Trauma Rounds

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Shotgun Ballistics and Shotgun Injuries

IAN LEVERTON, MD:* The patient is a 25-year-old white man who was admitted to the emergency department 20 minutes after having been shot in the right lateral thorax and right thigh with a 12-gauge shotgun. The estimated range was 5 to 10 yards; the empty shell casings at the scene confirmed the gauge and the fact that 00 buckshot had been the load. Upon physical examination, the patient was conscious and had a blood pressure of 70 systolic, a pulse of 120 and respiration of 34. There were multiple pellet holes in the right lateral thorax and right upper quadrant with injuries of the left forearm and left hand as well. There were multiple pellet holes in the right lateral thigh with an obvious fracture of the right femur. There were no pulses distal to the blast area in the thigh, and the foot was cold and ischemic.

Cutdowns were carried out in the left arm and left leg, and Ringer lactate was infused rapidly. Blood was drawn and sent for typing and cross matching, and x-ray films of the femur, abdomen and chest were taken en route to the operating room. At operation, four tangential wounds of the liver and omentum were seen. The tenth rib was shattered, producing a large tangential diaphragmatic defect. The diaphragm was repaired, the liver lacerations which were not bleeding were drained posteriorly, and bleeding points in the omentum were controlled. Local debridement of the entrance wounds was also carried out. Simultaneous exploration of the thigh showed a totally transected superficial femoral artery. The damaged segment was resected and primary anastomosis was carried out. Soft tissue debridement was done and an angiogram taken. Arteriography showed patent anastomosis but narrowing of the vessels in the thigh. The patient was placed in skeletal traction and transferred to the intensive care unit.

The patient's course was relatively benign and he was transferred from the intensive care unit on the sixth postinjury day. At present he is being managed in traction for his femur injury.

F. WILLIAM BLAISDELL, MD:† I would like to introduce our chief trauma resident, Dr. James Wilson, who during several years in the navy did special research on ballistics and wounding characteristics of missiles. Dr. Wilson, would you

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comment on the nature of shotgun injuries and principles of their management?

JAMES M. WILSON, MD:* If one were to analyze the factors most strongly influencing patient fatality following gunshot wounds in the civilian population, it would become immediately apparent that the type of weapon used is key, and that shotguns are responsible for a greater percentage of deaths than are any other type of firearm. Shotgun wounds are different from rifle and pistol wounds and by no means can be considered identical either from a ballistics standpoint or in wounding capability.

Shotguns are popular worldwide; more of these smooth-bore weapons are bought and used than are rifled types. In fact, many governments—such as those of Great Britain and the Soviet Union—discourage the use of rifles yet allow unrestricted use of shotguns.

The idea of using a blast of small pellets for hunting and even for fighting is as old as the use of firearms itself. The first guns were smooth bore or unrifled and as a result were grossly inaccurate. Rifling, or the grooving of the gunbarrel to produce spinning of the projectile, was not developed until about 1500—some 150 years after gunpowder was first used as propellant. Early American colonists began to use buckshot loads in their flintlock muskets because the general accuracy of the smooth bore barrel weapons was so poor. Use of buckshot also made it easier to hit moving targets or those in brush, where quick shooting was essential for acquiring food or for protection.

Modern shotguns date back to about 1750 when flintlock, and later percussion, caps were used. The LeFaucheaux pinfire was patented in 1836; this type of shell is still made and used in certain parts of Europe. In 1851 Charles Lancaster of England developed an improved centerfire breech-loading shotgun—a development which marked the end of the muzzle-loader era. Choke boring, or the narrowing of the end of the barrel to improve target coverage by pellets, was little known or used until about 1870. In that year, Fred Kimble of the United States developed it to near its present form.

In relation to powder charge, the first commercially successful smokeless powder was developed in 1864 by a Prussian, Captain E. Shultz. Earlier smokeless powder burned too fast, generating excessive pressures whereas Shultz's powder which burned slower was made from nitrated wood pulp, using a method which duPont later used for many years in the United States.

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TABLE 1.—*Common Shotgun Gauges and Corresponding Calibers*

10 gauge	0.775 caliber
12 gauge	0.730 caliber
16 gauge	0.670 caliber
20 gauge	0.615 caliber
28 gauge	0.550 caliber
410	0.410 caliber

Modern shot of uniform quality was developed by the Englishman William Watts in 1769. He dropped specific amounts of hot lead into a column of water, thus producing lead pellets.

As mentioned earlier, modern shotguns are smooth bore—that is, the barrels are smooth without any rifling or grooving. Shotguns come in almost every form imaginable: single shot, double-barreled side-by-side, double-barreled over-and-under, pump action or semiautomatic. The Winchester Model 97 pump action shotguns were used by American troops in short barrel form during World War I. A similar gun was used in World War II and in Vietnam for jungle fighting. Police have used this same riot gun—a 12 gauge with a sawed-off (20-inch) barrel loaded with double 0 buckshot. The advantages of this gun as a close range weapon will be made clear later in this text.

The gauge (or bore caliber) for a shotgun is designated differently than for a rifle or pistol. The classification system is antiquated, dating back to muzzle loading days. At that time, the gauge of a musket was expressed in terms of how many lead balls of an appropriate size would be required to weigh one pound. Therefore, a 12-gauge weapon originally had a bore of such diameter that a round lead ball weighing 1/12 pound could enter the barrel. This system of designation has persisted to modern times although there are two exceptions to the system: the 9-mm shotshell which has, indeed, a 9-mm bore, and the 0.410 gauge which is actually 0.410 caliber; that is, 0.410 inches in diameter. The common shotgun gauges are shown in Table 1 with their corresponding calibers.

The larger gauge guns—4, 8 and 10 gauge—have essentially disappeared from popular use since the advent of higher grade smokeless powder and of choke boring, which notably improved the performance of the smaller gauge weapons.

The 12 gauge is by far the most popular shotgun ever used in the United States for civilian sports and for military, police and criminal use. Indeed, more than half of the shotguns sold in this country each year are 12-gauge weapons. The 12, 16, 20 and 410 gauge are extensively manufactured and used in the United States but the advantages of each are a function only of personal preference, as we will show in the discussion on ballistic characteristics which follows.

The choke of a given shotgun designates the amount of constriction at the end of the weapon barrel, and it is the choke that actually determines the shot pattern at a given distance from the muzzle. The constriction acts much like the nozzle on a garden hose which, when partially constricted, gives a narrow stream of water for maximum shooting distance for a given, constant pressure. Full choke (or tight constriction), modified choke and cylinder bore (or no constriction) constitute the three basic types of barrels. A full-choke barrel will force approximately 70 percent of the pellets in a charge into a pattern circle with a 30-inch diameter at a 40-yard range; modified choke gives 60 percent and cylinder choke propels only 40 percent of the pellets into this circle pattern area. The velocity of the individual pellets is affected very little by choke or barrel length. Consequently, the choke of the barrel will directly affect the pattern or concentration of the pellets. Obviously, range will be the main determinant of the actual target pattern using any given choke. Sawed-off shotguns or riot guns, such as those used by police and in Vietnam produce an even wider pattern than do cylinder bore weapons; the reason for this is that they are not designed for range but more for target coverage at close range.

The ammunition unit is called a shot shell and consists of a plastic casing (or paper casing, in older shells) compressed into a brass cup which contains the primer. The powder is then compressed into the primer cup at the base of the shell. Next, a wad of plastic or paper, is placed between the powder and the shot charge and the shot is held within the casing by another thin wad of paper or plastic. The whole system is then compressed and the top edge of the casing crimped. When the gun is fired, it is the shot charge, along with the wadding, that leaves the barrel. Therefore, at close range a victim is hit not only by pellets but also by the wadding and casing debris.

One additional point about the powder deserves comment. As aforementioned, shotgun powder is quite fast burning and is designed for use only in shotguns where relatively low chamber pressures are generated. As a result, serious injury will be inflicted if this powder is used by novices in home-loading rifle or pistol cartridges.

The shot, then, is a collection of individual pellets. They were once made of pure lead but are now usually made of a lead and antimony alloy. Problems with pellet deformity and fouling of the barrel subsequently led to the practice of coating the pellets with a copper-zinc alloy. This coating is especially common in magnum loads.

The pellets come in various sizes and are loaded into the shot shells usually in increments of approximately one ounce. The No. 6 shot is the most common shot load used; it is designed for use on most medium-sized fowl and, when used in 12-gauge weapons, is an excellent all-around shell. Therefore, because the No. 6 shot shell used in a 12-gauge weapon is the most popular combination, it is the one most commonly involved in shotgun wounds. The No. 6 pellet is 0.11 inches in diameter and each shell contains 340 pellets (weighing about 1½ ounces). At close range, therefore, the concentration of pellets within the target pattern is extensive.

The other type of pellet which is worthy of special mention is the No. 00 buck; this was the size pellet used to wound the patient presented today. The double 0 buckshot was designed originally for killing larger animals and its diameter is 1/3 inch.

The shot charge radiates from the muzzle in a cone-like distribution and the pellets should be evenly distributed at the base of this cone. The pellet distribution is known as the "shot pattern" and is dependent, as mentioned earlier, upon the choke of the barrel and the range at which the shell is fired. Effective range for most shotguns is 20 to 40 yards from the target. At a range of under 20 yards, the dense shot pattern destroys most game being shot. while at more than 40 yards the pattern is too sparse to give any effective killing power. The shotgun is seldom used against humans at a range of over 40 yards, as most shotgun wounds seem to be inflicted at close range—15 yards or less.

From a ballistics standpoint, the shotgun is quite different from the single projectile, high-velocity rifle. In the case of the latter, all ideal characteristics of a projectile—good ballistic shape, high sectional density, high velocity and deep penetration with controlled expansion—are met. But in the shotgun, all these ideal properties are sacrificed in order to obtain target area saturation, therefore making it possible to hit a small, fast-moving target.

The wounding capacity of a given weapon is a function of both the projectile mass and its velocity. Consequently, shotgun wounds should be classified along a wide spectrum ranging from injury inflicted by a single pellet to that caused by an entire charge of hundreds of pellets together with wadding and debris, which all enter the victim.

As stated earlier, range is the major determinant of wounding capacity using any given load. When a 12-gauge shotgun blast loaded with No. 6 shot is observed clinically, at 6 feet the wound inflicted is essentially a central blast, whereas at 24 feet the pattern is that the bulk of pellets has begun to spread out concentrically (although they are still contained within a 6-inch circle). For instance, a 12-gauge shotgun loaded with a No. 6 shell gives a muzzle velocity of about 1,300 feet per second and will penetrate a 4-inch thick telephone book when fired from a distance of 12 feet; it will produce a 6 cm defect and will release 2,300 foot-pounds of energy. As noted in a previous discussion on wound ballistics,[1] the ideal antihuman projectile would be one that dissipates all its energy within 15 cm of the point of penetration. At close range, the highly lethal shotgun certainly meets this criterion. As with other firearms, the kinetic energy expended is equal to

$$\frac{\text{mass} \times \text{velocity}^2}{2g}.$$

When one studies the kinetic energy of pellets fired at different ranges, it becomes apparent why shotgun charges and rifle projectiles behave so differently at ranges over a few yards. At a range of 40 yards—a small distance for a high-powered rifle—shotgun pellets would have lost more than half of their original energy. But, at close range an interesting comparison can be made between the 55-grain, 5.56 mm M-16 rifle (used by the United States armed forces in Vietnam) and the 12-gauge shotgun. The M-16 has a muzzle energy of 1,250 foot-pounds, whereas a 12-gauge shotgun with No. 5 shot has an energy of 2,247 foot-pounds. Again, range is the key factor. It can easily be seen why the shotgun is so lethal at close range.

Buckshot—the most common load used by police and military personnel—warrants special comment as well. It was originally designed for use on larger game animals such as deer and its larger mass makes buckshot much more effective at longer ranges. To make this point more clear, consider that each pellet hits the body at a velocity of more than 1,000 feet per second and that each 00 buckshot pellet is about the size of a .22 caliber bullet. Each blast from this type of load, then, contains about nine pellets with an obvious wounding effect.

One additional point should be made concerning the use of magnum shells. Unlike pistol and rifle cartridges, the magnum shotgun shell does not necessarily produce vastly higher velocities. For example, the standard 12-gauge shotgun load has a muzzle velocity of 1,255 feet per second, whereas the so-called "high velocity" 3-inch magnum shell (3-inch denoting the length of the shell) has a muzzle velocity of only 1,315 feet per second. Therefore, very little is actually gained in missile velocity or energy at various ranges by employing magnum shells. What is gained, however, is that a larger load can be discharged. Therefore, the extra powder (that is, magnum) charge is used to propel *more* pellets, not to increase the velocity of the standard load. One can easily tell if a magnum load has been used by examining the spent shell since, with the magnum load, the brass base cup is longer than that of the standard shell.

The clinical characteristics of shotgun wounds are distinctly different from high velocity rifle bullet wounds. In fact, the scope of possible shotgun injuries is so great that only a few general observations can be made.

A person struck by a single pellet which is smaller than BB size is seldom seriously injured unless hit in the eye. As noted previously, most serious human wounds occur at ranges much closer than 20 yards where most of the total pellet charge hits the victim. Again, range is the most important determinant of the amount of damage inflicted by a given shotgun charge. The range can be estimated in about 80 percent of shotgun cases, as can the type of shot used—whether small (like No. 6) or large (like 00 buck).

Wounds made by 00 buck deserve further mention. As noted earlier, each pellet is about the size of a .22 caliber bullet and has a velocity which can exceed 1,000 feet per second.[2] Consequently, each of the pellet wounds should be treated as separate low-velocity pistol wounds, and more or less independent of range. As might be expected, victims of close range 00 buckshot wounds seldom reach the hospital.

One brief word should be said about rifled slugs. These shells are single projectiles originally designed for killing larger animals and can be fired from any standard shotgun. In relation to the popular 12-gauge weapon, the slug would be 0.730 caliber with a weight of 295 grams; the .357 magnum, in contrast, is about 90 grams. The muzzle energy is 2,480 foot-pounds and these rifled slugs are quite accurate up to about 125 yards. They are huge—approximating those used in buffalo guns of the Wild West days, and they produce tremendous wounds. Human wounds of this type are very rare, but awareness of this injury is the key to successful management. Their wounding characteristics are similar to other medium-velocity (muzzle velocity of 1,800 feet per second) projectiles except that the mass of the bullet is much greater.

Once the approximate range is ascertained, an intelligent approach to wound management can be formulated. Sherman and Parrish[3] have classified shotgun wounds into three categories:

Type I shotgun injuries. These are sustained at long range (greater than 7 yards). This would correspond to an across-the-street injury and such wounds involve penetration of subcutaneous tissue or deep fascia.

Type II shotgun injuries. These are sustained at close range (3 to 7 yards). They correspond to across-the-room range injuries. These types of wounds usually involve structures deep to the fascia.

Type III shotgun injuries. These are sustained at a very close range, that is, less than 3 yards. These wounds usually involve massive tissue destruction and correspond to more or less point-blank range injuries.

Type I injuries usually produce a scatter type wound. At 40 yards, however, a No 6 shot blast has lost most of its energy and thus penetrates minimally to moderate distances (Figure 1). At ranges of 20 yards or more, these small shot may penetrate the abdomen and cause an incredible number of holes in the bowel. Several authors have advocated expectant management of those scatter-type wounds caused by small shot at relatively long distances.[4] The rationale behind use of nasogastric suction and broad spectrum antibiotic therapy rather than immediate operative intervention stems from the fact that these small pellet holes may be enormous in number and the individual holes quite small—often no greater in diameter than a 14-gauge needle. Furthermore, there is usually no outpouching of mucosa and relatively little spillage so that they will often seal —without sequelae. No further generalizations can be made, but the choice of therapy should be made intelligently taking into consideration the range and type of pellets used to inflict the injury as well as the clinical findings. As in the case of all shotgun injuries, tetanus toxoid is prescribed along with admission to hospital for observation. Frequent examinations for evidence of blood vessel or nerve injury of the extremity are also indicated.

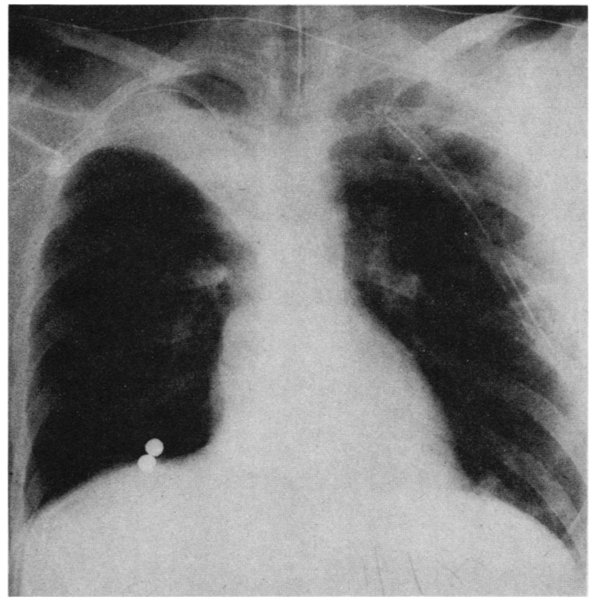

Figure 1.—Roentgenogram showing intrathoracic buckshot.

Type II wounds cause a tighter pattern of injury and will usually demand a more aggressive approach to management (Figure 2). Injury at this range is usually to structures deep in the fascia and one must be alert to the possibility of vessel injury, nerve injury, and more extensive damage to the bowel than from simple small perforations. The expectant management of abdominal injuries of this type cannot be justified because velocity in this range can be sufficient to cause tangential tears in bowel, and because small groupings of pellets can destroy segments of bowel. Upon exploration, small perforations should be sutured and major areas of bowel injury resected. Injuries to the liver, spleen, stomach, kidney and colon should be managed no differently than any other low-velocity missile wound. Perforation of the aorta and vena cava are usually successfully managed by simple suture. Type II injuries which penetrate the chest can be managed most often by chest-tube drainage. One must be on the alert, however, for cardiac injury with subsequent tamponade and for major vessel injury. Angiography should be used liberally as part of the evaluation process. Esophageal injuries are also a possibility and when mediastinal penetration is likely, esophagrams should be obtained utilizing soluble contrast material. Type II injuries of the head, neck and extremities are managed like any other low-velocity injury but with a high index of suspicion for vascular injury. The incidence of arteriovenous fistula formation post-shotgun injury is quite high. The liberal use of angiography or direct exploration if the index of suspicion is high can help identify these injuries.

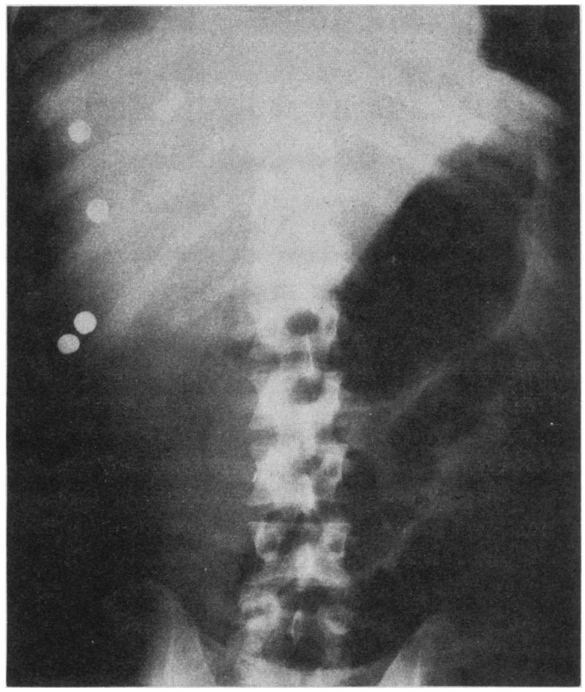

Figure 2.—Flat plate roentgenogram of abdomen showing buckshot.

Type III injuries can tax the skills of a multitude of surgical specialists (Figure 3). They usually cause massive local destruction, and hemorrhage is the immediate lethal factor in most cases. Not only pellets, wadding, gunpowder debris and casing debris are blasted into the body, but also other foreign material such as wood (if the victim is behind a door, for example), clothing and skin. Consequently, massive bacterial contamination is the rule, and development of gangrene and necrotizing fasciitis are relatively common. Therefore, almost all of these wounds require extensive debridement and exploration. Repeat exploration or use of second-look procedures to further debride necrotic tissue are often advisable as well. Type III wounds of the chest carry the highest mortality. Chest wall

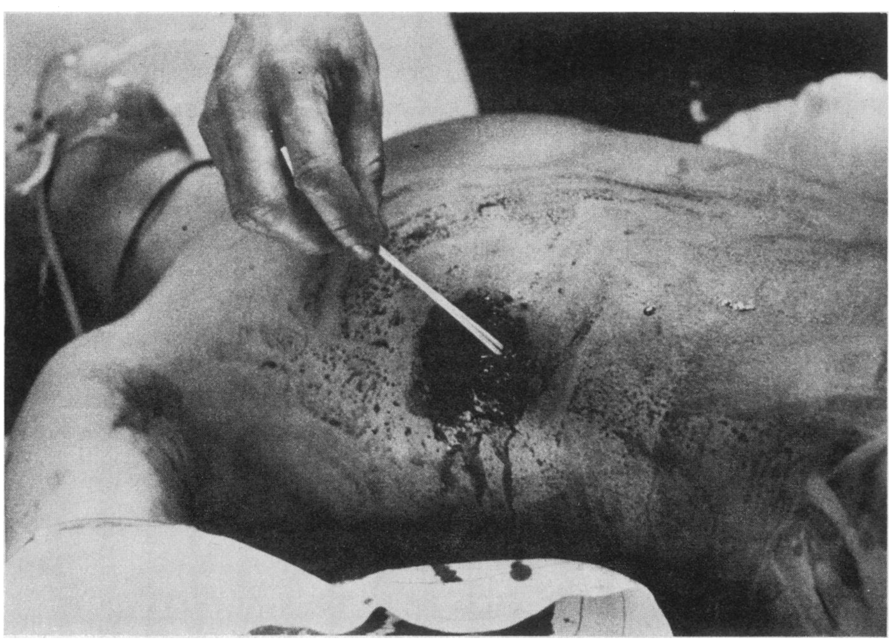

Figure 3.—External entrance wound showing pronounced tissue destruction of close-range shotgun blast.

defects are common and lobectomy or pneumonectomy are often required for definitive treatment.

The mortality rate for Type I injuries in most reports is low (ranging from 0 to 5 percent), while for Type II injuries it is about 5 percent to 10 percent. Type III gunshot wounds have an associated mortality rate of 15 percent to 20 percent. When one examines the causes of death, the only common denominator is the range from which the missile was fired. Among all types of shotgun injuries, 85 percent to 90 percent of the deaths will be due to Type III injuries, with hemorrhage being the single most common cause of death. In the study by Sherman and Parrish,[3] the average period of survival of those patients dying was 2.3 hours, which emphasizes the importance of prompt, vigorous resuscitation and immediate definitive operation.

In summary, one can most successfully manage shotgun injuries by employing the following general guidelines.

- Carry out prompt and vigorous volume resuscitation.
- Inspect the wounds because, unlike the deceiving high-velocity rifle wound, inspection of the shotgun wound is most informative and is the key to treatment and prognosis.
- Treat all buckshot wounds as if they were multiple low-velocity bullet wounds.
- Use angiography evaluation liberally whenever there is any possibility of vascular injury.
- Explore aggressively all Type II and Type III wounds.
- Debride all devitalized tissue and reoperate, as necessary, to reevaluate any questionably viable tissue.

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Management of Facial Paralysis Due to Temporal Bone Fracture

It is very important to determine if facial paralysis has been delayed or is immediate. Most delayed paralyses get better by themselves. Most immediate ones do not get better. If immediate, and the nerve is out electrically—not excitable—then explore routinely. When to explore it? On the 21st day. Usually we have to graft the nerve because we have no way in the fallopian canal to mobilize the nerve and get the ends together after we have cut out the bad part. If the nerve has been damaged enough to cause the paralysis, you usually have to graft it. Why the 21st day? The time when the nerve cell body is maximally able to push axoplasm is at three weeks. After that time it descends, until at about one year it reaches almost the asymptote, and ever after that the nerve cell body is less and less able, until finally the nerve cell body degenerates in the brain stem. At one year, almost half the nerve cell bodies in the facial nucleus are gone. They are simply wiped out. . . . If the paralysis is immediate and the nerve retains its excitability—wait. But keep testing. And finally, if the paralysis is immediate or delayed and the nerve loses its excitability—explore.

—BRIAN F. McCABE, MD, *Iowa City, Iowa*

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