.[68]

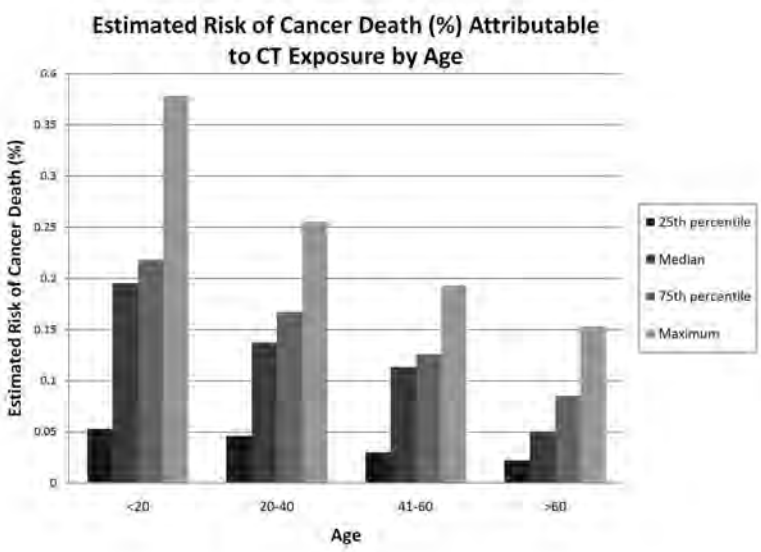
Clinical decision rules for obtaining a CT scan have been successful for pediatric head injury[68,69] and C-spine injury,[70] and are being investigated for abdominal trauma.[66] Unfortunately, just as with adults, there is no clinical decision rule for using pan-scan in the pediatric trauma population. Use of a pan-scan is not routinely recommended in stable children without abnormal physical exam findings or a mechanism that induces concern for significant injury. Selective scanning of body areas, rather than whole-body scanning, results in a statistically significant decrease in all organ doses and total effective dose.[61]

Other Considerations

An Imperfect Test. While CT has been shown to have generally superior ability to identify injuries, it is not a perfect test. Alone, CT has demonstrated insufficient sensitivity to rule out diaphragm injury, although its positive predictive value appears to be very good.[71] (*See Figure 5.*) Similar concern has been expressed for other radiographically occult injuries such as diffuse axonal injury, hollow viscus injuries, and mesenteric injuries, but Tan showed that patients with surgically confirmed hollow viscus and mesenteric injuries were very likely to have had an abnormal CT scan.[72] Positive trauma scans are conclusive, but negative results require subsequent confirmation.[17] Injuries initially missed on CT are uncommon; while these falsely negative scans can sometimes delay management, they have not yet been shown to affect the mortality rate.[73] In that vein, second readings are advocated to avoid missed injuries not seen on the initial preliminary "hot read,"[74] at least in patients with intermediate to high pretest probability for injury.

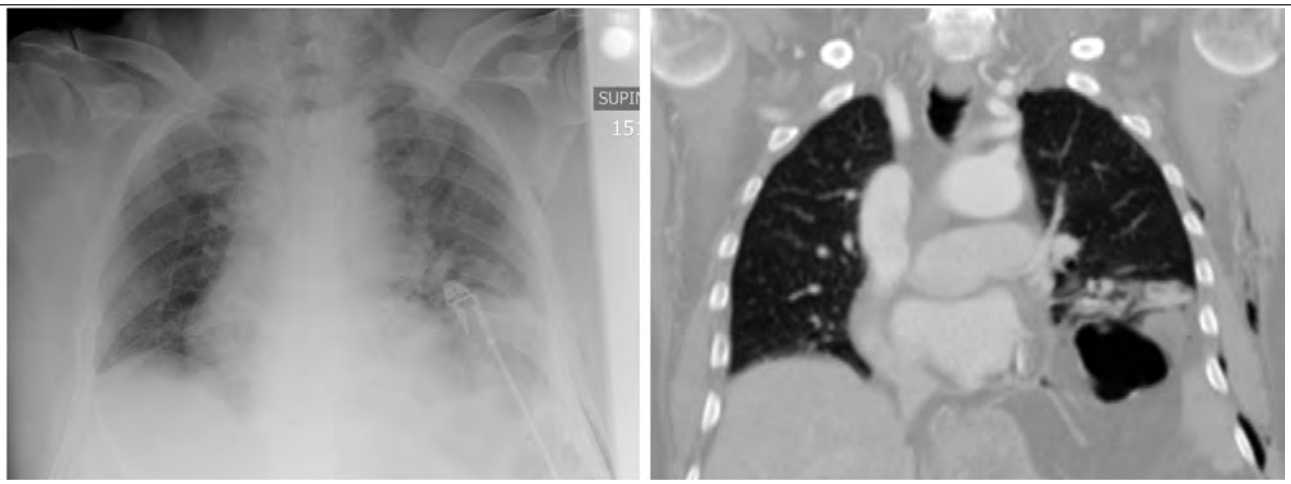
Imaging Prior to Transfer. Emergency medicine practitioners who do not work at designated trauma centers will certainly be responsible for the occasional trauma patient, and if the patient meets criteria for transfer to a trauma center, the question of whether to obtain imaging prior to transfer may arise. From a practical standpoint, the role of the practitioner is to stabilize the patient to the best of his or her abilities and to facilitate transport to the receiving facility for definitive management as soon as possible. As noted previously, CT is sensitive for diagnosing life-threatening injuries and can be used as a tool for determining disposition after trauma.[18] In a stable trauma patient with clinically suspected injuries based on mechanism or examination, CT might elucidate the need for further specialized management or it can obviate the need for admission or transfer. If a patient meets criteria for transfer prior to imaging, it is important to communicate with the receiving facility regarding the expectation of, or necessity for, imaging at the referring center. However, if a patient clinically requires transfer to a trauma center, sophisticated diagnostic studies may help with eventual management but should not delay transfer. Between 53% and 58% of transferred patients receive repeat imaging upon arrival at the receiving trauma center.[35,75] The reasons for repeating studies are varied, including change of clinical status during transfer, inadequate original technique, software incompatibility, and even simple human error such as misplacing or forgetting to send the original scans. It is notable that patients who received repeat imaging tended to be more severely injured

Figure 4. Risk of Death and CT Exposure



Estimated risk of death attributable to CT exposure by age. Adapted from: Laack TA, Thompson KM, Kofler JM, et al. Comparison of trauma mortality and estimated cancer mortality from computed tomography during initial evaluation of intermediate-risk trauma patients. *J Trauma* 2011;70:1362-1365.

Figure 5. Pan-scan Showing Rib Fractures, Left Hemidiaphragm Injury, and Large Flank Hematoma



Following a motor vehicle crash, a clinically stable 84-year-old man complained of mild left flank pain. His wife died as a result of the crash. Pan-scan revealed a number of rib fractures, a left hemidiaphragm injury, and large flank hematoma, which were not evident on plain radiograph and FAST examination. Images courtesy of University of Maryland School of Medicine Department of Emergency Medicine.

but also suffered longer delays[75] as well as additional radiation and financial charges. Lastly, incidental findings are found in up to one-third of trauma patients,[39] and trauma patients are notoriously often lost to follow-up,[76] which begs the question of who will arrange follow-up on these patients if incidental abnormalities are found during a formal over read after transfer.

Recommendations

Unfortunately, there is no universally accepted algorithm regarding routine whole-body CT compared with selective CT. A hospital could benefit from the development of a standardized CT protocol. Standardizing the radiologic workup of trauma patients needs to balance the risks of complications, cost, and incidental findings from CT versus the risk of missed injuries, repeat imaging, and delay in disposition or treatment.

Pan-scan is a noninvasive and effective method of injury determination in the hemodynamically stable trauma population, but it must be used with an awareness of its associated problems. Indiscriminate use without proper clinical evaluation or concern is inappropriate. Efforts to reduce radiation exposure should be focused toward younger patients and those with obviously minor injuries or trauma mechanisms. Pan-scanning may reduce but does not eliminate the incidence of missed injuries and is not a substitute for a thorough clinical evaluation, appropriate repeat examinations, and follow-up. Single-pass pan-scans reduce scan time and radiation compared with conventional sequential imaging. Comprehensive secondary reading of a scan after a preliminary read may lower the rate of missed injuries.

Further research is needed. Currently in progress is the REACT-2 trial, a prospective, multicenter, multi-national study investigating the effects of immediate pan-scan CT during the primary survey on clinical outcomes compared with the use of conventional imaging and selective CT. The intervention group undergoes immediate whole-body CT, completely eliminating plain radiographs and the FAST exam. This is a novel approach and is focusing on the primary outcome of in-hospital mortality as well as secondary endpoints such as effects on morbidity, radiation exposure, and cost-effectiveness. It is hoped that this study, and those to follow, will delineate an appropriately balanced diagnostic approach for trauma patients.

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CME/CNE Questions

1. Of the following, what is the most appropriate choice for a 48-year-old pedestrian who was struck by a motor vehicle with a moderate impact, is hemodynamically stable, and has no major physical exam findings except chest wall tenderness and a Glasgow Coma Scale (GCS) score of 13?
   A. separate head and chest CT scans
   B. head CT scan and chest radiograph only
   C. single-pass pan-scan
   D. no imaging; observation only

2. Which of these patients would most benefit from a pan-scan?
   A. any blunt trauma patient, regardless of mechanism
   B. a hemodynamically stable patient injured in a motor vehicle crash, with no obvious physical findings, whose passenger died on scene
   C. a hemodynamically stable 8-year-old boy with no physical findings after falling from a 5-foot ladder
   D. a hemodynamically stable pedestrian struck at 10 mph with right knee and hip pain

3. Which of the following statements regarding contrast-induced nephropathy (CIN) in patients undergoing enhanced CT after trauma is correct?
   A. The incidence may be as high as 12%, although this may be an associative rather than causative effect.
   B. CIN is defined as an increase of 25% or 0.5 mg/dL in creatinine from baseline.
   C. An Injury Severity Score of 16 or higher may be a risk factor for CIN.
   D. The higher the dose of contrast administered, the higher the risk of CIN.
   E. All of the above
   F. Only A, B, and C are correct.

4. You are a physician at a community hospital and have just placed a chest tube to stabilize a woman who was injured in a motor vehicle collision. She arrived with a pneumothorax caused by multiple rib fractures. The FAST exam is positive, and you have to transfer her to the nearest trauma center for surgery. What is the most appropriate approach to imaging?
   A. The patient is stable, so send her to CT for pan-scan.
   B. The patient is stable, but imaging should not delay definitive management; transfer her immediately.
   C. Scan the chest and abdomen, then transfer with accompanying images.
   D. Send the patient to CT, because the receiving facility will probably want a scan.

5. Regarding pediatric blunt trauma patients, which of the following is true?
   A. Children can be unreliable during history and physical, so they should be pan-scanned.
   B. The FAST exam is a reliable way to rule out surgical abdominal injuries in stable children without abdominal pain.
   C. Children receive the same effective radiation doses from CT as adults, but these doses carry a higher risk of secondary cancer.
   D. Pan-scan is a good way to rule out surgical injuries for all pediatric trauma patients.

6. Which of the following statements about lifetime cancer risk associated with pan-scan is true?
   A. The risk of trauma-related mortality is approximately six times that

of CT-related cancer mortality in all-comer intermediate-level trauma patients.
B. Age is a factor in CT-related cancer risk, and the risk is proportional to age.
C. The mean lifetime cancer risk after whole body CT in 3-year-old boys is 1 in 133 (0.75%) and 1 in 166 (0.60%) in girls.
D. The background radiation received on a yearly basis in an urban environment is almost as much as a single pan-scan.
E. B and D are correct.
F. A and C are correct.

7. Incidental findings are detected in approximately what percentage of trauma patients undergoing CT?
   A. 1%
   B. 10%
   C. 33%
   D. 50%

8. In a recent poll of emergency physicians and trauma surgeons about the components of the pan-scan obtained for individual trauma patients the physicians thought were necessary, which of the following is true?
   A. The ED physicians and trauma surgeons always agreed on which scans were necessary.
   B. ED physicians desired 35% fewer scans, and < 1% of these undesired scans would have led to a predefined "critical action."
   C. The trauma surgeons desired fewer scans than the ED physicians.
   D. All scans were ordered at the discretion of the ED physician.

9. Which of the following statements regarding clinician ability to rule out injury based on physical exam is true?
   A. The sensitivity of ruling out injuries in specific body regions steadily decreases with higher pretest probabilities of injury.
   B. Multiple studies have shown that physical exam is superior to CT scan for ruling out injuries.
   C. All patients with abdominal injuries found on CT will have abdominal tenderness.
   D. Ruling out injury based on physical exam findings is reliable in patients with altered mental status.

10. Which of the follow statements about the use of CT is true?
    A. The use of CT in EDs declined between 1998 and 2007.
    B. A typical "pan-scan" is a non-contrast CT of the head, followed by contrast-enhanced scans of the neck, chest, abdomen, and pelvis.
    C. A typical "pan-scan" is a non-contrast CT of the head, followed by contrast-enhanced scans of the neck, chest, abdomen, and pelvis and CT angiography of the extremities.
    D. CT accounts for approximately 70% of radiation exposure in medical populations.
    E. B and D are true.

CNE/CME Objectives

Upon completing this program, the participants will be able to:

- discuss conditions that should increase suspicion for traumatic injuries;
- describe the various modalities used to identify different traumatic conditions;
- cite methods of quickly stabilizing and managing patients; and
- identify possible complications that may occur with traumatic injuries.

CNE/CME Instructions

HERE ARE THE STEPS YOU NEED TO TAKE TO EARN CREDIT FOR THIS ACTIVITY:

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Rhabdomyolysis: Review and Update

Major Causes of Rhabdomyolysis

- Exertional
  - Genetic predisposition
- Trauma
- Drugs
- Toxins/venoms
- Infection
- Environmental
  - Heat or cold
- Electrolyte abnormalities
- Food

Hereditary Conditions Associated with Rhabdomyolysis

- Carnitine Metabolism Disorders
  - Carnitine palmitoyl transferase (CPT2) deficiency
  - VLCAD (very long chain acyl CoA deficiency)
- Adenosine monophosphate deaminase deficiency (AMPD)
- McArdle's disease (glycogen storage disease type 5)
- Malignant hyperthermia
- Phosphorylase kinase deficiency
- Duchenne muscular dystrophy
- 11-hydroxylase deficiency
- Phosphofructokinase deficiency

Trauma Conditions Associated with Rhabdomyolysis

- Crush injury
- Compartment syndrome
- Physical torture and abuse
- Exercise
- Heat stroke
- High voltage electrical injury
- Lightning
- Elevated ambient temperature (heat exposure)
- Low ambient temperature (cold exposure)

Medication/Drug Causes of Rhabdomyolysis

- Ethanol
- Cocaine and other sympathomimetics
- Anticholinergic agents
- Sedatives and hypnotics
- Metabolic poisons (cyanide, carbon monoxide)
- Colchicine
- Steroids
- Zidovudine
- Statins
- Propofol (infusion)
- Daptomycin
- Sunitinib and Imatinib
- Leflunomide
- Serotonin syndrome
- Neuroleptic malignant syndrome

Envenomations Associated with Rhabdomyolysis

- Ants (fire ants in particular)
- Bees
- Centipedes
- Wasps
- Scorpions
- Snakes (hemotoxic and myotoxic snakes)

Infections Associated with Rhabdomyolysis

Viral

- Influenza (H1N1; A; B)
- Coronavirus
- Herpesvirus
- HIV
- Dengue
- Parainfluenza
- Varicella
- West Nile encephalitis
- Mononucleosis (Epstein-Barr)
- Cytomegalovirus (CMV)
- Coxsackie

Bacterial

- *Staphylococcus aureus*
- *Salmonella typhi*
- *Pseudomonas aeruginosa*
- *Mycoplasma pneumoniae*
- *Bacillus cereus*
- *Clostridium tetani*
- *E. coli*
- *Listeria monocytogenes*
- *Legionella pneumophila*
- Tularemia
- Tetanus

Protozoan

- P. vivax (malaria)

Miscellaneous Causes of Rhabdomyolysis

Electrolytes

- Hypokalemia
- Hypernatremia
- Hypocalcemia
- Hypophosphatemia

Food

- Quail ingestion (coturnism)
- Mushrooms
- Licorice
- Red yeast rice (Monascus purpureus)

Endocrine

- Thyrotoxicosis
- Hyperaldosteronism
- DKA

Other

- Status asthmaticus
- Massage
- Polymyositis
- Dermatomyositis
- Neurosarcoidosis
- Sjögren's syndrome

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The Roles and Risks of Whole-Body Computed Tomography Scans in the Trauma Patient

Emergency departments in the United States are frequently confronted with trauma patients with varying degrees of injury. Clinically significant injuries may be missed, with devastating consequences for the patient. Concern for not missing any potentially serious injuries has led to an aggressive diagnostic approach with a goal of not missing any injuries. The CT scan has facilitated this approach, providing substantial information guiding management. However, CT scans have risks, especially when the pan-scan approach is used. The authors review the uses, advantages, and disadvantages of the pan-scan.

— Ann M. Dietrich, MD, Editor

Background

Emergency departments (EDs) in the United States received approximately 35 million trauma-related visits in 2007.[1] According to the Centers for Disease Control (CDC), unintentional injury accounted for 123,706 deaths in the same year, making it the fourth leading cause of death overall and the primary cause of death among people between 1 and 44 years of age.[2]

The trauma population constitutes a remarkably high-risk cohort for emergency care providers and trauma surgeons. The principles of Advanced Trauma Life Support (ATLS) aim to provide a simple and effective standardized approach for the assessment and care of injured patients. Between the patient with minor isolated trauma and the unstable patient with multi-trauma requiring immediate surgical intervention lies a complex group of various injury patterns that represents a significant gray area for any trauma care provider. Patients who are stable after initial clinical evaluation still might have serious injuries that require an expedient evaluation performed in an organized manner to avoid the significant morbidity and mortality associated with delays in localization and intervention.[3,4] Approximately 15% to 22.3% of trauma patients in whom injuries are missed have injuries that are clinically significant.[5] This prevalence of missed serious injury has led to an aggressive diagnostic approach with an emphasis on high sensitivity and early identification of all injuries. Initially, this aggressiveness was illustrated by the use of diagnostic peritoneal lavage (DPL), an invasive but highly sensitive diagnostic screening tool that decreased the number of missed intra-abdominal injuries. With the advent of computed tomography (CT), emergency care providers and trauma surgeons have increasingly relied upon this technology as an integral part of trauma evaluation and resuscitation.[6] The "traditional" imaging strategy includes plain radiographs of the chest, pelvis, and lateral cervical spine (C-spine), in accordance with ATLS guidelines; a Focused Assessment with Sonography for Trauma (FAST) exam; and selected CT scans as deemed necessary based on the physical examination, radiographs, or ultrasound assessment.[7]

The first generations of CT scanners suffered from a significant lack of

Executive Summary

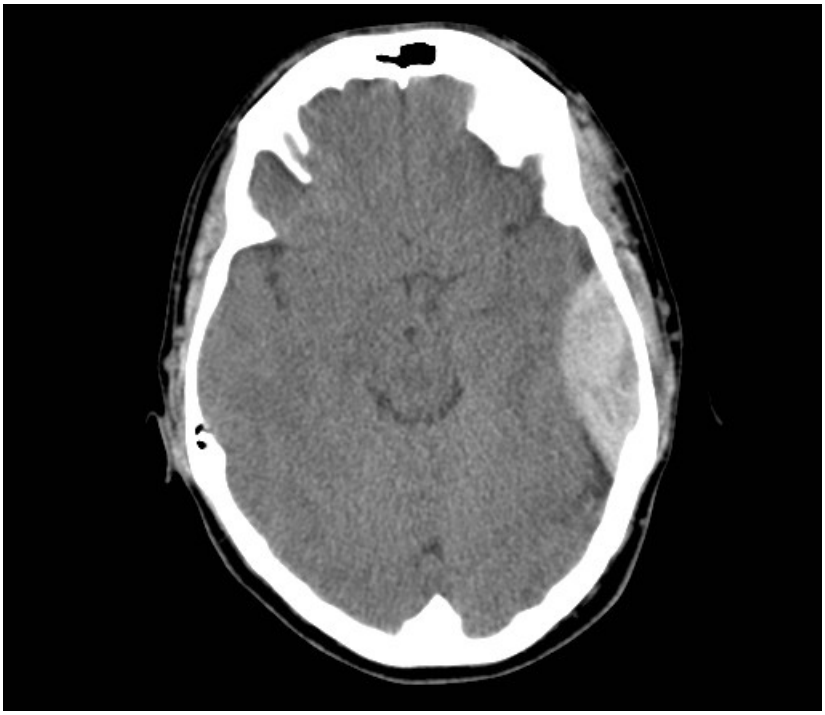
- Approximately 15% to 22.3% of trauma patients in whom injuries are missed have injuries that are clinically significant. This prevalence of missed serious injury has led to an aggressive diagnostic approach with an emphasis on high sensitivity and early identification of all injuries.
- Multiple studies have validated the hypothesis that CT is superior in accuracy and reliability compared with physical examination, laboratory screening, plain radiographs, and sonography alone in the evaluation of most serious traumatic injuries.
- A typical pan-scan involves a non-contrast CT scan of the head and contrast-enhanced scans of the neck, chest, abdomen, and pelvis.
- Recent studies have shown the single-pass pan-scan to be a viable, if not superior, alternative to conventional segmental whole-body protocols. The single-pass technique has been found to be accurate and timesaving, reducing acquisition time by as much as 42.5% and decreasing radiation dose.

sensitivity and specificity and were limited by the amount of time required for the scan (separating the patient from the monitoring of the trauma resuscitation bay). The introduction of multi-slice CT scanners has both improved diagnostic accuracy and reduced the time of scanning significantly.[8] Multiple studies have validated the hypothesis that CT is superior in accuracy and reliability compared with physical examination, laboratory screening, plain radiographs, and sonography alone in the evaluation of most serious traumatic injuries.[9-16]

The number of CTs performed in EDs for injury-related conditions nearly doubled between 1998 and 2007.[6] CT now has a well-established role in the secondary evaluation of trauma, and the concept of a whole-body CT scan, or "pan-scan," has become more accepted as an adjunct for definitive assessment of injuries during the early stages of trauma management.[6,17,18] A typical pan-scan involves a non-contrast CT scan of the head (*see Figure 1*) and contrast-enhanced scans of the neck, chest, abdomen, and pelvis. Some protocols also include dedicated reconstructed views of the rest of the spine or other osseous structures. (*See Figure 2.*) Modern multi-detector CT scanners have the ability to produce specialized studies such as fine cuts through the facial, orbital, and temporal bones, as well as CT angiography of the body and extremities (these are not included in most "standard" pan-scans).[19] Naturally, since departmental policies and CT manufacturers differ, institutions tend to have slightly different whole-body CT protocols. Strategies for reducing scan time, improving image quality, and decreasing radiation exposure are being investigated.[17,19,20]

Recent studies have shown the single-pass pan-scan to be a viable, if not superior, alternative to conventional segmental whole-body protocols. A single-pass CT scan captures the neck and body portions in a single scan, usually with multi-phased contrast injection. Conventional pan-scans usually incorporate pauses and multiple overlapping scans to

Figure 1. Epidural Hematoma



CT of a 26-year-old male on warfarin for a mechanical heart valve replacement. He fell from a ladder, sustaining an epidural hematoma. Image courtesy of University of Maryland School of Medicine Department of Emergency Medicine.

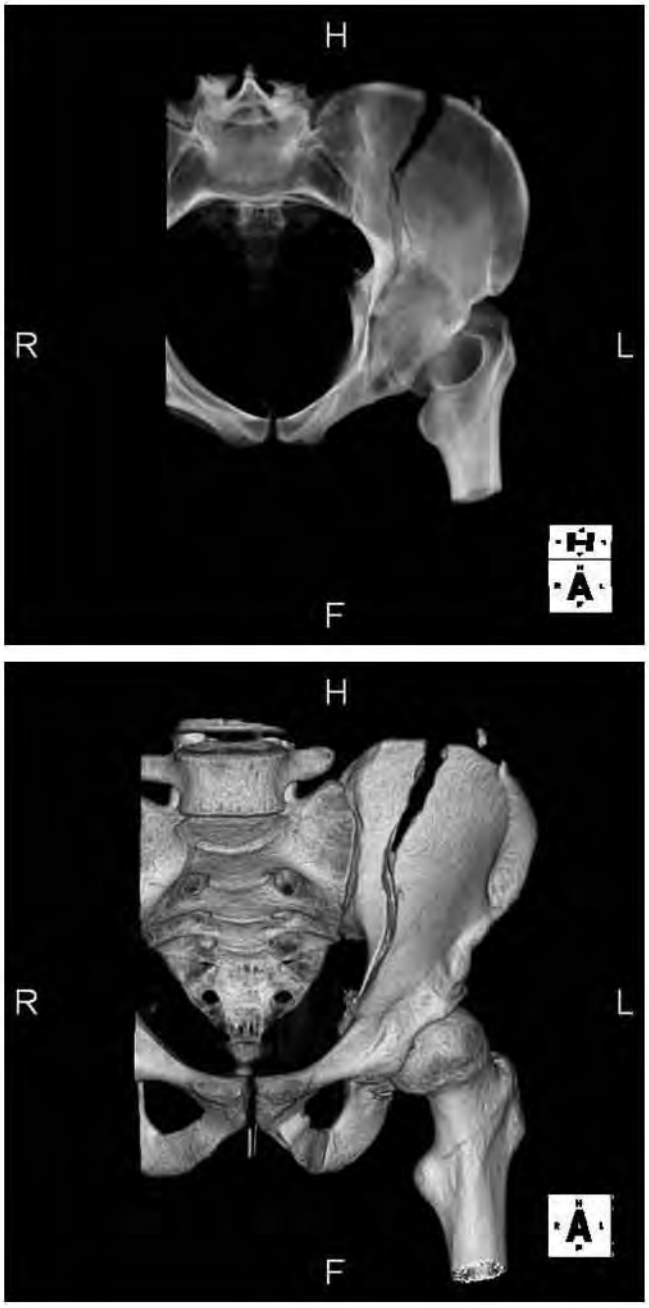
achieve separate portal and arterial phases. The single-pass technique has been found to be accurate and time-saving,[17,21] reducing acquisition time by as much as 42.5%[19] and decreasing radiation dose.[22]

The immediate benefits of CT are easy to recognize: A significant amount of clinical information can be gained in a short period of time in a noninvasive manner, which aids in triaging, surgical planning, and disposition. Multiple studies have suggested that the sensitivity of CT has progressed to the point that a negative study can effectively eliminate the possibility of significant traumatic injuries, allowing patients who otherwise might have required observation for hours or days to be discharged home earlier.[8,17,23-26] Few experts dispute the necessity of pan-scanning patients with significant physical evidence of multi-trauma (*see Figure 3*), those with massive blunt or penetrating injuries, and those in whom the physical examination is unreliable because of altered mental status, depressed level of consciousness, or significant distracting injuries.[27-29] However, an ongoing debate focuses on the utility of the pan-scan as a standard part of the evaluation of patients with moderate trauma and of those without clinically evident injuries who have normal laboratory values and plain radiographs.[30,31] The concerns are not without merit, as the pan-scan protocol poses several risks for the patient: radiation exposure, allergic reaction to contrast, contrast-induced nephropathy, and contrast extravasation.

Potential Benefits of Pan-Scan

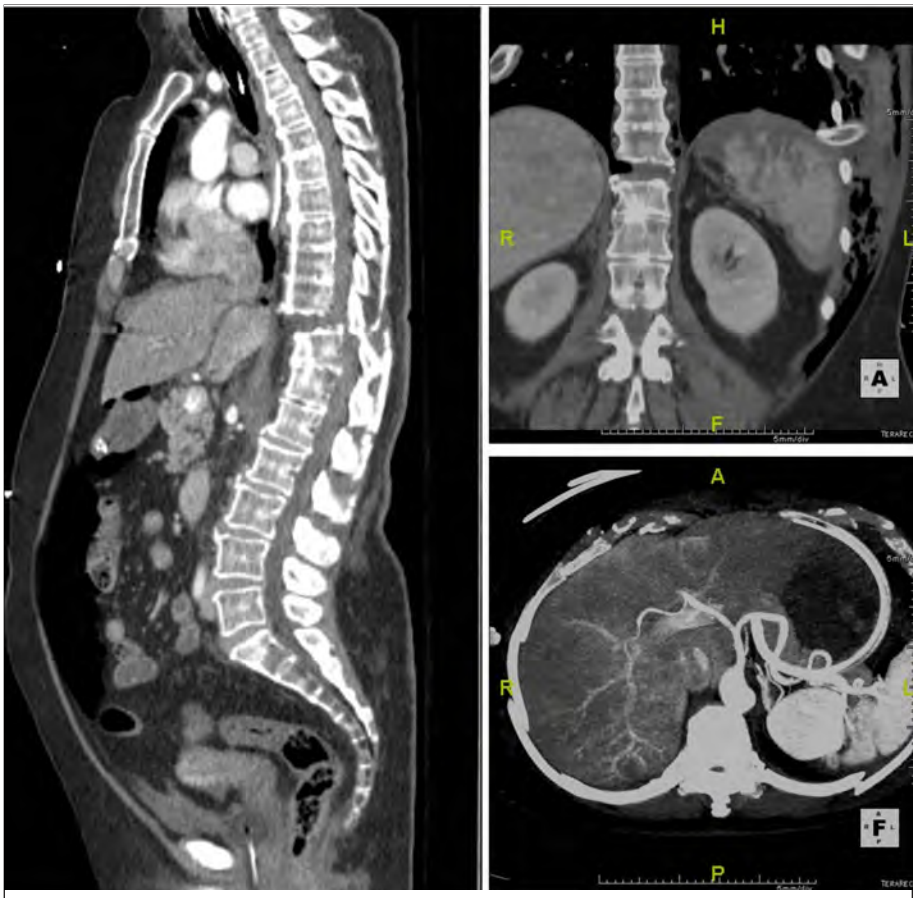
Diagnostic Yield. As discussed above, the initial management of trauma patients involves an aggressive attempt to identify all injuries early. The use of whole-body CT for this purpose has been supported by studies that suggest that a pan-scan identifies more injuries and leads to a change in management more often than following selective CT protocols.[18,32] In the study by Salim and colleagues,[18] 18.9% of patients had a change in management as a result of a finding on whole-body CT, including earlier discharge and procedural or surgical intervention. The study's data analysis focused on the abdominal portion of the pan-scan and found that 20.3% of patients who had a normal abdominal examination had a change in management after abdominal CT. Six of these patients required laparotomy. These

Figure 2. Iliac Wing Fracture



Two versions of 3D reconstructions of an iliac wing fracture in a 24-year-old male who was injured in a high-speed motor vehicle crash. Images courtesy of University of Maryland School of Medicine Department of Emergency Medicine.

Figure 3. Pan-scan of Serious Injuries



In this 64–year-old woman who was involved in a high-speed motor vehicle crash, pan-scan identified a number of serious injuries, including spinal fracture/dislocation, grade 3 splenic laceration, and grade 5 liver injury. Image courtesy of University of Maryland School of Medicine Department of Emergency Medicine.

results suggest that CT can identify injuries in patients with normal results on the physical examination. In another study, 18 emergency physicians' clinical judgment showed relatively high sensitivity (69.9% to 100%) in excluding injuries without a pan-scan if a patient's pretest probability of injury was "very low."[33] The sensitivity of excluding injuries in specific body regions steadily decreased with higher pretest probabilities of injury, supporting the idea that the accuracy of clinician judgment worsens in the assessment of severely injured patients.

Multiple studies have failed to develop a clinical decision rule that could completely exclude all types of intra-abdominal injuries after blunt trauma without performing CT.[15,25,34] In two of these studies, the presence of abdominal pain or tenderness achieved 100% sensitivity in detecting intra-abdominal injuries requiring surgical intervention,[25,30,34] even though it missed non-surgical injuries. Because the primary outcome of these studies was identifying all injuries, the clinical decision rules were viewed as failures. This illustrates two viewpoints as to what is the most important endpoint when evaluating the use of CT in trauma. Should the endpoint be finding any injury, or should it be finding only injuries that require surgical or medical intervention? Do clinicians really need to know about an injury that does not require treatment?

Gupta and colleagues presented a study that further illustrates this debate.[35] They polled emergency physicians and trauma surgeons about which components of the pan-scan obtained for individual trauma patients they thought were necessary. All scans were ordered at the discretion of the trauma surgeon. The ED physicians would have ordered 35% fewer scans, but in doing so would have missed 10% of injuries. However, only 0.3% of these injuries would have led to a predefined critical action. This suggests that although CT is superior in identifying objective injuries that the physical examination and clinical suspicion might miss, very few of these injuries prove to be emergently dangerous. Of note, the authors had difficulty agreeing on the true importance of the abnormal findings. The emergency medicine authors thought the projected miss rate of 0.3% (the number of missed injuries that would have required predefined critical actions) supported a more selective use of CT based on physician judgment. The trauma surgeon authors pointed to the projected missed injury rate of 10% (the number of all missed injuries, regardless of requiring a critical action or not) as justification for more liberal use of CT.

Survival/Mortality. Although most of these studies have used injuries identified on CT or change in management based on CT as the primary outcome, some studies have indicated a possible decrease in the mortality rate with a liberal CT approach. Hutter et al[36] studied the effect on survival before and after the institution of a liberal pan-scan policy at a major high-volume trauma center in Germany. The study included patients who did not undergo a pan-scan due to the unavailability of the method, patients who were eligible but were not pan-scanned due to physician discretion, and eligible patients who underwent a pan-scan. Patients who actually underwent a

pan-scan had a statistically significant reduction in overall mortality, with an odds ratio (OR) of 0.17 (95% CI, 0.1–0.28) and a total risk difference of 7%. The relative impact of a patient receiving a pan-scan on the mortality rate was small compared with the effect of Injury Severity Score (ISS) or neurologic function.

Huber-Wagner and associates[37] suggested that the use of whole-body CT in the management of trauma patients increased the probability of survival compared with the predicted mortality rate based on the Trauma Injury Severity Score (TRISS) and Revised Injury Severity Classification (RISC) scores. This study has been criticized because more patients in the whole-body CT group were treated at trauma centers, and it was acknowledged that the predicted mortality rate for the whole-body CT group was likely increased due to clinically insignificant findings that would in turn elevate the ISS.[38] Van Vugt et al[39] demonstrated that clinically insignificant findings found on CT do indeed elevate the ISS, artificially inflating mortality rate estimates beyond the true mortality rate, potentially altering the statistical importance of the pan-scan on survival. As overall survival in trauma generally continues to trend upward,[37] it is important to keep in mind that these observed effects are likely caused by complex systemic changes and that assigning a causal relationship to any one intervention is probably not appropriate.

Potential Pitfalls of Pan-Scan

Because the rates of CT use in EDs have skyrocketed in recent years, more attention is being directed toward the weaknesses of this diagnostic modality.[6]

Contrast-Induced Nephropathy (CIN). Published reports contain significant variability regarding the effect of intravenous (IV) contrast for CT on renal function. The incidence of CIN, most commonly defined as an increase in creatinine of 0.5 mg/dL or 25% from the baseline creatinine level, has been estimated to be anywhere from 0% to 12%, depending on the study and the underlying risk factors of the patients.[40-46] Importantly, it remains unclear whether IV contrast is the actual cause of the rise in creatinine. One literature review noted that in two studies in which control groups of patients did not receive IV contrast, no association was found between IV contrast and a rise in the serum creatinine level.[47-49]

Research into the true risks of IV contrast is ongoing. Mitchell and Kline found an incidence of CIN of 11% in a population of 633 general ED patients who underwent contrast-enhanced CT.[44] Of the 70 patients in whom CIN developed, renal failure developed in 7 (1% of the overall population), defined as an increase in serum creatinine of 3 mg/dL or more. Six of those seven patients died, and in four cases it was believed that renal failure significantly contributed to death.

Unfortunately, there is not a large body of literature investigating renal failure after contrast CT in the trauma patient. However, Matsushima and colleagues[50] did find an ISS of 16 or greater to be a risk factor for contrast-induced acute kidney injury, although the dose of contrast received was not associated with an increased risk, suggesting the possibility of an association rather than causality.

Overall, although there is still controversy about CIN and the exact risks associated with acute renal failure, especially in regard to the trauma population, the consensus seems to be that there is a small but very real risk of CIN following CT with IV contrast, a point all providers should consider when ordering CT scans.

Cancer Risk. CT is responsible for more than 70% of medical radiation exposure; 16.2 million scans were ordered for ED patients in 2007.[51,52] Brenner and Hall estimated that 1.5% to 2.0% of all cancers in the United States might be attributable to ionizing radiation from CT, including many types of scans other than those done during trauma assessments. The probable death rate is much lower, at about 0.1 to 0.35%.[38,53,54] These and other estimates are not universally accepted because they are based on a linear no-threshold relationship that assumes the incidence of cancer induction is proportional to

Table 1. Average Adult Effective Doses of Various Radiologic Studies

Radiograph	Average Effective Dose (mSv)
Single chest	0.02
Cervical spine	0.1
Thoracic spine	1.0
Lumbar spine	1.5
Pelvis	0.6
CT	**Average Effective Dose (mSv)**
Head	2
Neck	3
Chest	7
Abdomen	8
Pelvis	6
Spine	6

Adapted from Mettler FA Jr, Huda W, Yoshizumi TT, Mahesh M. Effective doses in radiology and diagnostic nuclear medicine: A catalog. *Radiology* 2008;248:254-263.

Table 2. Intermediate Level Trauma Patients (per MIEMSS* protocols)

Category B

- Glasgow Coma Scale (GCS) score 9-14
- Paralysis or vascular compromise of limb
- Amputation proximal to wrist or ankle
- Crushed, degloved, or mangled extremity
- Penetrating injuries to extremities proximal to elbow or knee
- Combination trauma with burns

Category C

- Age < 5 years or > 55 years
- Patient with bleeding disorder or patient on anticoagulants
- Dialysis patient
- Pregnancy > 20 weeks
- EMS provider judgment
- High-risk auto crash
  - Intrusion > 12 in. occupant site; > 18 in. any site
  - Ejection (partial or complete) from vehicle
  - Death in same passenger compartment
  - Vehicle telemetry data consistent with high risk of injury
- Exposure to blast or explosion
- Falls greater than 3 times patient's height

Intermediate trauma classifications based on the trauma decision tree protocols promulgated by the Maryland Institute for Emergency Medical Services Systems. Please refer to local trauma classifications and regulations for management in other jurisdictions. Adapted from The Maryland Medical Protocols for EMS Providers. Baltimore, Maryland: MIEMSS, 2011.

exposure, which some argue is not congruent with biological and animal data.[55] Most models are based on data extrapolated from atomic bomb survivors, but there has been debate about the level of radiation that leads to an increased cancer risk. A full explanation of this debate is beyond the scope of this article, but some have concluded that there is no significant carcinogenic risk with a dose up to 150 to 200 millisieverts (mSv) to normal tissues,[55,56] while others estimate that the safe dose is less than 100 mSv.[53] The sievert (Sv) is a measure of the effective dose of radiation on biological tissues based on the stochastic effect of ionizing radiation. The average underlying exposure from everyday background radiation is about 3 mSv per year.[54] Most patients receive an effective dose of about 20 to 50 mSv from a single pan-scan,[54,57] depending on the scanner power and scan technique. Table 1 includes a list of the average effective doses from individual radiologic studies.[58]

The risk of death from severe trauma has been estimated to be 50 to 100 times higher than the risk of a cancer death from CT-related radiation exposure.[59,60] In the trauma population, use of whole-body CT is usually not questioned because of the significant risk-benefit ratio. The population of particular interest and debate, however, has intermediate-level trauma, such as category B or C patients (*see Table 2*) or priority II patients; in other words, those who have potentially life-threatening, but not immediately life-endangering injuries. In this subset of patients, which has not been well-studied, trauma-related mortality is still a real concern, estimated between 0.6% and 2%,[38,57] but there is a larger proportion without serious injuries. In a recent study of 642 adult intermediate-level trauma patients, Laack and colleagues estimated that the risk of trauma-related mortality was six times greater than the cancer risk.[38] Trauma-related mortality was highest in older patients, and the risk of cancer death was inversely proportional to age; therefore, the youngest patients have the most potential danger from radiation — patients younger than 20 years have four times the estimated risk of those older than 60 years. (*See Figure 4.*) It is notable that no one younger than 80 died in Laack's study, and all deaths were caused by head injuries. The mortality rate and median ISS were relatively low compared with the findings in a smaller study by Winslow and associates, who examined the amount of radiation to which intermediate trauma patients were exposed.[57]

Pediatrics. Because children are more susceptible to the carcinogenic effects of ionizing radiation, efforts to reduce unnecessary radiation exposure are paramount. CT remains the diagnostic test of choice for evaluation of blunt trauma in children, but the risk of inducible cancer is much higher than in adults. Mueller et al[61] showed that the effective radiation dose during CT is on par with adults, but doses to organs such as the thyroid gland fell within the range of radiation doses historically correlated with increased cancer risk. Based on a model by Berrington de Gonzalez and associates, the mean lifetime cancer risk after whole-body CT in 3-year-old boys and girls is 1 in 133 and 1 in 166, respectively.[62] At 15 years of age, the risks were estimated at 1 in 250 for girls and 1 in 500 for boys.

Although the FAST exam is well-established in adult trauma, its utility as a screening exam in pediatric trauma is not universally supported.[7,26,63] CT has been shown to be sensitive for identification of injuries in children, similar to adults. An important consideration for pediatric

trauma, however, is that solid organ injuries in children are being treated increasingly non-operatively,[64,65] so discovery of these injuries in hemodynamically stable children does not automatically lead to surgical intervention.[66] On the other hand, a review of three prospective studies looking at intra-abdominal injury determined that the negative predictive value (NPV) of abdominal CT was 99.8%, suggesting that routine admission and serial exams after a normal abdominal CT and a normal physical exam may not be necessary.[68]

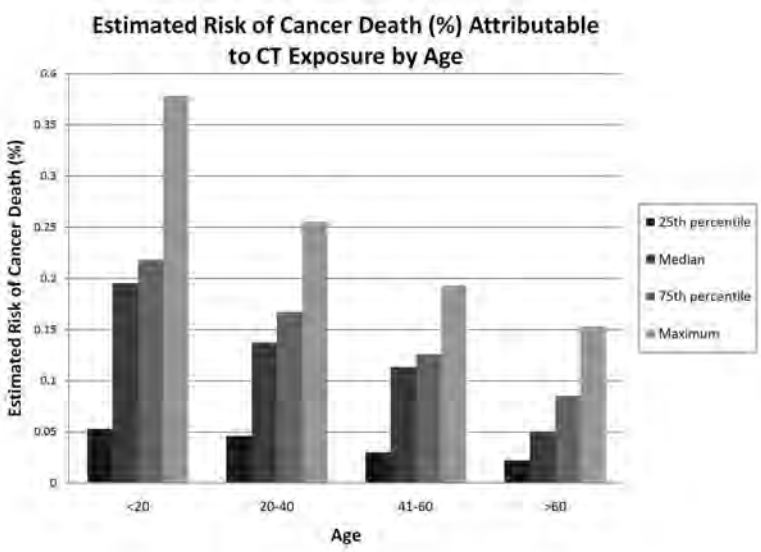
Clinical decision rules for obtaining a CT scan have been successful for pediatric head injury[68,69] and C-spine injury,[70] and are being investigated for abdominal trauma.[66] Unfortunately, just as with adults, there is no clinical decision rule for using pan-scan in the pediatric trauma population. Use of a pan-scan is not routinely recommended in stable children without abnormal physical exam findings or a mechanism that induces concern for significant injury. Selective scanning of body areas, rather than whole-body scanning, results in a statistically significant decrease in all organ doses and total effective dose.[61]

Other Considerations

An Imperfect Test. While CT has been shown to have generally superior ability to identify injuries, it is not a perfect test. Alone, CT has demonstrated insufficient sensitivity to rule out diaphragm injury, although its positive predictive value appears to be very good.[71] (*See Figure 5.*) Similar concern has been expressed for other radiographically occult injuries such as diffuse axonal injury, hollow viscus injuries, and mesenteric injuries, but Tan showed that patients with surgically confirmed hollow viscus and mesenteric injuries were very likely to have had an abnormal CT scan.[72] Positive trauma scans are conclusive, but negative results require subsequent confirmation.[17] Injuries initially missed on CT are uncommon; while these falsely negative scans can sometimes delay management, they have not yet been shown to affect the mortality rate.[73] In that vein, second readings are advocated to avoid missed injuries not seen on the initial preliminary "hot read,"[74] at least in patients with intermediate to high pretest probability for injury.

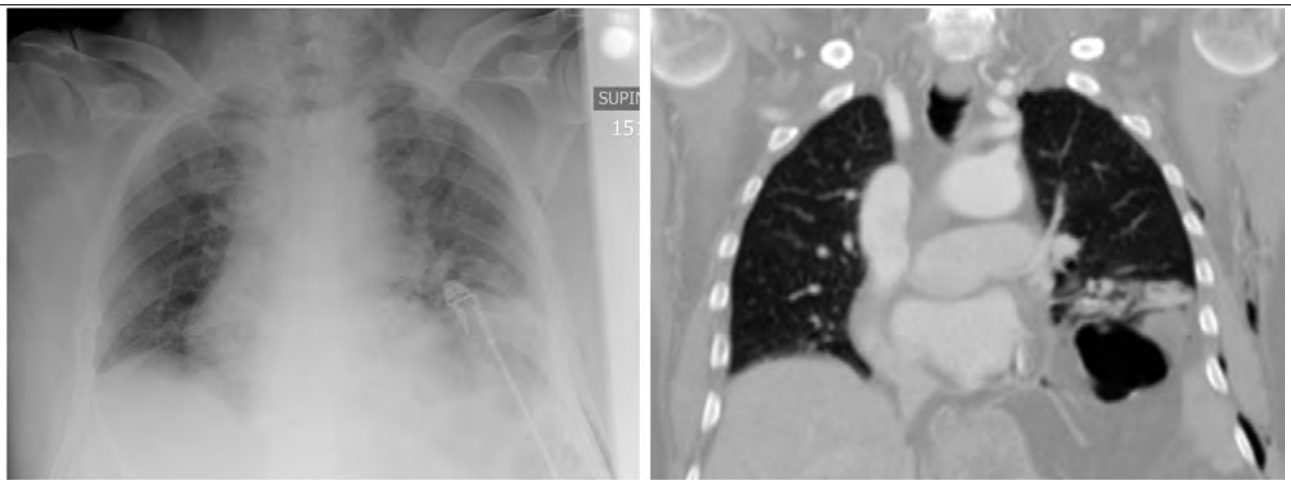
Imaging Prior to Transfer. Emergency medicine practitioners who do not work at designated trauma centers will certainly be responsible for the occasional trauma patient, and if the patient meets criteria for transfer to a trauma center, the question of whether to obtain imaging prior to transfer may arise. From a practical standpoint, the role of the practitioner is to stabilize the patient to the best of his or her abilities and to facilitate transport to the receiving facility for definitive management as soon as possible. As noted previously, CT is sensitive for diagnosing life-threatening injuries and can be used as a tool for determining disposition after trauma.[18] In a stable trauma patient with clinically suspected injuries based on mechanism or examination, CT might elucidate the need for further specialized management or it can obviate the need for admission or transfer. If a patient meets criteria for transfer prior to imaging, it is important to communicate with the receiving facility regarding the expectation of, or necessity for, imaging at the referring center. However, if a patient clinically requires transfer to a trauma center, sophisticated diagnostic studies may help with eventual management but should not delay transfer. Between 53% and 58% of transferred patients receive repeat imaging upon arrival at the receiving trauma center.[35,75] The reasons for repeating studies are varied, including change of clinical status during transfer, inadequate original technique, software incompatibility, and even simple human error such as misplacing or forgetting to send the original scans. It is notable that patients who received repeat imaging tended to be more severely injured

Figure 4. Risk of Death and CT Exposure



Estimated risk of death attributable to CT exposure by age. Adapted from: Laack TA, Thompson KM, Kofler JM, et al. Comparison of trauma mortality and estimated cancer mortality from computed tomography during initial evaluation of intermediate-risk trauma patients. *J Trauma* 2011;70:1362-1365.

Figure 5. Pan-scan Showing Rib Fractures, Left Hemidiaphragm Injury, and Large Flank Hematoma



Following a motor vehicle crash, a clinically stable 84-year-old man complained of mild left flank pain. His wife died as a result of the crash. Pan-scan revealed a number of rib fractures, a left hemidiaphragm injury, and large flank hematoma, which were not evident on plain radiograph and FAST examination. Images courtesy of University of Maryland School of Medicine Department of Emergency Medicine.

but also suffered longer delays[75] as well as additional radiation and financial charges. Lastly, incidental findings are found in up to one-third of trauma patients,[39] and trauma patients are notoriously often lost to follow-up,[76] which begs the question of who will arrange follow-up on these patients if incidental abnormalities are found during a formal over read after transfer.

Recommendations

Unfortunately, there is no universally accepted algorithm regarding routine whole-body CT compared with selective CT. A hospital could benefit from the development of a standardized CT protocol. Standardizing the radiologic workup of trauma patients needs to balance the risks of complications, cost, and incidental findings from CT versus the risk of missed injuries, repeat imaging, and delay in disposition or treatment.

Pan-scan is a noninvasive and effective method of injury determination in the hemodynamically stable trauma population, but it must be used with an awareness of its associated problems. Indiscriminate use without proper clinical evaluation or concern is inappropriate. Efforts to reduce radiation exposure should be focused toward younger patients and those with obviously minor injuries or trauma mechanisms. Pan-scanning may reduce but does not eliminate the incidence of missed injuries and is not a substitute for a thorough clinical evaluation, appropriate repeat examinations, and follow-up. Single-pass pan-scans reduce scan time and radiation compared with conventional sequential imaging. Comprehensive secondary reading of a scan after a preliminary read may lower the rate of missed injuries.

Further research is needed. Currently in progress is the REACT-2 trial, a prospective, multicenter, multi-national study investigating the effects of immediate pan-scan CT during the primary survey on clinical outcomes compared with the use of conventional imaging and selective CT. The intervention group undergoes immediate whole-body CT, completely eliminating plain radiographs and the FAST exam. This is a novel approach and is focusing on the primary outcome of in-hospital mortality as well as secondary endpoints such as effects on morbidity, radiation exposure, and cost-effectiveness. It is hoped that this study, and those to follow, will delineate an appropriately balanced diagnostic approach for trauma patients.

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CME/CNE Questions

1. Of the following, what is the most appropriate choice for a 48-year-old pedestrian who was struck by a motor vehicle with a moderate impact, is hemodynamically stable, and has no major physical exam findings except chest wall tenderness and a Glasgow Coma Scale (GCS) score of 13?
   A. separate head and chest CT scans
   B. head CT scan and chest radiograph only
   C. single-pass pan-scan
   D. no imaging; observation only

2. Which of these patients would most benefit from a pan-scan?
   A. any blunt trauma patient, regardless of mechanism
   B. a hemodynamically stable patient injured in a motor vehicle crash, with no obvious physical findings, whose passenger died on scene
   C. a hemodynamically stable 8-year-old boy with no physical findings after falling from a 5-foot ladder
   D. a hemodynamically stable pedestrian struck at 10 mph with right knee and hip pain

3. Which of the following statements regarding contrast-induced nephropathy (CIN) in patients undergoing enhanced CT after trauma is correct?
   A. The incidence may be as high as 12%, although this may be an associative rather than causative effect.
   B. CIN is defined as an increase of 25% or 0.5 mg/dL in creatinine from baseline.
   C. An Injury Severity Score of 16 or higher may be a risk factor for CIN.
   D. The higher the dose of contrast administered, the higher the risk of CIN.
   E. All of the above
   F. Only A, B, and C are correct.

4. You are a physician at a community hospital and have just placed a chest tube to stabilize a woman who was injured in a motor vehicle collision. She arrived with a pneumothorax caused by multiple rib fractures. The FAST exam is positive, and you have to transfer her to the nearest trauma center for surgery. What is the most appropriate approach to imaging?
   A. The patient is stable, so send her to CT for pan-scan.
   B. The patient is stable, but imaging should not delay definitive management; transfer her immediately.
   C. Scan the chest and abdomen, then transfer with accompanying images.
   D. Send the patient to CT, because the receiving facility will probably want a scan.

5. Regarding pediatric blunt trauma patients, which of the following is true?
   A. Children can be unreliable during history and physical, so they should be pan-scanned.
   B. The FAST exam is a reliable way to rule out surgical abdominal injuries in stable children without abdominal pain.
   C. Children receive the same effective radiation doses from CT as adults, but these doses carry a higher risk of secondary cancer.
   D. Pan-scan is a good way to rule out surgical injuries for all pediatric trauma patients.

6. Which of the following statements about lifetime cancer risk associated with pan-scan is true?
   A. The risk of trauma-related mortality is approximately six times that

of CT-related cancer mortality in all-comer intermediate-level trauma patients.
B. Age is a factor in CT-related cancer risk, and the risk is proportional to age.
C. The mean lifetime cancer risk after whole body CT in 3-year-old boys is 1 in 133 (0.75%) and 1 in 166 (0.60%) in girls.
D. The background radiation received on a yearly basis in an urban environment is almost as much as a single pan-scan.
E. B and D are correct.
F. A and C are correct.

7. Incidental findings are detected in approximately what percentage of trauma patients undergoing CT?
   A. 1%
   B. 10%
   C. 33%
   D. 50%

8. In a recent poll of emergency physicians and trauma surgeons about the components of the pan-scan obtained for individual trauma patients the physicians thought were necessary, which of the following is true?
   A. The ED physicians and trauma surgeons always agreed on which scans were necessary.
   B. ED physicians desired 35% fewer scans, and < 1% of these undesired scans would have led to a predefined "critical action."
   C. The trauma surgeons desired fewer scans than the ED physicians.
   D. All scans were ordered at the discretion of the ED physician.

9. Which of the following statements regarding clinician ability to rule out injury based on physical exam is true?
   A. The sensitivity of ruling out injuries in specific body regions steadily decreases with higher pretest probabilities of injury.
   B. Multiple studies have shown that physical exam is superior to CT scan for ruling out injuries.
   C. All patients with abdominal injuries found on CT will have abdominal tenderness.
   D. Ruling out injury based on physical exam findings is reliable in patients with altered mental status.

10. Which of the follow statements about the use of CT is true?
    A. The use of CT in EDs declined between 1998 and 2007.
    B. A typical "pan-scan" is a non-contrast CT of the head, followed by contrast-enhanced scans of the neck, chest, abdomen, and pelvis.
    C. A typical "pan-scan" is a non-contrast CT of the head, followed by contrast-enhanced scans of the neck, chest, abdomen, and pelvis and CT angiography of the extremities.
    D. CT accounts for approximately 70% of radiation exposure in medical populations.
    E. B and D are true.

CNE/CME Objectives

Upon completing this program, the participants will be able to:

- discuss conditions that should increase suspicion for traumatic injuries;
- describe the various modalities used to identify different traumatic conditions;
- cite methods of quickly stabilizing and managing patients; and
- identify possible complications that may occur with traumatic injuries.

CNE/CME Instructions

HERE ARE THE STEPS YOU NEED TO TAKE TO EARN CREDIT FOR THIS ACTIVITY:

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