Imaging Assessment of Gunshot Injuries

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Gunshot wounds are the third-leading cause of injury-related death nationwide. Most people with gunshot injuries undergo diagnostic imaging to evaluate their injuries in the clinical or forensic setting. Radiologic technologists must be knowledgeable about common injuries associated with gunshot wounds. Digital radiography and computed tomography play essential roles in the assessment of gunshot injuries. When clinically indicated, magnetic resonance imaging also is a valuable imaging modality for evaluating these injuries. Radiologic technologists should obtain quality images to assist with proper assessment of gunshot injuries.

After completing this article, the reader should be able to:

- Discuss the role of imaging modalities in assessing gunshot injuries.
- Describe the benefits and challenges of various imaging modalities in a variety of gunshot injury cases.
- Explain how gunshots injure the tissues, organs, and structures of the body.
- Describe how medical imaging modalities are used in the forensic assessment of gunshot injuries.
- Recognize the role of imaging in the field of forensic science.

On April 16, 2007, at 7:15 AM, Seung Hui Cho began shooting students in a dormitory at Virginia Polytechnic Institute and State University in Blacksburg. Less than 3 hours later, he entered a classroom building on campus, chained the doors shut, and began shooting at students and teachers in a second attack. Cho killed 32 people and wounded another 17 during the shootings. When police arrived, Cho turned the gun on himself and committed suicide. Two years later, on November 5, 2009, Nidal Malik Hasan opened fire inside the Fort Hood Soldier Readiness Processing Center in Fort Hood, Texas. Hasan killed 13 people and wounded 32 others, before being taken into custody.

Armed with a rifle, shotgun, and handgun, James Eagan Holmes began shooting moviegoers at the Cinemark Century 16 movie theater in Aurora, Colorado, on July 20, 2012. Twelve people were killed, and 58 were wounded. Holmes was sentenced to life in prison without the possibility of parole in August 2015. Several months after the Aurora movie theater shooting, Adam Lanza killed 27 students and staff and wounded 2 others during a shooting spree at Sandy Hook Elementary School in Newtown, Connecticut. Before arriving at the school, Lanza killed his mother in her home. He committed suicide at the school as police arrived.

These events had the highest casualty counts of victims killed and wounded in active shooter incidents in the United States between 2000 and 2013. A 2014 report conducted by the Federal Bureau of Investigation (FBI) outlined 160 active shooter incidents in the United States during that period; an average of 11 incidents occurred annually. During these mass shootings, 486 people were killed and 557 were wounded. The FBI report

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revealed a steady increase in U.S. mass shootings over the 14-year period.\textsuperscript{1,2}

Mass shootings cause many casualties at once, but they are not the only cause of firearm wounds and deaths. Gunshot wounds follow poisoning and motor vehicle accidents as top causes of injuries in the United States.\textsuperscript{3} Firearm homicide and suicide rates for U.S. men aged 15 to 24 years are roughly 20 times higher than in any other industrialized country.\textsuperscript{4} In 2010, gunshot injuries resulted in 73 505 U.S. emergency department visits,\textsuperscript{5} and firearms took the lives of 31 076 Americans through homicides and suicides.\textsuperscript{3}

Patients with gunshot wounds typically undergo medical imaging to clinically assess their injuries. Imaging also is used in forensics to evaluate gunshot wounds. Digital radiography (DR) and computed tomography (CT) provide critical information in the evaluation of gunshot injuries.\textsuperscript{4,5} Magnetic resonance (MR) imaging also is valuable when clinically indicated.

**Wounding Agents**

The use of handguns, rifles, or shotguns can cause different types of injuries.\textsuperscript{5,6} There are 2 main categories of handguns: revolvers and auto-loading pistols.\textsuperscript{6} Handguns produce a low-velocity projectile that releases most of its energy within the target.\textsuperscript{5,6} Often, people with a gunshot wound involving a handgun have an entrance wound but no exit wound because the bullet explodes into fragments, causing most of its damage inside the body.\textsuperscript{5} Fragmented bullet pieces can exit the body, however.\textsuperscript{6} A rifle has a longer barrel length than a handgun, which results in a high-velocity, high-energy projectile.\textsuperscript{5,6} Rifles are categorized into 2 main classifications: assault rifles, used mostly for military purposes, and hunting rifles, used mostly for recreation.\textsuperscript{6} Shotguns also have long barrels, but the guns produce low-velocity, low-energy projectiles.\textsuperscript{5,6} Shotguns can fire either a single bullet called a slug or multiple pellets contained within a shell, and both can cause significant damage.\textsuperscript{5,6}

**Bullet Characteristics and Construction**

The basic unit of firearm ammunition is referred to as the round. A round contains a primer, casing, propellant, and projectile. The primer ignites the propellant that surrounds the projectile within the casing. The casing acts as an accelerant to help propel the projectile, or bullet. When a shooter fires a gun, the round is released from the barrel and projected into the air.\textsuperscript{5}

Caliber refers to the diameter of a bullet. The caliber is independent of mass, velocity, and construction. Most bullets are composed of lead alloy primarily, but lead-free metallic bullets are available.\textsuperscript{6} A bullet might be surrounded by a metal jacket.\textsuperscript{5,6} Partially jacketed bullets have exposed or hollowed tips; these bullets typically flatten or “mushroom” when striking soft tissue.\textsuperscript{5,6}

The tips of full metal jacketed bullets are enclosed by the metal to prevent flattening deformation.\textsuperscript{5,6}

**Mechanisms of Gunshot Injuries**

The maximum wounding potential is a function of the bullet’s mass and velocity. Additional projectile characteristics, such as bullet mass, shape, and construction, determine the resulting injury.\textsuperscript{5} As the projectile comes into contact with tissue, injury stretch and crush mechanisms cause tissue damage, a process called cavitation. The stretch mechanism refers to the radial stretching of the projectile tunnel that forms a temporary cavity; the effect is similar to the ripples caused by a stone tossed in water. A crush mechanism results from the projectile boring through tissue and forming a permanent cavity. The entire tissue injury can be slightly larger than the crush cavity but often is smaller than the stretch cavity.\textsuperscript{5,7}

A bullet’s tip affects how much tissue is crushed, or the size of the permanent cavity, as well as the amount of stretched tissue, which is the size of the temporary cavity.\textsuperscript{5} Figure 1 illustrates the cavitation phenomenon. Partially jacketed bullets are designed to deform soft tissue upon impact and lead to a greater region of tissue crush.\textsuperscript{6,8} Other mechanisms of gunshot injuries include precession and nutation. Precession is the rotation of a bullet around its center of mass. Nutation is the wobbling action that occurs when the bullet spins in circular movements surrounding the tip of the bullet. Figure 2 demonstrates nutation caused by an object rotating around its axis. Bullets do not follow straight paths through tissue; they can tumble in flight, which can enlarge the permanent cavity significantly.\textsuperscript{5}

When a bullet breaks into fragments, it separates all or parts of the projectile and can cause greater damage.
Entrance and Exit Wounds

Human skin comprises 3 layers of tissue: epidermis (superficial layer), dermis (middle layer), and hypodermis (deep layer). Examination of the skin changes produced by a projectile often helps legal authorities distinguish between entrance and exit wounds. The edges of an entrance wound often are inverted by the projectile coming into contact with the skin surface. An ecchymotic, or discolored, ring forms around the entrance wound as blood vessels in the dermis rupture and hemorrhage. This purple-colored rim can be seen in exit wounds as well.

Exit wounds are produced by the projectile and projectile fragments, or in combination with other elements carried during the trajectory, such as clothes, buttons, bones or bone fragments, teeth, cartilage, organ fragments, and muscle tissue. Exit wounds generally are everted, or turned outward; they bleed and have irregular edges. Exit wounds usually are larger in diameter than entrance wounds. Depending on the mechanism of injury, people with gunshot wounds might present with no exit wound or multiple exit wounds.

Forensic Evaluation and Imaging

Radiography plays a primary role in the forensic setting for evaluation of gunshot wounds. DR and CT can assist forensic examinations for crime scene reconstruction and fatal gunshot wound assessment. Ballistics, the discipline involving the analysis of projectiles in motion, comprises 3 categories:

- Internal ballistics – study of a bullet within a firearm.
- External ballistics – study of a projectile in flight.
- Terminal ballistics – study of a projectile’s interaction within a given target.

Terminal ballistics includes wound ballistics, the interaction of bullets with the human body.
breath, or other discomfort aside from left lower extremity pain. In the absence of an obvious exit wound, the attending physician ordered laboratory tests; radiography of the chest, femur, and knee; CT of the abdomen, pelvis, and head; and CT angiography of the abdominal aorta and iliofemoral artery. The CT scan revealed a bullet track extending from the anterior aspect of the left knee that traveled cephalad subcutaneously and entered the peritoneal cavity while simultaneously perforating the distal descending colon. The bullet track continued through the retroperitoneal space at a posterior-medial angle and was found adjacent to the spleen and posterior chest wall, with no injury to the lungs, kidneys, or spleen. Based on the patient’s stability during the initial assessment, it was difficult to evaluate the extent of his injuries without performing adequate imaging. This case demonstrated the unpredictable nature of a gunshot wound trajectory independent of the bullet’s entry point. It also suggests that ordering a full-body CT scan for people with gunshot injuries regardless of the entrance wound location can improve response time for surgical intervention, especially if an exit wound is not present and the patient is stable.

Two studies acknowledged the benefits of CT in displaying bullet trajectory in gunshot victims.\textsuperscript{11,12} One study assessed the use of CT on 10 cadavers. Each of the deceased died from a single gunshot wound to the head; 5 were victims of homicide and 5 of suicide.\textsuperscript{11} The study found that CT assisted with identification of the bullet entrance and exit wounds as well as the bullet’s pathway in the brain. The use of CT in these 10 cases also helped medical examiners formulate hypotheses regarding the bullet trajectory to confirm circumstantial evidence about cause of death as homicide or suicide.\textsuperscript{11}

The second study evaluated the use of CT to identify bullet trajectory in 2 leg phantoms.\textsuperscript{12} Both leg phantoms were shot with a rifle at multiple trajectory angles and then scanned using multidetector CT. Radiologists identified all the bullet trajectories in the phantoms. In addition, using a PACS angle tool, the radiologists estimated a trajectory angle and were within 5% of the actual angles for all gunshot wounds.\textsuperscript{12} In this study, CT scanning helped forensic personnel estimate the location of the gun when it was fired with respect to the entrance wounds on the victim’s body. Additional research beyond the use of anatomic ballistic phantoms is warranted to further assess the benefits of using CT to identify the exact bullet angle and trajectory inside the human body.

**Gunshot Residue**

Gunshot residue is made up of unburned or partially burned propellant powder, particles from the ammunition primer, smoke, grease, lubricants, and metals from the round and weapon.\textsuperscript{8,13} Gunshot residue adheres to the projectile and leaves the barrel of the weapon along with the projectile.\textsuperscript{9} When the bullet penetrates the skin, these materials can contaminate the entrance wound.\textsuperscript{9} Typically, only entrance wounds contain such contamination.\textsuperscript{8,14}

Gunshot residue examination also is helpful in evaluating the firing range in gunshot fatalities.\textsuperscript{14} DR is excellent at detecting gunshot residue. As expected, the greater the firing distance, the less gunshot residue is present around the entrance wound.\textsuperscript{8,14} When the issue of suicide, homicide, or accidental firing is in question, the forensic investigation of gunshot residue is significant.\textsuperscript{15} Firing ranges typically are classified as contact, intermediate, or distant.\textsuperscript{7}

**Determining Manner of Death**

Determining the manner of death when gunshot wounds are involved can be challenging, especially if the circumstances of the incident are unclear and crime scene investigation is inadequate. Postmortem CT is recognized as a valuable tool among forensic personnel in distinguishing victims of suicide from victims of homicide.\textsuperscript{16-20} For example, a 53-year-old man was found dead after a fire had been extinguished at his residence.\textsuperscript{16} Even though a revolver was recovered beside his body, no gunshot wound was evident on his body because of severe charring. His wife and 2 children also were found dead at the scene, but entrance and exit wounds were identified on their bodies. A postmortem CT scan was conducted on the man’s body before an autopsy began.\textsuperscript{16}

The CT scan revealed an entrance gunshot wound in the middle of the posterior pharynx with loss of soft tissue.\textsuperscript{16} An internal bullet trajectory was assumed to pass.
Postmortem CT examination of the 63-year-old victim's skull and neck revealed a gunshot wound to the middle of the maxilla with loss of the upper incisors. The bullet track passed through the left massa lateralis of the atlas. Bullet remains were identified in the paramedian neck musculature on the left at the C1-C2 level. No exit wound was found on the postmortem CT scan (see Figure 3). Autopsy findings verified the CT results, detailing a severely damaged spinal cord.17

The medical examiner deemed the manner of death to be a homicide caused by respiratory paralysis as a result of a gunshot-induced medulla injury. The 58-year-old man had shot and killed the 63-year-old man, dumped his body, and then shot himself inside the vehicle. Although most intraoral shooting fatalities are the result of a suicide, this particular case study uses postmortem CT to display the bullet path to demonstrate the possibility of a homicide.17

Postmortem CT is useful to identify the precise location of a bullet, bullet fragments, and bullet trajectory and is helpful to investigators during unusual cases involving multiple gunshot wounds. Multiple self-inflicted gunshot wounds are rare and usually present a challenge to the forensic pathologist in determining the manner of death (see Box 1).18-20

**Imaging of Common Gunshot Injuries**

**Head Injuries**

Cranioencephalic injuries from gunshots are associated with a high mortality, especially after attempted suicide incidents, 88% of which result in mortality.21 Given the emergency circumstances surrounding a gunshot head injury, an imaging examination can be challenging.4 Once the patient is stabilized, a CT scan of the head can
demonstrate cerebral damage, and CT angiography can provide additional information about vascular injuries. Over a 10-year period at a university hospital in Pakistan, researchers identified 51 cases involving penetrating craniocerebral gunshot wounds. Most cases were the result of homicides, and only 4% were suicide attempts. Imaging revealed the frontal lobe to be the most common site (43%) for gunshot wounds to the head followed by the parietal region (22%). The most common complications experienced by the survivors in this study included motor deficits, occurrences of aphasia, seizure activities, and cranial nerve palsies. Researchers determined that the site and angle of penetration, projectile velocity, and the gun’s caliber all are factors in the extent of head trauma. In general, frontal gunshot wounds were associated with better prognosis compared to posterior fossa injuries.

Combat Head Wounds

Gunshot wounds to the head are common injuries in military conflicts. In combat hospitals, CT scans often are interpreted by primary care physicians who do not have specialty training in radiology. As a result, some gunshot wounds to the head have been diagnosed as fatal or requiring permanent life support for the patient. However, Folio et al noted that some soldiers who underwent dramatic craniectomies survived and required no permanent life support. To prevent future misdiagnoses, the authors developed a reporting software to complement head CT scans that could help physicians make more informed decisions regarding treatment and prognosis. The software is called Semi-automated Modeling and Anatomic Reporting of Trajectories (SMART). It uses the gunshot wound entrance location and terminal bullet fragment location to calculate a projected fragment trajectory that corresponds to an estimation of penetrating head injury; the software is undergoing additional study.

Gelatin Models

Recent studies investigated the use of CT on gelatin head models to further evaluate bullet trajectory. Experimental shots into blocks of gelatin have been performed for decades to compare the effects and properties of various types of bullets. One study’s aim was...
to determine whether adding a mixture of color (acrylic paint) and barium sulfate contrast inside the gelatin model would enhance CT’s ability to better identify the bullet pathway. A The researchers shot several gelatin head models containing the color-contrast mixture. Shots were fired from various distances, and CT scans were acquired 24 hours later. Image quality facilitated accurate measurements of the bullet trajectories.

In a similar study involving gelatin head models filled with a color-contrast mixture, researchers investigated the use of CT to better display the temporary cavity caused by a projectile. This study used several contrast agents including diatrizoate meglumine and diatrizoate sodium (Gastrografin), meglumine ioxitalamate (Telebrix), and barium sulfate (Micropaque). The results revealed that water-soluble contrast media (Gastrografin and Telebrix) did not provide sufficient detail of the temporary cavity and caused diffusion artifacts. The best results were obtained using a barium sulfate mixture.

**Facial Injuries**

Maxillofacial firearm injuries vary in clinical presentation based on the anatomical structures involved. In the upper face, gunshot injuries to the orbits or cranial contents are common. A bullet penetrating the orbit often exits through the contralateral temporomandibular joint region. In the lower face, damage to the intraoral lining and comminuted fractures of the mandible are significant issues. Many mandibular fractures are accompanied by extensive soft-tissue trauma caused by a tumbling bullet and bone and teeth fragments. Injuries to the lateral and posterior mandible can cause significant bleeding and evolve into gross swelling, which poses an immediate threat to the patient’s airway. Gunshot wounds to the lower face are more common, reflecting the high incidence of suicide attempts made with shotguns discharged under the mandible. Most firearm injuries to the face are classified by their primary locations: the central face, the lateral mandible, the lateral midface and orbit, and the lateral cranio-orbital region.

**Neck Injuries**

Gunshot injuries to the neck threaten several vital anatomical structures. The neck comprises vascular, gastrointestinal, respiratory, endocrine, lymphatic, skeletal, muscular, and nervous systems, which makes imaging of penetrating neck injuries particularly challenging. Approximately 15% to 25% of penetrating firearm neck injuries result in an arterial injury. Nearly 80% of penetrating firearm-related arterial injuries of the neck involve the carotid arteries, and up to 43% involve the vertebral arteries. Venous injuries are seen in 16% to 18% of patients who have penetrating gunshot injuries to the neck. CT angiography best demonstrates arterial and venous injuries by visualizing partial or complete occlusion, pseudoaneurysm, intimal injuries, arteriovenous fistula, active bleeding, and luminal caliber changes.

**The Esophagus**

Gunshot wounds involving the cervical esophagus are uncommon; however, mortality rates from penetrating gunshot injuries to the esophagus are high, mostly because of delayed diagnoses. Clinical history, physical examination, and chest radiography findings often do not indicate an esophageal gunshot injury. Although CT angiography can suggest an esophageal injury, a water-soluble esophagogram or endoscopy is needed to detect such injuries. If results of a water-soluble esophagogram are normal when an esophageal injury is suspected, some recommend a second study using a barium sulfate suspension. Research indicates water-soluble contrast material alone is safe, reliable, and cost-effective. Depending on the severity of the injury, it can be difficult, if not impossible, to perform an esophagogram on a patient with an esophageal gunshot injury. The patient might not be able to tolerate swallowing, which warrants the need for endoscopy to evaluate the injury.

**Injuries to the Trachea and Larynx**

Tracheolaryngeal injuries are rare in gunshot victims, but clinicians should evaluate patients for these when in doubt because of the potential for life-threatening airway compromise. CT scans that complement the clinician’s physical examination help identify penetrating injuries to the trachea and larynx. Incidents with indeterminate CT findings should be followed up with endoscopy and bronchoscopy to investigate the upper airway.
Thoracic Injuries

Hemothorax, hemopneumothorax, and pneumothorax are the most common injuries associated with gunshot wounds to the thoracic area.\(^4,21\) These injuries should be diagnosed and treated immediately. If the patient is in stable condition, chest radiography can demonstrate expansion of the lung and mediastinum.\(^7\) A chest tube, the most important therapeutic intervention, is warranted in all cases with a pneumothorax larger than 2 cm.\(^28\) Confirmation of tube placement is verified on a subsequent chest radiograph. Figure 4 demonstrates bilateral chest tubes placed in a patient with a gunshot injury to the chest.\(^21\) Identifying cardiac injuries in patients who reach the hospital for treatment is rare because those injuries often are lethal while the victim still is at the scene.\(^4,21\)

A blast injury is a direct consequence of a blast wave generated by a high-explosive detonation upon the body. A blast lung injury often is characterized as respiratory difficulty and hypoxia without obvious external injuries to the chest. The lungs are particularly vulnerable to a blast injury because of their delicate infrastructure. The shock wave or other type of transmitted pressure (blast) causes shearing of the alveoli, pulmonary parenchyma, and vasculature, creating pneumatoceles and causing pulmonary contusion. Pneumatoceles are cavities in the lung parenchyma filled with air that result from pulmonary trauma.\(^30\) Box 2 describes a fatal blast lung injury.

Abdominal Injuries

Surgical intervention once was the standard management for all penetrating gunshot wounds to the abdomen.\(^21,31\) However, a high number of these operative procedures have been identified as unwarranted, and non-operative treatment has increasingly gained acceptance.\(^21\) Physical examination that is complemented with medical imaging, specifically CT, provides the most efficient means of assessing the need for surgical intervention in patients with abdominal gunshot injuries.\(^31\)

In one case, a 30-year-old man sustained a gunshot injury to the left upper abdomen.\(^31\) The patient was in stable condition with no signs of respiratory distress or active bleeding. Chest radiography demonstrated clear lung fields with no indication of injury; the abdominal radiographs revealed a bullet in the left upper quadrant lateral to the first lumbar spine. Based on the history and radiographic findings, the bullet trajectory was estimated to have encountered the left lung, left dome of the diaphragm, stomach, left lobe of the liver, splenic vessels, body of the pancreas, and left kidney.\(^31\)

Even though the patient was stable, physicians ordered a CT scan of his chest and abdomen to detect

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**Box 2**

**Blast Lung Injury**

A 46-year-old man was found dead at his home with a shotgun between his legs and blood around his mouth. Several suicide notes were found as well. Postmortem CT of the head and face revealed multiple skull, lower face, and mandibular fractures. Findings were consistent with an intraoral shotgun discharge. A CT scan of the chest revealed aspirated bone fragments in the tracheobronchial tree, pleural effusions, and abnormal lungs with bilateral pneumatoceles. These additional findings were confirmed on an autopsy and identified as a secondary blast lung injury caused by the gunshot.

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potentially serious internal injuries resulting from the estimated bullet trajectory. CT images showed the bullet lying posterior and medial to the left kidney just lateral to the spine. All thoracic and abdominal structures were without injury. The patient was admitted for observation, remained clinically and vitally stable, and was discharged after 48 hours. Despite the estimated bullet trajectory and possible internal injuries, the patient was managed nonoperatively, largely because of information from radiographs and CT scans (see Figure 5).

Bollinger et al tested a method for forensic study of abdominal gunshot wounds using a synthetic pelvic girdle made of polyurethane and sealed with a gelatin coat. The investigators fired multiple bullets toward the model’s right acetabulum, midsacrum, and left acetabulum. CT scans provided accurate ways to measure crack lengths radiating from the entrance wound along the bullet channel. This type of simulation provides

Figure 5. A. Erect abdominal image demonstrating a bullet in the upper left quadrant. B. Lateral abdominal radiograph demonstrating a bullet lateral to the spine (circle). C. CT transverse view of the abdomen demonstrating a bullet lodged posterior and medial to the left kidney. Reprinted under the terms of the Creative Commons Attribution License 2.0 Generic from Khan MS, Khan BM, Naz S, Pirzada MT. Is estimated bullet trajectory a reliable predictor of severe injury? Case report of a thoracoabdominal gunshot with a protracted trajectory managed nonoperatively. BMC Res Notes. 2013;6(1):63-66. doi:10.1186/1756-0500-6-63.
Bullet Embolism

Bullet retrieval from the body of a gunshot victim is one of several tasks performed during a postmortem forensic examination. Locating the bullet based on images produced while the victim was alive can be challenging for the forensic personnel. When a bullet is not found in the expected location based on entry wound and expected trajectory, or as evident in diagnostic imaging, forensic personnel assume the bullet has been deflected from its previous course by hard tissues, exited through natural body orifices, or migrated to a distant location. In this case, embolism refers to the migration of a particle from its point of origin to a distant site. Emboli can occur after death.33

Embolism is demonstrated in the case of a 27-year-old man admitted to a hospital after being shot by low-velocity bullets.33 Physicists located entrance wounds on the right and left sides of the man’s chest and in his abdomen above the right iliac crest. They performed emergency surgery to stop the victim’s bleeding. Following surgery, a CT scan of the chest and abdomen revealed a bullet between T11 and T12, a second bullet between the spinous processes of L1 and L2, and a third near the splenic flexure. Despite repeated surgical attempts to control bleeding, the victim died 18 days after the shooting.33

Forensic personnel struggled to find the third bullet near the splenic flexure. The third bullet had penetrated the colon through a tiny laceration and then moved after the initial imaging procedures. The bullet’s migration mostly was the result of peristalsis. However, the bullet never was expelled from the body through the rectum; it was located by forensic personnel in the sigmoid colon after additional radiographs of the abdomen were performed.33

Spinal Injuries

Gunshot injuries to the spine make up the third most common cause of spinal injury.21,28,34 A wound track extending through the spinal canal suggests a spinal cord injury.34 It is common for bone and bullet fragments to align along the track through the spinal canal, but spinal cord injury can result occasionally from secondary cavi
tation from a bone or bullet fragment without the entire bullet entering the spinal canal.28 MR scans can display spinal cord injuries better than CT can, provided no retained metallic bullet fragments of unknown composition or other contraindications are present.21,28,34

Trahan et al investigated gunshot wounds that occurred between 2007 and 2011 in patients treated at a trauma hospital in New Orleans, Louisiana.34 The aim of the study was to assess the epidemiologic characteristics of patients with gunshot injuries to the spine. Of the 147 patients studied, 40 (27%) had cervical injuries, 53 (36%) had thoracic injuries, and 54 (37%) had lumbosacral injuries.34 In addition, 88 (60%) patients received an admission toxicology screening; of those, 73 (83%) tested positive for marijuana, cocaine, or alcohol.34 Regarding management, 127 (86%) patients were treated nonoperatively. Of the 20 patients who had surgical procedures, 13 had injuries below T11, and 7 had injuries above T11.35 Ten (7%) patients died from the gunshot-related injury during hospitalization. Because the incidence of gunshot wounds to the spine in New Orleans was more than 3 times higher than that in the next most violent city, the authors reported that there was a correlation between gunshot wounds to the spine and positive toxicology.35

Spinal Immobilization

Spinal immobilization in a penetrating gunshot injury to the spine is a controversial topic.35–38 Widmeier et al reported on a 29-year-old man who arrived by private vehicle to a community hospital.36 The patient had a single gunshot wound to the upper, posterior thoracic region just left of the spinal column. He went into respiratory and cardiac arrest soon after arriving. Emergency interventions included resuscitation, intubation, and placement of a chest tube, nasogastric tube, and urinary catheter. A portable chest radiograph demonstrated a bullet near the level of the upper thoracic spine. Arrangements were made to transfer the patient to a level 1 trauma center approximately 4.5 miles away. The transport team was made aware of the patient’s condition, and discussed whether full spinal immobilization was indicated. Several people maintained spinal alignment during movements. The patient’s body habitus prevented use of a cervical collar,
however, and the transfer team used an alternative immobilization approach with towel rolls and tape. At the level 1 trauma center, multiple health professionals helped transport him to the emergency department. Spinal CT scans identified a bullet lodged in the soft tissue to the right of the spine at C2 as well as posterior fractures of C4 through C7 with bony fragments from C5 and C6 entering the central canal. The patient died 8 days after the incident. 

Health care providers could have exacerbated the patient’s injuries. However, the spinal cord damage likely was caused by the initial bullet penetration and possibly worsened during the private vehicle ride to the hospital. The care team was mindful to maintain full spinal alignment during the required log rolling maneuver. Recent data has suggested penetrating gunshot wounds are associated with a higher incidence of mortality when a cervical collar is used. One study acknowledged a correlation between cervical collar use and an increase in intracranial pressure. Evidence supporting spinal immobilization in patients with penetrating gunshot wounds is unclear.

**Extremity Injuries**

Gunshot injuries of the extremities are difficult to manage, primarily because damage to arteries and nerves can be serious and can significantly affect patient outcomes, including long-term complications. Even though complications are possible, overall survival rates are high with gunshot injuries to the extremities.

**Upper Extremities**

A study from Pereira et al reported on 89 patients who sustained complex gunshot wounds to the hand and wrist and were admitted to a university hospital between 1997 and 2007. Most of the injuries were caused by firing of a low-velocity handgun. Of the 89 patients, 62 required surgical debridement and rigid internal fixation. Comminuted fractures of the phalanges and metacarpals were the most common fractures in this population. Specific fracture sites included the distal radius (4), distal ulna (6), metacarpal (16), proximal phalanx (9), middle phalanx (7), and distal phalanx (3). Follow-up telephone questionnaires discovered that 65% of the patients reported being disabled from work because of pain. However, the quality of life and ultimate function was rated good in 61%, fair in 26.1%, and bad in 13%.

Upper extremity wounds also can be examined for forensic purposes. Radiography helped to identify the cause of injury in a mummified hand on display in the medical museum at the University College Dublin School of Medicine and Medical Science. Two areas of trauma were evident on the hand: a perforating wound to the palm and a corresponding wound on the posterior aspect. Sharp-force trauma to the distal forearm also was present. DR demonstrated the absence of the proximal half of the third metacarpal, damage to the base of the fourth metacarpal, and dorsal displacement of the remaining third metacarpal and distal portion of the fourth metacarpal. Possible bullet material was identified near the fourth metacarpal and trapezium. No degenerative joint changes were evident, and bony trabeculation appeared normal. A CT scan was conducted on the mummified hand to further evaluate the bullet trajectory. Imaging and anthropological assessment determined that the victim was shot by a low-velocity projectile that entered the palm and exited the back of the hand. The bullet track suggested the victim raised the hand for protection, or the victim accidentally discharged a shot while cleaning or inspecting the firearm. The hand was most likely amputated during surgery or was removed during postmortem examination; the hand was preserved as a wet specimen and later donated to a museum collection.

**Lower Extremities**

The way in which indirect fractures of the lower extremities associated with gunshot injuries are produced is highly debated. The bone can break at a location remote from the bullet trajectory, and some victims recall walking or running after sustaining the injury before collapsing. Some patients insist the fracture is caused by falling and not related to the gunshot injury.

Using femurs from deer embedded in a gelatin mold, Kieser et al assessed the occurrence of lower extremity fractures. The 4 most common types of military and civilian bullets were fired at the gelatin femur models. The researchers then flexed the model femurs to replicate walking or running, which caused spiral fractures.
The study indicated the remote femur fractures were directly related to expansion of the temporary cavity caused by the bullet. The authors suggested that the fight-or-flight response dulls the pain and allows the victim to move the fractured limb following an actual gunshot injury involving the femur. Inevitably, the multidirectional stresses of gait and expansion of the temporary cavity cause fracture displacement, and the victim falls to the ground.41

Dougherty et al also found from studying cadavers’ tibias and femurs that indirect fractures were the result of expansion of the temporary cavity caused by a bullet.42 This study was limited to expansion fractures in elderly osteopenic bone.42 Future research is warranted to validate the findings of these studies using younger bone, which has a higher strain tolerance.

Other Considerations

Additional concerns for imaging professionals regarding patients who have gunshot-related injuries include plumbism, or lead poisoning, and other trauma situations that imitate gunshot wounds. Awareness of incidental findings when imaging victims of firearm shots also is a consideration for patient care.

Plumbism

An uncommon yet potentially fatal delayed effect of retained bullets is plumbism, which can occur within a few days to years after initial injury.5,43 Plumbism is greatly increased in gunshot wounds that include bullet fragmentation.5,43 Lead fragments within joint spaces are more susceptible to plumbism because of their solubility in synovial fluid.5,43 On radiographs, lead toxicity can be observed from complications, such as mechanical damage and synovitis, and looks similar to an arthrogram with contrast injected into the joint spaces.5 Identification of bullet fragments on medical imaging can aid the radiologist and referring physician in recognizing fragments in areas likely to cause systemic lead poisoning.5

In one case, a 62-year-old man was admitted for evaluation of a tumor on the right soft palate. DR identified a metallic foreign body in his left maxillary sinus.43 The patient recalled being shot in the face with an air gun pellet when he was 12 years old but received no medical attention at that time. The patient also had a history of chronic tobacco use. Physicians decided to remove the air gun pellet at the same time as the tumor biopsy. The pellet was removed without complications, and the biopsy revealed a low differentiated squamous cell carcinoma of the soft palate. The patient’s toxicological blood analysis showed no increased blood lead level. However, the lead-containing air gun pellet embedded in the maxillary sinus for 50 years could not be excluded as a possible human carcinogen. Future research is required to evaluate the complex interactions of combined long-term lead and cigarette smoke exposure on cancer development.41

Conditions that Mimic Gunshot Injuries

Some injuries or conditions unrelated to firearms can mimic gunshot wounds clinically or at autopsy. Imaging can help determine cause of injury. In one case, a 61-year-old man was found dead in a dorsal position near a running circular saw.44 The victim was covered in blood, and blood traces were found on the ground between the circular saw and the body. Investigators identified an oval-shaped defect resembling a distant range gunshot wound at the upper left frontal region of the victim’s chest, immediately below the clavicle. Forensic personnel diagnosed an open chest injury as the primary cause of death and classified the nature of the injury as a gunshot wound. DR demonstrated a metallic object near the left scapular region as well as fractures of the second and fifth left ribs. An autopsy revealed the metallic object to be a metal nail fragment that was forcefully hurled toward the victim’s chest from the circular saw, not a bullet. The nature of the victim’s injury was changed from a gunshot wound to fatality associated with a circular saw accident.44

Incidental Findings

Imaging also can reveal incidental findings when evaluating gunshot wounds, as demonstrated in a case reported by Turk et al. After he was shot with a hunting firearm, a 27-year-old man was taken to an emergency department via ambulance.45 He had a 7-cm open wound on the anterior aspect of the right hemithorax. Because the gunshot injury was on the right side of the chest, attending physicians assumed the heart and major vessels...
were not involved. However, a portable chest radiograph revealed the victim’s heart and stomach were on the right side (a condition known as *situs inversus totalis*), and he required immediate surgical intervention to assess the heart and any major vessel injury. The chest radiograph also revealed multiple rib fractures and multiple gunshot pellets (see Figure 6). The patient underwent surgery to repair small lacerations of the lung parenchyma and soft tissue. He gradually improved and was discharged 8 days later.45

Many people with *situs inversus totalis* are unaware of their unusual anatomy until they seek medical attention for an unrelated condition. Turk et al reported the first case study of *situs inversus* and a firearm injury.46 Chest and abdominal organs usually are transposed to the exact opposite position in patients with *situs inversus* involving the heart (*dextrocardia*). In addition, a 2-lobe lung, a spleen on the right, and liver and 3-lobe lung on the left indicate *situs inversus totalis*.46 Variations can be seen in blood vessel courses and bronchi. Radiographers must be cautious when marking images of these patients to avoid undesirable results when an emergency or forensic surgical intervention is required.46

**Open Autopsy vs Autopsy With CT**

Use of CT imaging in forensic investigations and autopsies has demonstrated equivalent and at times superior performance to conventional autopsy for gunshot-related injuries.11,46 Forensic personnel acknowledge the benefits of using CT to identify and recognize bullet entrance and exit wounds, if present, and the bullet trajectory to attempt to determine the dynamics of these traumatic events.10-12,16-20 In addition, CT scanning helps reveal and locate projectile fragments in the body.5,9,16,17,30,54,46

Ampanozi et al documented the use of CT in identifying a large left tension pneumothorax as the cause of death in a 59-year-old woman.46 The postmortem CT scan also revealed an old gunshot injury to the face, with bullet fragments detected near the victim’s right orbit. Detecting a pneumothorax during conventional autopsy can be difficult.46,47 Moreover, many forensic institutions do not routinely assess the presence or absence of air in the pleural cavity during autopsy investigations.46 The study from Ampanozi et al demonstrated the need to perform a CT scan before an autopsy to report a pneumothorax as a cause of death in suspected cases.46,47

Postmortem CT also has become an important complement to conventional autopsy in detecting traumatic or putrefactive gas accumulations.46 Gebhart et al compared gas accumulations in trauma cases involving gunshot and stab wounds with nontrauma cases. The authors found gas in 98% of trauma victims and in 80% of those who did not die from trauma. In the Gebhart study, postmortem CT was found to be valuable to identify gas accumulations in open trauma cases.46
the use of postmortem CT, the detection of gas depends on careful examination by the forensic pathologist. Most autopsies involve dissection using water, so detecting visible intravascular gas bubbles in the brain vessels or ascending gas bubbles from the right heart chamber can be challenging. Gas frequently is seen in the intracranial cavity in victims of firearm injuries.

Studies also have reported several limitations of CT in the forensic setting for investigating gunshot wounds. Makhlof et al documented that CT could help determine contact and intermediate firing ranges but was unable to determine distant firing ranges. This same study showed CT was superior to conventional autopsy in identifying facial fractures and pneumothoraces but limited in demonstrating skull base fractures and contusions of the brain. The authors reported that CT was not as effective as an autopsy in detecting injuries to solid organs, with the exception of the kidneys.

Peschel et al compared the projected bullet trajectory in the skull as indicated on CT reconstruction to the actual trajectories documented on autopsy reports. Of the 5 cases studied, 3 demonstrated an excellent correlation, one case was not applicable because the original brain was not available for CT reconstruction, and one case showed a difference of 1 cm to 2 cm. This difference was attributed to only part of the skull being available for image reconstruction. These findings suggest postmortem CT can reconstruct bullet trajectories adequately but should be used carefully in cases of incomplete skulls.

**Other Imaging Techniques**

New techniques in CT forensic study continue to be developed. Other imaging modalities can be useful in forensic investigations of gunshot-related deaths.

Postmortem MR rarely is used to assess death from gunshot injuries primarily because MR equipment and staff are not readily available in morgues or affiliated hospitals. A lack of information about the behavior of projectiles also limits the use of MR. The magnetic properties of lodged projectiles and the use of MR have not been extensively researched. Gascho et al described a homicide case in which the victim had a gunshot entrance wound to the occipital region of the head but no visible exit wound. The victim underwent a whole-body postmortem CT scan and postmortem MR scan. A conventional autopsy was performed immediately following the postmortem MR examination.

Imaging revealed projectile movement between the postmortem CT and MR scans. The bullet did not produce excessive artifacts on the postmortem MR scan. The autopsy revealed no heating effects around the bullet, indicating that the postmortem MR scan created no thermal effect. The autopsy also revealed the bullet had no ferromagnetic properties. Thus, the projectile movement was attributed to transferring the victim’s body from the CT table to the MR suite, not to magnetic torque during the postmortem MR scan. Ultimately, the study revealed that postmortem MR provided better anatomical detail of the bullet trajectory within soft tissue. However, using MR in gunshot-related injuries is predicated on knowing the ferromagnetic properties of a bullet.

**Comparing Imaging Modalities**

Amadasi et al relied on DR to evaluate changes in metallic gunshot residue in cremated adult ribs. The researchers shot 31 ribs each with a single bullet at several close-range shooting distances and then charred them in an electric oven. Digital radiographs of the ribs were acquired before and after the charring to evaluate changes in metallic gunshot residue. Images revealed metallic residue in every rib sample, even after the charring process. Although this study revealed that metallic gunshot residue can survive extreme charring processes, DR is not helpful in distinguishing between metal residues and other residues such as glass or soil. Thus, in a real situation involving a burned corpse, contamination by environmental agents might be a factor. Further research in this potentially problematic area is warranted.

To further study the detection of metallic gunshot residue, Amadasi et al replicated their previous study on cremated adult rib bones using DR. In the later study, however, investigators used CT and MR. Results indicated that DR was superior in detecting metallic gunshot residue. CT demonstrated less ability to detect residue, and MR exhibited a high sensitivity for residue in soft tissue. This study marked the first of its kind in leading toward detailed studies comparing the use of DR, CT, and MR in other gunshot injury scenarios.
Cha et al compared CT and MR images with conventional autopsy findings. The authors combined postmortem CT with postmortem MR for forensic investigations. Using 5 victims who died from gunshot injuries, the investigators conducted a postmortem CT scan, followed by a postmortem MR scan, and an autopsy. The CT and MR images were sent to a cardiologist, chest radiologist, abdominal radiologist, neuroradiologist, and head and neck radiologist. Each performed their evaluations blinded to the autopsy findings. MR provided more information about soft tissues, and autopsy confirmed the results of both types of scans. The researchers recommended the simultaneous use of CT and MR in postmortem imaging because the modalities complement one another effectively.

The Future of Forensic Radiography

As imaging to evaluate gunshot wounds continues to improve, several current and emerging technologies show promise. In addition to assessing injuries associated with gunshot wounds, DR can aid forensic personnel in victim identification by determining sex, estimating age, demonstrating bone morphology and prosthetics, and recognizing previous injuries and pathologies. Dental arches, paranasal sinuses, mastoid air cells, and the shape of the sella turcica all can provide significant clues to victim identification.

Cross-sectional Imaging Acceptance

Evidence supporting the use of CT and MR appears to be growing. Postmortem CT displays a bullet’s trajectory and pinpoints the location of a bullet and bullet fragments. This helps clarify the cause of death before an autopsy is performed. Potential benefits of cross-sectional imaging include greater acceptability by families who object to conventional autopsy for religious and cultural beliefs and reduced invasiveness (and appearance) of sensitive areas such as the head and face from conventional autopsy. Institutions performing cross-sectional imaging in addition to conventional autopsies need a strong infrastructure that includes staffing, equipment, and support. In addition, adding cross-sectional imaging requires training for personnel who perform postmortem imaging and for those who interpret these studies.

Micro-CT

Micro-CT is a relatively new approach to assessing gunshot injuries. The tomographic technique has a resolving power in the micrometer range. As a result, micro-CT provides much greater spatial resolution than conventional CT and overcomes limitations associated with its image quality and detail. In particular, micro-CT has proven useful in determining firing ranges related to recent gunshot wounds and those in the process of decomposition. In addition, micro-CT can detect radiopaque substances around entrance wounds, which helps distinguish between gunshot entrance and exit wounds. The high-resolution tomographic technique used in combination with other autopsy and crime scene findings potentially can play an important role in reconstructing the crime scene following a shooting incident.

Two studies discussed the use of micro-CT to detect gunshot residue to estimate the firing distance and assist legal authorities in distinguishing suicide from homicide victims. The first study used micro-CT complemented with image analysis software to quantify gunshot residue and determine the firing distance. Fifty shots were fired at human legs that were surgically amputated for various medical reasons; the shots were fired from a pistol at various distances. The results indicated that by increasing the firing distance, micro-CT analysis demonstrated a clear decreasing trend in the mean gunshot residue percentage around the entrance wound. This study was the first application of micro-CT analysis in the field of forensic ballistics. The researchers demonstrated micro-CT to be an objective, rapid, and inexpensive tool for estimating the firing range in firearm fatalities.

A second study further evaluated the role of micro-CT in determining the firing distance using recent and decomposing gunshot wounds. The researchers stated that gunshot residue can be altered or obscured by after-death events such as putrefaction, autolysis, environmental effects, and even damage by animals. Using 3 different firing distances, 60 shots were fired at fresh...
Imaging Assessment of Gunshot Injuries

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and decomposing human calves surgically amputated for medical reasons. Results revealed that micro-CT detected gunshot residue on all of the investigated entrance wounds. The researchers also discovered micro-CT analysis potentially could be a screening tool for differentiating between decomposing entrance and exit gunshot wounds. Because of its limited availability, the use of micro-CT in the forensic discipline still is an emerging technology.

Nano-CT systems are based on the same principles as micro-CT but compromise versatility of sample size for improved resolution. Like micro-CT, nano-CT systems are not common but have potential forensic applications. Nano-CT might be attractive in investigating the role of small intradural venules as potential origins of hemorrhage in cases of nonaccidental head injury. Vascular corrosion casting procedures of the cerebral vasculature would benefit greatly from the enhanced level of detail achievable from nano-CT imaging.

Conclusion

The past 2 decades have witnessed an increase in the use of medical imaging in forensic practice. CT has become one of the most frequently used modalities in medical imaging and is increasingly a tool for forensic studies and medical-legal practice. Some reports in the literature argue that postmortem CT should become a standard in forensic practice to help determine cause and manner of death, especially in incidents involving firearms. DR, CT, and MR provide essential information in the assessment of gunshot injuries. Radiologic technologists should be aware of common injuries associated with gunshot wounds and obtain quality diagnostic images to assist in the proper assessment of those injuries.


Imaging Assessment of Gunshot Injuries

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Read the preceding Directed Reading and choose the answer that is most correct based on the article.

1. As a projectile comes into contact with tissue, injury stretch and crush mechanisms cause tissue damage, a process called:
   a. cavitation.
   b. precession.
   c. mutation.
   d. fragmentation.

2. Which of the following statements are true regarding bullet fragmentation?
   1. Bullet fragments become individual projectiles.
   2. Bullets can fragment when they strike bone.
   3. Bullet fragments can do greater damage than bullets that do not fragment.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

3. The study of a projectile's interaction within a given target is referred to as _______ ballistics.
   a. internal
   b. external
   c. terminal
   d. wound

4. Two studies acknowledged the benefits of computed tomography (CT) in the investigation of gunshot wounds and found that CT assisted in:
   1. identification of entrance and exit wounds.
   2. visualizing the bullet’s pathway in the brain.
   3. estimating the location of the gun when it was fired.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3
5. The **most** common injuries associated with gunshot wounds to the thoracic area include:
   1. hemothorax.
   2. hemopneumothorax.
   3. pneumothorax.

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

6. A(n) ______ is a cavity in the lung parenchyma filled with air that results from pulmonary trauma.
   a. contusion
   b. effusion
   c. pneumatocele
   d. pneumothorax

7. According to Dougherty et al, indirect tibia and femur fractures associated with gunshot wounds most likely originate from:
   a. a fall from a height following the shot.
   b. bullet migration.
   c. a higher strain tolerance.
   d. an expansion of the temporary cavity caused by the bullet.

8. Which of the following statements are **true** regarding plumbism and retained bullet fragments?
   1. Plumbism is greatly increased in incidents with bullet fragmentation.
   2. Lead fragments within joint spaces are more susceptible to plumbism.
   3. Plumbism only occurs years after initial injury.

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

9. Limitations of CT in the forensic setting include:
   1. inability to determine distant firing ranges.
   2. difficulty demonstrating skull base fractures and contusions of the brain.
   3. ineffectiveness in detecting injuries to kidneys.

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

10. Which of the following is **false** regarding micro-CT?
   a. It provides greater spatial resolution than does conventional CT and overcomes limitations associated with its image quality and detail.
   b. It can be useful in determining fire ranges related to recent gunshots wounds.
   c. It cannot detect gunshot residue.
   d. It can help distinguish between entrance and exit wounds.

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