

Wound Ballistics: Analysis of Blunt and Penetrating Trauma Mechanisms

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Abstract

Background: The tissue factors important in wound ballistics provide a useful insight into the pathophysiology of organ injury in all traumas. Wound ballistics includes penetrating and blunt trauma mechanisms. Although the mechanism of a traumatic event may be pure blunt or penetrating trauma, the mechanism of tissue injury may be mixed.

The aim of the present study was to review the literature about Blunt and Penetrating Trauma Mechanisms.

Method and Material: The method that was used for the realization of the research is the search of articles, researches and papers to the internet (MEDLINE, EMBASE and CINAHL databases) in order to become a review of the Hellenic and the foreign bibliography from 1988 until today.

Results: The varied ability of different types of tissue to tolerate the physical displacement of tissue stretch in gunshot wounds and the inability of any tissue to survive being crushed by a bullet is a model for the relative abilities of different tissues to tolerate blunt trauma and penetrating trauma of all types. Center-fire rifle bullets crush tissue as they pass through it, as does any penetrating trauma agent. This crushed tissue does not survive. Center-fire rifle bullets also cause blunt trauma by tissue displacement (temporary cavitation). The ability of different tissues to survive this blunt trauma is related primarily to tissue elasticity and cohesiveness.

Conclusions: The blunt and penetrating trauma aspects of wound ballistics can be used to explain the response of all tissue to blunt and penetrating trauma of all types, assisting in predicting and explaining the severity or lack of severity of tissue injury in trauma in general.

Keywords: blunt trauma, gunshot wounds, penetrating trauma, wound ballistics

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Introduction

In all penetrating trauma, tissue is crushed by the penetrating object. That tissue does not survive. Similar to the effect of a bullet passing through tissue, if a penetrating object other than a bullet is large enough or moving fast enough, some blunt trauma, due to displacement of tissue adjacent to the path of the penetrating object, will occur. This is identical to the type of blunt trauma occurring during temporary cavitation in certain gunshot wounds. The ability to survive temporary cavitation blunt trauma is very specific. More elastic, more cohesive tissue, such as skeletal muscle, lung, empty intestine, nerve, blood vessel and to some extent bone, can tolerate this quite well. Less elastic, less cohesive organs, such as liver, brain and heart, do not tolerate temporary cavitation blunt trauma well¹.

In typical urban gunshot wounds, all of the tissue injuries are caused by tissue crushed by the bullet, its fragments or the secondary missiles it creates by breaking apart the structures through, which it passes. Significant temporary cavitation is very uncommon in urban gunshot wounds, because the most are caused by less potent handguns. A center-fire rifle or large handgun is usually required to fire a bullet capable of causing significant temporary cavitation².

Blunt trauma can be local, such as from being struck with a hammer or the local blunt trauma of temporary cavitation associated with penetrating trauma. Blunt trauma can be diffuse, such as that resulting from falling from a height or being an unrestrained passenger in a high-speed motor vehicle accident. The tissues that tolerate well the blunt trauma from tissue displacement during temporary cavitation stretch also tolerate blunt trauma from other causes well³.

WOUND BALLISTICS

Wounding potential

Missile mass and velocity establish the upper limit of the tissue damage a moving bullet can cause: the bullet's wounding potential. Bullets of equal wounding potential may produce wounds of very different severity. The amount of wounding potential actually used and the amount of resulting tissue disruption depend on bullet construction and the physical properties of the tissue penetrated². Whether the bullet has enough mass and velocity to reach the depth of vital structures can determine final outcome⁴.

Bullets crush the tissue and run into, killing that tissue. The bullet may also cause a splash in tissue, stretching tissue by displacement (temporary cavitation). This may or may not damage tissue, depending on tissue type⁴.

Bullets with equal wounding potential often do not produce similar wounds. Even if similar amounts of wounding potential are available, this potential may or may not be used up in the wounded subject. If used, the same amount of wounding potential may be used as varying amounts of tissue crush and tissue stretch (temporary cavitation), depending on the velocity, mass and diameter of the bullet². No matter how much wounding potential is used, the severity of the wound produced is very tissue dependent. Tissue stretch will be tolerated very differently by different tissues. A heavier and slower bullet crushes more tissue but induces less temporary cavitation, most of the wounding potential of a lighter, faster bullet is likely to be used up forming a larger temporary cavity, but this bullet leaves a smaller permanent cavity (crushes less tissue)⁴.

The physical properties of a tissue through, which a missile passes (tissue elasticity, density, cohesiveness, internal architecture), the diameter, shape, mass and velocity of the projectile, whether it expands into a mushroom shape or breaks and fragments, its internal construction, the length of the wound path and whether it is sufficiently long to allow bullet deformation or yaw to 90° are all primary determinants of wounding². A center-fire "high-velocity"

rifle bullet, if it traverses only elastic tissue, such as skeletal muscle, does not yaw significantly, does not fragment or deform and does not hit a major blood vessel or nerve. It usually causes a fairly minor wound. It will exit the extremity with most of its wounding potential unspent. If this same bullet hits a large bone, fragments and does not exit, it will crush a large volume of tissue, will create secondary missiles, such as bone fracture fragments, which also crush tissue and is likely to disrupt the neurovascular integrity of the area wounded, expending all its wounding potential in the patient and usually producing a severe wound. The amount of tissue crushed by a bullet depends on its size and shape and whether it deforms or fragments⁵.

If the tissue wounded is relatively elastic and cohesive, the amount of tissue crushed is the primary determinant of wounding². All crushed tissue is killed. Tissue stretch (temporary cavitation) often has relatively little wounding effect in elastic cohesive tissue, such as skeletal muscle or lung. If an organ is inelastic, near-water density and not very cohesive, such as brain or liver, temporary cavitation can cause a severe wound⁵.

Bullet penetration depth is directly related to bullet mass and bullet velocity and inversely related to bullet diameter (including the effect of increased diameter from mushrooming). If a bullet lacks sufficient mass or velocity or expands to such an extent that it uses up its wounding potential crushing superficial tissues and causing temporary cavitation stretch, it may not reach the depth of vital structures, such as the heart. It will not hurt what it does not reach^{4, 5}.

It is wrong to think that one can predict the wound produced according to whether a bullet is "high velocity" or "low velocity." Bullet velocity is only one factor in wounding and in some wounds it may be a minor factor. Kinetic energy expended in elastic tissue may produce little damage, as tissue stretch may be well tolerated. If a rubber ball and a raw egg of equal weight are dropped onto a cement floor from the same

height, then it is possible these two missiles of equal kinetic energy to sustain different degrees of damage. The rubber ball behaves like skeletal muscle or lung and the raw egg like brain or liver. The amount of kinetic energy in tissue is not a good predictor of wound severity. Collisions between bullets and tissue are not elastic and kinetic energy is not conserved. Most is lost as heat^{4, 5}.

An understanding of wound ballistics allows the physician to evaluate and treat missile wounds without repeating the errors of "conventional wisdom". Many papers have been printed suggesting harmful and unnecessary treatment for gunshot wounds as a result of common misconceptions about wound ballistics⁴. An example of such an unnecessary and harmful recommendation is for mandatory surgical excision of the tissue surrounding the bullet path whenever an extremity wound is caused by a high-velocity bullet. Military and civilian experts have taught that, such excision of the wound path, to be important, because tissue exposed to temporary cavity formation rarely survives and will become necrotic. Clinical experience and research show this notion to be false, particularly in the case of extremity wounds⁴. Experiments in wounding mammalian animals with military rifle bullets have been performed. An important feature of these experiments is that a control group of animals was wounded, but not treated surgically. These experiments have disproved the assertion that all tissue exposed to temporary cavitation does not survive. They also show that in extremity wounds, complete excision of the bullet path and extensive debridement usually are not necessary. This finding corroborates many observations in humans with rifle bullet wounds of the extremities. In addition, the large exit wound produced by the M16 or AK-47 military rifle bullet often creates its own excellent wound drainage, which assists healing⁵.

Intense local vasospasm after the passage of a high velocity bullet lasts about 3 hours and often includes a substantial amount of tissue around the permanent wound channel. If patients are operated on

very soon after wounding, the extent of apparently devitalized tissue will be increased by this intense vasoconstriction around the bullet path. The tissue, when examined at surgery, may have poor colour, bleeding, contractility and consistency. These are the four C's, by which surgeons sometimes decide whether tissue is viable. After a rifle bullet extremity wound, more tissue often is viable than is apparent at the initial surgical examination⁶. After the initial period of vasoconstriction, a period of hyperemia follows.

Mechanisms of wounding

Missiles are passing through tissue wound by only two mechanisms. These are crush and stretch. Tissue crush is the crushing of the tissue struck by the projectile (forming the permanent cavity). Tissue stretch refers to the radial stretching of the projectile path walls (during temporary cavity formation). The sonic pressure wave preceding the bullet through tissue does not damage tissue².

Both missile and tissue characteristics determine the nature of the wound. Bullet mass (which is related to bullet diameter and length) often determines whether the bullet will penetrate tissue to the depth of vital structures, bullet construction determines whether the bullet will deform or fragment and bullet shape and center of mass determine how soon it will yaw in its path through tissue. If it does not deform into a mushroom shape, the thickness of the body part wounded determines whether the bullet has a long enough path through tissue to deform or yaw tissue type (e.g. femur, lung, liver). Also, it decides tissue elasticity, density, specific gravity and internal cohesiveness and determines how well the tissue will withstand temporary cavitation stretch. All of these characteristics are extremely important, in addition to bullet velocity, in determining the nature of the wound produced. Wound classification systems based on bullet kinetic energy or velocity markedly overemphasize the importance of velocity, in determining the wound produced and largely ignore the other factors^{2, 6}.

Crushing of tissue

A missile crushes the tissue it strikes, thereby creating the permanent cavity. Yaw is the angle between the longitudinal axis of the bullet and its path of flight. If the bullet is traveling with its pointed end forward and its longitudinal axis parallel to the axis of flight (0° yaw angle), it crushes a tube of tissue no greater than its diameter. When the bullet yaws to 90°, the entire longitudinal axis of the bullet strikes the tissue. The amount of tissue crushed may be three times greater than at 0° yaw angle. If the bullet strikes an intermediate target, before striking the patient, the bullet may yaw, deform or decelerate. Its wounding properties will be altered, sometimes increasing wound severity and other times decreasing it^{1, 7}.

When striking soft tissue with sufficient velocity, soft point and hollow-point bullets are designed to deform at the tip into a mushroom shape. This flattening of the bullet tip increases the bullet's surface area and the tube's diameter of tissue crushed, decreasing the penetration depth. If the mushroomed diameter is 2.5 times greater than the initial diameter of the bullet, the cross-sectional area of the tissue's tube crushed by the bullet is 6.25 times greater than the amount that would have been crushed by the unreformed bullet. Thus, the deformed bullet makes a larger diameter hole (the permanent cavity) than would the original unexpanded bullet have made^{1, 7}.

Unjacketed lead bullets cannot be driven faster than 2000 ft/sec (610 m/sec), without some of the lead stripping off in the barrel. This barrel fouling is avoided, if a bullet jacket made of a harder metal (such as copper or a copper alloy) is used to surround the lead. The jacket of a military bullet completely covers the bullet tip (a full metal-jacket or "ball" bullet). Full-metal-jacket bullets either stay intact or break and fragment when it is at 90° yaw angle. They do not deform into a mushroom shape⁷. Civilians often use hollow-point or soft point bullets. Hollow-point bullets have a hole in

the jacket at the bullet tip. Soft-point bullets have some of the lead core of the bullet exposed at the bullet tip. These constructions weaken the bullet tip, flattening on impact (into a mushroom shape). If it does not deform, a pointed civilian bullet will behave like a full-metal-jacket bullet, yawing at some point in its path through tissue⁸.

If a bullet is partially or completely jacketed, the bullet jacket usually cannot be distinguished from the lead core on standard radiographs, as the entire bullet. If the bullet has some lead exposed, it often loses small flakes of lead along its path through tissue, even if it does not break into large fragments⁸. Sometimes, as the bullet deforms or breaks into fragments, the bullet jacket separates from the bullet and is visible on a radiograph. When a full-metal jacket bullet yaws to 90° and if it breaks at the cannelure (the circular groove in the bullet where it is crimped into the cartridge case), the bullet jacket may come off portions of the broken bullet, especially the back half. When an unreformed bullet is seen on a radiograph, it is usually not possible to state accurately whether the bullet is fully jacketed, without recovering the bullet^{3,8}.

Although soft-point and hollow-point bullets from center fire rifle rounds usually expand into a mushroom shape in tissue, many soft-point and hollow-point handgun bullets from various manufacturers fail to expand. This failure often occurs, because of insufficient striking velocity, an excessively thick or unbending bullet jacket construction variability in manufacture of the bullet or occasionally, plugging of the tip of a hollow-point bullet by material from an intermediate target, such as drywall or heavy clothing, through which the bullet passed before penetrating the wounded subject. This lack of expansion is most likely with short-barreled handguns and those of less potent calibers (e.g. 25 and 32), which have slower bullet velocity. Overall, about one-third of soft-point and hollow-point handgun bullets fail to expand in human soft tissue. Lack of expansion can lead to disastrous results owing to perforation of the

target, leading to the wounding of bystanders⁹.

Overexpansion can result in insufficient tissue penetration to reach and disrupt vital structures. Usually, a bullet penetration depth of 12-20 inches (approximately 30-50 cm) is required to reliably reach and disrupt vital structures in humans. This depth is needed, because many bullets travel on an oblique course through the body, lengthening the wound path to the center of the body. Also, bullets often pass through other body parts, such as extremities, held up in front of the trunk for defense or offense. Possibly, the bullet must still be able to penetrate to the body center and once there, have enough wounding potential left to disrupt the vital structures^{8,9}.

Bullets of the hollow-point or soft-point variety are more likely to fragment in tissue than a full metal-jacket bullet, adding to tissue disruption. Because of bullet expansion into a mushroom shape and bullet fragmentation, civilian hollow-point and soft-point bullets used in rifles and large handguns are usually more damaging to tissue than military full metal-jacket bullets fired from rounds otherwise configured identically^{4,9}.

Bullets are not sterilized by the heat of firing. They can carry bacteria from the body surface deep into the wound. They can also spread bacteria from perforated organs (e.g. colon) along their entire tissue path¹⁰.

Stretching of tissue

Fired from an appropriate and well-designed firearm, a bullet flies in the air with its nose pointed forward and it yaws only 1° to 5°. It is stabilized in this point-forward position by bullet spin imparted by the rifling (spiral grooves) in the gun barrel. Yaw occurs around the bullet's center of mass. In pointed rifle bullets, the center of mass is behind the midpoint of the bullet's longitudinal axis¹.

Although the bullet's spin is adequate to stabilize gyroscopically against yaw in its flight through air, its spin is not adequate to stabilize it in a point-forward position in tissue, because of the higher density of

tissue relative to the air. If it does not deform in tissue, a pointed bullet eventually yaws to a base-forward position. This is true for both an unreformed civilian bullet and an intact military full-metal-jacket bullet¹.

After the bullet deforms into a mushroom shape or if unreformed, yaws to 90°, crushing its maximal amount of tissue (unless it breaks into fragments, which will crush more tissue owing to increased surface area of the fragments compared to the intact bullet). It is slowed down rapidly, as its wounding potential is used up moving tissue radially away from its path. This force creates the temporary cavity⁴.

Temporary cavitation is a splash in tissue: a bullet at 90° of yaw causes a much larger splash than one with little yaw². This is entirely analogous to the minimal splash a diver makes with a good dive compared to the large splash produced by a belly-flop. In tissue, this splash and the temporary cavity can produce injury from localized blunt trauma if it is large enough to stretch the tissue and displace beyond its breaking point. The maximal temporary cavity occurs several milliseconds, after the bullet has passed through the tissue³.

The temporary cavity caused by common handgun bullets is generally too small to be a significant wounding factor in all. Center-fire rifle bullets and some large handgun bullets often induce the formation in tissue of a large temporary cavity 10-25 cm (4-10 inches) in diameter. This can be a significant wounding factor, depending on the characteristics of the tissue in which it forms¹¹.

In general, the wounding effect of temporary cavitation has been greatly exaggerated in the literature, particularly with regard to extremity wounds. Injuries of vessels, bones, nerves and organs remote or distant from the projectile path are commonly mentioned, but, in fact, are extremely rare¹². A review of 1400 rifle wounds from Vietnam (the Wound Data and Munitions Effectiveness Team study) found no cases of bones being broken or major vessels being torn that were not penetrated by the bullet, bullet fragments or secondary

missiles. In only two cases, an organ that was not hit (but was within a few centimeters of the projectile path) suffered some disruption. In the vast majority of gunshot wounds, all tissue injured significantly, has been crushed by the intact bullet, bullet fragments or secondary missiles (Fig. 1)¹².

Near-water-density, less elastic tissue (such as brain, liver or spleen), fluid-filled organs (including the heart, bladder or fluid-filled intestine) and dense tissue (such as bone) may be damaged severely, when a large temporary cavity contacts them or forms within them. More elastic tissue (such as skeletal muscle) and lower-density elastic tissue (such as lung) are less affected by the formation of a temporary cavity^{2, 12}.

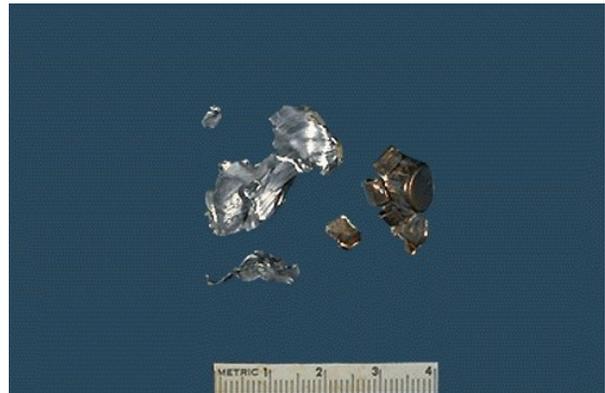


Figure 1: In typical urban gunshot wounds, temporary cavitation blunt trauma plays no significant role in wounding. The bullet, its fragments (if it breaks into pieces, as here) and secondary missiles created by the breaking up of structures the bullet passes through crush tissue.

The effect of the passage of a bullet through tissue

Experiments with ballistic gelatin have shown that the most rifle bullets with a full metal jacket yaw significantly only at tissue depths greater than the diameter of human extremities. The wound profile technique can be used to study bullet soft tissue wounds¹³. This technique was developed at the Letterman Army Institute of Research to measure the amount, type and location of tissue disruption produced by a given projectile. The entire missile path is

captured in one or more blocks of 10% ballistic gelatin at 4°. This gelatin reproduces the penetration depth, projectile deformation, fragmentation pattern, site of yaw, size and site of the permanent and temporary cavity produced by the missile in living swine muscle. Measurements are taken from cut sections of the gelatin blocks after mapping of the fragmentation pattern with two x-ray views at 90°. These data are then reproduced on a wound profile diagram³.

In the first 12 cm of a soft tissue wound path (the average thickness of an adult human thigh), there often is little or no difference between the wounding effect of low- and high- velocity bullets if the high-velocity bullet is of the military full-metal-jacket type¹⁴. This is particularly true of the relatively heavier military rifle bullets such as those fired by the AK-47 and NATO 7.62 mm rifles. A wound of an extremity caused by an AK-47 bullet, which does not hit bone, is often similar to a handgun bullet wound¹⁵. If a high-velocity, heavy bullet does not deform, fragment or hit a bone it may exit an extremity with much of its wounding potential unspent. These same bullets are often lethal in chest or abdominal wounds, because the trunk is thicker than an extremity and allows the bullet a sufficiently long path through tissue to yaw^{10, 13}. Maximal temporary cavitation induced by the full-metal-jacket AK-47 bullet usually occurs at a tissue depth around 28 cm, much greater than the diameter of a human extremity. In fact, this depth is even greater than the diameter of the human torso from most projections. This is why most torso wounds made by the AK-47, when firing the common nondeforming military bullet, resemble wounds made by much lower-velocity handgun bullets. Civilian soft-point or hollow-point rifle bullets deform soon after entering tissue and usually produce a much more severe extremity wound than do low-velocity handgun bullets¹⁵.

Because of the skin's toughness and elastic properties, a bullet that might have the capacity to penetrate 10-12 cm (4-5 inches) farther in tissue often is arrested subcutaneously at the end of the wound

path. It is held in by a trampoline-like action of the skin. Bullets can be caught below the scalp or subcutaneously in the rest of the body¹⁶.

When bullets penetrate thin portions of the skull, such as the squamous portion of the temporal bone, characteristic beveling may not be evident. In those cases and others, characteristic fracture patterns of the skull can sometimes be used to differentiate entrance and exit holes¹⁶. Skull fractures propagate across the calvarium faster than the bullet travels through the brain. Fractures radiating from the entrance wound extend across the calvarium unimpeded. However, those radiating from the exit will stop when they meet a previously made fracture radiating from the entrance hole. This technique of analysis is often used to determine the order of shots, when there are multiple calvarial penetrations or perforations. Concentric heaving fractures can occur in arcs between the linear fractures radiating from the entrance and exit holes, if sufficient temporary cavitation forces are generated in the brain¹⁷.

Handgun wounds of the extremities yield characteristic fracture patterns. Frequently seen, gunshot fractures include divot fractures of cortical bone, drill-hole fractures, butterfly fractures and double butterfly fractures. Divot fractures are the removal of a divot-like portion of the edge of a bone, always involving the cortex and occasionally some adjacent medullary bone. Longitudinal fracture line(s) may extend along the bone from the point of the divot fracture. Drill-hole fractures are characterized by a cylindrical core of bone removed by the bullet, with a diameter approximating the bullet's diameter on the entrance side and usually a larger defect on the exit side. Nondisplaced fracture lines sometimes radiate from these defects. These usually heal well^{2, 17}.

Spiral fractures can extend proximal or distal to the site of bullet impact on bone. This type of gunshot fracture is especially common in bones under torsional stress at the time of bullet impact. Torsional stress

can result either from twisting of the extremity or owing to the normal irregular shape of some bones from biomechanical forces, when the bone is placed under load. Torsion is always presented in a femur, because the femoral head is eccentric in the posterior view and is arched in the lateral view¹⁸.

Especially interesting are the rare spiral fractures that occur at variable distances proximal or distal to the fracture at the site of bullet passage. Sometimes there is a considerable length of normal intervening bone, particularly in the femur. These remote fractures probably occur, because of stress risers and the fact that the bone was under load or stress at the time of impact. This fracture has occasionally been attributed to a fall, which some patients report after being wounded. The site, where the fracture occurs, is a function of the peak-moment location and the allowable residual torsion^{17, 18}.

It is important to note the analogy between the remote spiral femoral fracture and the damage to aircraft structures subjected to small arms fire. A rifle bullet striking at a highly oblique angle may not even penetrate a thin-walled metal structure, such as an airplane wing, and may cause far more damage than a 90° drill-hole-type penetration. This is due in part to the stressed state of the structure and the wing-skin properties. Wing-skin functions in a manner similar to the cortex of a bone along the diaphysis⁴.

In gunshot fractures from rifles and large handguns, a greater extent of comminution may be seen⁴. The magnitude of bone fragmentation depends on the amount of pressure generated within the bone. Complications, such as wound infection, osteomyelitis, compartment syndrome and delayed union or non-union are more frequent in highly comminuted gunshot fractures, because of the soft tissue damage (including macro- and micro-vascular damage), caused by the bullet fragments and bone fragments as they crush tissue (Fig. 2)⁵. The severity of fracture comminution and the presence of air between muscle bundles

from temporary cavitation stretch can be a reliable indicator of the amount of wounding potential used to injure the extremity^{5, 18}.



Figure 2: The greater the comminution of a gunshot fracture, the more wounding potential was used to cause it and the worse the prognosis for the injured area. The surface area of the bullet is greatly increased by breaking up into small fragments. These fragments crush more tissue and cause all the wounding potential of the missile to be used up in the wounded object. Bone fragments (secondary missiles) also crush tissue. Comminuted gunshot fractures have more complications, such as compartment syndrome, infection (cellulitis and osteomyelitis), non union or delayed union.

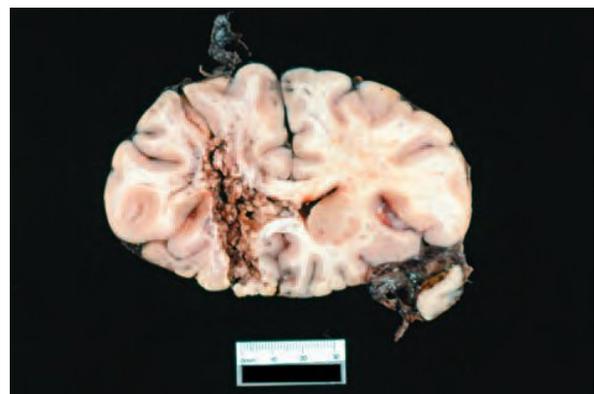


Figure 3: A penetrating object, whether it is a bullet, a knife, an ice pick, a nail or any other object, does not have to use a great deal of wounding potential to cause a serious wound. All it has to do is to pass

through a vital structure. In this case, a small-caliber handgun bullet with little wounding potential has caused a devastating injury by passing through the spinal cord.

The effect on the patient of the trauma sustained

Wounding is like real estate. The most important aspect is location. An ice pick stab wound or a small-caliber bullet of low wounding potential, which passes through the spinal cord or brain, can have a devastating effect (Fig. 3)¹⁹. A bullet with a great deal of wounding potential passing through the muscle of the thigh may cause a minor wound. This makes the job of the physician much easier. It is not important to know the details of what wounded the patient. The job of the physician is to examine the patient, to determine the location and severity of the injuries and to initiate treatment. Imaging studies play an important role^{18, 19}.

In penetrating trauma, the tissue is crushed throughout the length of the hole. That tissue does not survive. The effect depends on what organ was injured and on how completely it was injured¹⁹.

In blunt trauma, organs with inadequate tissue cohesiveness to tolerate displacement will fracture and tear. Often, multiple bleeding points and injured surfaces are seen (similar to the effect on the liver of temporary cavitation stretch, a splash in tissue). In gunshot wounds, the splash is confined to a small area around the bullet path. In an automobile accident or a fall, the amount of tissue volume affected by the tissue splash is much greater and can sometimes be the entire body (such as with whole-body-deceleration blunt trauma)¹⁸.

Trauma is frequently not purely blunt or purely penetrating. Impurity can result from the mechanism of injury or within blunt trauma from fracture fragments, clothing or adjacent objects penetrating tissue¹⁹. During blunt trauma, a pelvic fracture fragment, which penetrates the bladder, causes a penetrating injury of the bladder, even though the trauma mechanism is blunt. The overall mechanism of injury may be impure, as in the case of a person who is hit by a

train (blunt trauma), thrown through the air and impaled on a post (penetrating trauma)¹⁶.

Both blunt and penetrating mechanisms of organ injury can occur in blunt trauma, when bones fracture and their fragments penetrate adjacent tissue (Fig. 4). The pathophysiology intraperitoneal and extraperitoneal bladder rupture is a model of blunt and penetrating trauma in general. Extraperitoneal bladder rupture is more common (80-85% of bladder rupture cases), as blunt trauma is more common than penetrating trauma¹⁶. It is usually caused by blunt trauma causing pelvic fractures and bony spicules. Intraperitoneal bladder rupture (15-20% of bladder rupture cases) is the result of blunt trauma compression of a full bladder, causing a sudden rise in intravesical pressure and rupturing the bladder dome².

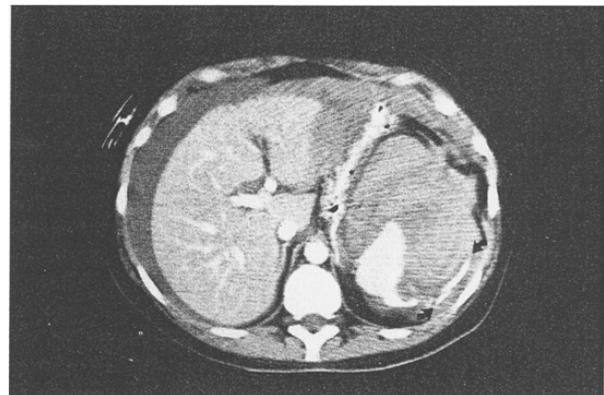


Figure 4: Penetrating trauma can be a feature of blunt trauma. This splenic laceration was caused by the displaced rib fracture fragments seen at the posterior left lateral margin of the spleen (arrows). Although the patient experienced blunt trauma, the spleen experienced penetrating trauma by the rib fragments. This is analogous to the creation of secondary missiles in gunshot wounds. In this case, the blunt trauma has created secondary missiles that have crushed tissue of the spleen, causing laceration and bleeding. The clot and serum layers surrounding the spleen, the intrasplenic pseudoaneurysm with swirling blood of the same density as the intra-

arterial and intravenous contrast medium and the moderate-size hemoperitoneum in the subphrenic spaces and gastrohepatic ligament are noted.

The bladder, like any organ, cannot remain uninjured after penetrating trauma (tissue crush). Bone fragments penetrate the bladder causing extraperitoneal bladder rupture. Even if the amount of tissue crushed is very small, when the integrity of an organ is violated, organ function is often compromised. In this case, the bladder leaks. In contrast, in blunt pelvic trauma, sometimes without pelvic fracture, intraperitoneal bladder rupture occurs, when the bladder is full and the dome of the bladder cannot tolerate the tissue stretch, caused by increased intravesical pressure due to bladder compression. The bladder dome tissue tears. Usually, the cohesive tissue of the bladder dome (elastic, stretchable musculature and mucosa) tolerates the tissue stretch due to the increased intravesical pressure from blunt trauma and does not tear. Most automobile accident patients with seat belt trauma to the pelvis do not have intraperitoneal bladder rupture or any bladder rupture^{1, 5}.

Complete or partial vascular occlusion can occur, when intimal injury and intravascular thrombus result from penetrating trauma or rarely, when tearing of the vessel results from tissue displacement (blunt trauma). Vascular tearing from blunt trauma, when it occurs, is

often at vessel branch points, where the vessel may be less mobile and therefore less able to tolerate displacement. Such vascular tears are uncommon, because of the elasticity and cohesiveness of vascular tissue²⁰.

For a given blood vessel, decreased blood pressure can be the result of systemic hypotension due to hemorrhage, local hypotension due to hemorrhage proximal to the point of blood pressure cuff placement or intimal injury with partial thrombosis of the vessel's lumen proximal to the point of blood pressure measurement²¹. It is important to compare and contrast the effect of bleeding into a big space (e.g. the peritoneal cavity or pleural space) with the effect of bleeding into a smaller contained space (e.g. the epidural or subdural space or the intact pericardial space). In the former case, a large volume of blood can be lost from the vascular compartment, leading to systemic hypoxia due to both diminished oxygen-carrying capacity and systemic hypotension due to lost intravascular volume. When bleeding into a small, confined space, local organ compression can cause severe injury or death, such as from compression of the brain or heart. This organ dysfunction is unrelated to the systemic effect of blood's loss from the vascular space. In this case, the blood is injuring by its mass effect^{20, 21}.

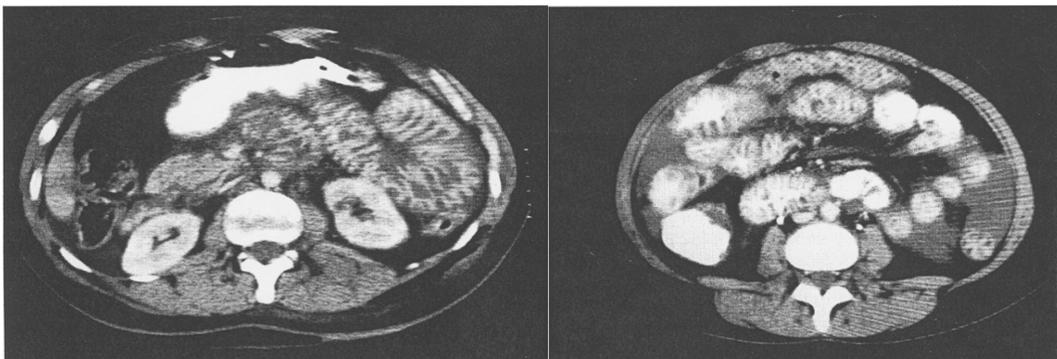


Figure 5: Left: In patients in hypovolemic shock, blood is shunted away from the splanchnic circulation. This process sometimes leads to stasis and edema in

intestinal walls, accentuating the mucosal pattern into spiculations. This has been previously described in pediatric patients as part of the hypoperfusion complex. If the

patient recovers hemodynamically, the CT appearance reverts to normal within hours. Note that the inferior vena cava (IVC) is flat and the aorta is small. The IVC can be flat on some scan slices in normal patients, but will be of normal caliber on others. When it is consistently flat on every scan slice, think of hypovolemia, particularly when the aorta and iliac arteries are also small. Right: Another example of shock bowel in a different patient. Moderate-size hemoperitoneum is seen in the paracolic gutters bilaterally, displacing the intestines away from the flank stripes. The IVC and aorta are more normal in caliber in this case than in the view at left.

Imaging can be very helpful in patient management by demonstrating intestinal injury, aortic injury, solid organ injury and active bleeding and it sometimes can assist in assessment of intravascular volume²¹. Computed tomography (CT) is particularly useful. The lack of exsanguinating hemorrhage after a gunshot wound does not rule out a through-and-through penetrating injury of the aorta. Conventional angiography or CT is required for adequate assessment, if the bullet path is near to the aorta. Injuries to large veins are sometimes treated by ligation (Fig. 5). This procedure may lead to long-term complications and sometimes requires later surgical revision for revascularization²¹.

Often, there are several different ways to image the same injury and demonstrate the same physiology. Sometimes more than one imaging modality is appropriate to the clinical situation, so choices must be made. For example, angiography, helical CT, CT angiography, Doppler ultrasound or magnetic resonance angiography may be appropriate for evaluation of a vascular injury^{20, 21}.

If imaging of organs in a body region of trauma is desired, one imaging modality may be preferred over another. In studies of CT vs. intravenous pyelography (IVP) for renal trauma, unsuspected splenic laceration, hepatic laceration or vascular injury has been shown on CT. Laparotomy based on CT findings is sometimes necessary, when clinical findings would suggest nonoperative

management. Intestinal injury detected by CT, but not clinically apparent is particularly important and requires laparotomy²¹.

Conclusion

The pathophysiology of organ injury in penetrating trauma has been well studied for firearm injuries. Center-fire rifle bullets crush tissue as they pass through it, as does any penetrating trauma agent. This crushed tissue does not survive. Center-fire rifle bullets also cause blunt trauma by tissue displacement (temporary cavitation). The ability of different tissues to survive this blunt trauma is related primarily to tissue elasticity and cohesiveness. Which tissue will be severely injured and which will survive relatively intact can be fairly well predicted in gunshot wounds. This article proposes that the already understood blunt and penetrating trauma aspects of wound ballistics can be used to explain the response of all tissue to blunt and penetrating trauma of all types, assisting in predicting and explaining the severity or lack of severity of tissue injury in trauma in general.

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