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Shotgun Wound Ballistics

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Shotguns are popular world wide and more of these weapons exist than the rifled types. With an increasing incidence and prevalence of gunshot wounds it is important for traumatologists to be familiar with shotgun wound ballistics. Shotgun wounds differ from those of other missiles because the spectrum of wound severity is large owing to the fact that the pellets scatter as they travel. Close-range shotgun wounds can be as destructive as those from a high-velocity rifle, but longer weapon-victim ranges may produce only minimal injury. The type of shot (size and weight of pellets) used also determines the type of injury, with more serious injuries produced by the larger type of buckshot (>0.14 inches in diameter). The severity of injury from birdshot depends mainly on the "effective" weapon-victim range which can be calculated from the shot size and shot pattern either clinically or from X-ray. Wounds may then be classified according to severity, yielding information on prognosis and extent of investigation and treatment required. We propose a four-level severity scale based upon birdshot pellet scatter patterns which correlate well with morbidity and mortality rates.

Possibly 50,000 deaths and 500,000 missile injuries occur annually in the United States, similar to the total number of American Viet Nam casualties (37, 44, 53). The present U.S. population is more heavily armed than any in history (57). More than 850,000 American civilians were killed by missiles from 1900 to 1976, and the numbers have been growing exponentially since (2). The figures for the entire world are not known but are probably at least a hundred times as great. Shotguns are popular worldwide and more of these weapons exist than the rifled type of weapons (54). Many governments, for example, Great Britain and the Soviet Union, discourage the use of rifles but allow the unrestricted use of shotguns (54).

With an increasing incidence and prevalence of missile injuries in certain areas it is essential that traumatologists be familiar with wound ballistics (44), which can help them determine the extent and type of injury from a known missile (1). Ballistics, the study of the natural laws governing projectile missiles and their predictable performances (21), can be divided into three phases: interior (actions within the firearm), exterior (from the end of the muzzle to the target), and terminal (after entering the target) (21). Wound ballistics relates specifically to the terminal phase of ballistics, i.e., study of the missile's effect on living tissue (53). This report discusses shotgun wound ballistics and explains how the type and extent of injury can often be determined, in order to provide better care for injured patients.

Penetrating Wounds. In civilian trauma, penetrating injuries are usually produced by stabbings or gunshots. Civilian gunshot wounds are usually caused by low-velocity handguns, high-velocity rifles, or shotguns. Other everyday accidents are caused by high-velocity fragments from the blades of lawn mowers, power tools, and other machinery. The path of a missile is usually a straight line, but deflection can occur in various tissues, particularly bone. Low-velocity missiles (including shotgun pellets) are more prone to erratic pathways, tending to follow tissue planes or paths of least resistance. Missile wounds penetrate more deeply than stab wounds and produce an area of damage surrounding the actual missile tract due to compression of the tissues. Shotguns are in the class of low-velocity weapons, propelling missiles at a velocity of less than 2,500 feet/second. Any missile may fragment when contacting bone, producing secondary missiles as well. Complications of gunshot wounds may occur with the entrance of fragments of debris from wadding and clothing that may contaminate the wound. A shotgun fired at close range injures by blast effect as well as by the penetrating missile.

Physicians should attempt to elicit certain facts that could greatly contribute to the evaluation of the patient, including the type of the weapon used, the distance from the gun to the victim at the time the gun was fired, the position of the victim at the time the gun was fired, and the suspected number of shots fired. If possible, spent shells may be collected and examined to help determine

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the type of weapon and ammunition used. These are usually near the scene and only the professional shootist will carefully remove them from the scene to eliminate incriminating evidence. Preservation of evidence does not supercede care of the injured victim; however, awareness of the details can lead to more responsible handling of evidence material.

Shotgun Wounds. Shotgun wounds differ from those of other missiles. The spectrum of severity of wounds is large, the amount of damage varying mainly with the weapon-victim range and the type of weapon and shot used. Pellets tend to scatter as they travel, which accounts for a wide spectrum of wounds. Although shotguns are low-velocity weapons (less than 2,500 feet/second), at close range the entire charge strikes the target as a single missile with a kinetic energy similar to that of a high-velocity military rifle (7). At longer ranges, with pellet scatter, the charge acts as multiple individual missiles, with the kinetic energy imparted separately by each pellet which strikes the target (7).

DEFINITIONS

Birdshot. A general term for small-sized lead shot used in shotgun shells, ranging from size two to size nine (equal to and less than 0.14 inches in diameter). Larger shot is called "buckshot" and smaller termed "dust shot."

Choke. The muzzle constriction in the bore of a shotgun barrel that serves to condense the shot pattern (i.e., prevents spread of the pellets). Choke varies as to degree and length (Table I).

Geneva Convention. The military use of shotgun type weapons is outlawed (44).

Grain. A unit of weight, there being 7,000 grains in an avoirdupois pound. Used for weight of powder charge and bullets.

Grapeshot. A cluster of small iron shot fired from a cannon and intended to spread in flight.

High-velocity Missile. Above 2,500 feet/second (1, 44), when the bullet can cause both shock waves and cavitation, which increase tissue destruction. Includes bullets from most rifles but not handguns and shotguns (21).

Impact Velocity. Velocity of the bullet as it strikes the target (1).

Killing Power. The ability of a projectile to kill, depending on such factors as velocity, shape, sectional density, weight, diameter, and material.

Lead. A metallic element, softest of the metals in commercial use. It has low tensile strength, is very malleable, and melts at 621° F. It has a high specific gravity and therefore packs more mass per volume than other materials from which bullets could be made. This greater mass increases the kinetic energy of a lead bullet, as opposed to one travelling the same velocity but composed of other materials.

Magnum Shell. A shell loaded with more gunpowder than the standard shells, supplying the projectiles with 20–60% more energy than a standard shell of the same caliber. For bullets, the increased energy is due to increased velocity (8). For shotgun shells the extra gunpowder is used to increase the load (number and weight of pellets) and not necessarily the velocity.

Missiles. Any projectile, including bullets, pellets, grenade fragments, and explosive shells (1).

Muzzle Blast. The surge of hot air and gases that bursts from the muzzle of a gun as the projectile exits which may cause serious injury or death at close range (e.g., blank ammunition). Also called powder blast.

Muzzle Velocity. Velocity at time of missile exit from gun barrel (1).

National Firearms Act. Developed in the U.S. in 1934, to control gangster weapons such as machine guns, silencers, rifles with barrel lengths less than 16 inches, and shotguns with barrel lengths less than 18 inches, through high taxes on these devices. The Amendments of 1968 made the control of these weapons more stringent through laws.

Normal Charge. The regularly prescribed quantity of powder used in a gun. Under other circumstances a reduced charge or supercharge (magnum or special) may be used.

Retardant Forces. Forces that tend to slow the missile once it enters the target. Greater retardant forces increase energy transfer to the tissue and thus produce greater tissue damage (1).

Rifle. By U.S. law a rifle's barrel is longer than 16 inches. The barrel is cut with spiral grooves to impart rotational energy to the bullet and thus stabilize its flight. Shotgun barrels are not rifled.

Shell. A shotgun cartridge, a hollow projectile adapted to be filled with an explosive, or an empty cartridge case.

Shotgun. Single or multiple missiles or pellets are fired from the same shell, and at close range the resulting wounds should be considered as high-velocity type wounds. The average 12-gauge shell is loaded with 1⅛ ounces of number six shot, which contains 253 individual lead pellets and has a muzzle velocity of 1,255 feet/second.

Shotgun—"Sawed-off." A shotgun with a shortened barrel which allows easier concealment. The spread of the pellets is much greater than with a standard length barrel and "choke," so fewer pellets will hit the target as

TABLE I
American chokes

American Chokes	Degree of Constriction (thousandths of an inch)	European Equivalents	Length of Choke
Cylinder bore	None	Cylinder bore	0
Improved cylinder	5 to 10	¼ choke	⅝ inches
Modified	20	½ choke	1¼ inches
Improved modified	30	¾ choke	1⅞ inches
Full choke	40	Full	2½ inches

the distance increases from 6 to 12 feet. A sawed-off shotgun blast at a range of more than 12 feet may cause only minimal trauma unless a vital structure is injured. The National Firearms Act includes shotguns with barrels less than 18 inches in length. Also called a "scatter gun."

Shotgun Shell. Consists of a paper or plastic body, brass head at one end, primer, base wad, powder charge, over-powder wad, filler wads, shot charge, and folded crimp. At ranges of less than 6 meters any or all of these components may be propelled into the wound.

Special Shell. Extra gunpowder in the shell.

Standard Shell. Regular amount of gunpowder in the shell.

Stock. The rigid member of a gun to which the barrel is attached.

Wounds. Classified as: non-penetrating—contusions or abrasions without penetration of the skin: a) blast injury, or b) a grazing wound; penetrating—an injury with an entrance wound but no exit wound; perforating—a injury with an entrance and an exit wound and the primary wounding agent is not retained within the tissues.

Velocities Required to Cause Damage. The minimum velocity required to cause injury has been determined for round projectiles. An impact velocity of 150 feet/second is required to penetrate skin, and 195 feet/second to break bone. Vulnerable tissues such as the eye can be damaged at velocities considerably lower than these. Moreover, death can be caused at low velocities from vital organ damage, if the appropriate structure is hit. Clothing and especially ballistic protective garments considerably increase the critical velocity required to penetrate the skin (44). The author has shown how even a thick head of hair (like a large "Afro") can add some protection from missile injuries of the head.

Shotgun Ammunition. Although gauge or bore caliber of shotguns is standardized, the system is antiquated, and different from that used for rifles and handguns. The gauge of a shotgun refers to how many lead balls of an appropriate size are required to weigh a pound. For example, a 12-gauge weapon originally had a bore enabling a round lead ball weighing 1/12 of a pound to enter its barrel. There are two important exceptions to this rule: the 9-mm shotshell which has a 9-mm bore, and the .410 gauge which is actually .410 caliber or inches in diameter. The most popular shotgun in the U.S. for all civilian activities as well as military, police, and criminal use is the 12-gauge. The shotgun shell contains one or more pellets, or shot. Number 6 shot (the most commonly used in the U.S.) and smaller is referred to as "birdshot", while number 2 shot and larger is referred to as "buckshot" (Table II). The type of shotgun, ammunition, and range of the weapon are all important in determining the wounding potential. Shotgun pellets are usually round, and therefore have poor ballistic characteristics, these ideal proportionalities being sacrificed in order to obtain target area saturation with multiple missiles, making it possible to hit a small, fast-moving target.

TABLE II
Characteristics of shotgun ammunition

Shot Size	Diameter (inches)	Maximum Range (yards)	No. of Pellets per Ounce
12-ga round ball	0.645	1,420	0.75
16-ga round ball	0.610	1,340	1
20-ga round ball	0.545	1,200	1.25
410-ga round ball	0.38	850	
00 buckshot	0.34	748	8
0 buckshot	0.32	704	9
1 buckshot	0.30	660	11
#1 shot	0.16	352	
#2 shot	0.15	330	90
#3 shot	0.14	308	
#4 shot	0.13	286	135
#5 shot	0.12	264	170
#6 shot	0.11	242	225
#7½	0.09	209	350
#8 shot	0.09	198	410
#9 shot	0.08	176	585
#12 shot (.22 shot cartridges)	0.05	110	2,385

Pellet Spread. The velocity of the shot falls off rapidly with distance, and so the kinetic energy and wound potential. Because the shot depends on a bolus blast effect to maintain velocity, spread of the pellets (may be measured by the diameter of all of the shot in flight, or the average distance between pellets) results in less velocity. Increased spread of the pellets may be caused by: 1) range or distance from the shotgun, 2) lack of choke or constriction in the end of the shotgun barrel, 3) a shortened barrel as in a "sawed-off" shotgun or scattergun, or 4) pressure developed in the cartridge. Table II shows the maximum range of specific shotgun cartridges, presumably beyond which wounding potential would be minimal. The choke may range from "true cylinder" to "full choke" and has a marked influence on the degree of spread. There are means available to calculate the spread for any shotgun, choke, and ammunition combination. The length of the barrel is of most importance when it is shortened. In the U.S. the shortest barrel allowed for a shotgun is 18 inches. Shorter barreled shotguns are easier to conceal but result in maximum spread of the pellets, to the point that a "sawed-off" shotgun may cause minimal injury at a range of 12 feet. The pressure in the cartridge provides the propulsive force behind the shot and is related to the type and amount of powder in the charge. The greater the pressure developed, the greater the spread, and vice versa.

The choke (constriction at the end of the barrel) of a shotgun determines the shot pattern at a given weapon-victim range. For a "sawed-off" shotgun the choke is absent and not important. For a standard length barrel (greater than 18 inches in length) a full choke will force approximately 70% of the pellets into a pattern circle of

30-inch diameter at a 40-yard range; modified choke gives 60% and cylinder choke 40% (55).

Buckshot. Injuries caused by buckshot (pellets of 0.15 inches and greater in diameter, or No. 3 shot and larger) are much different than birdshot. Whereas birdshot produces major injuries only at close range, buckshot may produce significant damage up to 150 yards (55). Consider, for example, 00 buckshot of which nine pellets are in a shell and each is equivalent to a .22-caliber bullet when travelling greater than 1,000 feet/second. A birdshot blast (e.g., 12-gauge No. 5 shot) at close range can be compared to a 55-grain, 5.56-mm M-16 rifle wound with 2,247 and 1,250 foot-pounds of energy, respectively (55). But at a range of 7 yards and greater, each birdshot pellet is comparable to that of a BB gun (55). Each buckshot pellet wound must be considered as an individual low-velocity bullet wound, as one would consider multiple .22-caliber handgun wounds. Victims of close-range buckshot wounds probably present the most serious injuries caused by any civilian weapon (9, 28).

Determining Effective Weapon-victim Range for Birdshot. The most accurate way to determine the distance from which someone has been shot with a shotgun is to do a test-firing with the actual weapon and ammunition from the same batch. This is obviously difficult to do in the hospital and is usually only used for forensics. It may be assumed for clinical purposes that if the diameter of the entrance wound is an inch or less, then the distance of the shot was 18 inches or under, irrespective of the gauge or the degree of choke. Up to 2 feet there is very little difference in the spread from guns of various gauges and chokes, with the hole being slightly over an inch in diameter. At 3 feet the hole is nearly 1½ inches in diameter. Beyond 3 feet the difference between the two extremes of boring and choke become evident. At 6 feet the hole from a true cylinder has twice the diameter of that produced with full choke. Obviously, all of the wounds could result in significant injury when caused by a shotgun with a regular length barrel.

Beyond the range of 2 meters the spread can be calculated from the distance between pellets, assuming the barrel was regular length. At the maximum range of most shotguns of 100 meters, only a few pellets will hit the entire body. Between 2 and 100 meters the pellets spread out approximately 1 inch for each meter travelled (4). Measuring the size of the pellets (Table II, Fig. 1) will reveal the type of shot used and the number of pellets contained in one shell (assume 1½ ounces of shot used on average). If the diameter of the blast (or spread) can be measured on the patient then inches diameter are simply exchanged for meters range. If the diameter of the spread is larger than the size of the patient or the majority of pellets have missed the patient, then the density of the pellets can be used to calculate the range. Here, the number of pellets within a certain radius squared provides density (assuming a standard barreled shotgun)

$$\text{Range(meters)} = 2 \times \sqrt{\frac{\text{Pellets:load} \times \text{radius (inches)}^2}{\text{Pellets:counted}}}$$

where: *pellets:load* = pellets in a fully loaded shell (calculated from size of shot using X-ray with Figure 1, and assuming 1½ ounce loads, the number of pellets, using Table II). *Radius* = the radius measured which contains *pellets:counted*, in inches. *Pellets:counted* = The number of pellets counted within a given radius on the body. *Range* = The distance from the shotgun to the victim at the time it was fired, in meters.

Conversely, the range of the shotgun (standard barrel) can be approximated by measuring the distance between pellets and using the following formula

$$\text{Range (meters)} = 2 \times \sqrt{\text{pellets:load} \times \text{Distance:pellets (inches)}^2}$$

where: *distance:pellets* = Distance between individual pellets in inches. Figures 2–4 show patients in whom this formula was used.

Obviously, these calculations are only approximations and exact measurements depend on the accuracy of the factors mentioned above. They require the availability of the data in Table II and a calculator for the square roots. For practical purposes, the calculated results of the range of a "sawed-off" shotgun give an effective range of an equivalent standard choked shotgun. That is, even though the true range may be only 12 feet, the effective range that is calculated using the formula for pellet spread may be up to 100 yards. We have found this effective range of a "sawed-off" shotgun to be most closely related to the severity of injury, not the true range. The effective range is independent of the barrel length and choke. The severity of injury can be estimated using the effective range and Sherman's classification (46) of shotgun wound type. This discussion applies only to birdshot type wounds and not those of buckshot, which can produce significant injury at long ranges.

Wound Characteristics and Range. The wound created when the charge of a standard shotgun strikes a victim within a range of 6 meters is characterized by tissue destruction not unlike that caused by high-velocity missiles. Massive soft-tissue loss, bone and vessel disruption, and a high infection rate result (4, 11, 15, 18, 22, 29, 30, 42, 58). The entire charge, including shell fragments, wadding, and load of shot, penetrate the point of impact as a common mass at a muzzle-victim range of less than 2 meters. The presence of a wad in a wound provides very strong presumptive evidence that the shot was fired from less than 2 meters. From 3 to 6 meters the shot charge is still compact, but a few pellets will wandered off, spreading 2 to 5 inches from the wound center point (15). After the shotgun charge has travelled

SHOTGUN WOUND BALLISTICS

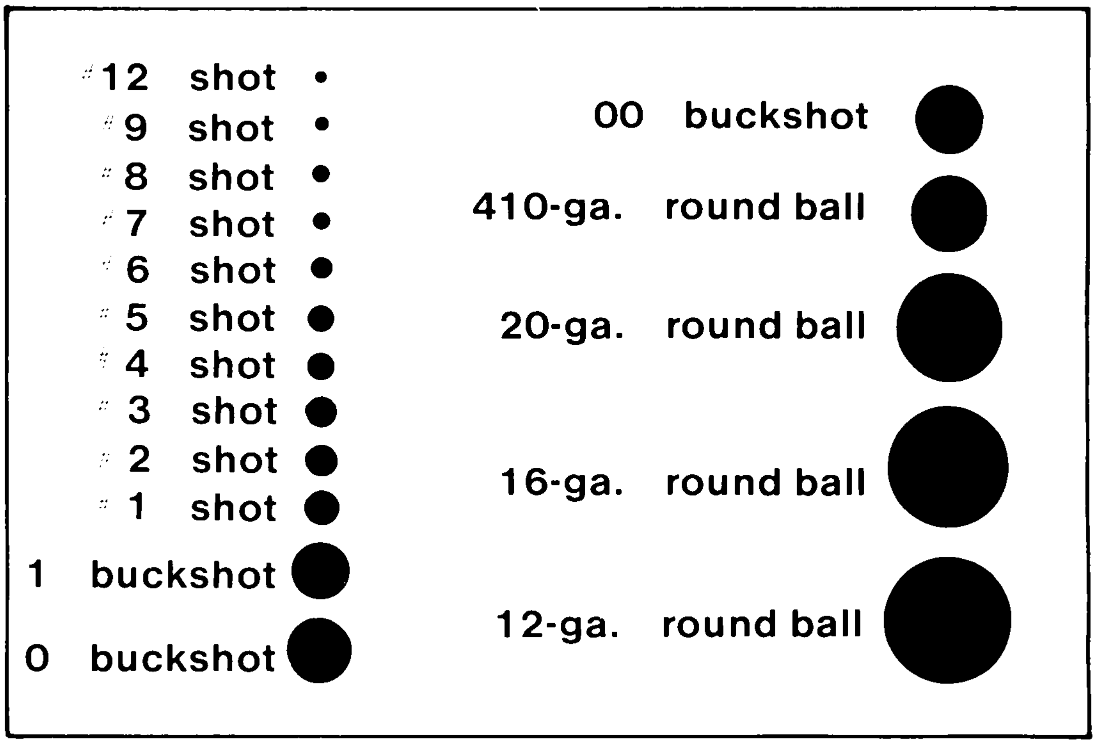

FIG. 1. Sizes of the shot in various gauges.

over 6 meters, the shell fragments and wadding fall away. The wound created is caused only by the spray of low-velocity pellets, mainly damaging friable structures, particularly the eye (15).

Birdshot Wound Severity. Sherman (46) classified shotgun wounds into three types, based on both range of the shotgun (in this case distance from gun to patient) and extent of tissue penetration. We have added a fourth type to indicate wounds with pellets that penetrate only the skin and cause significant morbidity only if they hit the eye. Deitch (7) showed that the severity of soft-tissue, bone, nerve, and vessel injuries increases markedly from 0% to up to 100% from Type I to III (Table III).

Magnum Loads. Magnum loads are sometimes used for shotgun shells. Unlike handguns and rifles the purpose of the extra gunpowder is not to increase the velocity of the missile but to increase the size of the load. For example, the standard 12-gauge shotgun shell has a muzzle velocity of 1,255 feet/second, whereas the "high-velocity" 3-inch magnum shell has a muzzle velocity of only 1,315 feet/second, but contains extra pellets in its load. The magnum shell can be distinguished from the standard shell by the longer brass cup at its base.

Slugs. Rifled single shotgun slugs are sometimes used, but fortunately are rare. They are easily purchased and can be fired from any appropriately gauged shotgun. These slugs are very large. For example, the 12-gauge is .730 caliber, with a weight of 295 grains (compared to 90 grains for a .357 magnum handgun bullet). Characteristically, these slugs also have a higher muzzle velocity than shot. They produce wounds with as high a mortality as those of high-velocity weapons with possibly even more tissue destruction due to their size and mass (39, 54).

Management of Shotgun Wounds. For shotgun injuries, Wilson (55) recommends the following approach: carry out prompt and vigorous volume resuscitation; inspect all wounds carefully, because inspection of the shotgun wound is more informative than that of the high-velocity wound and is the key to treatment and prognosis; treat all buckshot wounds as if they were multiple low-velocity bullet wounds; use angiography liberally whenever there is the possibility of vascular injury; explore aggressively all Type II and Type III wounds; and debride all devitalized tissue and reoperate, as necessary, to reevaluate any questionably viable tissue (54).

Proximity of Gunshot Wounds. When a gun is fired various substances are discharged from the muzzle in addition to the bullet or pellets. These other projectiles include metallic fragments of the bullet and cartridge, unburned grains of powder, burned grains of powder or soot, gases, and a metallic spray of primer (Table IV).

FIG. 2. Twelve .15-inch diameter pellets (#2 shot) are seen on this chest X-ray (See Table II). Using the formula provided to calculate range when the distance between pellets is known, the range is estimated to be 70 meters.

$$\text{Range (meters)} = 2 \times \sqrt{\text{pellets:load} \times \text{Distance:pellets (inches)}^2}$$

$$\text{Range (meters)} = 2 \times \sqrt{135 \times (3)^2} \text{ (pellets:load from text)}$$

Range (meters) = 70 meters.

If the weapon was a "sawed-off" shotgun then this value would be the effective range which can still be used to estimate the severity of injury. In either case, the wound would be classified as a Type 0 or 1 shotgun wound, indicating minimal injury may be present. In actual fact, most of the pellets were embedded in the epidermis of the skin and could be removed with forceps, but one pellet did penetrate the chest wall, diaphragm, and liver, resulting in a hemothorax and hemoperitoneum which required surgery. Thus even Type I injuries may occasionally cause significant morbidity or mortality.

Bullet Sterility. Because insufficient heat is generated, fired bullets are not sterile. Experiments have shown that even high-velocity missiles, if contaminated with bacteria before firing, will inoculate a sterile medium with these bacteria (50, 56). Other secondary projectiles such as skin, clothing, gunpowder debris, surrounding inanimate structures, and shotgun shell wadding may carry potentially pathogenic bacteria, as well as delay wound healing. These foreign bodies must be removed by debridement or irrigation (47).

Missile Migration. Free migration of shot may occur in any tubular structure or potential space within the body. We found 92 reported cases of vascular missile embolization (3, 5, 10, 17, 19, 20, 23–27, 31, 32, 38, 41, 43, 45, 47, 48–52), mainly due to shotgun wounds. Chapman reported an incidence of vascular embolization of 1.1% at autopsy (5). Migration of missiles has been seen in the spinal canal (49), kidneys (3, 19, 20, 31, 32), ureters (3, 19, 20, 31, 32), urethra (12, 16), GI tract (3, 19, 20, 31, 32), and lungs (3, 19, 20, 31, 32). X-rays should be obtained of any area, even distant from the wound, that is producing symptoms in the patient, in order to track embolized shot. Some feel that a total body X-ray should be taken when a patient has been wounded with multiple shot.

FIG. 3. Full load of No. 6 shot in right thigh. Using the formula provided the effective range for this wound was 12 meters. This would be 12 meters for a standard length shotgun or much closer for a "sawed-off" shotgun. This would make this wound a Type II, with a moderate amount of tissue damage and mortality rate of approximately 15–20%. The actual length of barrel used is not important as the effective range is known in this case. The effective range may be calculated in three ways for this wound. First, the full load produced a wound with a diameter of 14 inches which may also be measured by the pellet spread on X-ray. Assuming a spread of approximately 1 inch per meter from 2 to 100 meters range, this would indicate that the weapon-victim range was approximately 12 meters. Second, the effective range can be calculated after measuring the distance between pellets. The shot size is measured at .11 inches in diameter which is #6 shot (see Table II) and each 1½-ounce load would contain approximately 350 pellets. The average measured distance between pellets using either a measurement of wounds in the skin or by X-ray is 0.3 inches. Thus

$$\text{Range} = 2 \times \sqrt{350 \times 0.3^2}$$
$$\text{Range} = 12 \text{ meters}$$

Third, the "effective" range may be calculated from the number of pellets within a certain radius.

$$\text{Range} = 2 \times \sqrt{\frac{350 \times 7^2}{350}}$$
$$\text{Range} = 14 \text{ meters.}$$

Size of Shot on X-ray. In calculating the size of a missiles from X-rays, magnification of the object must be taken into account. Practically, to measure the size of the bullet from an X-ray the formula used is

FIG. 4. This X-ray shows 51 pellets of 0.15 inches diameter around the knee. Note that some of the pellets have mushroomed and others have fragmented when hitting the bone, although no fracture occurred. The diameter of the pellets should be measured from one that has not been distorted and is close to the X-ray when radiographed. Using Table II this shot is estimated to be #2 of which there are 90 to the ounce and 135 in each loaded 1½-ounce shell. The effective range can be calculated using either the radius of the entire wound and number of pellets involved, or by measuring the average distance between pellets. Note that in either case the best X-ray to use for measurements is one in which the X-ray beam is parallel to the direction the pellets travelled.

Using the average distance between pellets of 0.5 inches:

$$\text{Range} = 2 \times \sqrt{135 \times 0.4^2}$$
$$\text{Range} = 9 \text{ meters}$$

Using the wound radius of 4 inches:

$$\text{Range} = 2 \times \sqrt{\frac{135 \times 3^2}{51}}$$
$$\text{Range} = 10 \text{ meters.}$$

This yields an average effective range of 9.5 meters and this wound may be classified as a Type II injury. The extent of pellet penetration is evident from the fact that many of the pellets hit the bones. Significant soft-tissue damage could result from this type of wound, including vascular and nervous tissue injury.

$$\text{Object size} = \frac{\text{Focus:Object Distance} \times \text{Image size}}{\text{Focus:Film Distance}}$$

where: *Object size* = actual size of the bullet; *Image size* = size of the bullet on X-ray; *Focus:Film distance* = distance from the X-ray tube to the film; *Focus:Object distance* = distance from the X-ray tube to the actual bullet.

When viewing shot in the human body, the magnification will range from 1.0 to a maximum of 1.25 (6) (this is the same as an increase in the image size of 0 to 25%). For example, no magnification will occur for a pellet in the anterior chest on a P-A chest X-ray, with the pellet up against the X-ray film, using the usual *focus:Film distance* of 6 feet. The greatest conceivable magnification will result when an A-P chest X-ray is taken at a distance of 3 feet and the pellet is in the anterior chest wall. Here, the *focus:Film distance* is at a minimum and the *focus:Object distance* is at a maximum, resulting in a calculated 20% magnification. For practical purposes, if the pellet is close to the X-ray film (proven by taking a lateral film as well), magnification may be discounted in estimating pellet size. Other circumstances will require use of the above formula.

It should be noted that the modern X-ray and trauma tables which contain a compartment below the bed of the table for the X-ray plate increase the *focus:film*

TABLE III
Classification of shotgun wounds*

	Range		Injury	Mortality
	Standard Barrel	"Sawed-off" Shotgun		
Type 0	Long >12 meters	>4 meters	Superficial—penetrates skin only	0%
Type I	Long >12 meters	>4 meters	Penetrates only subcutaneous tissue and deep fascia	0–5%
Type II	Close 5–12 meters	2–4 meters	Penetrates beyond deep fascia	15–20%
Type III	Point blank <5 meters	0–2 meters	Extensive tissue damage	85–90%

Note—distance will vary with each type of shotgun, and will be significantly reduced for "sawed-off shotguns" as these are true ranges and not effective ranges.

* Modified from Sherman (46).

TABLE IV
Range of gunshot wounds determined by physical examination

The distances these substances may travel are as follows:
From a handgun
- Gases—1–3 inches
- Burned powder grains or soot—1–3 inches
- Unburned powder grains—1–2 feet (27)
- Metallic fragments—up to 6 feet

From a shotgun
- Wadding and shell fragments—less than 6 meters

From a rifle
- As for handgun

distance. We have found that this distance may be increased by as much as 4 inches.

Manufacturers maintain a degree of tolerance in shot size of only a few per cent, therefore, measurement of one nondeformed pellet should give an accurate diameter. The pellet measured should be close to the X-ray plate and nonfragmented and nondeformed in order to get an accurate diameter.

CONCLUSIONS

Based on the theories of wound ballistics, it is important to identify the type of bullet and the type of gun or rifle in order to disclose essential information regarding the severity and extent of the injury. An estimation of the effective range of the shotgun using the calculations described in this paper can allow Sherman type catagorization (46) of the wound. This can identify the patient's prognosis as well as the extent of the investigational procedures needed to evaluate the patient, the extent of the surgical debridement and repair necessary for each individual wound (35). A thorough knowledge of wound ballistics is mandatory for all physicians who may be involved in the care of shotgun victims.

REFERENCES

1. Adams, D. B.: Wound ballistics: A review. *Milit. Med.*, **147:** 831–835, 1982.
2. Adelson, L.: The gun and the sanctity of human life: Or the bullet as a pathogen. *The Pharos*, Summer, 1980, p. 15.
3. Bertini, J. E., Jr., Boileau, M. A., Fischer, R. P.: Buckshot colic. *Urology*, **13:** 167–169, 1984.
4. Breitenecker, R.: Shotgun wound patterns. *Am. J. Clin. Pathol.*, **52:** 250–269, 1969.
5. Chapman, A. J., McClain, J.: Wandering missiles: Autopsy study. *J. Trauma*, **24:** 634–637, 1984.
6. Christensen, E. E., Curry, T. S., Dowdey, J. E.: *An Introduction to the Physics of Diagnostic Radiology*, 2nd ed. Philadelphia, Lea & Febiger, 1978, pp. 113–212.
7. Deitch, E. A., Grimes, W. R.: Experience with 112 shotgun wounds of the extremities. *J. Trauma*, **24:** 600–603, 1984.
8. DeMuth W. E.: Ballistic characteristics of 'magnum' sidearm bullets. *J. Trauma*, **14:** 227–229, 1974.
9. DeMuth W. E., Nicholas, G. A., Munger, B. L.: Buckshot wounds. *J. Trauma*, **18:** 53–57, 1976.
10. DiMaio, V. J., DiMaio, D. J.: Bullet embolism: Six cases and a review of the literature. *J. Forens. Sci.*, **17:** 394–398, 1972.
11. Drye, J. C., Shuster, G.: Shotgun wounds. *Am. J. Surg.*, **85:** 438–443, 1953.
12. Early, J. L.: Urethral ballistics. *The Veterinary Record*, April: 412, 1984.
13. Fackler, M. L., Surinchak, J. S., Malinowski, B. S., et al.: Bullet fragmentation: A major cause of tissue disruption. *J. Trauma*, **24:** 35–39, 1984.
14. Finck, P. A.: Ballistic and forensic pathologic aspects of missile wounds. *Milit. Med.*, **130:** 545–550, 1965.
15. Flint, L. M., Cryer, H. M., Howard, D. A., et al.: Approaches to the management of shotgun injuries. *J. Trauma*, **24:** 415–419, 1984.
16. Freak, M. J.: Urethral ballistics. *The Veterinary Record*, April: 412, 1984.
17. Garzon, A., Gleidman, M. L.: Peripheral embolization of bullet following perforation of the thoracic aorta. *Am. Surg.*, **160:** 901, 1964.
18. Guerin, P. F.: Shotgun wounds. *J. Forens. Sci.*, **5:** 294–318, 1960.
19. Gutman, H., Rothberg, M., Johanson, K. E.: Ureteral obstruction by shotgun pellet seven years after injury. *Urology*, **13:** 170–172, 1984.
20. Hewitt, R. L., Sanders, P. W.: Acute ureteral obstruction from a gunshot: Report of an unusual case. *Ann. Surg.*, **162:** 261–264, 1965.
21. Holt, G. R., Kostohryz, G., Jr.: Wound ballistics of gunshot injuries to the head and neck. *Arch. Otolaryngol.*, **109:** 313–318, 1983.
22. Hopkinson, D. A. W., Marshal, T. K.: Firearm injuries. *Br. J. Surg.*, **54:** 344–353, 1967.
23. Iskecelli, O. K.: Bullet embolus of left femoral artery: Report of a case which occurred after abdominal gunshot wound. *Arch. Surg.*, **85:** 184, 1962.
24. Jones, A. M., Graham, N. J., Looney, J. R.: Arterial embolism of a high velocity bullet after a hunting accident: A case report and literature review. *Am. J. Forens. Med. Pathol.*, **4:** 259–264, 1982.
25. Kapp, J. P., Gielchinsky, I., Jelsma, R.: Metallic fragment embolization to the cerebral circulation. *J. Trauma*, **13:** 256–261, 1973.
26. Keely, J. L.: A bullet embolus to the left femoral artery following a thoracic gunshot wound: Probable entrance through thoracic aorta: Case report and resume of peripheral arterial bullet emboli. *J. Thorac. Surg.*, **21:** 608–620, 1951.
27. Ledgerwood, A. M.: The wandering bullet. *Surg. Clin. No. Amer.*, **57:** 97–109, 1977.
28. Luce, E. A., Griffen, W. O.: Shotgun injuries of the upper extremities. *J. Trauma*, **18:** 487–492, 1978.
29. Mandal, A. K., Boitano, M. A.: Principles and management of penetrating vascular injuries secondary to shotgun wounds. *Am. Surg.*, **44:** 165–173, 1978.
30. May, M., West, J. W., Hans Heeneman, H., et al.: Shotgun wounds to the head and neck. *Arch. Otolaryngol.*, **98:** 373–376, 1973.
31. McClellan, R. E.: Unusual case report: "Buckshot colic". *Univ. Mich. Med. Bull.*, **21:** 107–110, 1955.
32. Montealegre, A., Grossman, H. B.: Acute ureteral obstruction from buckshot. *Urology*, **15:** 159–161, 1980.
33. Noguchi, T. T.: *Coroner*. New York, Simon and Schuster, 1983, pp. 101–105.
34. Ordog, G. J.: Penetrating neck trauma. *J. Trauma*, **27:** 543–554, 1987.
35. Ordog, G. J., Albin, D., Wasserberger, J., et al.: 'Birdshot' shotgun wounds of the neck. *J. Trauma*, in press, 1988.
36. Owen-Smith, M. S.: *High Velocity Missile Wounds*. London, Edward Arnold, 1981, pp. 179–181.
37. Parkinson, J.: The ballistics of craniocerebral gunshot wounds. *Am. Assoc. Neurosurgical Nurses*, **14:** 232–238, 1982.
38. Patten, E. L., Morales, H. E.: Bullet emboli to the pulmonary artery: A rare occurrence. *J. Trauma*, **22:** 801–802, 1982.
39. Petty, C. S., Hauser, J. E.: Rifled shotgun slugs: Wounding and forensic ballistics. *J. Forens. Sci.*, **13:** 114–123, 1968.
40. Pradar, S. C.: Air gun pellet embolizing the intracranial internal carotid artery: Case report. *J. Neurosurg.*, **43:** 222–224, 1975.
41. Prean, G., Aragon, G. E.: Arterial embolism from a bullet: A case report. *Am. Surg.*, **42:** 863–865, 1976.
42. Raju, S.: Shotgun arterial injuries in the extremities. *Am. J. Surg.*, **138:** 421–425, 1979.
43. Reines, H. D., Dill, L., Saad, et al.: Neurogenic pulmonary edema and missile emboli. *J. Trauma*, **20:** 698–701, 1980.
44. Rich, N.M.: Missile injuries. *Am. J. Surg.*, **139:** 414–420, 1980.
45. Rich, N. M., Collins, G. J., Anderson, C. A., et al.: Missile emboli. *J. Trauma*, **18:** 236–239, 1978.
46. Sherman, R. T., Parrish, R. A.: Management of shotgun injuries: A review of 152 cases. *J. Trauma*, **3:** 76–85, 1963.
47. Stutzman, R. E.: Ballistics and the management of ureteral injuries from high velocity missiles. *J. Urol.*, **118:** 947–949, 1977.
48. Symbas, P. M., Harlaftis, N.: Bullet emboli in the pulmonary and systemic arteries. *Am. Surg.*, **185:** 318–320, 1977.
49. Tanguy A., Chabannes, J., Deubelle, A., et al.: Intraspinal migration of a bullet with subsequent meningitis. *J. Bone Jt. Surg.*, **64-A:** 1244–1245, 1982.
50. Torsby, F. P.: The mechanism of primary infection of bullet wounds. *Br. J. Surg.*, **54:** 359–360, 1967.
51. Trimble, C.: Arterial bullet embolism following thoracic gunshot wounds. *Am. Surg.*, **168:** 911–916, 1968.
52. Van Gilder, J. C., Coxe, W. S.: Shotgun pellet embolus of the middle cerebral artery. *J. Neurosurg.*, **32:** 711–714, 1970.
53. Vital Statistics of the U.S. *Statistical Abstracts of the U.S. 1980.* Rockville, Maryland, National Center for Health Statistics 1980, p. 187.
54. Wilson, J.: Wound ballistics (Trauma Rounds). *West. J. Med.*, **127:** 49–54, 1977.
55. Wilson, J. M., Trunkey, D. D., Blaisdell, F. W.: Shotgun ballistics and shotgun injuries (Trauma rounds—San Francisco General Hospital). *West. J. Med.*, **129:** 49–155, 1978.
56. Wolf, A. W.: Autosterilization with low-velocity bullets. *J. Trauma*, **19:** 115–116, 1979.
57. Wright, J. D.: The demography of gun control. *The Nation*, Sept. 20, 1976, p. 241.
58. Zumwalt, R. E., Campbell, B., Balraj, E., et al.: Wounding characteristics of "shotshell" ammunition: A report of three cases. *J. Forens. Sci.*, **26:** 198–205, 1981.