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SKELETAL TRAUMA

Basic Science, Management, and Reconstruction

VOLUME ONE

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CHAPTER 32

Gunshot Wounds of the Spine

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The epidemiology of gunshot wounds of the spine, wound ballistics, and patient evaluation and treatment are critical factors in understanding an increasingly more prevalent type of spinal injury. Other penetrating injuries of the spine also have the potential for structural and cord injury. The incidence and severity of gunshot wounds of the spine will probably continue to increase in the civilian population in the future, and although some of the details may change, the principles of evaluation and treatment will remain the same.

DEMOGRAPHICS AND EPIDEMIOLOGY

In 1993, the Major Trauma Outcome Study[5] published information regarding the severity and outcome of 114,510 trauma patients in the United States and Canada from 1982 through 1989. The overall incidence of spinal cord injury was 2.6%, and 13.6% of the spinal cord injuries were caused by gunshot wounds. The study found that 79% of the victims were male and 21% were female; this same distribution was seen for spinal cord injury cases in general and for penetrating wounds of the spine. The average age of the patients was 33.5 years. In another study,[80] only 9% of penetrating wounds of the spine were classified as job-related injuries (presumably occurring to security guards, policeman, workers shot during robberies, and others). One study demonstrated that the likelihood of spinal cord injury from a gunshot wound was higher among those who had had previous gunshot wounds (30%) or who had prior involvement in the criminal justice system (52%).[53] Unlike sports injuries, which peak nationwide during the summer months, the incidence of penetrating wounds of the spine remained the same throughout the year, and 40% of them occurred on a Saturday or Sunday. Approximately 47% of all persons with spinal cord injuries are paraplegics, and 53% are quadriplegics. Sixty percent of all thoracic and lumbar cord injuries are complete lesions, as are 48% of the cervical injuries. For penetrating wounds of the spine, however, a significantly greater proportion are complete, and there is a much greater shift toward thoracic spinal injuries as compared with injuries of the neck or lumbar spine (Fig. 32–1).

Using these older data, it appears that approximately 1400 new spinal cord injuries occur each year as a result of gunshot wounds of the spine. However, in many areas of the United States, the number of spinal cord injuries caused by gunshot wounds of the spine doubled during the 10-year period from 1981 through 1991,[7] and this estimate therefore may be an optimistically low number. The data from the Regional Spinal Cord Injury Center of the Delaware Valley suggest a similar trend.[16] Even more difficult to estimate is the number of patients with more minor gunshot injuries to the spine (i.e., those that cause no paralysis), because nationwide numbers are not available for this type of injury. Based on what is seen at our own medical center and spinal cord injury unit, the number of gunshot wounds of the spine without paralysis is similar to the number with associated paralysis. To add perspective, in 1989, it was estimated that 48,700 people would be killed in motor vehicle accidents in the United States and that slightly more than 30,000 civilians would be killed with firearms.[46] Five times as many people are wounded as are killed by gunshots.

WOUND BALLISTICS

The term *ballistics* is defined in *Webster's New Universal Dictionary*, second edition, as "the modern science dealing with the motion and impact of projectiles, especially those discharged from firearms." In a medical sense, the term is defined as "the study of effects on the body produced by penetrating projectiles."[13] To understand the basic con-

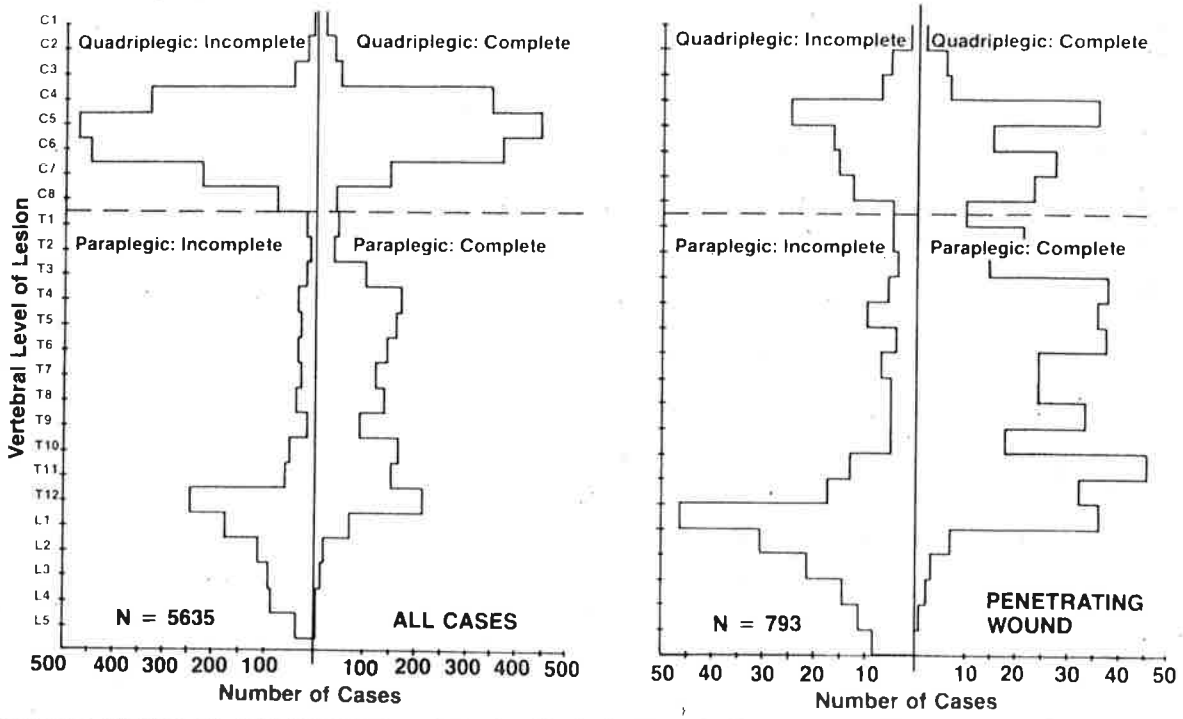

FIGURE 32–1. The bar graphs on the *left* represent the distribution of the levels of injury for all incomplete spinal cord injuries and all complete spinal cord injuries. The bar graph on the *right* shows the distribution for the penetrating wounds of the spine. A higher percentage of the penetrating wounds are complete injuries, and a proportionately higher number of thoracic injuries can be seen. (From Young, J.A.; Burns, P.E.; Bowen, A.M.; et al. Spinal Cord Injury Statistics: Experience of the Regional Spinal Cord Injury Systems. Phoenix, AZ, Good Samaritan Medical Center, 1982.)

cepts of ballistics, it is important to define some relevant terms:

Mass The weight of the bullet is usually measured in grams. Most are in the range of 2 to 10 g.

Velocity The velocity of the bullet can be given in feet per second or in meters per second. A .45 automatic handgun has a velocity of 869 ft/sec (265 m/sec); a .357 magnum has a velocity of 1393 ft/sec (425 m/sec); and an AK47 has a velocity of 2340 ft/sec (713 m/sec).

Fragmentation This term indicates the extent to which a bullet disintegrates into multiple pieces as it courses through tissue. It is often described by comparing the largest final bullet fragment with the original weight of the bullet. This is one of the most important factors affecting the extent of final tissue injury.

Permanent cavity This term refers to the permanent crush of tissue that results from passage of the bullet through the tissue.

Temporary cavity This is the tissue stretch caused by passage of the bullet through the tissue. Elastic tissues such as muscle are relatively resistant to damage from this type of stretching, whereas more solid tissue is damaged more significantly under the same circumstances.

To better understand the mechanism of tissue injury with gunshot wounds, it is helpful to study the courses of bullets in tissue or gelatin tissue simulants.[14, 15] Several such models are shown in Figures 32–2 through 32–4. The cross-sectional area of the permanent cavity varies widely despite similarities in missile velocities. The tissue effects of bullet fragmentation and yaw (i.e., end-over-end rotation of the bullet) can be appreciated in these illustrations.

In a review of common misconceptions about wound ballistics, Fackler[13] makes the transition from the mechanical science of projectiles to the clinical art of patient care. Among the major misconceptions, he lists an overemphasis on bullet velocity and an exaggeration of tissue damage resulting from the effects of the temporary cavity. He also states that many of the positive effects of the administration of systemic antibiotics have been incorrectly attributed to the surgical débridement of tissue. He points out that the incidence of clostridial myositis decreased from 5% in World War I to 0.08% in the Korean War, even though débridement techniques remained relatively unchanged. This improvement can be more appropriately attributed to the increasing use of antibiotics on the battlefield. Fackler emphasizes that appropriate patient treatment can best be determined by evaluating the patient clinically with a hands-on physical examination and by standard roentgenography, looking for evidence of bullet fragmentation.

Composition of Bullets

The bullet projectile is usually composed of lead, but a portion of it may be copper or brass. A systemic toxicity may be caused by lead that leaches out of the bullet. This situation has been well described for bullets bathed in

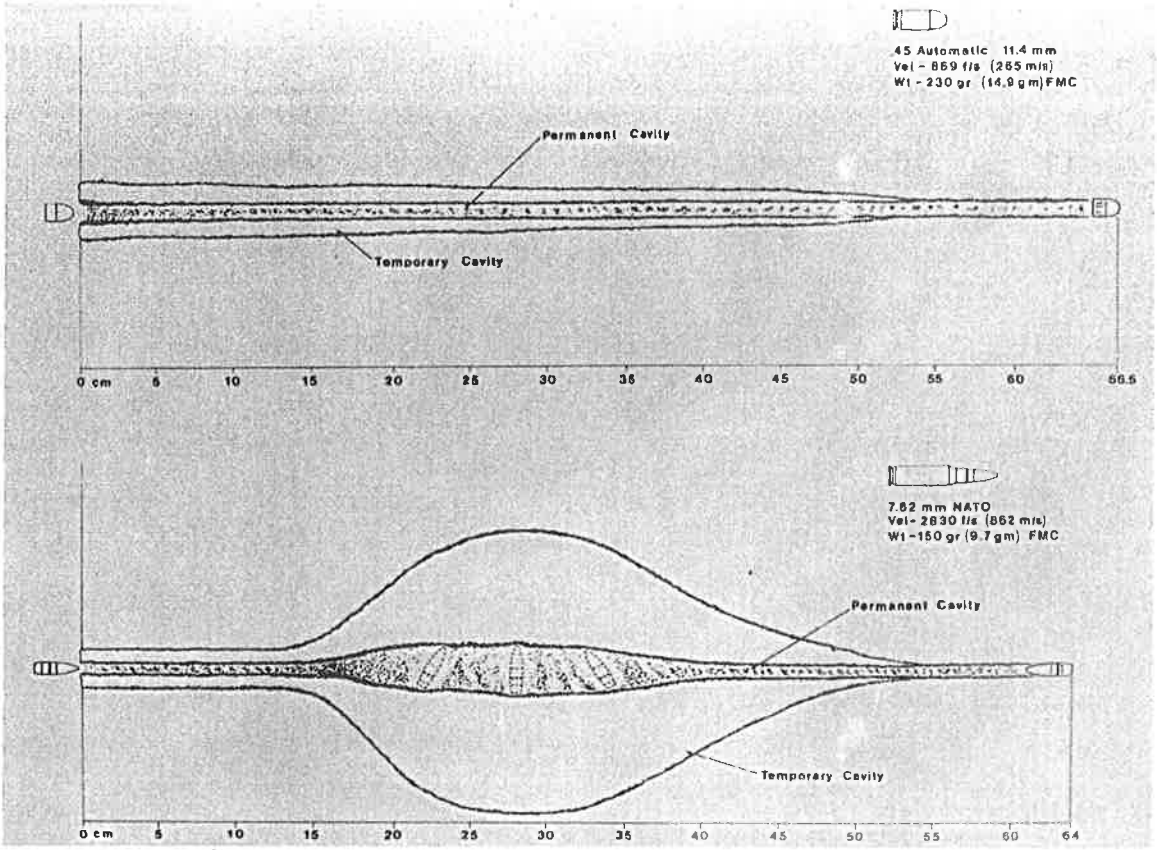

FIGURE 32–2. Injury profile after discharging weapons through a gelatin medium. For the first 15 cm of travel through tissue, the injury patterns are extremely similar despite a significant difference in bullet velocity. It is not until the bullet yaws that the permanent cavity becomes significantly larger for the rifle injury than for the handgun injury. (From Fackler, M.L.; et al. J Trauma 28[Suppl 1]:S21–S29, 1988.)

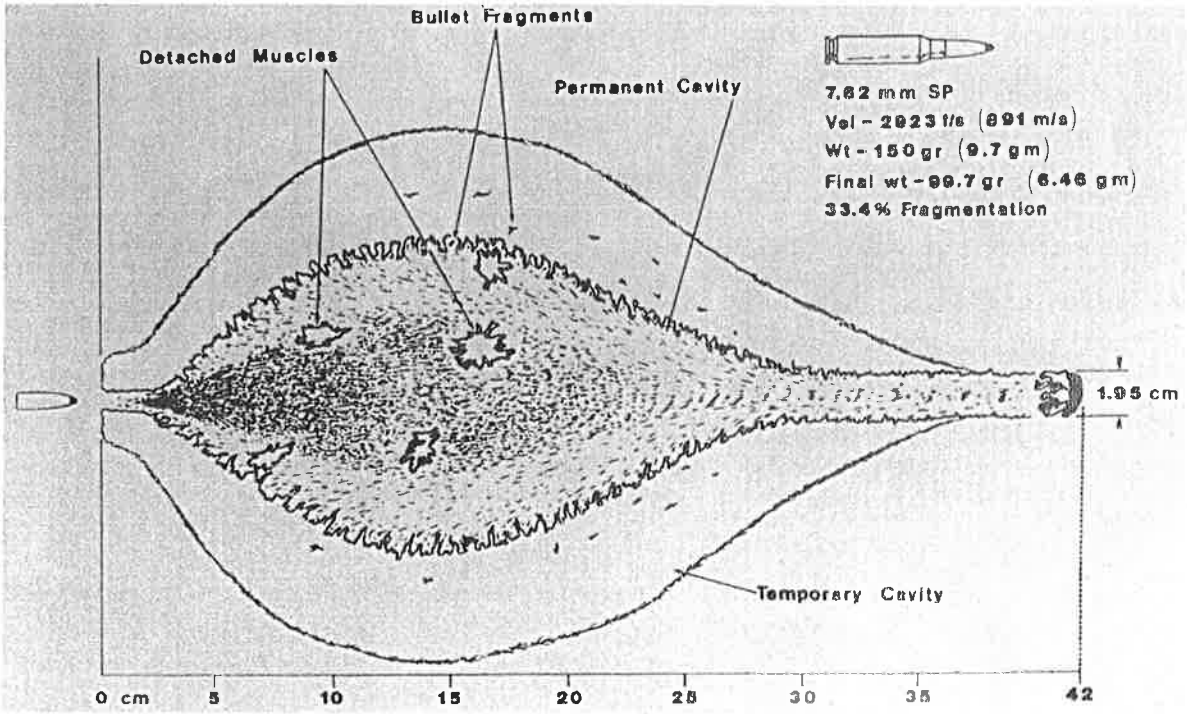

FIGURE 32–3. This wound profile is from the same rifle as that in the lower graph in Figure 32–2. The permanent cavity is significantly larger in this case because of the use of a soft-point bullet, which leads to significant bullet fragmentation. (From Fackler, M.L.; et al. J Trauma 28[Suppl 1]:S21–S29, 1988.)

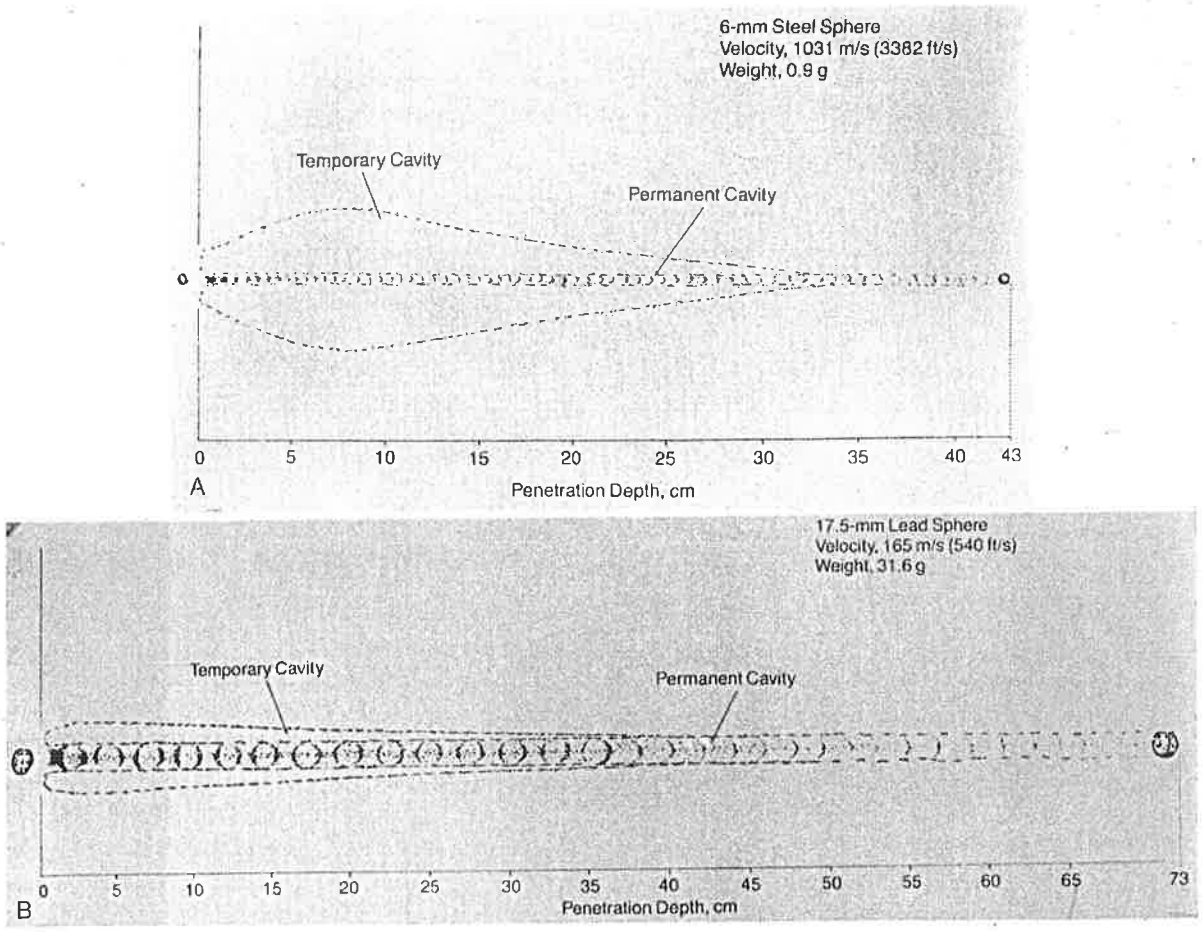

FIGURE 32–4. Wound profiles were obtained using a small sphere at a high velocity (*A*) to compare the injury with that of a large sphere at a slower velocity (*B*). The kinetic energy ($E = \frac{1}{2}mv^2$) is the same in each of these two examples. However, the larger sphere penetrated 30 cm deeper and produced a permanent cavity more than 50 times the volume of that produced by the smaller sphere. (From Fackler, M.L. JAMA 259:2730–2736, 1988. Copyright 1988, American Medical Association.)

synovial joint fluid[43, 71, 76] and lodged in the intervertebral disc space.[23] The exact incidence of this complication with gunshot wounds of the spine is unknown, but it is thought to be uncommon. If leaching is suspected, serum lead measurements can be obtained; if they are significantly elevated, bone marrow aspiration may be required to assess hematopoietic toxicity. If lead toxicity can be proved, surgical excision of the bullet is indicated.

The toxicity of lead, copper, and brass on a more local level has been investigated in brain tissue.[9, 64, 65] In the monkey brain, copper causes a severe necrotic local reaction, but the reaction is minimal with lead or with nickel-coated pellets. Although these other metal pellets remain where placed, the necrotic reaction can be severe enough to allow significant migration of the copper-coated pellet through the brain.[65] This is also seen when a copper powder is sprayed on monkey brain, causing a severe necrotizing foreign body reaction and death of the animal.[9]

The effect of metallic fragments on the spinal cord has been studied in rabbits,[72] using aluminum, lead, and copper fragments with one half of the fragments placed extradurally and one half placed intradurally. As expected, the extradural fragments had no effect on the neural tissue. Of the intradural fragments, the aluminum had no effect on the normal tissue, the lead caused mild to moderate neural tissue destruction, and the copper caused marked neural tissue damage (Figs. 32–5 to 32–7). Based on this study, we recommend that copper-jacketed bullets be removed from the spinal canal regardless of other considerations to avoid the local toxicity effects on the neural tissue. Most often, however, it is not known whether the bullet in the patient is copper jacketed.

The presence of wadding in the back of a shotgun cartridge must be appreciated for clinical reasons. The shotgun pellets are easily seen on plain films, but the wadding is not apparent. The shotgun wadding often acts as a significant foreign body unless it is removed. If a patient is shot with a shotgun at the close range of 6 m or less, the material should be sought within the wounds (Fig. 32–8).[4, 47]

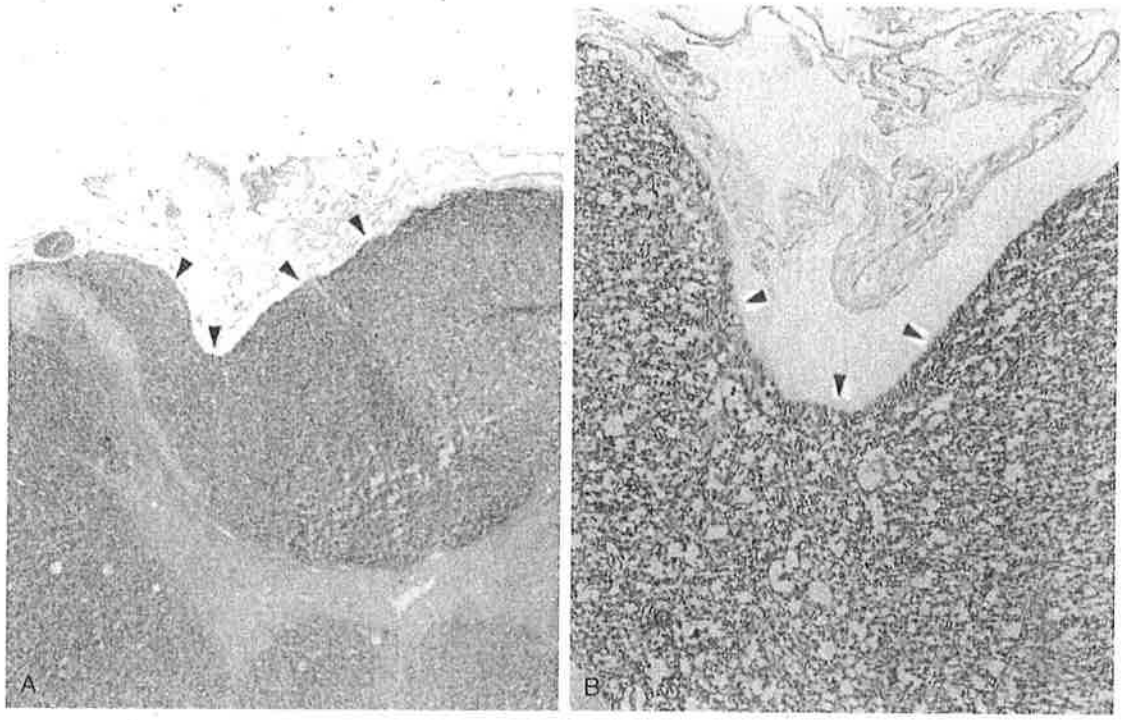

FIGURE 32–5. Axial cross sections through a rabbit spinal cord with an implanted intradural aluminum fragment. *A*, Some indentation of the spinal cord has occurred *(arrowheads)* (Solochrome Cyanine R, ×5). *B*, The underlying spinal cord tissue has minimal or no gliosis. The surrounding connective tissue matrix remains well organized (Solochrome Cyanine R, ×20). (From Tindel, N.L.; et al. J Bone Joint Surg Am 83:884–890, 2001.)

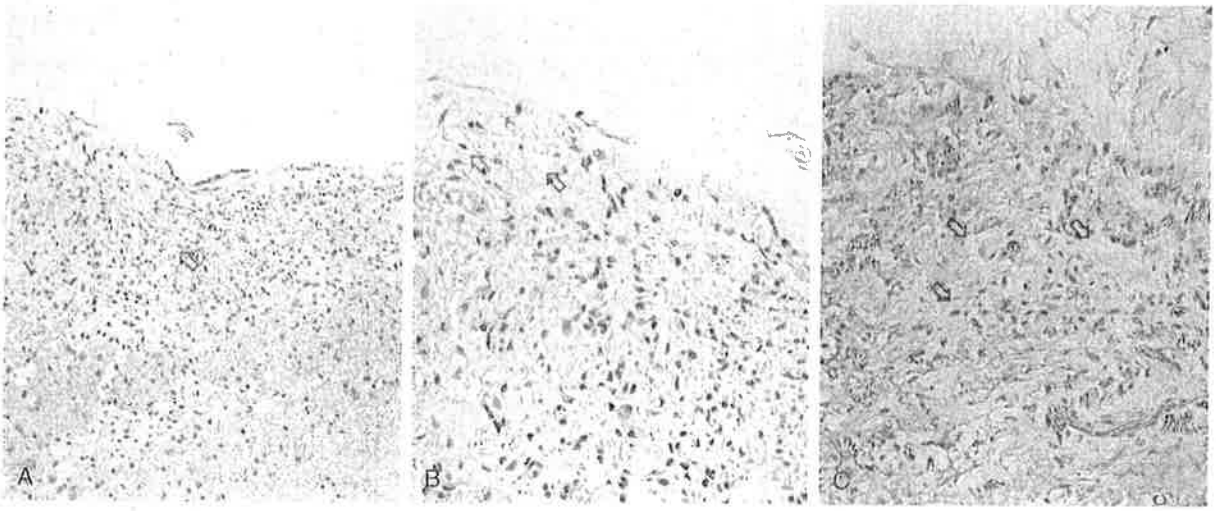

FIGURE 32–6. Axial cross sections through a rabbit spinal cord with an implanted intradural lead fragment. *A*, Indentation of the dorsal column with a small area of gliosis adjacent to the area of depression *(arrow)* (H&E, ×20). *B*, Areas of gliosis and breakdown of the supporting matrix *(arrows)* (H&E, ×40). *C*, Loss of axonal elements with disorganization of the surrounding connective tissue adjacent to the area of fragment implantation *(arrows)* (Solochrome Cyanine R, ×40). (From Tindel, N.L.; et al. J Bone Joint Surg Am 83:884–890, 2001.)

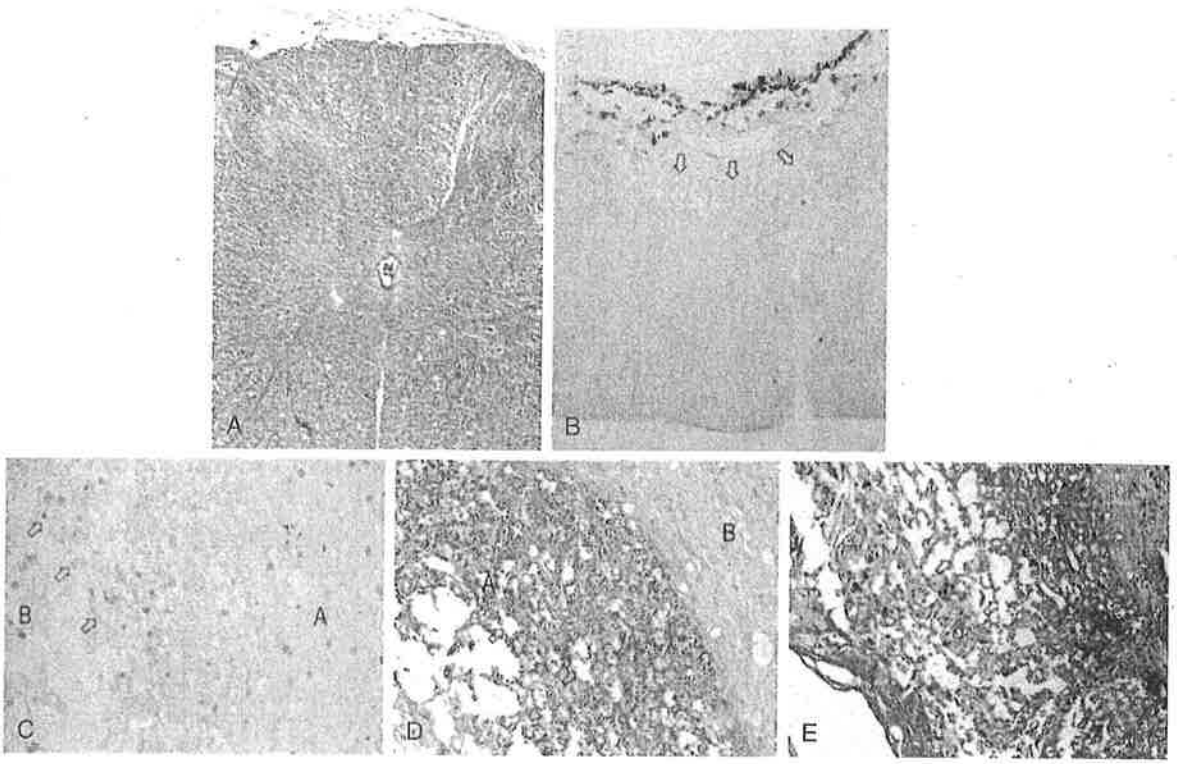

FIGURE 32–7. Axial cross sections through the spinal cords of rabbits with an implanted copper bullet fragment. *A,* An extradurally placed fragment caused no deformation or injury to the underlying spinal cord (trichome, ×5). *B,* Indentation and injury occurred to the underlying spinal cord tissue from an intradurally placed copper fragment *(arrows)* (×5). *C,* Destruction of the spinal cord parenchyma *(arrows).* The damage is confined to the white matter *(A);* the gray matter *(B)* is preserved (H&E, ×40). *D,* Vacuolization of the adjacent spinal cord tissue *(arrows)* with damage localized to the white matter *(A);* there is no damage in the gray matter *(B)* (Solochrome Cyanine R, ×40). *E,* Disruption of the connective-tissue matrix adjacent to the site of implantation of the bullet fragment *(arrows)* (trichrome, ×40). (From Tindel, N.L.; et al. J Bone Joint Surg Am 83:884–890, 2001.)

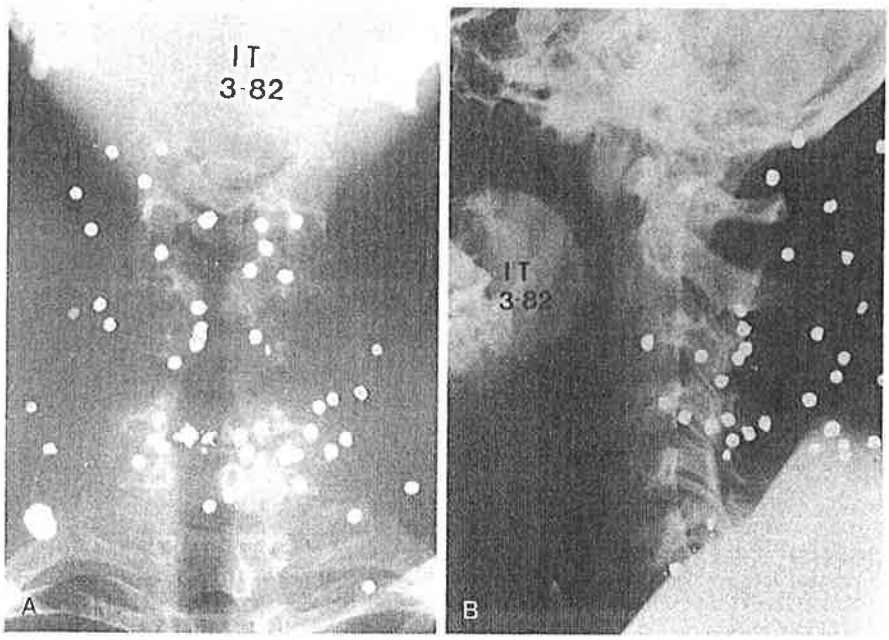

FIGURE 32–8. *A, B,* This patient was shot in the back of his neck with a shotgun using pellets. He was a complete quadriplegic as a result of this injury. Removal of the pellets is not indicated, but surgical débridement and especially removal of the shotgun wadding are necessary to prevent infection, because this was a close-range injury.

Pathology of Spinal Gunshot Wounds

Pathologic specimens were collected and described after World War I. The War Office Collection of 50 specimens has been described in the literature.[34] They show considerable variation, from relatively mild bone or ligament injuries to severe disruptions of the spinal column. The spinal cord often was intact, even though the patient sustained a complete spinal cord injury, presumably as a result of contusion of the spinal cord. With gunshot injuries to the posterior arch or pedicles, it was common to have associated secondary fractures of the vertebral body. If the vertebral body was the primary site of injury, there was seldom secondary injury to the posterior elements. The reason for this contrast was presumably that the vertebral body is composed primarily of cancellous bone, which is more easily deformed and hence transmits less energy to adjacent structures.

Klemperer and colleagues[37] investigated the pathology of indirect injuries to the spinal cord in animal models. They produced gunshot injuries to the posterior spinous processes or interspinous ligaments in anesthetized animals and found great variation among species in the presence and degree of spinal cord injury. The differences most likely correlated with the size of the spinal canal in relation to the size of the spinal cord. In animals with extremely small canals, the incidence of spinal cord injury was very high. The pathologic sections of the spinal cord varied as would be expected, but even in animals that had not sustained paralysis, there were often significant pathologic changes within the spinal cord.

PATIENT EVALUATION

The evaluation of patients with gunshot wounds of the spine should include the same detailed history, physical examination, and radiographic evaluation as would be performed for patients with other suspected spinal injuries. Attention is first given to the ABCs of emergency treatment protocols.

The history should include a general description of the weapon (e.g., handgun, rifle, assault weapon). Typically, this information is unavailable, but it can be helpful if known. The patient should be questioned about the presence of paralysis or paresthesias immediately after the injury. If the patient had an episode of transient paralysis, a more detailed neurologic follow-up is indicated.

The importance of the physical examination cannot be overemphasized. It should include examination of the entrance and exit wounds and palpation of the tissue to assess the presence of crepitation and the general turgor of the tissue. A very large exit wound with crepitus and increased tissue turgor is consistent with wounds that have a large permanent cavity and may very well have significant tissue necrosis.[13]

The physical examination should also include a detailed neurologic examination, as outlined in Chapter 25. The presence of paralysis or abnormal reflexes should be documented.

Radiographic evaluation of the patient is extremely important. Attention should be paid to the fracture type and the degree of bone comminution. The radiograph should be scrutinized to determine whether the bullet has remained in the torso and to assess the extent of bullet fragmentation. With increased bone comminution and increased bullet fragmentation, the wound is more likely to have a significant permanent cavity. If this is the case, the wound may be one of the few that require significant débridement.[13]

A computed tomography (CT) scan may help to further assess the extent of the spinal injury and the degree of spinal canal encroachment by bone or bullet fragments. The stability of the spine also can be better assessed with the help of a CT scan; this is addressed later in the section on Spinal Stability.

Magnetic resonance (MR) scans are not routinely performed on patients with gunshot wounds to the spine. There is, however, a report of 19 patients with gunshot wounds of the spine being studied with MR.[17] Six were studied within 3 weeks of injury, and the remaining 13 were studied 1 month to 6 years after injury. Ten had bullet fragments within the spinal canal. No patient reported untoward effects of the MR scan. The scans showed only mild artefact. The results of the MR scans led to surgical treatment for 3 of the 19 patients. The treating physician must understand that, if the projectile is ferromagnetic, there may be further local tissue damage. The same information may perhaps be obtained more safely with a postmyelogram CT scan of the spine in patients requiring imaging of the neural axis after a gunshot wound to the spine.

The general surgical team helping to assess the patient may recommend other studies (e.g., barium swallow, MR angiography, arteriography, intravenous pyelography) to evaluate the extent of soft tissue injuries to structures adjacent to the spine.[2]

TREATMENT OF GUNSHOT WOUNDS OF THE SPINE

Wound Care

Local wound care should be administered in the emergency department or in the formal operating room. The latter setting would be more appropriate for injuries that involve large exit wounds and those that by the physical and imaging findings may be associated with large permanent cavities. Although this type of wound is uncommon in civilian practice, such cases may be encountered.

Because of the proximity of the esophagus, the major blood vessels,[18, 21] and the larynx and trachea, general surgeons traditionally have strongly advised operative exploration of wounds of the neck, including all neck-penetrating wounds.[21, 60] Current recommendations more often advocate that the wounds should be explored only in patients with specific warning signs of serious injury and that those without such signs should be observed.[48, 50, 63] The same is true for penetrating injuries of the chest and abdomen.[2] The availability of emergency arteriography

coupled with the use of intravascular hemostatic coils has also changed the indications for emergency exploratory surgery. Many cases that previously required surgery to achieve hemostasis can now be managed with minimally invasive techniques (Fig. 32–9).

Wound cultures should always be taken from the bullet tract. If the wound has been contaminated by passage of the bullet through the pharynx,[61, 62] esophagus, or colon,[58] or if contamination of the wound occurred after injury, it is even more essential that appropriate cultures be taken. For routine, uncontaminated spinal injuries, we recommend 3 days of treatment with parenteral antibiotics such as a second-generation cephalosporin at maximal intravenous dosage.[26] For contaminated wounds, such as a transcolonic gunshot wound of the spine, a 7- to 14-day antibiotic regimen is recommended (see the Associated Injuries section).[35, 39, 45, 58]

Spinal Stability: Assessment and Treatment

Most civilian gunshot injuries of the spine are stable.[30, 70, 79] In the cervical spine, 36% of the weight of the head is normally supported through the anterior vertebral bodies and discs, and 32% is supported through each of the two posterolateral columns (i.e., facet joints and lateral masses).[51] If none of these three columns is compromised, immobilization is not recommended.

If one of the columns is disrupted, a rigid cervical collar is recommended. If two or all of the three columns are disrupted, halo vest immobilization is recommended. In a review of 36 gunshot wounds of the spine,[30] 12 patients had cervical spinal injuries, and 4 were unstable, requiring a halo vest and then a rigid brace.

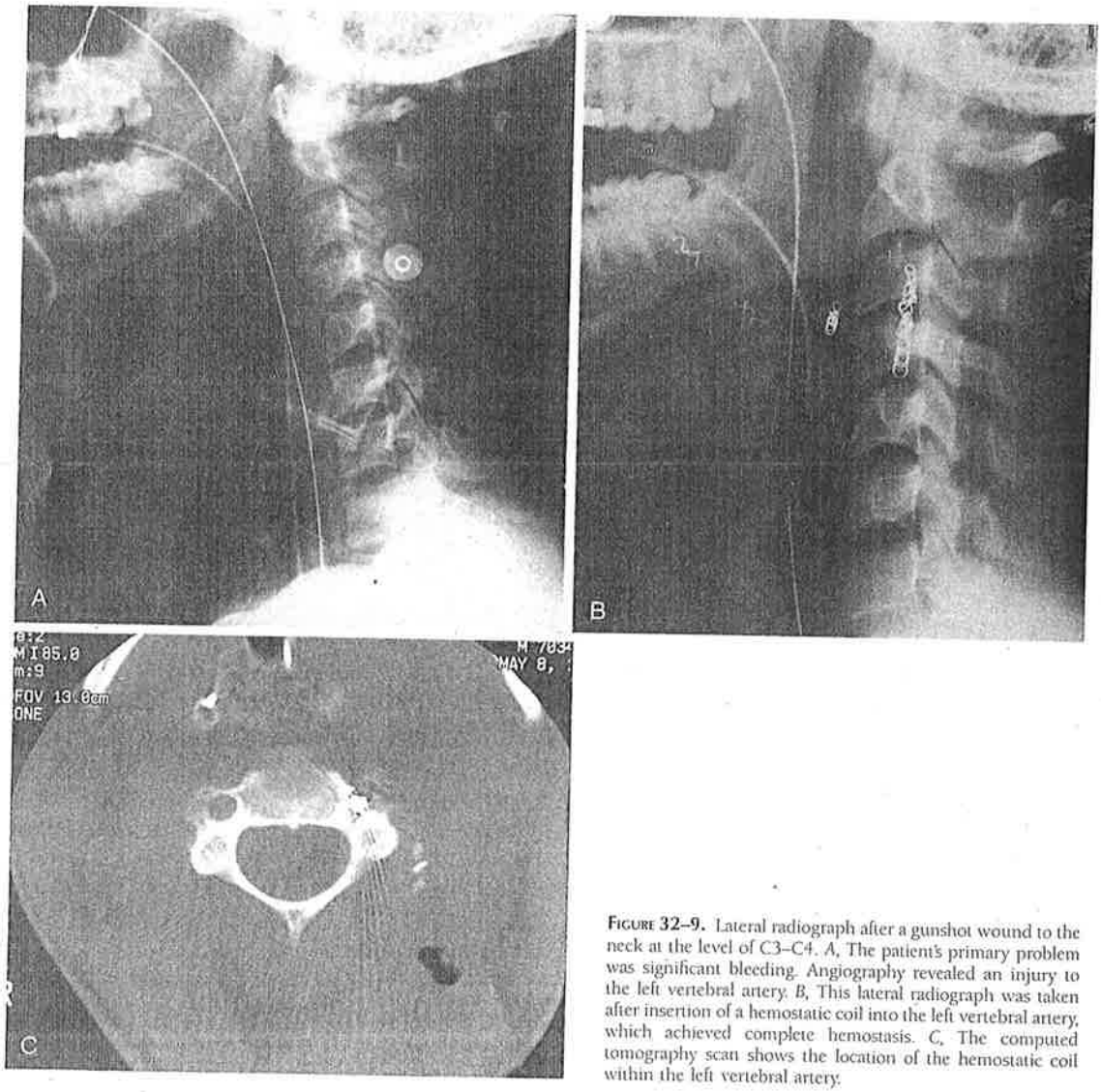

FIGURE 32–9. Lateral radiograph after a gunshot wound to the neck at the level of C3–C4. *A*, The patient's primary problem was significant bleeding. Angiography revealed an injury to the left vertebral artery. *B*, This lateral radiograph was taken after insertion of a hemostatic coil into the left vertebral artery, which achieved complete hemostasis. *C*, The computed tomography scan shows the location of the hemostatic coil within the left vertebral artery.

In the thoracic and lumbar spine, the three-column concept of Denis[11] can be applied, but the mechanism of destruction is considerably different from that seen in the closed injuries for which this classification was designed. If destruction is limited to one of the three columns, no particular immobilization is needed; if two or three columns are compromised by the gunshot wound, a thoracolumbosacral orthosis (TLSO brace) should be worn whenever the patient is out of bed. In the same review[30] of the 24 patients with thoracic and lumbar injuries, only 1 was unstable and was successfully treated in a brace. None required surgery for instability.

In contrast to closed spinal injuries, gunshot wounds of the spine rarely require operation for purposes of establishing stability. Immobilization for these injuries in any part of the spine usually lasts for 6 to 8 weeks. After that time, flexion and extension radiographs of the affected region are obtained to establish whether the spine has adequately healed and is stable.

The most unstable injuries are seen in small children, in whom the size of the vertebra is relatively small compared with the size and kinetic energy of the bullet. Other factors predisposing to a significant instability of the spine are injuries with severe bone comminution and bullet fragmentation and the effects of a previous laminectomy.[70] Even if the instability is significant, surgical treatment is seldom indicated. The temporary use of skull tong traction for severe instability of compound cervical spinal injuries or Roto Rest bed treatment for severe thoracic or lumbar compound injuries may be indicated for 2 to 3 weeks to allow early healing before routine mobilization with the braces described previously.

Associated Injuries

It is important to consider associated viscus injuries in patients with gunshot wounds of the spine. If the bullet first penetrated the pharynx,[61, 62] the esophagus, or the colon[58] before entering the spine, extra precautions should be taken to prevent spinal infection. This is essential only when the bullet has first penetrated the viscus and then penetrated the spine, and it does not seem to be important if the bullet first traversed the spine and then perforated the viscus. The general surgical team performs emergency surgery to repair the viscus,[2] places adequate drains, and recommends broad-spectrum antibiotics to cover organisms normally found in the viscus. This is less important for injuries of the stomach, duodenum, and small intestine, which normally have sterile contents, although spinal sepsis has been reported with gunshot wounds to these segments of the gastrointestinal tract.[25] In contrast to recommendations in the mid-1980s promoting radical spinal débridement,[59] the best results have been reported by Roffi and co-workers,[58] who recommended minimal or no spinal débridement and protection with 1 to 2 weeks of treatment with parenteral antibiotics. The broad-spectrum antibiotics should be directed at the bacteria normally associated with injury of the particular viscus. If the viscus repair has complications, the duration of antibiotic coverage may have to be extended. With this treatment protocol, the incidence of spinal infection has been dramatically decreased and is now in the range of 5% to 15% for these severe injuries involving the pharynx, esophagus, or colon.

Treatment of transperitoneal colon injuries with a 2-day course of antibiotics plus irrigation of the missile tract at surgery has been recommended.[35] However, considering the findings of Roffi and co-workers and the small number of patients with colon injuries in this reported series, we recommend the longer course of antibiotics (1 to 2 weeks).

Bullet in the Disc Space

Three considerations influence whether surgery is indicated when the bullet is located in the disc space. The first consideration is whether the patient is likely to develop lead poisoning. There is good evidence to suggest that when a lead bullet is bathed in synovial fluid, the lead is leached out and can cause lead poisoning.[43, 71, 76] One article suggests that this may also be the case with a lead bullet located within the disc space,[23] and we have had a similar case at our institution. Because the literature does not reveal what percentage of patients with bullets in the disc space go on to develop lead poisoning, we are unable to make a sound recommendation about whether surgery should routinely be carried out. An alternative to routine surgical removal would be to obtain serum lead measurements in patients who are suspected of having signs of lead toxicity; if there is a rise of the serum lead to an abnormal level, the bullet should be removed.

The second consideration regarding surgery is whether there is mechanical disruption of the motion segment caused by the bullet within the disc space. Medical experience for this problem is also anecdotal. The patient can be monitored clinically, and if new symptoms of a mechanical problem develop (e.g., worsening of a local pain when upright and active and a decrease in pain with recumbency), consideration can be given to removal of the bullet with or without local fusion.

The third consideration is whether there has been disc extrusion as a result of the gunshot wound. If a disc extrusion has occurred and is causing significant neural compression that is symptomatic, surgery is indicated for removal of the disc fragments to achieve neural decompression. This condition is extremely uncommon, but it has been reported in the literature.[57]

Bullet in the Spinal Canal

Many articles have been written concerning removal of bullets from the spinal canal,[10, 28, 31, 40, 52, 66, 67, 70, 77] but this problem was not reviewed in a scientific fashion until recently. For conclusions to be valid, there must be two groups with equivalent pathologic conditions, with one group undergoing bullet removal and the other group having bullets left in place. It is also important for the study to be done on a prospective basis with adequate documentation of neurologic information and quantitative assessment of pain and other symptoms. Such a review was performed by Waters and Adkins.[73] They reviewed 90 patients, 32 with bullet removals and 58 with bullets left in

place. They were able to conclude that, at the levels of T12 through L5, there was statistically significant neurologic motor improvement with removal of the bullet from the spinal canal (Fig. 32–10). However, there was no difference in improvement in the two groups with regard to sensation or pain experienced by the patients. In the thoracic spine (T1 through T11), there was no statistical difference in the two groups for complete or incomplete injuries. Similarly, there was no difference with bullet removal in the cervical spine, although the number of patients with injuries in the cervical spine was too small to draw statistical conclusions.

Adding our own subjective opinion to these data, we recommend that patients with cervical injuries undergo

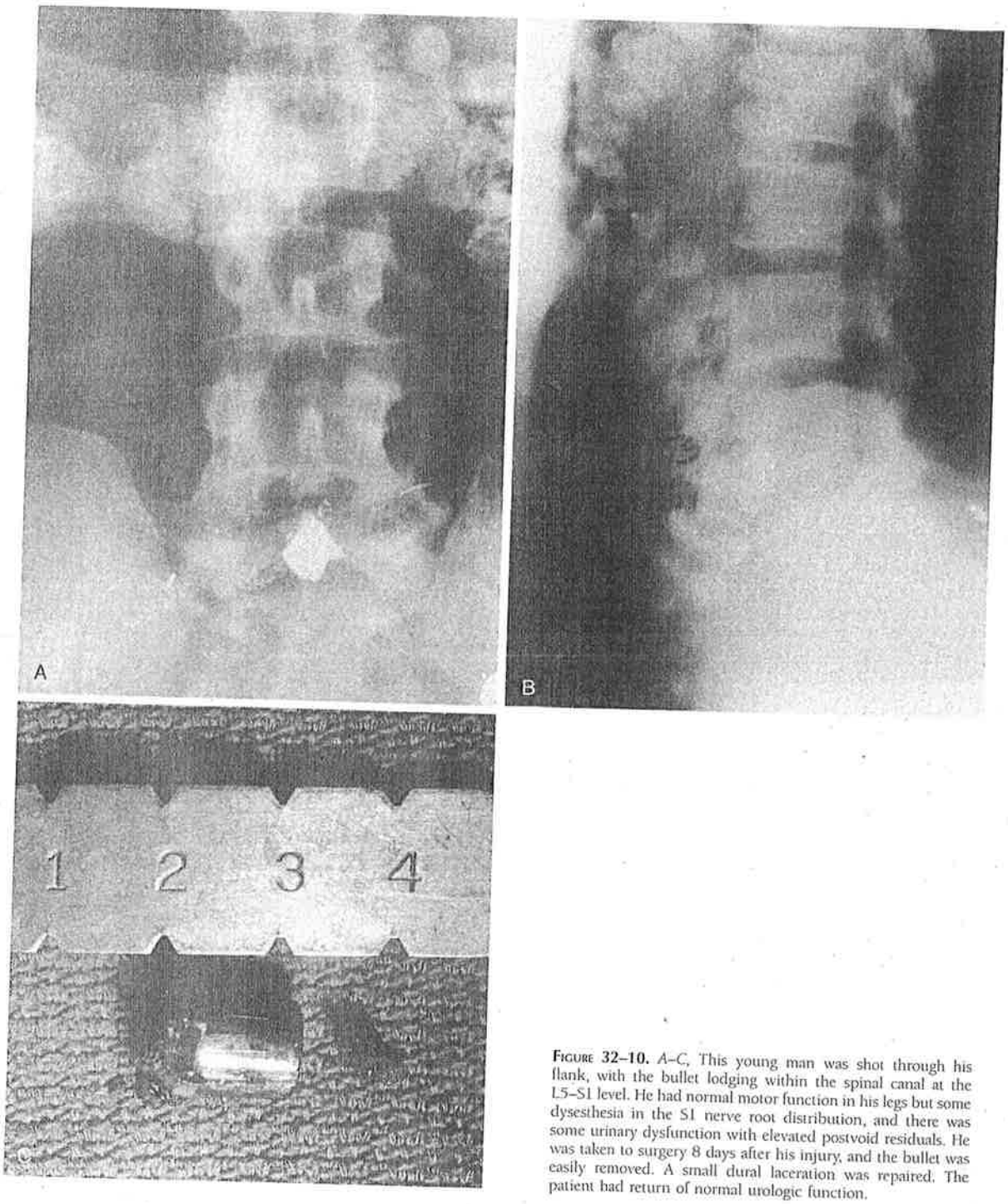

FIGURE 32–10. *A–C*, This young man was shot through his flank, with the bullet lodging within the spinal canal at the L5–S1 level. He had normal motor function in his legs but some dysesthesia in the S1 nerve root distribution, and there was some urinary dysfunction with elevated postvoid residuals. He was taken to surgery 8 days after his injury, and the bullet was easily removed. A small dural laceration was repaired. The patient had return of normal urologic function.

bullet removal, because this procedure significantly decreases the degree of spinal cord compression.[6] We recommend this approach even in complete injuries, with the expectation not of cord return but of nerve root improvement at the adjacent level over time. The rationale is the same as for closed spinal cord injuries of the cervical spine that have significant residual neural compression by bone or disc fragments and can improve after elective decompression.[1, 3]

It is generally agreed that surgery is indicated for patients with bullets within the spinal canal who are experiencing neurologic deterioration. We emphasize, however, that surgery should be performed only in patients with documented compression of the neural elements by bone, disc, bullet, or hematoma. Such deterioration is extremely uncommon but is occasionally seen (Fig. 32–11). In contrast, there can be neurologic deterioration on the basis of ascending spinal cord necrosis with no residual neural compression, and this particular pathology cannot be helped and may be worsened with surgery.

After the decision has been made to perform surgery to remove the bullet from the spinal canal, a scout radiograph should be taken in the operating room before the incision is made. The bullet can occasionally migrate within the spinal canal, depending on the position of the patient,[24, 33, 42, 54, 78] especially in patients with large spinal canals and relatively small bullets.

We usually recommend that surgery for removal of bullets from the spinal canal be performed 7 to 10 days after the injury, because at that time, cerebrospinal fluid (CSF) leakage, dural repair, and other problems are simplified considerably (Fig. 32–12). This approach does not apply if there is significant neurologic deterioration; such patients should be treated with immediate surgery, as described previously.

Rate of Neurologic Recovery

Most spinal cord injuries improve to some extent over time. Complete spinal cord injuries usually have root improvement at one or two levels, and incomplete injuries have a chance for dramatic improvement in spinal cord function and local root function. An early review of closed and open spinal cord injuries at the University of Miami showed statistically significant neurologic improvement at the 6-month follow-up in patients with complete or incomplete open spinal cord injuries (most of which were caused by gunshot wounds), but the improvements started slightly later than in those with closed injuries (Fig. 32–13).[22]

COMPLICATIONS OF GUNSHOT WOUNDS TO THE SPINE

Neurologic Injury

The use of steroids is contraindicated in the treatment of patients with spinal cord injury from gunshot wounds. In a retrospective review[26, 27] of patients treated with methylprednisolone or dexamethasone compared with those treated without steroids, the investigators found a higher incidence of complications but no difference in neurologic function using the American Spinal Injury Association (ASIA) motor score or Frankel grades. Infections were increased in the combined group receiving steroids as compared with those not receiving steroids (6.6% compared with 2.6%), but this finding was not statistically significant ($P = .23$). Gastrointestinal complications were increased in the dexamethasone group ($P = .021$), and pancreatitis was more frequent in the methylprednisolone group ($P = .040$). A second retrospective review similarly did not show any difference between those treated with or without steroids in neurologic function using Frankel scores.[44] This study, however, did not find a statistically significant difference in complications between the two groups.

The clinical outcome of paralysis resulting from gunshot wounds to the spine has been well studied and reported by Waters and associates.[74] Motor and sensory evaluations were performed on patients with neurologic injuries resulting from gunshot wounds. The study found that 57% of the injuries were complete and 43% were incomplete. At the 1-year follow-up examination, 67% of patients with complete lesions and 64% of those with incomplete lesions had no improvement in the neurologic level of injury (i.e., the most caudal intact motor and sensory level did not change). Overall, however, the patients had a statistically significant improvement in the ASIA motor index score at 1 year after injury ($P < .0001$), and more improvement was seen with incomplete injuries than with complete injuries.

Late neurologic deterioration in patients with an existing neurologic deficit caused by a gunshot wound to the spine has been reported by Gellad and colleagues.[19] Eleven such patients were prospectively evaluated clinically, radiologically, and surgically. The study found a syringomyelic cavity in seven patients, an arachnoid cyst in three, and osteomyelitis in one. The results of this study emphasize the need for immediate evaluation of patients who have sustained a gunshot wound to the spine and have further deterioration imposed on an initial deficit.

Late neurologic deterioration in patients who were initially intact is uncommon, but it has occurred even many years after a gunshot wound of the spine.[8, 32, 33, 38, 69] Instances of bullet migration within the spinal canal and the subsequent development of a neurologic deficit have been reported.[33] There are also cases of late development of spinal stenosis[32, 69] or cauda equina syndrome.[8] Late deterioration can be caused by an intraspinal bullet fragment causing local spinal canal narrowing[32, 69] or a combination of neural compression and local neurotoxic effects resulting from the type of metal in the bullet fragment.[38, 69, 72] These problems of late neurologic deterioration can often be successfully treated surgically. Although the algorithm for treatment of neurologic deficits associated with gunshot wounds to the spine has already been described, these cases suggest a cautious approach to the management of patients with retained bullets in the spinal canal.

FIGURE 32–11. *A–D,* This young boy was accidentally shot in his neck and had progressive quadriparesis. Twenty-four hours after the injury, he had lost all motor function in his legs. Plain radiographs revealed that the bullet was filling the right side of the spinal canal. He was taken to surgery emergently, and an anterior cervical procedure was performed. His trachea and esophagus were found to be intact. A corpectomy of C5 and C6 was performed to remove the bullet. An anterior cervical fusion was then performed using autologous iliac crest bone graft. The patient regained ambulation, and his only residual weakness involved his arms.

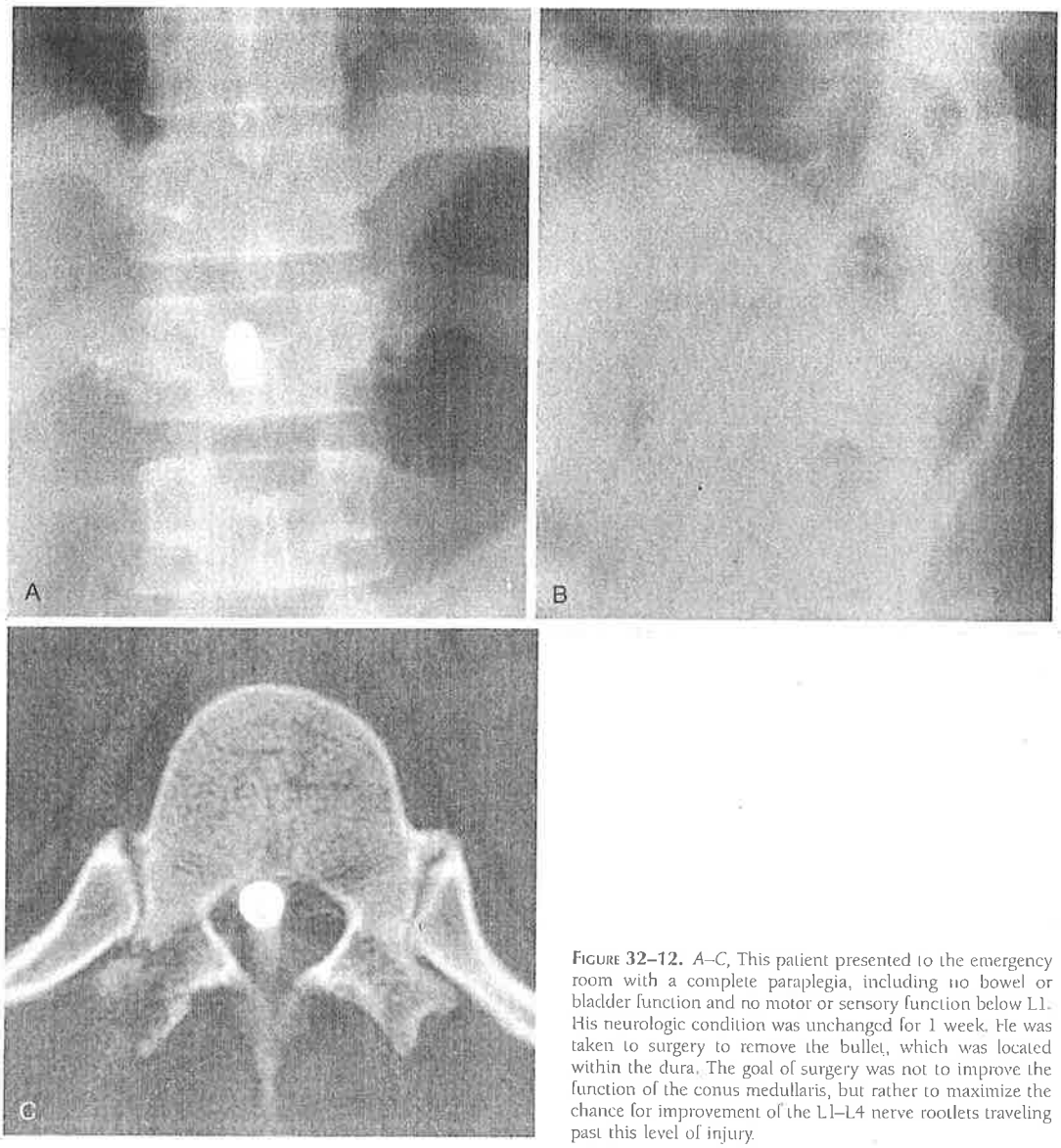

FIGURE 32–12. *A–C,* This patient presented to the emergency room with a complete paraplegia, including no bowel or bladder function and no motor or sensory function below L1. His neurologic condition was unchanged for 1 week. He was taken to surgery to remove the bullet, which was located within the dura. The goal of surgery was not to improve the function of the conus medullaris, but rather to maximize the chance for improvement of the L1–L4 nerve rootlets traveling past this level of injury.

Pain with Associated Spinal Cord Injury

Chronic dysesthetic pains have been reported as a complication of gunshot injuries to the spinal cord.[19] Most commonly, this is described as a searing, burning type of pain that radiates into the paralyzed extremities.

These pains often persist and may be completely disabling. They may often be helped with the use of gabapentin (Neurontin). Amitriptyline (Elavil) has been helpful in patients with burning diabetic neuropathic pain and postherpetic neuralgia,[41, 55, 75] and it seems to help patients with dysesthetic spinal cord injury pain. If none of the medications helps, a course of carbamazepine (Tegretol) may be tried.

Prevention or minimization of future pain is often cited as an indication for removal of bullet fragments in patients who have had a spinal cord injury (Fig. 32–14). Although patients who have sustained a spinal cord injury from a gunshot wound have an increased incidence of pain compared with patients with closed spinal cord injuries, studies show that surgical removal of the bullet is not helpful in reducing pain early after the injury or at 1 year.[56, 73] If surgery is contemplated for the different pain associated with gunshot wounds to the spine, then the dorsal root entry zone (DREZ) lesioning procedure with intraoperative assessment can offer some patients significant pain relief.[49, 68] This technique is best used in patients without distal motor function, because there is always a risk of increasing the distal neurologic deficit with this procedure.

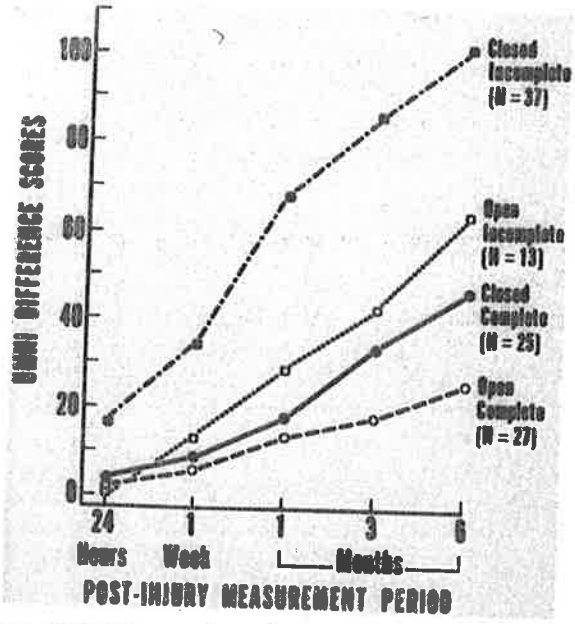

FIGURE 32–13. The graph shows that penetrating injuries of the spine have a worse prognosis for recovery than closed injuries. This is true for complete and incomplete injuries. (From Green, B.A.; et al. Comparison of open versus closed spinal cord injuries during the first year post injury. Paper presented at the Annual Meeting of the American Spinal Injury Association, New Orleans, 1981.)

Cerebrospinal Fluid Fistulas

CSF fistulas have been described after gunshot wounds to the spine. The fistulas can connect with skin or with other body cavities. Occasionally, they are seen as a direct result of a gunshot wound to the spine,[73] but they occur most commonly after acute surgical treatment with laminectomy (Fig. 32–15). Stauffer and co-workers[70] described their experience with 185 patients and observed that CSF cutaneous fistulas did not occur in patients who had not had laminectomies. In those treated with laminectomy, spinal débridement, and bullet removal, the incidence was 6%.

The fact that most CSF cutaneous fistulas occur after acute surgical treatment is another reason to delay removal of the bullet for 7 to 10 days, except when emergency surgical decompression is needed, as described in the preceding section. When surgery is performed to remove the bullet, meticulous dural repair and closure of the paraspinous muscles, deep fascia, and skin are necessary to minimize the chance of postoperative fistula.[12] At the time of repair of the dura, the seal should be checked with a Valsalva maneuver to make certain that it is watertight. If a watertight seal cannot be achieved, a lumbar subarachnoid drain (Fig. 32–16) should be placed to divert spinal fluid, promote proper healing, and prevent such problems as CSF cutaneous fistulas and subsequent meningitis.[36]

Subarachnoid pleural fistula is a relatively uncommon complication of gunshot wounds to the spine, and the diagnosis and treatment of this problem may be difficult. Often, the fistula is not clinically apparent immediately after the injury but is discovered later in the course of the hospitalization as a pleural effusion or with the development of postural headaches. Radionuclide scanning can be an effective method for localization of the fistula.[19] Delayed images are obtained after introduction of the radionuclide into the subarachnoid space through a lumbar puncture. The CT myelogram is also an effective means for detecting the fistula, although it may not be as sensitive. We recommend use of a lumbar subarachnoid drain as the first line of treatment for acute or semiacute injuries with a CSF pleural fistula. Conservative treatment

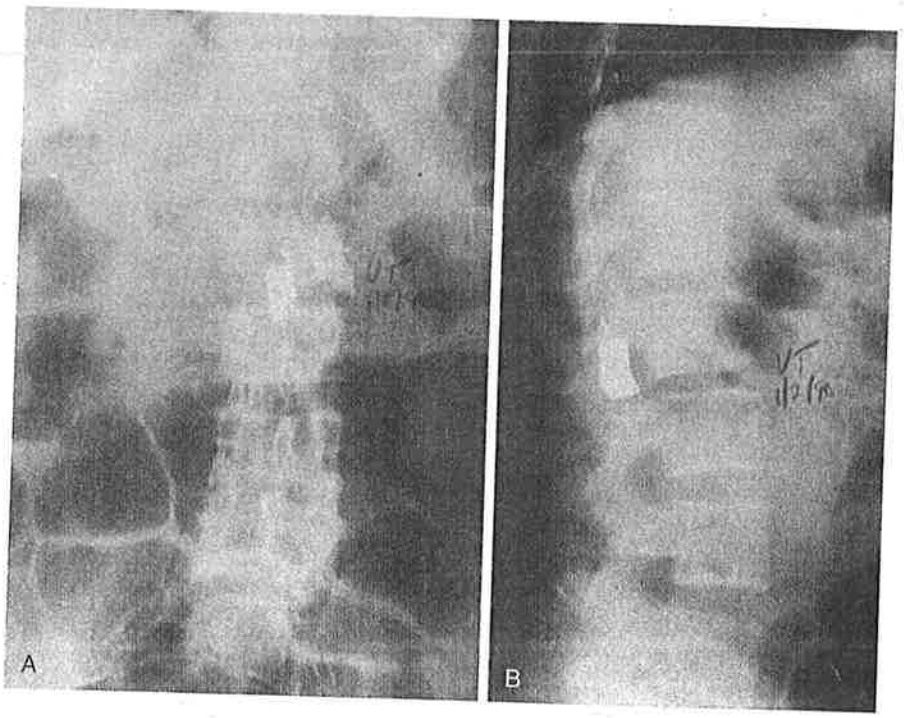

FIGURE 32–14. *A, B,* This patient had incomplete paraplegia caused by a gunshot wound of his spine. He had some function in almost every muscle group below this level of injury, but his main problem was severe pain radiating into his extremities. He had failed medical treatment using amitriptyline and allowing time to pass. After removal of the bullet, the patient had significant pain improvement. Unfortunately, this type of positive response with relief of the pain cannot be predicted with bullet removal.

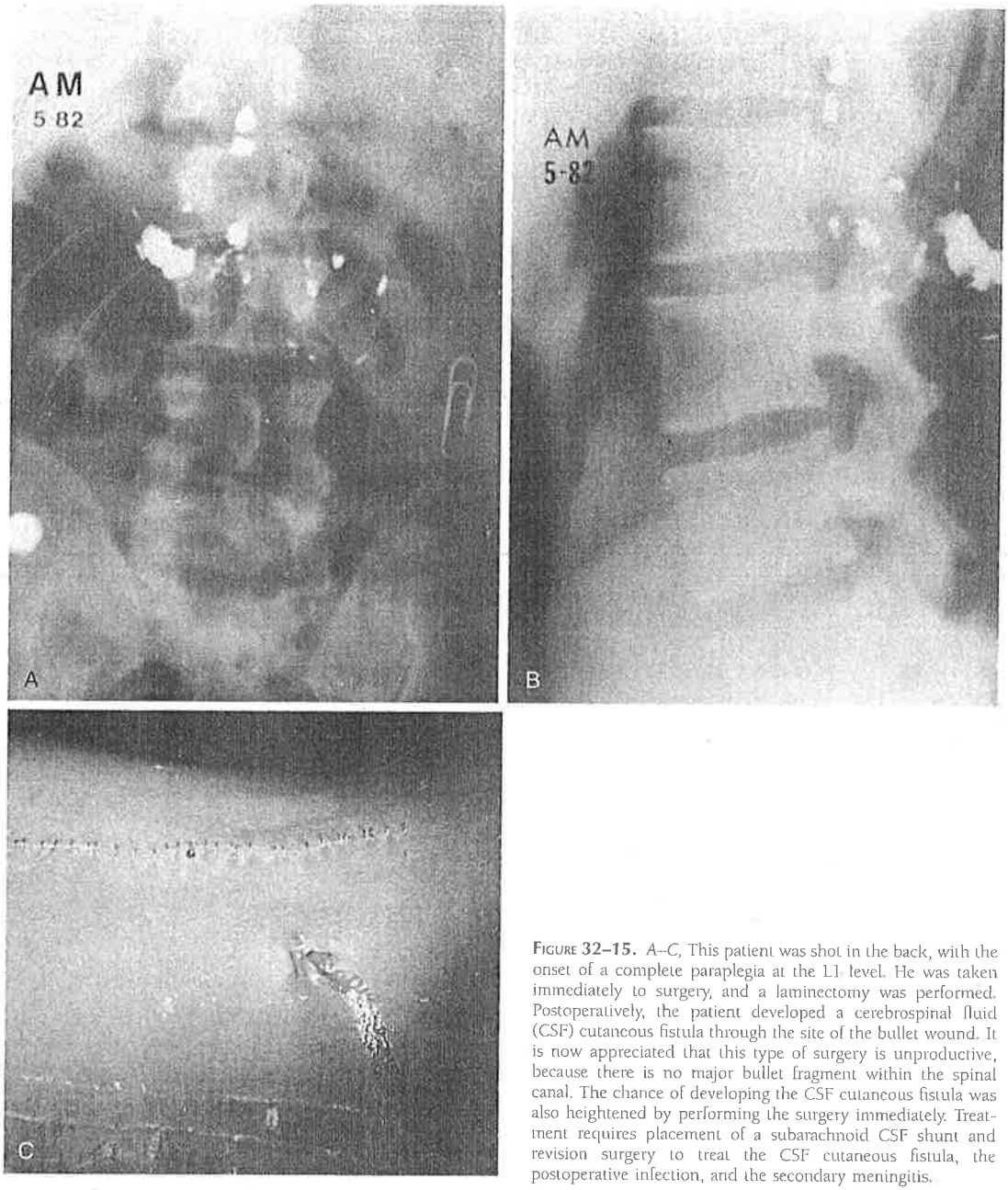

FIGURE 32–15. *A–C,* This patient was shot in the back, with the onset of a complete paraplegia at the L1 level. He was taken immediately to surgery, and a laminectomy was performed. Postoperatively, the patient developed a cerebrospinal fluid (CSF) cutaneous fistula through the site of the bullet wound. It is now appreciated that this type of surgery is unproductive, because there is no major bullet fragment within the spinal canal. The chance of developing the CSF cutaneous fistula was also heightened by performing the surgery immediately. Treatment requires placement of a subarachnoid CSF shunt and revision surgery to treat the CSF cutaneous fistula, the postoperative infection, and the secondary meningitis.

has not been effective with an established fistula, and surgical repair of the dural tear has been the only successful form of treatment.

Spinal Infections

Spinal infections occur infrequently after gunshot wounds to the spine. Most of those that do occur follow injuries to the pharynx,[61, 62] esophagus, or colon.[58] They seldom occur after injury to any other organs, including the stomach or small bowel. The preceding sections described treatment methods to minimize this complication, including routine use of antibiotics for 72 hours after injury and for 7 to 14 days after associated injury of a contaminated viscus.[58, 61, 62]

The other common source of infection after gunshot wounds of the spine is iatrogenic infection after surgery. Stauffer and co-workers,[70] in their review of patients treated with laminectomy for bullet removal, found that 4% developed postoperative wound infections. These infections can be treated like any postoperative infection of the spine.[20]

Significant fistula formation may be seen in patients with spinal infections (Fig. 32–17). In patients with a contaminated viscus injury, there may be a fistula from the

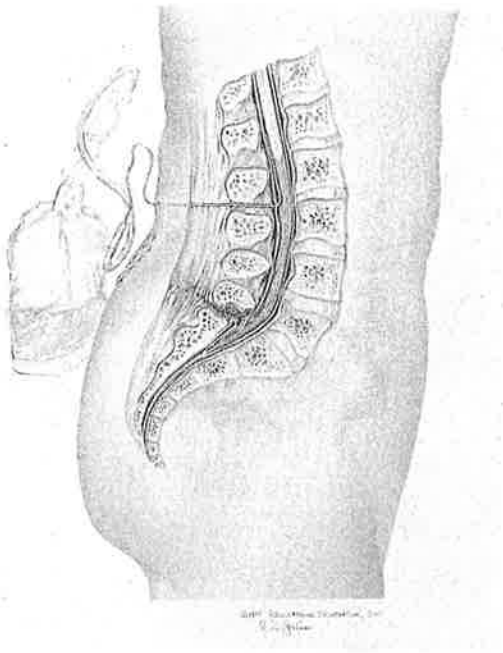

FIGURE 32–16. Use of a cerebrospinal fluid (CSF) subarachnoid-cutaneous shunt allows decompression of the dura and allows the original CSF cutaneous fistula to heal. (From Kitchell, S.; et al. J Bone Joint Surg Am 71:984–989, 1989.)

viscus to the spine. In these cases, it is not possible to resolve the infection without adequate correction of the pharyngeal, esophageal, or bowel fistula. This may require tactics such as diversionary drainage and prolonged hyperalimentation. Some patients have a cutaneous fistula leading down to a vertebral osteomyelitis or disc space infection, but it is much more common for this to occur in patients with a viscus fistula.

The indications for surgical treatment of patients with spinal infections after gunshot wounds of the spine are the same as for any patient with a spinal infection. They include progressive paralysis associated with the infection, progressive deformity, lack of a known organism, suspected foreign body associated with the infection, and failure of conservative treatment. In most cases, the spinal infection is not identified until several weeks after the injury, and at that time, we normally recommend a CT-guided needle biopsy of the spine, followed by a 6-week course with maximal-dose parenteral antibiotics. Open surgery is reserved for the cases described previously.

OTHER PENETRATING INJURIES OF THE SPINE

Impalement Injuries

Impalement injuries of the spine are uncommon. The trauma is usually massive, and there is usually more gross wound contamination than in other injuries to the spine.[29] Patients with impalement injuries of the spine should be taken to surgery for spinal débridement. Cultures for aerobes, anaerobes, and fungi should carefully be obtained. Unlike the relatively clean gunshot wounds described previously, these injuries require a minimum of 3 weeks of parenteral treatment with broad-spectrum antibiotics designed to cover each of the organisms found during the original débridement. It is also extremely

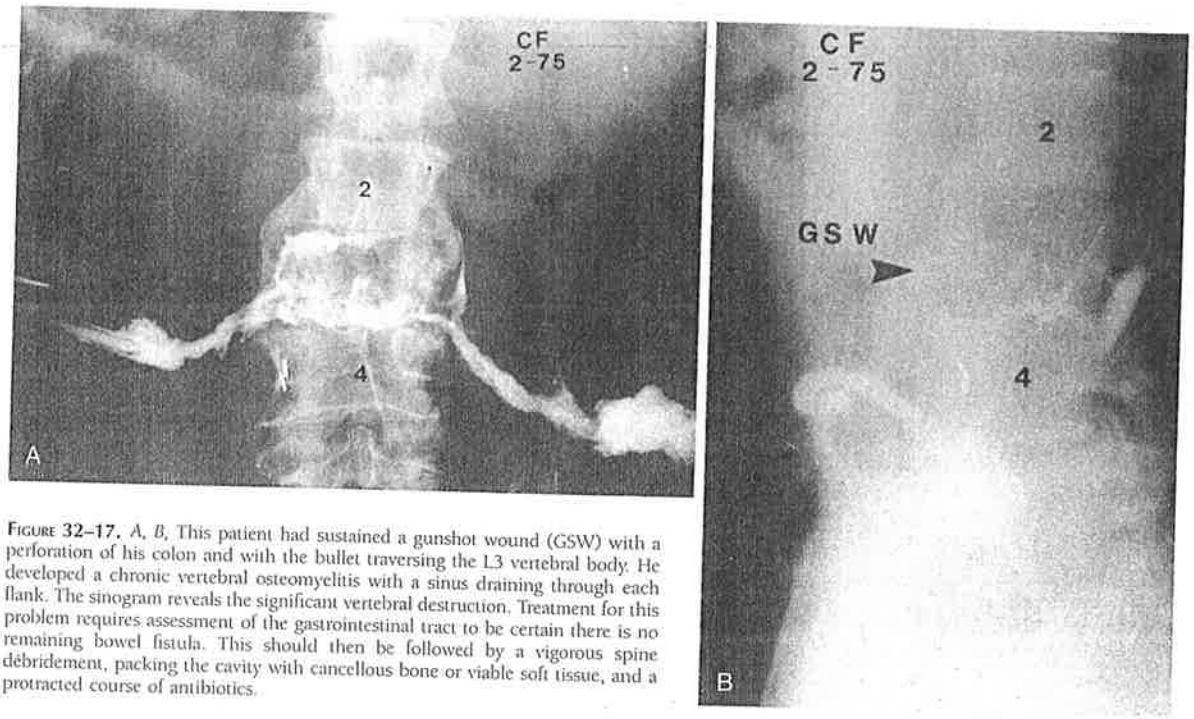

FIGURE 32–17. *A, B,* This patient had sustained a gunshot wound (GSW) with a perforation of his colon and with the bullet traversing the L3 vertebral body. He developed a chronic vertebral osteomyelitis with a sinus draining through each flank. The sinogram reveals the significant vertebral destruction. Treatment for this problem requires assessment of the gastrointestinal tract to be certain there is no remaining bowel fistula. This should then be followed by a vigorous spine débridement, packing the cavity with cancellous bone or viable soft tissue, and a protracted course of antibiotics.

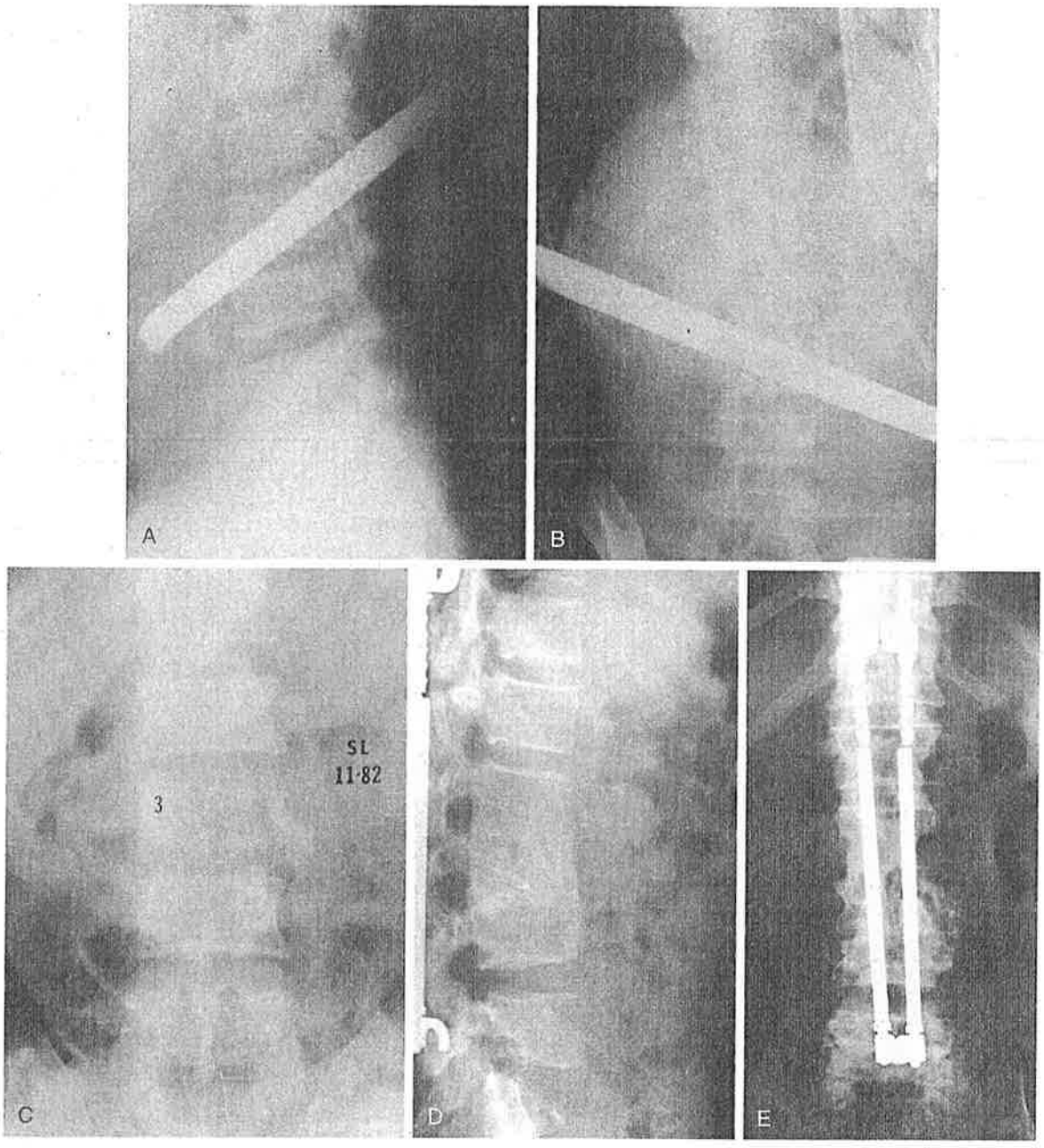

FIGURE 32–18. *A, B,* This patient was impaled on a reinforcing rod after a motorcycle accident. The rod was removed in the operating room with the use of anterior and posterior exposure of the spine. A spinal sample was cultured to identify pathogens, and the spine was vigorously débrided at the time of his initial emergency surgery. *C,* Despite coverage with 3 weeks of broad-spectrum antibiotics, the patient developed a persistent vertebral osteomyelitis with pain and continued vertebral destruction. Six weeks after his injury, he was returned to surgery for a simultaneous anterior and posterior débridement, fusion, and stabilization. Pieces of clothing were found within the vertebral body, and culture samples taken at surgery revealed standard pyogenic organisms and a fungus infection. *D, E,* Radiographs taken 10 years after the injury reveal complete resolution of the infection. Broken rods and a flat back deformity can be identified, but the patient is asymptomatic and is able to participate in full wheelchair activities with no pain.

important to rule out significant foreign bodies (e.g., pieces of clothing), which can be driven into the spine at the time of the injury (Fig. 32–18).

Patients who have sustained an impalement injury of the spine often have recurrent spinal infections and spontaneous drainage from sinus tracts. Successful treatment usually requires sinograms to define the course of the sinus and CT scans immediately after the sinogram to define the bone or disc pathology, followed by surgery to débride the spinal source of infection and excise the chronic sinus tract. Injection of methylene blue into the sinus tract helps to identify the tissue that needs to be excised (Fig. 32–19). However, this dye should never be used if there is a possibility of a dural cutaneous fistula, because intrathecal injection of methylene blue is fatal.

Stabbing Injuries

Stabbing injuries of the spine are seen much less often than gunshot wounds of the spine in the United States, but in some countries, they are the most common type of penetrating injury of the spine. Radiographs should be taken immediately to ensure that no foreign body remains. These foreign bodies are not sterile and can be the source of a persistent late infection; if found, they should be removed surgically (Fig. 32–20). Stab wounds are often associated with the Brown-Séquard type of paralysis and have the best prognosis of the incomplete spinal injuries. The general prognosis is significantly better than for patients with gunshot wounds of the spine with the same extent of incomplete paralysis.

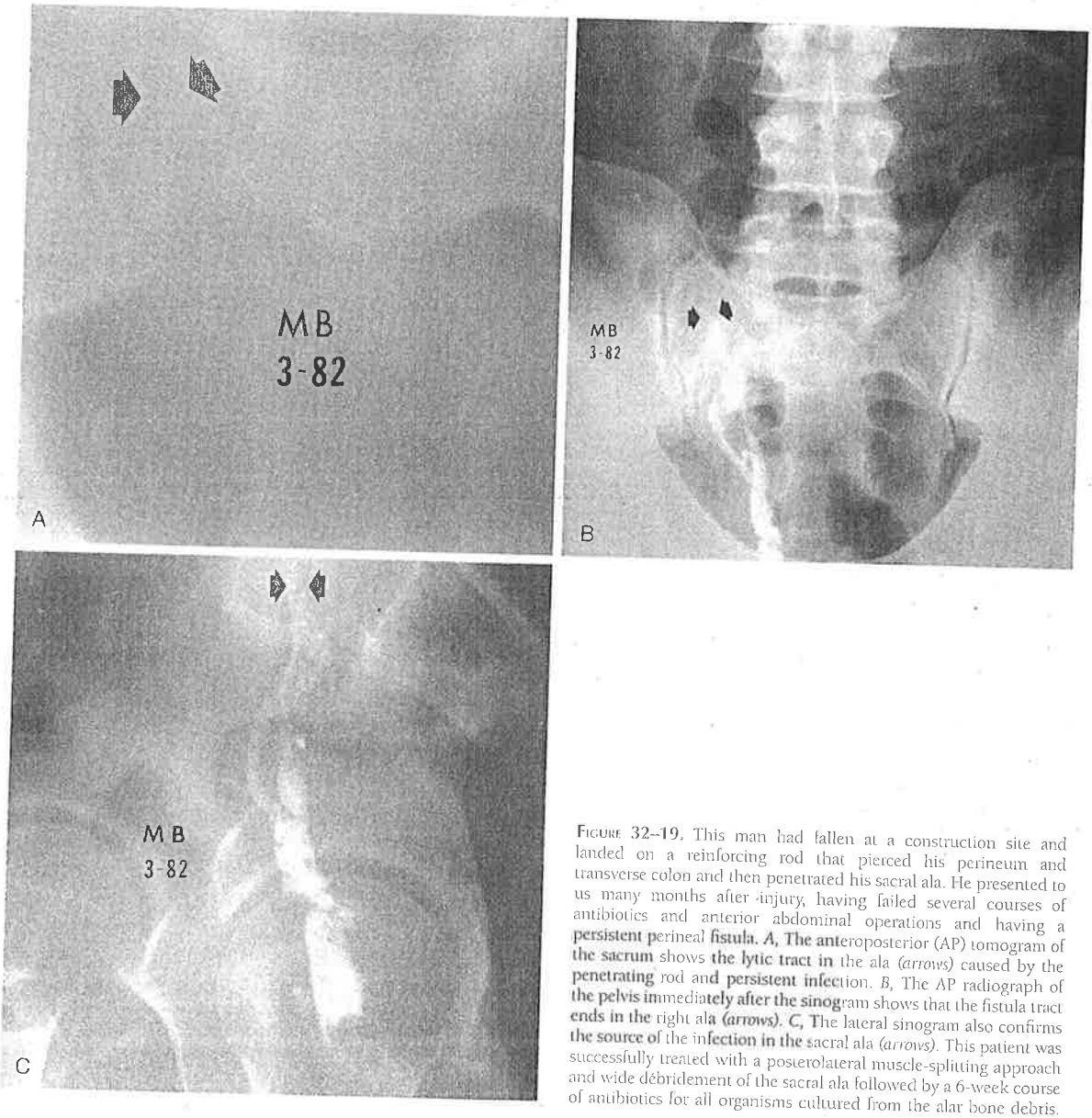

FIGURE 32–19. This man had fallen at a construction site and landed on a reinforcing rod that pierced his perineum and transverse colon and then penetrated his sacral ala. He presented to us many months after injury, having failed several courses of antibiotics and anterior abdominal operations and having a persistent perineal fistula. *A*, The anteroposterior (AP) tomogram of the sacrum shows the lytic tract in the ala *(arrows)* caused by the penetrating rod and persistent infection. *B*, The AP radiograph of the pelvis immediately after the sinogram shows that the fistula tract ends in the right ala *(arrows)*. *C*, The lateral sinogram also confirms the source of the infection in the sacral ala *(arrows)*. This patient was successfully treated with a posterolateral muscle-splitting approach and wide débridement of the sacral ala followed by a 6-week course of antibiotics for all organisms cultured from the alar bone debris.