6. Trauma

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General Considerations

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The magnitude of the problem of trauma in the USA is probably not adequately appreciated. In this country trauma is the leading cause of death in the first three decades of life. It ranks overall as the fourth leading cause of death in the USA today; if arteriosclerosis is considered as a single entity, trauma is the third leading cause of death. Fifty million injuries occur annually in the USA, over ten million of them being disabling. Over 100,000 deaths occur each year from accidents. Automobile accidents kill more Americans each year than were lost during the entire Korean conflict. Unlike many serious disease entities in the USA, the incidence of and mortality from injuries is increasing each year.

Accident patients take up to 22 million hospital bed days a year in the USA - more than are needed to take care of the delivery of all the babies in a given year, more than are needed by all the heart patients, and four times more than are needed by all cancer patients.

Initial Resuscitation of the Severely Injured Patient

The patient with multiple injuries is best managed by one physician. When the responsibility is divided, evaluation of the patient's overall problems may be lacking and complications may not be recognized for several hours.

Priority By Injury

There are three categories of patients, according to immediacy of injury. The first group includes injuries which interfere with vital physiologic function and therefore immediately threaten life, such as obstruction of an airway or bleeding from a gunshot wound. The primary treatment is to establish an airway and control the bleeding. This type of patient may require surgical treatment for massive internal bleeding within 5 to 10 minutes following arrival in the emergency room. The operating room should be alerted when the patient is admitted to the emergency room, and no time is wasted in getting the patient into "operative" condition. Often the control of hemorrhage is dependent on a rapid thoracotomy or laparotomy to occlude injured major vessels.

A second group of patients are those with injuries which offer no immediate threat to life. These include patients who have received gunshot wounds, stab wounds, or blunt trauma to the chest and abdomen but whose vital signs are stable. The majority of injured patients are in this category. Although they will require surgical procedures within 1 to 2 hours, there is time for additional information to be obtained. Blood for typing and cross matching is drawn, and blood is made available if there is any possibility that the patient will require surgical intervention. If vital signs are stable, x-rays may be obtained to determine the course of the missile and the extent of possible associated injuries, such as fractures. Cystography and pyelography may be performed to assess hematuria. Since patients with penetrating and blunt abdominal injuries may develop shock at any moment, a physician must be in constant attendance during all evaluations. Patients who suddenly develop shock are immediately taken to the operating room without additional diagnostic procedures.

The third group of patients are those whose injuries produce occult damage. This group is composed primarily of patients who have sustained blunt trauma to the abdomen which may or may not require surgical intervention and in whom the exact nature of the injury is not apparent. These patients usually have time for extensive laboratory studies, x-rays, and more complete physical examination. Surgical intervention in this group may be delayed hours or days, as with delayed rupture of the spleen.

Patients who are severely injured are admitted to the emergency room in a trauma area equipped for emergency resuscitation. This room should contain such items as intravenous fluids, overhead operating-room light, oxygen, cardiac monitor and defibrillator, and a portable carriage which is suitable for an operating-room table in an emergency situation. A cabinet should be in the room containing a tracheostomy tray, closed drainage tray, venous section tray, central venous catheters, closed-chest drainage tubes, intravenous fluids with tubing, needles, and syringes for four-quadrant abdominal paracentesis, and pericardiocentesis and peritoneal lavage catheters. The cabinet shelf should have clearly visible labels under each tray or set of instruments. These trays and instruments should be kept in this trauma room and not in central supply, as a waiting period of even 5 minutes may prove fatal.

Adequate Airway. The first and most important emergency measure in the management of the severely injured patient is to establish an effective airway. A cabinet should be available at the head of the emergency room carriage in which a laryngoscope and cuffed endotracheal tubes of various sizes are available. Endotracheal intubation is the most rapid method of obtaining an adequate airway. Once an airway is established, a means of positive-pressure breathing such as an Ambu bag or anesthesia machine should be available, and a cuffed endotracheal tube is desirable, so that positive-pressure breathing may be accompanied if needed in the resuscitation or in the administration of anesthesia. Either wall suction or portable suction machine must be available in the trauma room to remove pulmonary secretions, foreign bodies, and frequently, blood from the upper respiratory tract. When an endotracheal tube cannot be readily inserted, a tracheostomy may be done.

Shock and Hemorrhage. Shock is usually controlled while the patient's airway is being cleared by another person. Internal hemorrhage will require immediate surgical intervention. Hypovolemic shock is best prevented or controlled by starting intravenous infusions in at least two extremities, using 18-gauge or larger catheters. A balanced salt solution such as Ringer's lactate solution is usually started until blood is available. Blood for typing and cross matching is drawn at the time the intravenous fluid is started, and the balanced salt solution is given in addition to the blood. Shock resulting from a blood loss of 750 mL can usually be corrected by rapid administration of 2 litres of Ringer's lactate solution over a 15- to 20-, minute period. Blood loss in excess of 750 mL usually requires the administration of whole blood in addition to balanced salt solution. Often, 2 litres of balanced salt solution will replace the volume and correct hypotension so that no blood is necessary, reducing the possibility of blood transfusion reaction. When a patient initially responds to 1 to 2 litres of balanced salt solution, as evidenced by a normal blood pressure and decrease in pulse rate, but subsequently becomes hypotensive, whole blood usually is indicated. However, by this time, type-specific blood usually is available and often cross-matched, which reduces the chances for a transfusion reaction. Should a patient not respond to the rapid administration of 2 litres of balanced salt solution, uncross-matched, type O, Rh-negative blood is administered without hesitation.

External bleeding is best controlled by direct finger pressure on the bleeding wound or vessel. Tourniquets are of little benefit in the control of major arterial bleeding and often injurious if they occlude collateral circulation. A frequent mistake is the placement of a tourniquet on an extremity tight enough to obstruct venous return but loose enough not to inhibit arterial flow; this only increases the blood loss and edema. The danger of tissue loss from tourniquet use is always present.

Superficial vessels may be ligated if they are readily seen. However, wounds are not probed in a blind attempt to place a hemostat on a vessel. As soon as bleeding is controlled, the wound is covered with a sterile dressing, and the patient is taken to the operating room, where the wound is more adequately visualized and proper instruments are available. The needless probing of wounds in the emergency room may lead to severe infection, which can be avoided by proper exploration including adequate irrigation and sterile surgical technique in the operating room.

Neurological Evaluation. After an adequate airway has been obtained and hemorrhage has been controlled, a gross neurologic evaluation of the patient is undertaken. Motor function in the four extremities should be verified. A progressing neurologic deficit following injury to the spinal cord may indicate the necessity for an emergency laminectomy. Decompression of a hematoma may result in return of function. Thoracoabdominal injuries usually take precedence over orthopaedic or neurologic injury.

Chest Injuries. Airway obstruction may be due to mucus, fragments of bone from facial fractures, dirt and debris, and, commonly, broken teeth or dentures. If the patient does not ventilate normally after an endotracheal tube is inserted, or a tracheostomy has been performed, several injuries should be considered. These include pneumothorax, hemothorax, cardiac tamponade, flail chest, and ruptured bronchus.

Pneumothorax. If a pneumothorax is questionable, an 18-gauge needle may be inserted into the chest in the anterior axillary line and aspiration done to reveal the presence of air. A chest x-ray is preferable, but often severe respiratory distress precludes time for x-ray confirmation. Tension pneumothorax with mediastinal shift is suggested by displacement of the trachea to the opposite side. Auscultation of the chest may reveal decreased breath sounds. The patient with a pneumothorax is treated with closed-chest drainage. As there is little danger from the insertion of a chest tube in the absence of a pneumothorax, and anterior chest tube should be inserted if there is doubt.

Hemothorax. Diagnosis of hemothorax is similar to that of pneumothorax. If the patient on the emergency-room cart is in distress, a needle may be inserted in the eight interspace in the posterior axillary line and aspiration done to reveal a hemothorax. This is best drained with both anterior and posterior chest tubes. The anterior chest tube is placed in the second interspace in the midclavicular line and the posterior chest tube is placed in the eight interspace in the posterior axillary line in the region between the midaxillary and posterior axillary line. Chest tubes are of large caliber so that adequate drainage may be maintained. Thoracotomy may be indicated, depending on the rate of bleeding or the presence of intrathoracic clots.

Cardiac Tamponade. During initial observation, an unsuspected cardiac tamponade may develop secondary to blunt or penetrating trauma. This is often not present on arrival in the emergency room but may develop after 1 to 2 hours of observation. The clinical signs pathognomonic for cardiac tamponade are increased venous pressure, decreased pulse pressure, particularly with a paradoxical pulse and with or without cyanosis, and subsequent development of hypotension and decreased heart sounds. Emergency treatment includes aspiration of the pericardial sac with an 18-gauge needle through the xyphocostal angle. Decompression of as little as 20 mL of aspirated blood may make a remarkable difference in the patient's vital signs. Depending on the cause of cardiac tamponade, immediate thoracotomy is usually required to repair the cardiac wound. When a patient arrives at the emergency room in shock without evidence of blood loss, this diagnosis should be suspected.

Flail Chest. Unless patients sustaining blunt trauma to the thorax and abdomen are fully disrobed in the emergency room, a flail chest may not be recognized. Patients sustaining flail chest are best treated immediately with tracheostomy and intermittent positive-pressure breathing (IPPB). This promptly expands the lungs and provides adequate ventilation, often preventing the development of atelectasis and pneumonia. Some type of stabilizing apparatus may be beneficial. However, towel clips alone may not be effective, since the patient may not ventilate as well without intermittent positive-pressure breathing. Sandbags are of little value and may lead to the development of pulmonary complications such as atelectasis.

Ruptured Bronchus. After rupture of a bronchus, respiratory distress, hemoptysis, cyanosis, and a massive air leak with both mediastinal and subcutaneous emphysema and/or tension pneumothorax may be observed. Often the diagnosis is not obvious. There is a close relationship between fractures of the first and second ribs and rupture of a bronchus. If extrapleural hematoma is noted, special views of the first ribs are indicated. A ruptured bronchus is treated initially with closed-chest drainage. If this does not effectively keep the lung expanded, open thoracotomy with repair of the bronchus is indicated.

Open Chest Wounds. The patient with a chest injury resulting in a sucking chest wound is best managed by immediately covering the open wound with whatever material is available, such as a large vaseline gauze bandage or a thin sheet of plastic wrap. This prevents further shifting of the mediastinum and allows ventilation of the opposite lung. Chest tubes are usually inserted prior to operation, and immediate surgical intervention is indicated.

Ruptured Thoracic Aorta. The diagnosis may be suspected from chest x-ray showing a widened mediastinum and confirmed by arteriography. Immediate operation usually is indicated.

Penetrating Wounds of the Abdominal Wall. All penetrating injuries to the abdominal wall are explored locally in the emergency room to determine if the peritoneal cavity is penetrated. Exploration is usually accomplished by extending the stab wound and determining its depth. In the event that the extent of penetration cannot be determined or if the stab wound violates the peritoneal cavity, the abdominal cavity is lavaged. The mortality and morbidity from a negative abdominal exploration is negligible, but failure to discover such injuries as colon or liver injury for several hours may allow peritonitis and other complications to develop. All gunshot wounds of the abdomen should be explored whether penetration is evident or not. Shock waves from nonpenetrating gunshot wounds of the abdominal wall can easily transect bowel or lacerate the liver or spleen without entering the abdominal cavity. Most gunshot wounds enter the peritoneal cavity damage a vessel, organ, or hollow viscus.

The Unconscious Patient. Patients with closed head injuries who are unconscious must have an airway established immediately. Hypotension rarely results from a closed head injury but is almost always caused by blood loss, usually in the thorax or abdomen. The cause of the blood loss is most rapidly determined by using an 18-gauge needle for immediate abdominal and chest taps, which may reveal nonclotting blood. The absence of blood does not rule out an intraabdominal or thoracic injury. Extreme care should be used in moving unconscious patients until injuries of the spine have been ruled out.

Immediate Nonoperative Surgical Care

Hematuria. A Foley catheter is routinely inserted, particularly following blunt trauma to the abdomen, to determine the presence of hematuria as well as to follow the urinary output during and immediately following the surgical procedure. Gross hematuria is evidence of urinary tract injury resulting from contusion, laceration, or rupture. If the patient's vital signs are stable and hematuria is present, a combined cystogram and intravenous pyelogram should be done. A single 15-minute film is usually adequate to determine kidney function as well as indicate extravasation from the bladder, ureter, or kidneys. Failure to demonstrate extravasation does not rule out the possibility of a ruptured bladder or kidney. Should a nephrectomy be required during a laparotomy, functioning of the kidney on the opposite side should be proved. It is useless to attempt to visualize the kidneys by intravenous pyelogram when the patient is hypotensive. X-rays are delayed until the patient has been resuscitated and bleeding has been controlled in the operating room. If time is not available preoperatively for an intravenous pyelogram, a cassette may be placed under the patient prior to the start of surgical procedures and a pyelogram obtained intraoperatively.

Fractures. Fractures of the extremities are best managed immediately with splints for the extremities. Immobilization may prevent additional nerve and blood vessel injury and conversion of a closed fracture to an open one. The presence or absence of pulses in the fractured extremities should be noted on initial examination. Intravenous infusions should not be started in an injured extremity. Massive thoracoabdominal bleeding takes precedence over fractures, unless there is an accompanying arterial injury of such magnitude that there is danger of loss of limb. In such instances, it is often necessary to have two surgical teams working simultaneously.

Pelvic fractures usually are managed conservatively with a pelvic binder, traction, or only bed rest. Inability to insert a Foley catheter into the urethra following a pelvic fracture may indicate a fractured urethra.

Arterial Injuries. Any penetrating injury in the region of a major blood vessel or nerve deserves evaluation by arteriography. On initial examination, 18 percent of subsequently proved arterial injuries are noted to have a normal pulse distal to the arterial injury, and one-third of the patients have a palpable but diminished distal pulse. Vessel exploration in the region of the neck should be done under endotracheal anesthesia and may require resection of a portion of the clavicle for adequate visualization. Early recognition of an arterial injury is the most important factor in preserving a viable extremity or functioning distal organ.

Diagnosis and Management of Unapparent Injury

Blunt trauma to the abdomen may produce severe intraperitoneal or retroperitoneal injury with minimal physical findings. Bowel sounds may not be lost for several hours, and evidence of retroperitoneal or intraabdominal injury may not become apparent for as long as 18 hours.

An abdominal paracentesis may be performed early in the observation period in patients with injuries from blunt trauma to the abdomen. A 95 percent diagnostic accuracy is associated with the positive abdominal tap. A negative abdominal tap does not rule out intraabdominal injury. If injury is still suspected, peritoneal lavage is indicated. Patients with signs of peritoneal irritation require exploratory laparotomy even in the absence of a positive abdominal tap or peritoneal lavage.

Radiographs. These are taken when a patient's vital signs remain stable but are omitted for patients in severe shock. X-rays of the chest and abdomen are routinely performed to rule out foreign bodies such as knife blades within the depths of the wound. Patients sustaining gunshot wounds should have x-rays when possible in an attempt to trace the course of the missile. Patients sustaining blunt trauma often require multiple x-rays to rule out obscure fractures of the vertebral spine and retroperitoneal injuries. X-rays of extremities will be of value in determining whether or not the missile struck bone, fractured bone, or passed near vital structures.

Nasogastric Intubation. A Levin tube is routinely inserted in the severely injured patient. Passage of the tube may provoke vomiting and empty the stomach of large particles, preventing subsequent aspiration during anesthesia. Esophageal or gastric injury from penetrating or blunt trauma may be diagnosed by finding bright red blood in the Levin tube drainage. Gastric intubation prevents gastric dilatation during tracheal intubation and aids in the prevention of postoperative distension of the small bowel.

Prophylactic Antibiotics. Antibiotics are administered preoperatively to all patients sustaining penetrating wounds of the abdomen, beginning as soon as possible after the injured patients arrives in the emergency room. They may be discontinued if exploratory laparotomy is negative. Considerable experimental evidence indicates that prophylactic antibiotics in trauma are of benefit if administered within the first 3 hours following injury. A retrospective review of a group of patients who sustained penetrating abdominal injuries showed that there was a decrease in the incidence of infections in those patients who received antibiotics preoperatively or intraoperatively as opposed to those who received antibiotics in the immediate postoperative period or therapeutically. This was significant for gunshot but not stab wounds. A prospective study now being conducted indicates coverage should be against both aerobes and anaerobes.

Tetanus Prophylaxis. Following injury, immunized patients are administered a tetanus toxoid booster. In unimmunized patients the wound is debrided, and 250 units of tetanus human immune globulin is administered. Patients who were previously immunized but are now taking steroids, immunosuppressive therapy, or chemotherapy or who have had extensive irradiation should receive human immune globulin, since they may not have normal antibody response. Severely contaminated wounds should be left open or converted to open wounds when feasible.

Metabolic Response to Trauma

Malcolm O Perry

Trauma acutely and extensively alters the delicate integration of endocrine and metabolic systems in humans (see Chap. 1). The wide range of response correlates with magnitude of injury and the metabolic adjustments of which the patient is capable. Moore has divided the metabolic response into four phases: (1) the initial injury reaction, lasting 2 to 4 days; (2) the turning point, requiring 1 to 2 days; (3) an anabolic period, characterized by protein synthesis and lasting 2 to 5 weeks; (4) a period of several months of final adjustment in which "fat gain" is preponderant. These metabolic responses can be conveniently grouped into two categories: endocrine and catabolic.

Endocrine Response

Following injury, there is increased urinary excretion of epinephrine, norepinephrine, and their metabolic products. Although the measurement of blood levels of catecholamines does not always correlate well with the clinical findings, sympathicoadrenal activity is present. During the early stages the patient frequently exhibits tachycardia, sweating, and vasoconstriction, and is pale and apprehensive. Although the clinical signs may disappear relatively rapidly, elevated urinary levels of catecholamines and their metabolic products may persist for 1 or 2 days. If no complications follow the initial traumatic episode, the primary effects of sympathicoadrenal action are noted only during the early stages of the injury and pass rather rapidly.

Many of the metabolic changes noted following injury are similar to those induced by the administration of excessive amounts of cortisone or hydrocortisone. Urinary excretion of conjugated steroids is increased in the post-traumatic period. The normal excretion of 10 to 20 mg of 17-hydroxycorticosteroids may be tripled during the first 2 to 4 days following an injury of moderate severity. If shock or liver injury has not occurred, peak blood levels of 17-hydroxycorticosteroids are obtained about 6 hours after trauma. This reaction appears to be nonspecific and more closely related to the severity of the injury than to the specific type of injury. There is a less exact correlation between the negative nitrogen balance and the increasing levels of corticosteroid production. It has been observed that even in adrenalectomized rats urinary nitrogen excretion increases after injury if the animals are maintained on constant amounts of adrenocortical extracts, suggesting that the metabolic changes which follow injury are not directly related to the absolute level of corticosteroid production. This observation accords with the concept of the corticosteroids exerting a "permissive" or "conditioning" action.

The exact relationship between injury and the function of other endocrine glands remains unclear. The increase in oxygen consumption and carbon dioxide production following injury suggests that the thyroid gland may plan an essential role, but similar effects can be produced by a variety of influences in the absence of trauma. Various measurements of thyroid function fail to correlate well with energy changes in the traumatized patient. The increased calcium excretion following injury can be related quite well to immobilization, and parathyroid function need not be invoked to explain calcium loss. Somatotropin, or growth hormone, has a profound effect on body metabolism, particularly skeletal growth and the synthesis of protein. Normal growth and development seem to be directly related to its presence, but there is no evidence that this hormone is necessary for normal convalescence. At the present time, the exact reaction of these other endocrine glands to injury is unclear.

Catabolic Response

Catabolism is increased following injury. Dissolution of body protein is reflected by increased urinary nitrogen excretion; after extensive trauma or with infection, levels of 15 to 20 g/day may be reached. The increased rate of excretion may persist for 3 to 5 days in the uncomplicated case. This can be reduced by the administration of exogenous protein and other compounds which supply calories, thus decreasing the effect of starvation. The inability to prevent these nitrogen losses completely indicates a definite catabolic effect in excess of that produced by starvation.

If water gain and loss are kept at minimal rates, careful weight measurements will reveal a loss of body tissues. A urinary loss of approximately 10 g of nitrogen represents about 62 g of protein loss, or about 3000 g of wet lean muscle. The protein in bone and connective tissue and in plasma less readily reflect these changes. There can be, in fact, large losses or gains in protein without detectable changes in the concentrations of plasma proteins.

As initial responses to injury dissipate, a relatively abrupt change toward normal occurs in urinary nitrogen excretion. With sufficient caloric intake, protein balance is restored. If subsequent complications do not occur, net protein gain is prominent and recovery proceeds rapidly. This gain, however, is usually much slower than the initial loss. It will often require three to six times as long to repair the protein deficit as it took to create it. If protein and caloric intake are satisfactory, the level eventually obtained is quite close to that prior to the loss.

Metabolic Requirements

Energy. The normal person at rest may require 2000 kcal/day, but a febrile, severely injured patient may use 4000 kcal in a single day. Variable periods of starvation almost inevitably follow severe trauma, and weight loss in excess of water loss may reach as high as 100 g daily as the energy demands are met by the consumption of body tissue.

Initial energy needs are supplied by the body stores of carbohydrate, 300 to 500 g being present as liver and muscle glycogen. The supply is exhausted within 14 to 18 hours after severe trauma, and subsequent energy requirements must be supplied by body tissues. In the postinjury period, 200 to 500 g of fat may be oxidized daily to yield 1800 to 4500 kcal.

This is greatly in excess of the 1000 to 1300 kcal liberated by the oxidation of 100 to 150 g of fat/day in starvation.

Although the major contribution to energy needs comes from oxidation of fat, protein catabolism yields a significant number of calories. Normal daily intake of 70 g of protein results in the urinary excretion of some 10 g of nitrogen daily. Following extensive injury, urinary nitrogen may reach levels as high as 20 g/day, representing the liberation of more than 500 kcal.

The production of energy is dependent upon the oxidation of metabolites via the tricarboxylic acid cycle. The two carbon fragments, active acetate or coenzyme A (CoA), assume a pivotal position in this important process. Acetyl CoA combines with oxaloacetic acid to form citric acid, which is subsequently degraded stepwise to yield eight hydrogen atoms, two molecules of carbon dioxide, and oxaloacetic acid. The eight electrons liberated by specific dehydrogenases then are introduced into the electron transport charge for transfer to oxygen. By oxidative phosphorylation the energy of foodstuffs is thus converted to adenosine triphosphate (ATP), which is the ultimate driving force for most of the energy reactions within the cells.

Intravenously administered carbohydrate solutions may supply a significant portion of the caloric needs for these energy processes. These solutions also may exert a protein-sparing effect, thus reducing the dissolution of lean body tissue. Approximately 100 g of carbohydrate appears to be adequate to obtain maximal protein sparing. As the first phase of injury passes, parenteral feeding is replaced by oral intake, and anabolic processes approach normal although the need for increased caloric supply often continues. Moore indicates that approximately 1 g of nitrogen and 20 kcal/kg of body weight per day are necessary to ensure restoration of body tissues during early convalescence.

Carbohydrates. Although present in relatively small amounts, the monosaccharide glucose occupies a very important position because of its ready availability for energy. The two carbon fragments are intermediates in fatty acid metabolism and energy production. Via transamination reactions, glucose eventually may be converted to amino acids and proteins. Thus, glucose is an important precursor to fat and protein, as well as a supplier of oxidative energy.

Approximately 55 percent of absorbed carbohydrate is rapidly introduced into the Krebs cycle and converted into energy, carbon dioxide, and water. A portion of the remaining carbohydrate is converted to fat or protein, and about 5 percent is stored as liver and muscle glycogen. The carbohydrate in muscle is not readily available for use except by the muscle, but liver glycogen can easily be broken down and used elsewhere in the body. This glycogen is rapidly depleted in periods of starvation and in less than 5 hours may be exhausted if gluconeogenesis is interdicted. Without supplemental carbohydrate body tissues must be used to meet energy requirements.

Fat. Fat is rapidly oxidized to yield energy during starvation. From 75 to 100 g daily is mobilized under these conditions, but after extensive injury, as much as 500 g/day may be used. In addition to energy, free water is obtained. Although neutral fat contains little free water, the oxidation of 1 kg of fat liberates more than 1000 mL of water.

Vitamins. The suggested daily requirements of vitamins have been outlined by the National Research Council Committee on Nutrition. The exact vitamin requirements of the injured patient are not known, but it is probable that the vitamin C requirement is increased out of proportion to those of the other vitamins. There is a great individual variability in requirement for ascorbic acid in healthy adults, and it has been observed that blood level of buffy coat determinations for vitamin C do not necessarily reflect the magnitude of the deficit. It is widely held that the failure of wound healing and subsequent dehiscence is related more to the lack of vitamin C than to actual caloric starvation or protein depletion. It appears reasonable that the intake of vitamin C required to maintain normal body function in the posttraumatic patient is considerably higher than that customarily given for daily maintenance. If vitamin C is given intravenously in high levels, the renal threshold is soon exceeded, and a large portion of the administered dose is lost in the urine.

Most patients on parenteral therapy for short periods following surgical procedures for trauma will not require supplemental vitamins A and D. However, in addition to C, thiamine is certainly needed, as body stores of thiamine are rapidly depleted after the administration of large amounts of glucose. One of the important coenzymes in the tricarboxylic acid cycle necessary for oxidative decarboxylation of pyruvate to acetyl CoA is cocarboxylase, or thiamine pyrophosphate. The defect in oxidation of pyruvate therefore may be related to a preexisting thiamine deficiency in some patients.

Management

Most patients will reach the operating room in satisfactory nutritional status, but this desirable goal is not easily attained after extensive trauma. Preexisting nutritional and vitamin deficits may further complicate the severe metabolic response following trauma. Patients with hypoproteinemia may exhibit diminished tolerance to blood loss and reduced antibody production. There may be impaired wound healing and delayed union of fractures, and perhaps fatty infiltration of the liver in patients who are severely hypoproteinemic.

Although the normal patient at bed rest can be maintained easily on approximately 1 g of protein and 30 kcal/kg of body weight, after extensive trauma these requirements may be doubled or tripled. In the past it has been quite difficult to supply sufficient calories by the intravenous route.

Although protein may be supplied via administered blood plasma or albumin, these solutions are expensive, they require considerable metabolic work for their assimilation and caloric equilibrium for maximal use, and their caloric values are quite low. At one time there was widespread interest in the use of intravenous solutions containing protein hydrolysates and fat emulsions, which theoretically appeared to be more useful. However, this nutritional technique was not extensively employed because of doubtful effectiveness in preventing nitrogen losses and because of certain hazards attending their use. In 1968, Dudrick and associates reported that large quantities of protein hydrolysates and dextrose could be administered through a catheter inserted in the superior vena cava to consistently and safely achieve a positive nitrogen balance and weight gain. In over 300 patients, Dudrick and his colleagues induced weight gain and promoted healing of fistulas and wounds by this technique of *parenteral hyperalimentation.* Intravenous solutions containing adequate protein, essential amino acids, fat, carbohydrate, and vitamins to meet chronic nutritional requirements are now available. This important development in the pre- and postoperative care of patients is particularly useful when protein and caloric requirements are quite high and convalescence is prolonged.

Improvements in infusion technique are primarily responsible for the success of parenteral hyperalimentation, particularly the technique of catheterizing the subclavian vein to approach the superior vena cava for instillation of the concentrated solutions. As the subclavian vein is large, the catheter does not usually produce irritation of the vein wall and subsequent thrombosis, and the rapid blood flow prevents clotting and reduces bacterial growth. Placement of the catheter tip in the superior vena cava permits rapid dilution of the hypertonic solutions, thus decreasing the incidence of chemical phlebitis. Rigid sterile technique in placement and care of these catheters has allowed an acceptably low infection rate.

It is clear that with careful attention to strict asepsis and antisepsis in preparing and infusing these solutions (see Chap 2) parenteral hyperalimentation may be considered a primary mode of both acute and long-term therapy, rather than a modified method of intravenous treatment, and can provide all essential nutrients without exceeding the daily fluid requirements. Initially, the solutions were prepared just prior to administration, but commercial products with a wide range of constituents now are available. Minor adjustments of essential amino acids, vitamins, and ion supplementation facilitate the preparation of individualized solutions.

Anesthesia

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Complicating Problems

The injured patient shares in all of the considerations presented by the elective surgical patient. In addition several unique problems characterize the traumatized patient. The major problem are possible airway difficulties, lack of comprehensive preoperative evaluation, multiple injuries, the full or nonemptied stomach, intoxication with alcohol or drugs, and uncorrected hemorrhage.

Airway Obstruction. Establishment and maintenance of the patient's airway may be the most important step in successful resuscitation. Some form of artificial airway is indicated for any patient with respiratory obstruction, inability to clear secretions, need for artificial ventilation, or unconsciousness. The type of airway must be individualized, but oropharyngeal or nasopharyngeal airways, orotracheal tubes, nasotracheal tubes, or tracheostomy should be considered.

Endotracheal intubation, if technically possible, is an effective method of rapidly clearing an airway obstruction to allow a more orderly, unhurried tracheostomy. Intubation should be performed under direct vision with a laryngoscope so that loose fragments of bone, teeth, or tissue will not be carried into the trachea by the advancing tube. The tube may be left in place for 48 hours or longer, if necessary, to support ventilation or maintain the airway until the patient can satisfactorily perform these functions. Meticulous care is as important for the indwelling endotracheal tube as for the tracheostomy. Inspired gases should be completely humidified. Periodic saline solution instillation followed by suctioning with a sterile catheter and hyperinflation of the lungs every other hour are prerequisites for proper management. Chest physiotherapy consisting of postural drainage, percussion, and vibration is beneficial in preventing and treating atelectasis.

The period of induction of anesthesia is probably the most hazardous time in the anesthetic period. During this time, hypotension, hypoxia, arrhythmias, and vomiting are likely to occur. The patient should be preoxygenated, allowing time for placement of intravenous infusions, further appraisal of the patient's status, and protection against hypoxia during induction. If general anesthesia is selected for the emergency repair of trauma, tracheal intubation is necessary. After consideration of the preanesthetic condition, the patient may be intubated while awake or following rapid sequence induction. Awake intubation may avoid many dangers which may occur in induction of anesthesia, is generally easily performed, and is far less distressing to the patient than most physicians anticipate. Use of topical anesthesia will facilitate awake intubation in the more alert patient with a full stomach or hypotension. Awake intubation is contraindicated in patients with penetrating injuries of the eye or neck and in patients with elevated intracranial pressure.

Intubation under general anesthesia will require consideration of other factors such as restoration of circulating volume and identification of associated injuries. Following rapid intravenous induction, a cuffed endotracheal tube is inserted. The lungs must not be manually ventilated until the endotracheal tube is in place and the cuff is inflated, except when intubation has been unsuccessful and hypoxia must be prevented or treated.

Many recent developments have improved a traumatized patient's chances of survival with respiratory obstruction. The use of the esophageal airway by the EMTs (Emergency Medical Technicians) and evacuation of the unconscious injured in the lateral or prone position have saved many lives. In the desperate asphyxial emergency from supraglottic obstruction, oxygenation can be established by insufflating oxygen at a high flow through a 16-gauge over-the-needle catheter inserted into the larynx via the cricothyroid membrane. Retrograde catheter-guided endotracheal intubation and fiberoptic intubation have made intubation possible in cases in which it was previously felt to be impossible.

Lack of Comprehensive Preoperative Evaluation. Morbidity and mortality of trauma are inversely related to the preinjury state of health, but no patient should be assumed to have been completely healthy before injury. Evidence of prior disease, allergies, or chronic drug therapy should be sought from the patient or an available informant. The main categories of drugs which create hazardous interactions with anesthetics are hormones (corticosteroids, insulin), psychopharmacologics, antihypertensives (including diuretics), cardiac drugs (including digitalis), and anticoagulants.

Multiple Injuries. When injuries involve many areas, problems arise in establishing priorities for operative intervention. In patients with head injuries, associated injuries may compel initial consideration. However, one must be alert to any change in the patient's neurologic status during the anesthesia. Usually the pupils are the best indicators, and reduced requirement for anesthesia may indicate progression of the neurologic deterioration. Conversely, if the head injury is the primary surgical target, the anesthesiologist should be alert for progression of associated trauma, such as tension pneumothorax, hemoperitoneum, and cardiac tamponade. As shock is rarely directly caused by head injuries, its occurrence in the presence of head injury should engender suspicion of other injury. Unusual diagnostic skill may be needed to assess associated injuries with effects that become apparent only after an operation is progressing in another area. For example, hemorrhage from a torn spleen or liver may be minimal at the beginning of operation to correct extremity trauma but will require careful consideration if hypotension occurs. The diagnosis may be masked and delayed by the empiric administration of vasopressors for hypotension of uncertain cause.

The Full or Nonemptied Stomach. The chief hazard of the unprepared stomach is vomiting and aspiration of the vomitus. Peristalsis may cease at the time of the accident because of shock, anxiety, or abdominal or central nervous system trauma. For this reason all traumatized patients should be managed as if the stomach were full regardless of the interval since the last oral intake. Where appropriate, regional anesthesia should be selected for these patients, although aspiration remains a hazard. Regional analgesia is technically contraindicated for agitated, intoxicated patients and for those with significant hypovolemia.

Awake intubation with or without topical anesthesia has been shown to be safe for the emergency patient with a full stomach. An alternative choice for a vigorous patient is rapid induction with an intravenous thiobarbiturate followed by a paralyzing dose of succinylcholine to facilitate tracheal intubation. The hazard of anesthetic overdosage exists if, following intubation, volatile inhalation agents in high concentrations are pumped into the lungs by controlled ventilation. The stomach should be decompressed with a nasogastric tube. A clear antacid, 30 mL orally, as 7.5% sodium bicarbonate or 0.3 M sodium citrate should be given just prior to induction of anesthesia. Following administration of the thiobarbiturate, an assistant should exert continuous pressure on the cricoid cartilage to occlude the esophagus. This should not be released until the tube is securely in the trachea and the cuff inflated. The endotracheal tube should not be removed until the patient is conscious postoperatively and has protective laryngeal reflexes to prevent aspiration during extubation.

Two clinical pictures of aspiration have been described. First is the aspiration of undigested food resulting in respiratory obstruction and distress. Depending on the amount of material aspirated, patients may have acute respiratory distress with cyanosis and cardiac arrest or may exhibit a milder, chronic course leading to lobar pneumonitis and lung abscess. A second form, Mendelson's syndrome, is caused by aspiration of liquid acid gastric secretions. This is equally hazardous in terms of morbidity and mortality and is manifest by generalized bronchospasm, dyspnea, tachypnea, and cyanosis. In severe cases cardiac arrest may develop. Immediate therapy includes oxygen, endotracheal suctioning, and positive-pressure ventilation. Steroids and prophylactic antibiotics are no longer considered to be of value. Bronchoscopy is indicated if particulate material is found in the vomitus or if signs of obstructive atelectasis develop. Tracheobronchial lavage with large volumes of saline solution is no longer recommended.

Alcohol and Drug Intoxication. Based largely on animal studies, the statement has been repeatedly made that the manifestations of shock are more severe in the drunk patient than in the sober patient. However, mild to moderate intoxication (blood alcohol less than 250 mg/100 mL) is reported to have no effect on the incidence of hypotension, morbidity, or mortality of surgical treatment for trauma. Higher levels of blood alcohol are expected to increase intraoperative anesthetic complications. Regional anesthesia is not technically feasible for the agitated and intoxicated patient; intravenous induction is preferred. The airway should be protected by rapid endotracheal intubation.

Patients intoxicated with cannabis, LSD, and/or amphetamines may exhibit altered responses to anesthetics. Intoxication with barbiturates and methyl alcohol may result in delayed emergence from anesthesia. Pulmonary edema, hypoxia, cardiac failure and dangerous arrhythmias are common in patients who are chronic intravenous drug abusers.

Shock. The severely hypovolaemic patient, unresponsive to pain or verbal stimulus, should receive no anesthetic drugs which may depress the cardiovascular system. Such a patient needs endotracheal intubation, ventilation with oxygen, and restoration of circulating volume. Satisfactory operating conditions should be provided, with muscle relaxants and analgesic concentrations of nitrous oxide.

Other aspects of care for the severely hypotensive, hypovolaemic patient include (1) simultaneous infusion of large quantities of blood and electrolyte solutions, warmed to avoid myocardial hypothermia and irreversible cardiac arrhythmias; (2) administration of calcium as an antagonist to hyperkalemia, to prevent citrate intoxication and to strengthen myocardial force; (3) administration of sodium bicarbonate to correct the acidosis produced by anaerobic metabolism and infusion of acidotic blood; and (4) administration of large doses of steroids, although their efficacy is not firmly established.

Simultaneous infusions of type-specific whole blood or its equivalent and balanced salt solutions are used for the resuscitation of patients in hypovolaemic shock. Balanced salt solutions are infused to correct the deficit in functional extracellular fluid volume which has been demonstrated to occur in hypovolemic shock and severe tissue trauma. The following guidelines are followed in the rational and moderate approach to the treatment of hypovolemic shock: (1) balanced salt solutions are not a substitute for whole blood; (2) blood should be given whenever losses approach 10 percent of blood volume; (3) balanced salt solutions are intended to replace deficits in functional extracellular fluid; (4) balanced salt solutions should be given to hypotensive emergency room patients while type-specific whole blood is being obtained; (5) during surgery, blood loss is replaced with blood plus balanced salt solution at a rate of 7 to 10 mL/(kg.hour); (6) patients with cardiac or renal disease deserve special consideration and care in fluid therapy; (7) intravenous infusions should be warmed; (8) microfiltration may be employed in massive transfusions of whole blood or packed cells; (9) packed cells should be reconstituted with normal saline prior to infusion to facilitate their passage through filters and warmers.

Assessment of the Patient's Status

Blood pressure, pulse, skin, color, capillary filling time, and pupil size should be monitored during all anesthesia. In addition, the central venous pressure of the severely traumatized patient should be monitored to detect early failure of the myocardium and overload with colloid solutions. The hourly urine output should be monitored to determine the efficacy of fluid therapy. Output should be at least 50 mL/hour if the extracellular fluid volume is being sufficiently replaced with a balanced salt solution. Monitoring of the pulmonary artery pressure and pulmonary capillary wedge pressure is required in some cases. (See Chap 4).

Premedication

The emphasis in anesthesia for trauma is on resuscitation. An obligation exists to relieve suffering of a patient whose physical condition will tolerate the effects of analgesic drugs. However, hypoxic agitation must be differentiated from suffering. Barbiturates should not be used if the patient is in pain, as in this circumstances they tend to produce the paradoxic response of excitement or depressed agitation rather than sedation. Narcotics are contraindicated for patients with closed head injuries, because they deepen the depression, produce miosis, and mask the progression of intracranial injuries. A preinduction antacid (i.e.).3 M sodium citrate) should be given in a single oral dose of 30 mL unless the patient has a penetrating injury of the gastrointestinal tract. For its drying effects and vagal depressant characteristics, an anticholinergic drug should be used for nearly all patients.

Choice of Anesthetic

The choice of agent varies from oxygen alone for the patient in hypovolemic shock to the full range of anesthetic agents for the patient with intact homeostatic mechanisms. Those agents and techniques should be chosen which tend to facilitate successful resuscitation. The patient who is hypoxic preoperatively should be managed with an anesthetic which can be given with the highest concentration of oxygen. Nitrous oxide is acceptable for obtunded and inebriated patients. Spinal anesthesia is useful for patients with injuries of the lower extremities if the central nervous system is not involved, if the blood volume has been replaced, and if the patient is not otherwise unamanageable.

A guiding principle in the choice of anesthetic agents and techniques is that complete suppression of sensation is not necessary and may be harmful if achieved by deep anesthesia. Extensive surgical procedures can be performed in analgesic planes of nitrous oxide, halothane, enflurane, or isoflurane or by combining light general and local anesthesia. Severely traumatized and unconscious patients will require oxygen only and perhaps a muscle relaxant.

Postoperative Management

Not all the effects of massive trauma may be apparent at the same time. Following definitive correction of damage in one area, the patient must be closely observed for evidences of injury in other areas. The usual principles of recovery-room care must be applied. These include oxygen by mask, at least until the patient is awake and oriented; periodic use of intermittent positive-pressure breathing; frequent turning from side to side; and monitoring of the blood pressure, pulse rate, adequacy of ventilation, urine output, fluid infusion, gastric suction, emergence from anesthesia, and evidences of continued or recurring blood loss.

Delayed emergence from anesthesia may be caused by many factors, including possible head injury from the initial trauma or brain damage from prolonged shock or hypoxia. Progression of nervous system lesions should be watched for even if head injury was not suspected prior to operation. If the patient remains motionless except for breathing, anesthetic overdosage may be the cause, but the differential diagnosis should include spinal cord injury, brain damage, persistent partial curarization, overdosage with curare antagonists, hypothermia, and alcohol or drug intoxication. Bizarre causes for failure to awaken include myasthenia gravis, hypothyroidism, hypoglycemia, sickle cell crisis, intermittent porphyria, and nonketotic hyperosmotic coma.

Hypoventilation is a difficult problem to assess clinically in the postoperative patient. It can be caused by one condition or by a combination of several perplexing conditions. The list of reasons for hypoventilation includes most of those considered in delayed emergence from anesthesia, ie, anesthetic overdosage or idiosyncrasy, relaxant overdosage or idiosyncrasy, overdosage with narcotics given for postoperative pain, endocrinopathies including myasthenia gravis and hypothyroidism, fluid overload, shock, neomycin or streptomycin administered intraperitoneally, upper and/or lower airway obstruction, respiratory restriction by dressings or casts, pneumothorax or hemothorax, abdominal distension, and pain.

An informed suspicion is required for the early diagnosis of hypoventilation, since the classic syndrome appears late and may be masked. Signs include restlessness, stridor or retractions, air hunger, disorientation or stupor, diminution of respiration (volume and/or frequency), hypertension which progresses to hypotension, tachycardia changing to bradycardia, and pallor or cyanosis. Chest radiographs may show atelectasis, pneumonitis, pneumothorax, or hemothorax. Spirometer measurements will confirm diminished tidal ventilation. Arterial blood-gas analysis will show hypercapnia, acidosis, and arterial unsaturation.

The proper treatment of hypoventilation is controlled positive-pressure ventilation. Other measures may be indicated for specific causes: atropine and neostigmine to reverse residual paresis from curare; naloxone to antagonize narcotics; and analeptics. All are useful but are secondary to good ventilatory support.

Principles in the Management of Wounds

Ronald C Jones, G Tom Shires

Primary Wound Management

The most important single factor in the management of contaminated wounds is adequate debridement. This old surgical principle frequently has been forgotten since the advent of antibiotics. All tissue which is dead, has a poor blood supply, or is heavily contaminated should be removed if at all possible. This is particularly true of subcutaneous fat and muscle. Skin with impaired blood supply should be removed initially because of its tendency to become infected. Granulation tissue formation and later grafting procedures are preferable. Following sharp debridement and hemostasis, the wound is irrigated with copious quantities of saline solution, depending on the area and degree of soft tissue injury and contamination. That the incidence of wound infection is inversely proportional to the amount of irrigation and debridement at the time of injury has been demonstrated by Singleton and by Peterson and confirmed clinically many times.

Local Care of Wounds

Glass or sharp instruments usually carry a minimal amount of foreign material into a wound and cause a minimal amount of tissue trauma. X-rays should be taken of any area in which the depth of the wound cannot clearly be seen. It is not uncommon for the deep portion of a stab wound to contain the tip of a knife blade or other foreign body. Stab wounds of soft tissues are explored in the emergency room with the gloved finger or under local anesthesia by extending the length of the laceration to determine the direction and extent of the wound and to rule out any major vessel, nerve, or organ injury. The wound is then irrigated with copious amounts of saline solution. If the wound is found not to penetrate the peritoneal cavity, a small soft-rubber Penrose drain is inserted and the wound is left open for drainage. The drain is removed in 24 hours. Gunshot wounds are debrided externally and left open for drainage. Suturing these wound leaves a close contaminated space, and the infection can easily spread to surrounding soft tissue structures. Deep lacerations involving the extremity with damage to major vessels and tendons and massive muscle injury are managed by controlling major vessel bleeding and immediately wrapping the wound in sterile dressings. An x-ray is taken, if indicated, but a severe laceration is not explored until the patient is in the operating room. This procedure prevents undue contamination of the wound in the emergency room before the patient is adequately prepared. Minor lacerations can be managed in the emergency room.

Fascia usually can be approximated, and, depending on the type of wound, the skin and subcutaneous tissue may or may not be closed initially. These wounds are often left open and have delayed primary closure in 3 to 5 days. Damaged muscle due to gunshot wounds is debrided, hemostasis is obtained, and the wound is irrigated as outlined above. The wounds are packed open and closed with delayed closure. All patients with such wounds receive antibiotics and tetanus toxoid.

Antibacterial soaps or detergent materials are not used to irrigate wounds when muscle, tendon, or blood vessels are visible. Severe chemical irritation to these structures may occur, with resultant structure impairment and delayed wound healing.

Many factors. such as the number and virulence of organisms, blood supply of tissue, host resistance, shock, adequacy of surgical debridement, tissue tension, dead space, hemostasis, age, and associated diseases, are responsible for infection. Condie demonstrated in dogs that obliterating dead space reduced the occurrence of wound infection in the presence of contamination. Viable bacteria can be demonstrated in many surgical wounds at the time of closure; however, few incisions become infected.

Cosmetic appearance is a secondary consideration; the primary aim is to avoid infection and cover vital structures. No attempt at plastic repair is made at the initial closure of a potentially contaminated wound. Jagged edges of skin with poor blood supply are trimmed, and any resulting unpleasant scar can be cared for at a later date when no infection is present. Most lacerations, regardless of location, will never need revision if they meet the criteria previously outlined for the primary closure.

Puncture Wounds. The most frequent puncture injury is that caused by a rusty nail in the foot. The patient is administered antibiotics both to prevent secondary infection and to aid in the prevention of tetanus, since this wound is not completely open to the air. Puncture wounds are debrided conservatively if they involve only the skin and subcutaneous tissue. Human tetanus immune globulin is given (250 mg) to the unimmunized patient. Debridement with conversion to an open wound and the administration of antibiotics and tetanus toxoid, whether or not the patient has been previously immunized, is also performed.

Power Mower Injuries. Injuries resulting from the use of power mowers have increased in recent years. These include injuries from flying objects thrown from the power mower and from the mower itself to the hands and feet, particularly the fingers and toes. Treatment has consisted of covering exposed bones with muscle and leaving the entire wound open. These injuries almost uniformly become infected if an attempt is made to close the wound primarily. Patients are treated with systemic antibiotics and tetanus prophylaxis, and the wounds are packed with fine-mesh gauze. Skin graftings and reconstructive procedures should be delayed.

Emergency Laparotomy

Incisions. A midline incision is regularly used for exploratory laparotomy in patients with abdominal trauma and does not endanger the abdominal muscle, blood supply, or nerve supply, or damage aponeuroses. Minimal ligatures are used on bleeders which are contained in small bits of tissue, as each extra ligature is a foreign body and enhances the chance of wound infection. Tissues should be kept moistened and gently handled. Surgical technique governs the development of wound infection as significantly as any single factor.

Suture. Number 0-Prolene is the suture material of choice for closing the uncomplicated midline abdominal incision, particularly in operations for traumatic lesions. It has not been the cause of draining sinuses following postoperative wound infections. Suture placement is probably the most important factor in the prevention of wound dehiscence. Sutures should not be placed at equal distances from the edge of the fascia, as they will fall in the same group of fibers; should one suture tear the fascia longitudinally, the tear may extend from suture to suture until dehiscence occurs. Sutures should be staggered or placed at varying intervals from the edge of the fascia. With such a closure, there should be no fear in having a patient cough vigorously for adequate postoperative pulmonary care. An occasional patient with minimal subcutaneous tissue will complain of pain in the incision when the suture is under a pressure point such as a belt. These sutures are easily removed under local anesthesia.

Simple interrupted suture is used to close the fascia and peritoneum in a single layer. This is felt to be superior to the figure-of-eight suture, because less tissue is gathered and the suture can be placed faster, thus reducing anesthesia time. Interrupted sutures are used instead of running sutures because a break in the suture material will not loosen the entire incision. Regardless of the type of suture or method of placement, the fascia should be loosely approximated and not strangulated. Tightening fascial sutures may lead to necrosis with the sutures subsequently cutting through the tissue. Retention sutures have not been regularly used. Routine antibiotic irrigation of the wound for the prevention of infection has not been necessary.

Through-and-Through Closure. Several local and systemic factors noted at the time of the original operation may make through-and-through closure the procedure of choice. This uses adjustable bridges and large braided nonabsorbable suture or German silver wire swaged on a large cutting needle. The bridges prevent cutting of skin by the wire and allow for swelling which occurs in the first 24 to 48 hours postoperatively. The bridges can be adjusted to compensate for swelling of tissues. Wounds massively contaminated from shotgun wadding and fecal material, in patients with steroids, or associated with massive infection and peritonitis are best handled with through-and-through closure. Often a single patient may have several indications for this type of closure such as chronic pulmonary disease, obesity, and/or chronic debilitating disease. Occasionally through-and-through closure is used at the end of a lengthy operation with a long incision to shorten anesthesia time if the patient is not tolerating the procedure well. This type of closure is routinely used in the patient requiring reoperation in the early postoperative period because of gastrointestinal bleeding or intestinal obstruction. The wires are left in place for 3 weeks. This measure has proved to be sure, safe, timesaving, and often lifesaving.

Infection. Infection and severe abdominal distension are frequently mentioned as causative factors in dehiscence. Routine use of the Levin tube may be prevented in the markedly contaminated abdomen by leaving the skin and subcutaneous tissue open down to the fascia for delayed primary closure. This method is frequently used in long operations or with excessive contamination such as from feces. Abdominal wounds frequently harbor coliform organisms if bowel injury has been sustained. These wounds are packed open with fine-mesh gauze, changed daily for debridement, and either closed at 5 days or allowed to granulate under closure. This procedure will usually result in an excellent scar.

Drains. Subcutaneous drains will not substitute for good hemostasis. Failure to obtain hemostasis will give rise to a hematoma which is an excellent culture medium for an already contaminated wound. Drains from the abdominal cavity are usually brought out through a separate stab wound and by the most direct route. This is especially true for some liver and pancreatic injuries. Drainage of the free peritoneal cavity is not attempted.

Antibiotics

Sepsis is related to the length of time which elapses between bacterial contamination of the traumatic wound or surgical incision and the start of treatment designed to prevent sepsis. The "golden period" for wound infection has been stated to be 6 hours, but the effectiveness of preventive antibiotics in surgical wounds has been shown to be no more than 3 hours. In fact, the shorter the time between contamination or surgical incision and the administration of antibiotics, the more effective are the antibiotics in preventing a bacterial infection.

Burke has demonstrated in animals injected with staphylococci that the steps which determine the size of a bacterial lesion take place very shortly after the bacteria reach the tissue. As the time interval between the injection of bacteria and the administration of an antibiotics increases, the antibiotic effect on the size of the lesion produced is decreased. Most of the antibiotic effect is over in 1 to 2 hours. As antibiotics injected more than 3 hours after staphylococci have been introduced have an effect on the size of the 24-hour lesion, it appears that there is little benefit from antibiotics administered 3 hours following the injection of staphylococci. This indicates that the antibiotic should be given early, so that it is in the tissue when the bacteria arrive.

Singleton has shown that the incidence of infection in wounds already 4 hours old can be reduced by freshening with gauze sponges before irrigation, as opposed to irrigation without scrubbing the wound edges. Scrubbing the wound with a solution was significantly more effective than instillation of the solution intraperitoneally. Howes found that irrigation of a contaminated crushed wound in rabbits before 3 hours resulted in a significant reduction in infections, but that infection was not prevented after 3 hours unless the wound was freshened with debridement.

A review of 400 patients sustaining gunshot and stab wounds to the abdomen indicated that the incidence of infection in patients with abdominal injuries who received prophylactic antibiotics penicillin and tetracycline in the emergency room or intraoperatively was lower (4.5 percent) than in patients who did not receive antibiotics until the immediate postoperative period or therapeutically (9 percent). Patients receiving gunshot wounds are at a four times greater risk of infection than stab wound victims. A more recent prospective study indicates it is important to provide antibiotic for both aerobic and anaerobic organisms. The infection rate is again much less following stab wounds than gunshot wounds. Cefoxitin appears to be as effective as the combination of clindamycin and tobramycin in the prevention of infection following abdominal trauma. If no significant injury is found at laparotomy, antibiotics are discontinued in the recovery room or postoperatively during the first 24 hours. With severe contamination, antibiotics are administered for 48 hours.

Viable bacteria can be demonstrated in many surgical wounds at the time of closure; however, only a minimal number later become infected. Therefore, the number of bacteria encountered in clean operations is not alone sufficient to produce sepsis. There is considerable evidence that other factors produce decreased host resistance.

Various regions of the body respond differently to wound contamination. Normal tissues have remarkable resistance to microorganisms, but devitalized tissues have limited resistance. Thus, the development of local wound infection depends greatly on the altered physiologic state of the wound.

Surgical materials and technique are also important. Suture material enhances the virulence of staphylococci severalfold. This occurs less with monofilament suture than with twisted or braided material. However, dead space is more important in the production of wound infection than is increased amount of suture material.

Approximately 80 percent of the organisms cultured from trauma patients with bacteremia are gram-negative. The mortality for polymicrobial bacteremia is almost twice that with single organisms. *Klebsiella pneumoniae, Bacteroides fragilis,* and *Pseudomonas aeruginosa* are the most frequent gram-negative organisms isolated. Enterococci remain the most common gram-positive organisms isolated from the blood cultures on the trauma services, and are frequently associated with intraabdominal abscesses and wound infection. The treatment of choice for enterococcal infection is penicillin and an aminoglycoside such as gentamicin or tobramycin.

The systemic antibiotic treatment of choice for suppurative peritonitis in the absence of identification of organisms includes penicillin, clindamycin, and an aminoglycoside such as gentamicin or tobramycin. The combination of penicillin and an aminoglycoside is effective against the enterococci, and the aminoglycoside is effective against over 95 percent of gram-negative organisms. Clindamycin is effective against anaerobes, particularly *B. fragilis.* Two-drug combinations such as penicillin and an aminoglycoside or clindamycin and an aminoglycoside are also usually effective. If a single antibiotic is preferred, cefoxitin or a third generation cephalosporin is the drug of choice. After cultures are available, antibiotics can be stopped or changed, occasionally to a single antibiotic, although mixed gram-positive and gram-negative infections are common.

Following severe abdominal trauma, intraabdominal abscess formation is common, even with prophylactic antibiotic therapy. The organisms recovered from abscesses and peritonitis include *E. coli, Klebsiella*, and *B. fragilis.* Gram-positive organisms include enterococci, anaerobic streptococci, and *Clostridium. B. fragilis* is the most common anaerobe isolated following penetrating abdominal trauma, and these organisms were significantly altered by the administration of a combination of clindamycin and an aminoglycoside. *B. fragilis* is the most significant anaerobe pathogen in infections below the diaphragm, and is the most common organism found in the colon, outnumbering gram-negative aerobes by a thousand times. Any abscess which fails to culture an organism is strongly suspected of containing anaerobes; this may be further supported by performing a Gram stain of the purulent material. Organisms present on Gram stain give some indication of which antibiotics are to be selected - ie, antibiotics for gram-positive, gram-negative, or a mixed infection.

A sinogram through any drain tract or wound is the simplest and most direct method of detecting an intraabdominal collection. Unless the patient is producing large quantities of purulent material through a drain tract, routine cultures of the drain tract are of limited benefit. However, if large volumes of purulent material are produced, the organisms isolated in this instance frequently are those present in a deeper abscess. Occasionally a sump drain may be placed through this drain tract and the abscess aspirated without the necessity of a formal laparotomy; however, the majority of these cases require formal drainage. Percutaneous catheter drainage by sonography is being performed, the success of which varies in each hospital. Prompt drainage and identification of the continued source of sepsis are most important.

Intraperitoneal Antibiotics. Intraperitoneal antibiotic irrigation is not routine on a trauma service. Toxic blood levels develop following intraperitoneal irrigation with kanamycin even with only 2 to 5 minutes of contact with the peritoneal cavity and a significant amount of the irrigant can not be recovered with suction. Patients with significant peritoneal contamination are given systemic antibiotics, the abdomen is irrigated with saline solution, the fascia is closed, and the skin and subcutaneous tissue left open for delayed primary closure, usually within 3 to 4 days. If the patient develops an infection following topical or intraperitoneal irrigation with antibiotics, the organisms isolated are usually resistant to the antibiotic used. This has been almost uniformly true in those patients receiving prophylactic antibiotics following penetrating abdominal trauma.

Bites and Stings of Animals and Insects

Ronald C Jones, G Tom Shires

Rabies

Incidence. In the USA an estimated 2 million human beings are bitten by animals yearly, and one-half million are bitten by dogs. Any mammalian animal may carry rabies. In 1981 there were 7221 laboratory-confirmed cases of rabies. The animals most frequently reported infected and the percentage of cases they accounted for were skunks (62 percent), foxes (3 percent), bats (12 percent), cattle (6 percent), dogs (3 percent), cats (14 percent), and racoons (7 percent). In 1981, for the first time, rabid cats outnumbered rabid dogs. Eighty-five percent of the rabies in this country was in wildlife species. Wildlife rabies has been reported in coyotes, opossum, otter, bobcats, bear, squirrel, deer, mink, woodchucks, coaties, and a badger. Domestic rabies has been reported in cattle, dogs, cats, horses, mules, sheep, goats, swine, and guinea pigs. The Communicable Disease Center estimates that this represents less than 10 percent of the cases that actually exist. In the past 5 years, there has been an average of two cases of human rabies per year. During the past 3 years, the incidence of rabies in wildlife has increased by 100 percent to levels seen 25 years ago. More cases of rabies in skunks and bats were reported in 1981 than ever before.

Epidemiology. Saliva from a rabid animal contains large numbers of the rabies virus and is inoculated through a bite, any laceration, or break in the skin. Animal experiments and at least two human infections indicate that animals and humans can become infected by bats, without being bitten, by inhalation of rabies virus. Girard examined bats and demonstrated rabies virus in the brain, kidney, urine, salivary gland, adrenal gland, and liver, using the fluorescent antibody test. Most cases of raccoon rabies previously reported were from Florida and Georgia, but they are now spreading north to Virginia and West Virginia.

The maintenance of wild and exotic animals such as skunks, raccoons, ocelots, and bobcats as household pets is discouraged since many of these animals are infected with rabies. If people insist on maintaining wild and exotic animals as household pets, these animals should be quarantined for a minimum of 90 days after capture and vaccinated at least 30 days prior to being released to an owner. Annual vaccination is recommended.

Dogs and cats bitten by a known rabid animal should be destroyed immediately. If the animal has been vaccinated within the previous 3 years, it should be revaccinated immediately and confined for 90 days.

Diagnosis. Circumstance of the Bite. Circumstances surrounding the attack frequently furnish vital information as to whether or not vaccine is indicated. Most domestic animal bites are provoked attacks; if this history is obtained, rabies vaccine can usually be withheld if the animal appears healthy. Children are frequently bitten while attempting to separate fighting animals or while teasing or accidentally hurting the animal. Bites during attempts to feed or handle an apparently healthy animal should generally be regarded as provoked. Frequently the patient has attempted to handle a sick animal.

Although vaccination of the animal does not totally rule out the possibility of transmitting rabies, it is over 90 percent effective. A small number of dog rabies have apparently involved vaccine failure.

Bites from rodents, including squirrels, chipmunks, rats, and mice, seldom require specific rabies prophylaxis. Each case of possible exposure must be studies individually before a conclusion can be reached as to whether antirabies therapy is indicated. An unprovoked attack is more likely to indicate that the animal is rabid.

Extent and Location of Bite Wound. The likelihood that rabies will result from a bite varies with its extent and location. For convenience in approaching management, two categories of exposure are widely accepted:

Severe. Multiple or deep puncture wounds, or any bites on the head, face, neck, hands or fingers.

Mild. Scratches, lacerations, or single bites on areas of the body other than the head, face, neck, hands, or fingers. Open wounds, such as abrasions, suspected of being contaminated with saliva also belong to this category.

Laboratory Diagnosis. The direct focus inhibition test of brain material is the recommended technique to diagnose rabies. The intracerebral inoculation of mice combined with the microscopic examination of brain tissue for Negri bodies is still one of the most useful tests in the laboratory diagnosis of rabies and should be used whenever human beings have been bitten by suspect animals and the direct focus inhibition test is negative.

Management of Biting Animals. Most animals bites of human beings are caused by dogs and cats, and in most instances it is possible to observe the biting animal for the development of rabies. Domestic animals that bite a person should be captured and observed for symptoms of rabies for 10 days. If none develop, the animals may be assumed to be nonrabid. If the animal dies or is killed, the head should not be damaged but should be sent promptly to a public health laboratory for examination. The tissue requires refrigeration, but not freezing, and transportation to the laboratory following death of the animal should be rapid. Clinical signs of rabies in wild animals cannot be interpreted reliably; therefore, any wild animal that bites or scratches a person should be killed at once (without unnecessary damage to the head) and the brain examined for evidence of rabies.

Information from the county healthy department regarding which animals, both domestic and wild, have been reported to be rabid within the past 10 years in the particular area may indicate a possible specific animal transmitting rabies.

Exposure of Persons Previously Immunized. For mild exposure of a person who has demonstrated an antibody response to antirabies vaccination received in the past, a single booster dose of vaccine is recommended. In the case of severe exposure, five daily doses of vaccine should be given followed by a booster dose 20 days later.

If it is not known whether an exposed person has had antibody, the complete postexposure antirabies treatment should be given. Because of variation in vaccine potency and individual response, immunization should not be considered complete until antibody is demonstrated in the serum. Farrar et al have demonstrated that most persons receiving three or more injections of any rabies vaccine within 4 years will show antibody in the blood 30 days after a single booster injection of duck embryo vaccine (DEV), a killed virus.

Preexposure Prophylaxis. Those whose vocations or avocations result in frequent contact with dogs, cats, foxes, skunks, or bats should also be considered for preexposure prophylaxis.

A significant number of citizens of the USA have been and, with increasing frequency, will continue to be exposed to rabies in other countries where rabies in dogs is a major problem. Because rabies in animals is widespread in large areas of Asia, Africa, and Latin America, the Foreign Quarantine Program of the US Public Health Service has recently advised that preexposure immunization against rabies be suggested for Americans traveling in these areas.

Three 1-mL injections of human diploid cell vaccine (HDCV) given intramuscularly in the deltoid area on day 0, 7, and 21 or 28 are required. This series of four injections can be expected to have produced neutralizing antibody in all patients. Rabies has been reported to develop in a patient following four doses of HDCV when human rabies globulin was not also given. A recent study from the Wistar Institute and University of Illinois demonstrated all patients who received the usual dosage of both HDCV and human rabies immune globulin (HRIG) developed high titers of neutralizing antibodies by day 35 and two-thirds had protective titers by 7 days. The simultaneous administration of HRIG did not significantly interfere with the antibody response.

Accidental Human Exposure to Vaccine. Accidental inoculation may occur in individuals during administration of animal rabies vaccine. Such exposures to inactivated vaccines constitute no known rabies hazard. There have been no cases of rabies resulting from needle or other exposure to a licensed modified live virus vaccine in the USA.

Postexposure Prophylaxis. Incubation period. It is generally accepted that the incubation period for rabies in human beings ranges from 10 days to 1 year, most cases occurring within 4 months of the time of exposure. In cases of exposure of the head, neck, or upper extremities, the incubation period is potentially less than 30 days.

Immediate Local Care. Not all persons bitten by rabid animals contracts the disease. Vigorous local treatment to remove possible rabies virus may be as important as specific antirabies therapy. Free bleeding from the wound is encouraged. Local care of an animal bite should consist of:

1. Thorough irrigation with copious amounts of saline solution.
2. Cleansing with a soap solution.
3. Debridement.
4. Administration of antibiotic when indicated to prevent bacterial infection.
5. Administration of tetanus toxoid.

6. Immediate suturing of the wound generally is not advised, since it may contribute to the development of rabies, but a severe laceration secondary to a dog bite may be sutured if exposure to rabies is unlikely.

Passive Immunization. Human rabies immune globulin (HRIG) in combination with HDCV is considered the best postexposure prophylaxis. HIRG, 20 IU/kg of body weight is recommended for most exposures classified as severe, for all bites by rabid animals or those suspected of having rabies, for unprovoked bites by wild carnivores and bats, and for nonbite exposure to animals suspected of being rabid. A portion of the HRIG is used to infiltrate the wound, and the remainder administered intramuscularly. When indicated HRIG is used instead of equine serum and is used regardless of the interval between exposure and treatment. HRIG is given only once, as early as possible following exposure. The use of human immune antirabies globulin is accompanied by five intramuscular 1.0-mL doses of HDCV. If HRIG is not available, the recommended dose of equine antibodies serum is 40 IU/kg of body weight.

Active Immunization. ***Primary Immunization.*** Over 35.000 people per year undergo postexposure prophylaxis after bites by suspected or proven rabid animals. Five intramuscular 1.0-mL doses of HDCV on days 0, 3, 7, 14, and 28 are administered. The routine serologic testing of persons who receive recommended preexposure or postexposure treatment regimens of HDCV is not necessary, nor is it necessary to perform routine serologic testing following booster doses of HDCV for persons given the recommended primary HDCV vaccination or those shown to have had an adequate antibody response to primary vaccination with duck embryo vaccine or other rabies vaccination. The vaccine may be stopped if the animal is proved nonrabid.

Booster Doses. For maintenance of long-term immunity in persons continuously exposed to the risk of rabies, booster doses of HDCV should be given at 2-year intervals. A previously immunized person with demonstrated rabies antibody who is exposed to rabies should receive two doses of 1 mL of HDCV, one immediately and one 3 days later. Laboratory workers in rabies biologic exposure should receive a booster dose every 6 months or be tested for rabies antibody and vaccinated when antibody levels fall below 16 units as measured with the rapid fluorescent focus inhibition test. HRIG is not indicated.

Side Reaction to Vaccine. Following vaccination with HDCV, reactions have included warmth, redness, pain, swelling, and itching at the injection site in approximately 15 to 25 percent of patients. Other side effects have included fever, nausea, vomiting and diarrhea, lymphadenopathy, headache, and dizziness. Rarely have systemic reactions including hives and anaphylaxis occurred.

Manifestations and Treatment of Disease. Rabid dogs are noted to have purposeless movements with snapping, drooling, and vocal cord paralysis. Death usually occurs in 2 to 5 days. Humans die essentially the same way. There are 2 to 4 days of prodromal symptoms before the patient reaches the excited stage. Paresthesia in the region of the bite is an important early symptom. Symptoms noted with the onset of clinical rabies include headaches, vertigo, stiff neck, malaise, lethargy, and severe pulmonary symptoms including wheezing, hyperventilation, and dyspnea. The patient may have spasm of the throat muscles with dysphagia. The outstanding clinical symptom of rabies is related to swallowing. Drooling, maniacal behavior, and convulsions ensue and are followed by coma, paralysis, and death.

Instead of sedation and symptomatic treatment only, it is now recognized that intensive respiratory supportive care may be beneficial, in view of a case of human rabies in which the patient survived. Strict attention was given to the management of airway, pulmonary care, cardiac arrhythmias, and seizures. This included tracheostomy, vigorous suctioning, Dilantin for seizures, close monitoring of blood gases, electrocardiograms, electroencephalograms, and a ventricular shunt. Nursing care is extremely important. Probably many organs are involved, including brain, heart, and lungs.

One case of human rabies has been treated with interferon in the USA. In animal studies interferon has been shown to offer protection against challenge by rabies virus only when it is administered before or shortly after virus challenge. Once clinical disease develops, the use of interferon is justified because clinical rabies is almost uniformly fatal despite active or passive immunization.

Snakebites

Incidence. In North America all the poisonous snakes of medical importance are members of the family Crotalidae, or pit vipers, with exception of the coral snake. Coral snakes are scattered from Florida to southern Arizona, are biologically related to the Indian cobra, and produce a different envenomation syndrome than the crotalids. The pit vipers include the rattlesnake, cottonmouth moccasin, and copperhead.

Approximately 8.000 persons are bitten each year by poisonous snakes. Over 98 percent of snakebites occur on the extremities. Thirty-five percent of snakebites occur in children less than 10 years of age, usually in an area around their homes. Since 1960, an average of 14 victims have died annually as a result of snakebites. Seventy percent of all such deaths occur in five states: Texas, Georgia, Florida, Alabama, and southern California. Rattlesnakes are responsible for approximately 70 percent of all deaths due to snakebite. Death from the bite of a copperhead snake is extremely rare, probably not exceeding an incidence of 0.01 percent.

Poisonous Versus Nonpoisonous Snakes. Pit vipers are named for the characteristic pit, a heat-sensitive organ, that is located between the eye and the nostril on each side of the head. As a rule, these snakes may be identified by their elliptical pupils, as opposed to the round pupil of harmless snakes. Nonpoisonous snakes do not have pits. However, the coral snake does have a round pupil and lacks the facial pit. Pit vipers have two well-developed fangs that protrude from the maxillae, whereas nonpoisonous snakes have rows of teeth without fangs. Pit vipers also may be identified by turning the snake's belly upward and noting the single row of subcaudal plates. Nonpoisonous snakes have a double row of subcaudal plates. The coral snake is a brightly colored small snake with red, yellow, and blacks rings. This color combination occurs also in nonpoisonous snakes, but the alternating colors are different. Only the coral snake has a red ring next to a yellow ring; when red touches yellow, it is a coral snake. The nose of the coral snake is black.

The venoms of poisonous snakes consist of enzymatic, complex proteins which affect all soft tissues. Venoms have been shown to have neurotoxic, hemorrhagic, thrombogenic, hemolytic, cytotoxic, antifibrin, and anticoagulant effects. Phospholipase A is probably responsible for hemolysis. Most venoms contain hyaluronidase, which enhances the rapid spread of venom by way of the superficial lymphatics. There may be considerable variation in the venom effect. Either neurotoxic features such as muscle cramping, fasciculation, weakness, and respiratory paralysis or hemolytic characteristics may predominate depending on the snake and the patient.

Clinical Manifestations of Snake Venom Poisoning. Pain from the bite of a poisonous snake is excruciating and probably the symptom that most easily differentiates poisonous from nonpoisonous snakebites. Poisonous snakes characteristically produce one or two fang marks, whereas nonpoisonous snakes may produce rows of punctures. Local signs and symptoms may include swelling, tenderness, pain, and ecchymosis and may appear within minutes at the site of the venom injection. If no edema or pain is present within 30 minutes following the injury, the pit viper probably did not inject any venom. Swelling may continue to increase for 24 hours. Hemorrhagic vesiculations and petechiae may appear in the first 24 hours, with thrombosis of superficial vessels and eventual sloughing of tissues. Systemic symptoms include paresthesias and muscle fasciculations. Muscle fasciculations are most common following a rattlesnake bite and often are in the perioral region. Hypotension, weakness, sweating and chills, dizziness, nausea, and vomiting are other systemic symptoms.

Rattlesnake. Most rattlesnakes probably eject less than 50 percent of their venom during a single biting act. Following a rattlesnake bite, ecchymosis, hemorrhagic vesiculation, swelling of the regional lymph nodes, weakness, fainting, and sweating commonly are reported. The venom produces deleterious changes in the blood cells, defects in blood coagulation, injuries to the intimal linings of vessels, damage to the heart muscles, alterations in respiration, and, to a lesser extent, changes in neuromuscular conduction. Pulmonary edema is common in severe poisoning, and hemorrhage into the lungs, kidneys, heart, and peritoneum may occur. Hematemesis, melena, changes in salivation, and muscle fasciculations may be seen. Urinalysis may reveal hematuria, glycosuria, and proteinuria. Red blood cells and platelets may decrease, and bleeding and clotting times are usually prolonged.

Coral Snakes. The coral snakes contributes only 1.5 percent of all deaths from poisonous snakes. Bites by the coral snake occasionally provoke blurred vision, ptosis, drowsiness, increased salivation, and sweating. The patient may notice paresthesia about the mouth and throat, sometimes slurring of speech, and nausea and vomiting. Pain is not a constant complaint, nor is edema a constant finding. Thus coral snake venom causes more extensive changes in the nervous system, but death may occur from cardiovascular collapse.

Laboratory Evaluation. Blood should be immediately drawn for typing and cross matching, since hemolysis may later make this difficult. Since hemolysis and injury to kidneys and liver may occur, it is important to follow alterations in clotting mechanism and renal and liver function as well as electrolyte status. Routine tests include a complete blood count, platelet count, prothrombin time, partial thromboplastin time, urinalysis, blood sugar, BUN, and electrolytes. Additional tests depending on the severity of the bite include fibrinogen, red cell fragility, clotting time, and clot reduction time.

Local Treatment of Snakebites. The treatment of the bite of a poisonous snake varies considerably but is related to the length of time from the bite until treatment is instituted. The tourniquet and incision and suction as well are appropriate if employed within 1 hour from the time of the bite. The Committee on Trauma of the American College of Surgeons in consultation with many experts in this field developed a poster for emergency department use entitled "Management of Poisonous Snake Bites".

Immobilization. Patients are kept quiet, and the extremity is immobilized. Splinting the limb may inhibit the local diffusion of venom by stopping the movement of muscle bellies within their sheaths. Snyder and Knowles have shown in animals that exercise greatly enhances the absorption of venom and as much as 30 percent may be absorbed within 30 minutes following vigorous exercise.

Tourniquet. The snake injects venom into the subcutaneous tissue and this is absorbed by the lymphatics. As almost none of the venom is absorbed through the bloodstream, the tourniquet is applied loosely to obstruct only venous and lymphatic flow. The index finger should be easily inserted beneath the tourniquet after its application. The tourniquet is not released once applied and may be left in place during the 30 minutes that suction is being applied. Snyder and Knowles have injected ^{131}I-tagged venom into dogs and have demonstrated that if the tourniquet is applied promptly, less than 10 percent of the venom leaves the leg of the dog in 2 hours. The tourniquet may be removed as soon as (1) an intravenous infusion is started, (2) antivenin is ready for administration, and (3) if the patient is not in shock.

Incision and Suction. Incision and suction should be accomplished as soon as possible, but within 30 minutes, after snakebite. Approximately 50 percent of subcutaneously injected venom can be removed when the suction is started within 3 minutes. Treatment in the first 5 minutes is important, since half the value of suction is lost after 15 minutes and almost all after 30 minutes. A 30-minute period of suction extracts about 90 percent of the venom which can be removed in this procedure. The incision should be 1/4 in long and 1/8 in deep, longitudinal and not cruciate. When two fang marks are seen, the depth of the venom injection is generally considered to be one-third of the distance between the fang marks. A good rule of thumb has been to incise the skin and subcutaneous tissue in length the same distance between the fang marks to ensure adequate drainage. A superficial incision may be easily accomplished by raising the skin with a pinch between two fingers. Severe bites may result in envenomation beneath the fascia, and surgical exploration may be indicated. Incisions made proximal to the bite will usually recover venom insufficient to make the procedure worthwhile and thus are contraindicated.

When a suction cup is not available after incisions have been made, mouth suction may be used if the mucosa of the mouth is intact. Snake venom is not absorbed through an intact oral mucosa but may be absorbed when there is any denuded area or minor laceration of the mucosa. The digestive juices neutralize poisonous snake venom if it is swallowed.

Russell has demonstrated the serosanguinous fluid removed during suction contains substances which when injected into animals produce a fall in systemic blood pressure and changes in respiratory rates and alterations in the electrocardiogram and electroencephalogram similar to those observed following injection of crude *Crotalus* venom. If exudate removed during suction contains venom, its removal should increase the chances of survival.

Excision. Snyder and Knowles showed that wide excision of the entre area around the snakebite within 1 hour from the time of injection can remove most of the venom. Excision of the fang marks including skin and subcutaneous tissue should be considered in severe bites and in patients known to be allergic to horse serum who are seen within 1 hour following the bite. However, the average snakebite does not require surgical excision. This procedure is reserved for the most severe envenomations. Most fatalities from snakebites do not occur for 6 to 48 hours following the bite, giving time to institute these first-aid measures.

Cryotherapy. This form of therapy has been used but is not recommended, as it only increases the local area of necrosis. McCollough and Gennard analyzed cryotherapy in relation to amputation and noted that 75 percent of children requiring amputation following snakebite has received cryotherapy. Cooling or refrigeration experimentally produces intense vasoconstriction and thus decreases the amount of antivenin getting into the area of the bite. Gill found that dogs developed edema and ecchymosis just as rapidly and extensively with cryotherapy as without it. There was no evidence to suggest inactivation of venom by tissue temperature of 15° and below.

Systemic Treatment. The most important treatment for a snakebite is antivenin, although many patients will not require it. Copperhead venom is not usually very toxic and rarely necessitates antivenin. Most snakebite fatalities in the USA during the past 20 years have involved either delay in obtaining treatment, no antivenin treatment, or inadequate dosage. Because antivenin contains horse serum, its administration requires prior skin testing. Epinephrine 1/1000 in a syringe should be available before antivenin is given.

Information concerning identification of a snake or proper antivenin frequently can be obtained from the nearest zoo herpetarium. A major problem with bites by exotic poisonous snakes is the choice and availability of suitable antiserum. Physicians confronted with this situation may obtain advice from the local poison control center or from the Antivenin Index Center of the Oklahoma Poison Information Center, Oklahoma City, Oklahoma (405-271-5454).

Because the rattlesnake, cottonmouth moccasin, and copperhead belong to the same biologic family, their bites can be treated by the same antivenin (antivenin Crotalidae polyvalent).

The coral snakebite is rare, and the antivenin is different from that for the pit vipers. A North American coral snake *(Micrurus fulvius)* antivenin has been developed. It effectively treats *Micrurus* coral snake bites but is not effective in treating bites of *Micruroides*, the genus native to Arizona and New Mexico. Coral snake antivenin can be obtained from many state public health departments. Also, a large supply has been stocked at the US Public Health Service National Communicable Disease Center in Atlanta, Georgia.

The time of antivenin administration depends upon the snake involved. If the bite is from a snake with quick-acting venom, such as a king cobra or mamba, an initial dose of antivenin may be required as part of the first-aid treatment. However, for bites by most snakes, such as rattlesnakes and others with less virulent venom, antivenin should be withheld until a physician can determine if it is indicated. Approximately 30 percent of all poisonous snakebites in the USA result in no venenation.

The indication for antivenin is governed by the degree of venenation, as outlined by Wood et al and modified by Parrish and by McCollough and Gennard:

Grade 0 - no venenation: One or more fang marks; minimal pain; less than 1 in of surrounding edema and erythema at 12 hours; no systemic involvement.

Grade I - minimal venenation: Fang marks; moderate to severe pain; 1 to 5 in of surrounding edema and erythema in the first 12 hours after bite; systemic involvement usually not present.

Grade II - moderate venenation: Fang marks; severe pain; 6 to 12 in of surrounding edema and erythema in the first 12 hours after bite; possible systemic involvement including nausea, vomiting, giddiness, shock, or neurotoxic symptoms.

Grade III - severe venenation: Fang marks; severe pain; more than 12 in of surrounding edema and erythema in the first 12 hours after bite; grade II symptoms of systemic involvement usually present and may include generalized petechiae and ecchymoses.

Grade IV - very severe venenation: Systemic involvement is always present, and symptoms may include renal failure, blood-tinged secretions, coma, and death; local edema may extend beyond the involved extremity to the ipsilateral trunk.

With frequent observations using this classification, the severity of the bite will be found to increase with time, and thus a change in grade is observed. Most bites will have reached a final staging within 12 hours.

Antivenin usually is not required for grades 0 or I venenation. Grade II may require three or four ampules, and grade III usually requires five to fifteen ampules. If symptoms increase, several ampules may be required during the first 2 hours. Because children are smaller, they receive relatively larger doses of venom, which places them in a higher-risk group. Thus, the smaller the patient, the relatively larger the required dose of antivenin. Proper dosage can be estimated by observing the clinical signs and symptoms. If systemic manifestations are severe, antivenin should be given rapidly, by intravenous drip, in large doses.

The injection of antivenin locally around the bite is not advised, as massive edema usually occurs in that area. Absorption from this area is poor, and additional antivenin fluid will further decrease perfusion and perhaps increase tissue anoxia.

Antivenin is given by intravenous drip in 250 mL of normal saline solution or 5% glucose solution. McCollough and Gennard have demonstrated in studies with radioisotopes that antivenin accumulates at the site of the bite more rapidly after *intravenous* than after *intramuscular* administration. The dose of intravenously administered antivenin can be more easily titrated with response to treatment, and the amount administered is based on improvement in signs and symptoms, not by weight of the patient. Antivenin is administered until severe local or systemic symptoms improve. When it is obvious that antivenin therapy will be instituted, the tourniquet should be left in place until antivenin is started intravenously. All patients who receive antivenin are admitted to the hospital.

If too much time has elapsed for excision to be effective and the patient is allergic to horse serum, a slow infusion of one ampule of antivenin in 250 mL of 5% glucose solution may be given in a 90-minute period with constant monitoring of the blood pressure and electrocardiogram depending on the seriousness of the bite. If an immediate reaction occurs, the antivenin is stopped, and a vasopressor, epinephrine, and perhaps an antihistamine may be required, depending on the severity of the reaction.

The incidence of serum sickness is directly related to the volume of horse serum injected. Of patients receiving 100 to 200 mL of horse serum, 85 percent will have some degree of sensitivity in 8 to 12 days following injection. This complication will have to be dealt with at a later time since some patients may require from 1 to 5 ampules of antiserum every 4 to 6 hours.

Steroids have been used but are of questionable benefit. Russell experimentally used doses of methylprednisolone up to 100 mg/kg in mice and noted that steroids neither affected survival nor prevented tissue damage and inflammation. When used in association with the antivenin, there is a decreased incidence of serum sickness. According to Parrish, cortisone and ACTH do not affect the survival rate of animals poisoned with pit viper venom. Tracheal intubation and prolonged ventilation may be required for respiratory failure. Acute renal failure may require renal dialysis.

Intravenous fluids are frequently required to replace the decreased extracellular fluid volume resulting from edema formation. Fascial planes may become very tense, with obstruction of venous and later arterial flow, requiring fasciotomy.

These patients may need blood, since anemia can develop from the hematologic effects. As afibrinogenemia has been reported, fibrinogen may be required. Vitamin K may also be required. Bleeding and clotting abnormalities are treated with antivenin in addition to blood components. Antibiotics are started immediately to prevent secondary infection, and tetanus toxoid is administered. The most common species of organisms isolated from rattlesnake venom are *P. aeruginosa, Proteus* species, *Clostridium* species, and *B. fragilis.*

Stinging Insects and Animals

Hymenoptera

The most important insects that produce serious and possibly fatal anaphylactic reactions are the arthropods of the order Hymenoptera. This group includes the honeybee, bumblebee, wasp, yellow and black hornet, and the fire ant. The venom of these stinging insects is just as potent as that of snakes and causes more deaths in the USA yearly than are caused by snakebites. Drop for drop, the venom of the bee is just as potent as that of the rattlesnake. Parrish noted that, of 460 deaths between 1950 and 1959, 50 percent were due to Hymenoptera, 30 percent due to poisonous snakes, and 14 percent due to spiders. Scorpions accounted for eight deaths. No other poisonous creature killed more than 5 persons.

Insects of the Hymenoptera group, except the bee, retain their stinger and are in a position to sting repeatedly, each time injecting some portion of the venom sac contents. The worker honeybee sinks its barbed sting into the skin, and it cannot be withdrawn. As the bee attempts to escape, it is disemboweled. The stinger with the bowel, muscles and venom sac attached are left behind. The muscles controlling the venom sac, although separated from the bee, rhythmically contract for as long as 20 minutes, driving the stinger deeper and deeper into the skin, and continuing to inject venom.

Bee venoms contain histamine, serotonin, acetylcholine, formic acid, phospholipase A, hyaluronidase, and other proteins. Once the proteins of these insects are injected, the patient may become sensitized and be a candidate for anaphylactic response with the next sting.

Clinical Manifestations. Symptoms consist of one or more of the following: localized pain, swelling, generalized erythema, a feeling of intense heat throughout the body, headache, blurred vision, injected conjunctiva, swollen and tender joints, itching, apprehension, urticaria, petechial hemorrhages of skin and mucous membranes, dizziness, weakness, sweating, severe nausea, abdominal cramps, dyspnea, constriction of the chest, asthma, angioneurotic edema, vascular collapse, and possible death from anaphylaxis. Fatal cases may manifest glottal and laryngeal edema, pulmonary and cerebral edema, visceral congestion, meningeal hyperemia, and intraventricular hemorrhage. Death apparently results from a combination of shock, respiratory failure, and central nervous system changes. Most deaths from insect stings occur within 15 to 30 minutes following the bite or sting.

Treatment. Early application of a tourniquet may prevent rapid spread of the venom. Affected persons should be taught to remove the venom sacs if present, being careful not to squeeze the sac. It may be necessary for some patients to carry an emergency kit, which is commercially available, supplied with a tourniquet, sublingual isoproterenol in 10-mg tablets, epinephrine hydrochloride aerosol for inhalation to reduce bronchospasm and laryngeal edema, and tweezers to remove the sting and venom sac until a physician is available. The patient should be taught to give himself an epinephrine injection. Patients having severe reactions should first receive 0.3 to 0.5 mL of a 1:1000 solution of epinephrine intravenously. Antihistamines also may be intravenously administered, and oxygen may be given. If wheezing continues, aminophylline may be given slowly intravenously. Occasionally, the patient may require a tracheostomy.

Desensitization. The Insect Allergy Committee of the American Academy of Allergy noted that 50 percent of people who had a severe generalized reaction to stings had no previous history of a severe reaction. A sharp rise was noted in the proportion of serious reaction after the age of thirty, suggesting increasing sensitivity as the total number of stings increase. Patients with a history of severe local or systemic involvement following insect stings should be desensitized.

For the past several years, treatment has been with whole-body extracts of stinging insects. Although insect venoms do contain antigens common to the insect bodies, the allergens responsible for the clinical symptoms of the disease appear to be secondary to the venoms.

It is now concluded that whole-body extract used for desensitization is not as effective as previously thought. In contrast, venom immunotherapy is safe and is highly effective within a few weeks. Venom immunotherapy is the recommended form of prophylaxis for insect sting allergy.

It has been suspected that a refractory period of 10 to 14 days persists following an insect sting during which skin tests may be negative. Therefore, skin tests should be delayed several weeks after stinging and be performed with extreme caution. Cross reactions to the wasp, bee, and yellow jacket may occur.

Stingrays

Approximately 750 persons each year are stung by stingrays. However, during the past 60 years, only two deaths in this country has been attributed to the venom of the stingray.

As the spine, which is curved and has serrated edges, enters the flesh, the sheath surrounding the spine ruptures, and venom is released. As the spine is withdrawn, fragments of the sheath may remain in the wound. The wound edges are often jagged and bleed freely. Pain is usually immediate and severe, increasing to maximum intensity in 1 to 2 hours and lasting for 12 to 48 hours.

Treatment. This consists of copious irrigation with water to wash out any toxin and fragments of the spine's integumentary sheath. Russell noted that the venom is inactivated when exposed to heat. Therefore, the area of the bite should be placed in water as hot as the patient can stand without injury for 30 minutes to 1 hour. After soaking, the wound may be further debrided and treated appropriately. Patients treated in this manner were shown to have rapid and uncomplicated healing of the wound. Patients not treated with heat had tissue necrosis with prolonged drainage and chronically infected wounds.

Portuguese Man-of-War

This coelenterate is commonly found along our southern Atlantic coast. Its tentacles are covered with thousands of stinging cells, the nematocysts, capable of emitting microscopic organelles, the nematocysts, each of which consists of a small sphere containing a coiled hollow thread. When activated by touch, the thread is uncoiled with such force that it can penetrate skin and even rubber gloves. On contact, venom in the cyst is injected into the victim through the thread. This sting produces extreme pain and often signs of clinical shock; however, no deaths have been reported due to this sting alone.

Following a severe sting there may be almost immediate severe nausea, gastric cramping, and constriction and tightness of throat and chest with severe muscle spasm. There is intense burning pain with weakness and perhaps cyanosis with respiratory distress.

Treatment. The most important emergency treatment is to inactivate the nematocysts immediately, to prevent their continuous firing of toxins. This is accomplished by application to the involved area of a substance of high alcohol content, such as rubbing alcohol. This is followed by application of a drying agent, such as flour, baking soda, talc, or shaving cream. The tentacles may then be removed by shaving. Alkaline agents, such as baking soda, are then applied to the involved area in order to neutralize the toxins, which are acidic. Antihistamines may be helpful in controlling the inflammatory response after these emergency treatments. Demerol and Benadryl may dramatically relieve the pain and symptoms. Aerosol corticosteroid-analgesic balm is helpful.

Spider Bites

Black Widow Spider

The most common biting spider in the USA is the black widow *(Latrodectus mactans)*. This spider is black and globular, with a red hourglass mark on the abdomen. *Latrodectus* venom is primarily neurotoxic in action and appears to center on the spinal cord. Following a bite by the black widow spider, the patient usually experiences sudden pain, and in a few minutes a small weal with an area of erythema appears. The most prominent physical finding is generalized muscle spasm. Even if bitten on an extremity, the spasm may involve the abdomen and chest. Although the abdomen is rigid, it is nontender. The severe symptoms last from 24 to 48 hours.

Treatment. Treatment has consisted of narcotics for the relief of pain and a muscle relaxant for relief of spasm. Either methocarbamol (Robaxin) or 10 mL of a 10% solution of calcium gluconate relieves symptoms. Methocarbamol can be administered intravenously, 10 mL over a 5-minute period, with a second ampule started in a saline solution drip. Specific treatment involves the use of an antivenin. This is administered intramuscularly, after appropriate skin tests, since it contains horse serum.

North American Loxoscelism

The distinguishing mark of the *Loxosceles reclusa* is the darker violin-shaped band over the dorsal cephalothorax. The spider is native to the south central USA and is found both indoors and outdoors and under cliffs and overhanging rocks. The first recognized and documented case in the USA of a bite by *Loxosceles reclusa* was not published until 1957.

Clinical Manifestations. The bite may go unnoticed because pain may not occur until 6 to 8 hours afterward. A generalized macular and erythematous rash may appear in 12 to 24 hours. Erythema develops, with bleb or blister formation surrounded by an irregular area of ischemia. A zone of hemorrhage with induration and a surrounding halo of erythema may develop peripherally. The central ischemia turns dark, an eschar forms by the seventh day and by the fourteenth day the area sloughs, leaving an open ulcer. Approximately 3 weeks is required for the lesion to heal. Severe systemic manifestations may occur in 24 to 48 hours in small children, with fever, chills, malaise, weakness, nausea, vomiting, joint pain, and even petechial eruption. The two principal systemic effects, hemolysis and thrombocytopenia, have been responsible for two deaths. Hemoglobinemia, hemoglobinuria, leukocytosis, and proteinuria may also occur. *Loxosceles* venom is chiefly cytotoxic in action.

Treatment. Immediate excision with primary closure has been advocated as the treatment of choice. This usually is not possible since the patient rarely can be certain of what bit him or has failed to recognize the type of spider. Several writers immediately administer steroids. The dose has varied from 30 to 80 mg of methylprednisolone daily, tapered over a period of several days. This seems to be the preferred treatment. Excision of the necrotic area with skin grafting may be required at a later date. Most spider bites are managed conservatively initially, reserving surgery for later if indicated.

Penetrating Wounds of the Neck and Thoracic Inlet

William H Snyder, G Tom Shires, Malcolm O Perry

Although penetrating injuries of the neck are uncommon in civilian surgical practice, the concentration of deep vital structures makes any cutaneous wound a potentially serious injury. Life-threatening consequences of unrepaired injuries of the larynx, trachea, pharynx, esophagus, and blood vessels of the neck and thoracic inlet mandate early diagnosis and operative correction. There is general agreement that penetrating wounds with over evidence of deep injuries require urgent operation. A difference of opinion exists regarding the necessity for operative exploration of patients without evidence of such injuries. Resolution of this controversy awaits documentation of the validity of normal diagnostic studies to exclude vascular and visceral injuries.

Before World War II, the treatment of penetrating wounds of the neck was largely nonsurgical unless major bleeding or deep injuries were obvious. Reported mortality rates were 18 percent of 188 cases in the Spanish-American War and 11 percent of 594 cases in World War I. During World War II the mortality rate fell to 7 percent, probably because of a variety of factors, including earlier tracheostomy, more frequent and expedient surgical exploration, antibiotics, and improvements in surgical and anesthetic techniques.

Since 1960, numerous civilian series have been reported and recent mortality rates approximate 5 percent. Most deaths are due to injured blood vessels, although tracheal and esophageal wounds account for some. Fogelman and Stewart pointed out that the mortality rate for their cases which were promptly explored was 6 percent, whereas for those in which surgical intervention was omitted or postponed the mortality rate was 35 percent. Their overall mortality was 11 percent. The results of reports proposing selective operative management of neck wounds are generally comparable to those recommending routine exploration. However, variations in the wounding agents and patient referral sources make such comparisons unreliable for formulating therapeutic recommendations. Exploration reveals a lesion requiring surgical repair in 45 to 65 percent of the patients operated upon, depending upon the criteria for operation.

It has been the policy at a big trauma service such as Parkland Memorial Hospital to "treat the platysma like the peritoneum" and explore virtually all neck wounds that penetrate the platysma. Explorations are performed in the operating room under general endotracheal anesthesia, regardless of the preoperative opinion as to the severity of the injury.

In 1867, Jones et al reviewed 274 penetrating neck wounds treated in this manner at Parkland Memorial Hospital. There were 11 deaths, for a mortality rate of 3.6 percent. Of the fatalities, four were due to complications from spinal cord injuries, three from massive hemorrhage, and the remainder from cerebral complications of vascular or laryngotracheal injuries. Of the 274 cases, 103 explorations were negative, ie, with no hematoma, no significant bleeding, and no damage to any named structure in the neck, although the tract of injury frequently was within millimeters of vital structures. In the negative explorations there were no deaths and the only complication was a superficial wound infection that cleared promptly with drainage. These patients usually were discharged within 72 hours to clinic follow-up if there were no associated injuries. Similar results have been documented more recently in the series reported by Sheely et al and Roon and Christensen.

Table 6-1 summarizes the injuries found in 15 patients in Jones' series with clinically "negative" neck wounds, ie, with no visible bleeding or hematomas, and no evidence of hemorrhagic shock. At some hospitals these wounds would not have been explored, and many probably would have healed uneventfully without surgical exploration. However, unexplored patients, apparently free of important injuries on examination in the emergency room, may bleed massively when a blood clot is shaken loose, or later develop a deep abscess from an unrecognized esophageal perforation. Even less serious injuries, those involving only subcutaneous tissues and muscles, may heal faster, and less frequently become infected, if hemostasis, debridement, and adequate drainage are accomplished. Bacteria thrive on extravasated blood and damaged tissue, and every penetrating wound is contaminated. The safest treatment for penetrating neck wounds is prompt and thorough surgical exploration under general anesthesia.

Table 6-1. Injuries in 15 Clinically "Negative"* Neck wounds

Total series = 274 patients

Innominate vein	2
Subclavian vein	1
Internal jugular vein	5
Thyrocervical artery	3
Thoracic duct	2
Esophagus (blast injury)	2
Ascending pharyngeal artery	1

* No visible bleeding, no visible hematoma, no shock.

Treatment. Initial Evaluation and Management. On admission to the emergency room, all patients with neck injuries are immediately evaluated regarding their systemic condition, ie, airway patency and adequacy of ventilation, blood pressure, pulse, and mental state. Peripheral signs of shock such as sweating, cold skin, and collapsed veins should be recorded. If there is external bleeding, pressure is applied for temporary hemostasis. Adequate ventilation may require endotracheal intubation in obtunded patients or tracheostomy if a laryngotracheal injury or a cervical hematoma has caused upper airway obstruction. One or two large-bore intravenous cannulas are inserted in peripheral veins and an infusion of Ringer's lactate solution is started while blood is drawn for typing and cross matching. If shock is present, the fluid is given rapidly; if there is no evidence of blood loss, the intravenous infusions are kept going by slow drip. When indicated, whole blood is administered as soon as it is available. Usually the salt solution will temporarily reverse the shock state until cross-matched blood is available. If shock is severe and is not improved promptly by the Ringer's lactate solution, type O, Rh-negative low-titer unmatched blood is infused rapidly until matched blood is available. Plasma has also been used but has no advantage over salt solutions; ie, both are quite helpful temporarily, although neither is a substitute for whole blood. Tube thoracostomy is often necessary for intrathoracic bleeding or pneumothorax from the commonly associated pulmonary injuries. If there is no clinic evidence of pneumothorax or hemothorax and the patient's condition is stable, an upright chest film is obtained with a physician in constant attendance.

If the extent of the injury is not apparent, the wound is very gently probed with a small hemostat, only to the depth of the platysma muscle. If the platysma has been penetrated, the probing is discontinued. Neck wounds should not be probed beneath the platysma muscle because hemostasis may be disrupted. No attempt is made to pass a nasogastric tube in the emergency room because of the danger of recurrent hemorrhage as a result of coughing or gagging.

Exsanguinating hemorrhage is the major initial risk for patients with penetrating injuries entering the mediastinum. The clinical presentation of such patients with vascular injuries varies from innocuous appearing cutaneous wounds to terminal hemorrhagic shock. Hemostasis may be transient and spontaneously break down or it may be disrupted by changes in intravascular or intrathoracic pressure. Acute hemorrhage from these injuries can sometimes be controlled by external pressure, but occasionally control requires an anterolateral thoracotomy in the emergency room. The innominate and right subclavian vessels can be controlled through a right thoracotomy, and the left subclavian artery controlled through a left chest incision.

Special x-ray studies such as contrast esophagography and arteriography may be useful, but are only considered in hemodynamically stable patients. Esophagography may locate the site of an esophageal wound to aid in the planning the operative approach, but its validity in excluding the presence of such a wound is questionable.

The potential benefits from preoperative arteriography can be related, in part, to the location of the wound. The neck proper extends from the base of the skull to about the level of the cricoid cartilage. This area corresponds to Zones II and III described by Monson or to the middle and upper neck. Penetrating wounds coursing inferior to the cricoid are considered wounds of the thoracic inlet or base of the neck (Zone I). An upper neck wound, whose course extends above the angle of the mandible (Zone III), often presents dangerous intraoperative problems. Arteriographic definition of the site and extent of arterial injury may importantly alter operative plans. Internal carotid injuries near the base of the skull are difficult to expose and cephalad control may be essentially impossible. Initial extracranial-intracranial arterial bypass (EC-IC) is a reasonable consideration in patients with such injuries. Cerebral protection, with an initial EC-IC, may occasionally be important in cephalad injuries with continued flow because intraluminal shunt insertion is often not possible. In addition, reconstruction of the internal carotid artery may not be technically feasible and ligation required. Operative control of midneck carotid wounds (between the mandible and the level of the cricoid cartilage - Zone II) is usually simple and arteriographic definition is less important. Vertebral artery injuries that may otherwise go undetected may be demonstrated if arteriography is performed on patients with injuries in this region.

Penetrating wounds of the low neck (Zone I) may involve vessels of the superior mediastinum and require thoracic incisions for adequate exposure. Arteriography is potentially helpful in such wounds, but the necessary delay poses substantial risk. In most anatomic sites, exacting arteriography accurately defines specific arterial lesions and confirms arterial integrity. In the superior mediastinum there are many important structures and risk of occult hemorrhage argues against substituting arteriography for operative exploration. The concentration of major arteries increases the likelihood of missing minor arteriographic defects that indicate the presence of major injuries. Such inaccuracies result because of the superimposition of dye columns caused by the spatial orientation of these vessels. The validity of "exclusion" arteriography, established for extremity injuries, cannot be transposed to the diagnostic evaluation of mediastinal wounds. For these reasons, operative exploration is indicated for most penetrating injuries suspected of entering the mediastinum.

Although arteriography may not reliably exclude mediastinal vascular injuries, it can be helpful in defining the site of arterial wounds. The decision to use arteriography for planning the operation must take into account delay and the risk of cardiovascular deterioration. The bleeding may be tamponaded by soft tissues, but this is tenuous as emphasized in a report by Flint of 146 patients with base-of-the-neck vascular injuries. Of the 90 patients initially normotensive, six (7 percent) became profoundly hypotensive en route to or shortly after arrival in the operating room. Rapid hemostasis was obtained operatively in all six patients and all survived, but the personnel and facilities available in the operating room played a major role. If these unanticipated events had occurred in the radiology suite, the outcome would most likely have been different. In summary, preoperative arteriography is frequently helpful in evaluating patients with potential arterial injuries of the neck and thoracic inlet, but it should not be used to obviate the need for operative exploration in patients with intrathoracic bleeding, and arteriograms should be considered only in stable patients.

The frequent absence of overt signs of vascular trauma and the minimal morbidity imposed by operative exploration was documented in Flint et al's review of 146 patients with base-of-the-neck vascular injuries. Thirty-two percent of these patients had no diagnostic signs of vascular injuries. Even innominate and subclavian vessel wounds had no overt manifestations in 29 percent of these patients with such injuries. Most of the injuries in these patients were adequately managed with cervical or transverse clavicular incisions, and very few of those without overt injury manifestations required thoracic incisions.

Anesthesia. Exploration is performed under general anesthesia, using an orotracheal airway with an inflatable cuff. The anesthetic agent varies considerably according to the specific problem, necessity for rapid induction, circulatory status, and preexisting disease. There are no specific contraindications in patients with neck injuries to any of the commonly used anesthetic agents or relaxants.

Anesthetic induction requires attention to different problems in patients with superior mediastinal injuries as compared to those with wounds of the neck proper. Intubation while awake is preferred in patients with wounds of the neck proper because difficulties imposed by cervical hematomas or upper airway edema may delay adequate oxygenation in paralyzed patients. In these wounds, disruption of existing hemostasis by retching or struggling with intubation is usually amenable to control by external pressure. On the other hand, intubation in patients with superior mediastinal wounds may produce major hemorrhage that cannot be controlled by local pressure. These patients less often have structural alterations of the upper airway, and intubation can more safely follow the infusion of muscle relaxants. Because gastric decompression is omitted to avoid sudden alterations in intrathoracic pressure, precautions are necessary in the technique of induction to minimize the aspiration risk. In either instance, preinduction preparation for emergency tracheostomy is essential.

The chest is again examined just before induction, because pneumothorax may develop slowly following a neck wound, appearing an hour or longer after an initially negative chest x-ray. Wounds in the base of the neck following a downward path may cause minimal apical pulmonary injuries so that a pneumothorax is not apparent initially and may not be manifest until after the patient is intubated. This should be kept in mind as a cause for hypotension or hypoxia during anesthesia.

Technique of Exploration. With adequate control of the ventilatory and cardiovascular systems, the surgeon can now safely and adequately explore the structures that may be injured. Patient positioning and preparation of the sterile field require foresight concerning operative exposure and the need for venous autografts. The supine position with some cervical extension is used. The prepared operative field includes the neck, chest, anterior shoulders, and a separate site for harvesting saphenous vein.

The incision is planned to allow full exposure of the tract of injury. Proximal and distal control of the major blood vessels must also be considered in the length and position of the incision. Incisions commonly used are the oblique incision along the anterior border of the sternocleidomastoid muscle, the horizontal clavicular incision with resection of the medial portion of the clavicle, median sternotomy, and anterolateral thoracotomy.

The tract of injury is followed to its depth, with systematic examination of each adjacent structure. Blast injury, especially from high-velocity missiles, may not be immediately apparent and requires careful evaluation. If injuries to the major blood vessels are suspected, tapes are passed around the vessels proximal and distal to the point of suspected injury before local clots are removed. Injured structures are repaired as outlined in the following paragraphs and muscles are anatomically approximated.

Most soft tissue neck wounds are drained for 24 to 48 hours using Penrose drains or Silastic suction catheters to prevent the accumulation of blood and serum. If the pharynx or esophagus is injured, drainage is continued for 4 to 8 days. In the case of a massive gunshot wound, such as a close-range shotgun injury, the wound is left open initially and, if possible, a delayed primary closure performed 3 to 4 days later.

Specific Injuries

Vascular Injuries. Clinical problems posed by acute vascular injuries are best considered by dividing the discussion into injuries of the neck proper and those of the base of the neck or thoracic inlet. Cerebral ischemia and tracheal compression from contained bleeding are the major concern with injuries of the middle and upper neck. External hemorrhage can usually be controlled by pressure and the diagnosis is signaled by an adjacent penetrating wound, a bruit, or a neurologic deficit. The major problems of vascular injuries of the thoracic inlet are exsanguinating hemorrhage, early diagnosis, and operative exposure. Operative techniques of vessel repair are straightforward and infrequently pose important management problems. Though the specific vessel injured is sometimes defined by preoperative arteriography, the surgical management of potential vascular injuries must often proceed without this information.

Cervical Blood Vessels. Major vascular injuries in this region include the common carotid artery and its extracranial branches, the vertebral artery, and the internal jugular vein. Special attention is directed to preoperative neurological evaluation because cerebral infarction may affect the intraoperative decision regarding flow restoration. Transient hypotension may exaggerate cerebral ischemia, but it does not appear to have a predictably deleterious effect on eventual neurologic status. Rapid fluid volume restitution and restoration of normal blood pressure is important for physiologic reasons and also allows a more accurate evaluation of the neurologic consequences of the injury. Vascular reconstruction is advisable in patients with mild deficits and in those with severe deficits in whom prograde flow is present preoperatively. Ligation was recommended in patients with severe neurologic deficits and no preoperative prograde flow. Ligation may occasionally be appropriate for patients with severe neurologic deficits and persistent prograde flow in whom thrombus exists in the cephalad vessels. If thrombectomy cannot be performed without risk of cerebral embolization, ligation may be the best choice. Arterial reconstruction, if feasible, was recommended in essentially all neurologically intact patients. The only exception is the patient with obstructed prograde flow and intraluminal thrombus in the cephalad vessel. If reconstruction risks cephalad embolization, ligation was suggested.

Controversy continues regarding the therapeutic implications of preoperative neurologic deficits. Recent reviews by Unger et al and by Liekweg and Greenfield support the recommendation that injured carotid arteries should be reconstructed, if technically feasible, in all except comatose patients with prograde flow. In these authors' opinion, flow should also be restored in patients without prograde flow, except those with severe or rapidly progressing deficits and seriously depressed sensoriums.

Operative Technique. Before the induction of anesthesia, preparations are made for the performance of emergency tracheostomy in the event of intubation difficulties. Stability of the cervical spine should be confirmed before intubation, particularly in high-velocity missile trauma. If an internal carotid injury near the base of the skull has been demonstrated arteriographically, exposure may be difficult and an additional 1 to 2 cm can be obtained by jaw dislocation. The mandible is pulled inferiorly and anteriorly and held in place with dental wires.

Patients with potential or proved carotid injuries should be handled with consideration given to the tenuous hemostasis provided by soft tissue tamponade and the likelihood of intraluminal thrombus. A vigorous antiseptic scrub may dislodge a clot and cause either bleeding or embolization. Preparation of the operative field preferably includes the shoulder and anterior chest in case further exposure is required, as well as a site for harvesting venous autograft.

Incision extensions that may be necessary are described with vascular injuries of the thoracic inlet. Shunts are rarely needed for repairs of common carotid injuries if the cephalad clamp does not occlude communication between the external and internal carotid arteries. Adequate collateral flow from the external carotid is easily verified by momentarily releasing the cephalad clamp. Following proximal and distal occlusion, with or without an intraluminal shunt, repair is carried out by standard vascular techniques. Injuries of the internal jugular vein are primarily repaired if this can be readily accomplished by lateral venorrhaphy, patch venoplasty, or end-to-end anastomosis. Unilateral ligation is well tolerated and the use of interposition grafts to restore venous continuity is not justified.

The common use of preoperative arteriography in recent years has uncovered an increasing number of vertebral artery injuries. In the past these injuries have been recognized infrequently, apparently because vertebral flow is not essential, and the size and course of the vessel make over manifestations uncommon. Acute complications of vertebral artery injury are rare, but massive hemorrhage may be lethal. An AV fistula is the not common late complication, usually diagnosed months or years after injury. The incidence of these sequelae is unknown. Meier et al recently described a series of 13 patients with acute vertebral artery trauma treated in a single institution during a 3-year period. During this same time period 54 carotid injuries were treated, yielding a comparative incidence of about 20 percent for vertebral artery injuries.

Because the frequency of untoward sequelae of vertebral injuries is unknown, the indications for operations in asymptomatic patients are not clear. Meier and his associates recommend ligation of injured vertebral arteries in all patients with normal contralateral arteries if no spinal cord branches arise from the injured vessels. The site of proximal ligation is immediately distal to the origin of the vertebral artery from the subclavian. The site of distal ligation depends on the location of injury, and can be performed as high as the C1-C2 interspace, when the artery is free of the bony canal.

Base-of-the-Neck (Thoracic Inlet) Vascular Injuries. Thoracic inlet injuries involve the vessels of the superior mediastinum that are proximate to the pleural spaces and separated from the surgeon by the claviculosternal "shield". The specific vessels include the innominate, the subclavian, and the proximal common carotid arteries and adjacent veins. Anatomic characteristics make the diagnosis of injured vessels difficult and impede rapid hemostasis and operative exposure for vascular control and repair. Exsanguinating hemorrhage is the predominant risk; bleeding may not be easily recognized because of free decompression into the pleural spaces. Abundant collateral blood supply generally protects against cerebral or upper extremity ischemia, but also disguises the injury by maintaining distal perfusion and exaggerates blood loss during operative exposure. The major clinical differences between these injuries and those in the neck proper are obscure hemorrhage, difficulty obtaining immediate hemostasis, the extensive incisions that may be required for exposure, and the infrequency of cerebral ischemia.

Rapid resuscitation, liberal surgical exploration, and a thorough knowledge of the operative approach are the necessary ingredients of success. Indications for early surgical exploration are listed in Table 6-2. Diagnostic errors and subsequent inappropriately conservative management rarely occur with overt signs of major vascular injury. Unfortunately, many of these injuries appear innocuous at the time of presentation, and a high index of suspicion is necessary. It is in this context that platysmal penetration and proximity of the wound to a major vascular structure are used as indications for surgical exploration. As previously discussed, arteriography to modify the principle of proximity and penetration exploration remains controversial. It may prove useful if immediately available, but valuable time should not be wasted with studies if objective evidence of major vascular injury exists.

Table 6-2. Findings Suggesting Major Vascular Injury

Obvious or direct evidence of injury:

1. Circulatory instability
2. Excessive external bleeding
3. A large or progressing hematoma
4. Distal pulse deficit
5. Neurologic deficit involving nerves anatomically adjacent to major vascular structures
6. Massive or continued intrathoracic bleeding

Indirect evidence indicating exploration:

1. A wound above the clavicle or manubrium that penetrates the platysma muscle
2. Thoracic wounds whose trajectory traverses the superior mediastinum or thoracic inlet
3. Mediastinal widening demonstrated radiographically.

Important factors in the management of these injuries are emphasized by the series of Flint et al. during an 11-year period, 146 patients with 206 injuries of major vascular structures at the base of the neck were treated. Arterial injuries accounted for 49 percent, including 36 injuries to the subclavian artery, 29 to the common carotid, and 7 to the innominate artery. Of the 74 venous injuries, there were 31 to the subclavian vein, 32 to the internal jugular, and 11 to the innominate vein. Signs and symptoms of major vascular injury were equivocal in many patients and totally absent in 32 percent of the patients. These patients were explored on the basis of platysmal penetration and the proximity of the wound to a major vascular structure. The overall mortality was 7.8 percent and was generally related to the magnitude of associated injuries or the extent of blood loss before operation. Thirteen percent of the patients with arterial trauma died, compared with three percent of those with venous injuries. Early and liberal surgical exploration with emphasis on adequate exposure resulted in low mortality and morbidity rates in this large series.

Operative Technique. Vessel exposure and control of hemorrhage are the major problems in the operative management of thoracic inlet injuries. The varied vessels and adjacent structures that may be involved and the overlying bony shield are the basis of these problems. The inaccuracy of preoperative wound localization and the wide exposure often required for vascular control make a flexible operative approach essential. A variety of incisions may be needed, often involving the mobilization of overlying bony structures. The initial incision may not provide adequate exposure and may require extension or another separate incision. Such extensions or additional incisions were required in 25 percent of 146 patients with these injuries reported by Flint et al. The supine position and a wide operative field including the entire neck, chest, and upper arms offers the most operative flexibility.

The approaches used to expose these injuries are the oblique cervical and horizontal clavicular incisions, median sternotomy, left anterolateral thoracotomy, and a musculoskeletal chest wall flap. The right oblique cervical incision generally is adequate to expose the entire right common carotid artery. The horizontal clavicular incision with subperiosteal resection of the medial half of the clavicle adequately exposes the right subclavian vessels. Extension to a median sternotomy is necessary to expose the innominate artery. The distal left common carotid artery is easily exposed through a left oblique neck incision, but the proximal vessel requires a sternal extension. The distal left subclavian artery can be reached through a horizontal clavicular incision, but its proximal portion requires a sternotomy or, more appropriately, a left anterolateral thoracotomy. A musculoskeletal flap, or "trapdoor", may be used to expose the proximal left carotid and entire left subclavian arteries and the left innominate vein. This is formed by combining horizontal clavicular, superior median sternotomy, and anterolateral thoracotomy incisions. Most base-of-the-neck injuries can be exposed through the oblique cervical and/or horizontal clavicular incisions. Major extensions should be made without hesitation when these incisions provide inadequate exposure. The vascular repair seldom is difficult and most often can be accomplished by lateral arteriorrhaphy or end-to-end anastomosis. When graft interposition is required, autogenous material is preferred.

The operative approach to penetrating injuries of the base of the neck is appropriately based on the presenting clinical picture, supplemented when possible by arteriography. The factors considered in choosing the primary incision are hemodynamic status, predicted wound course, side of the injury, and evidence of intrathoracic bleeding. Sound judgment and the flexibility to widely extend incisions result in maximal required exposure and minimal incisional complications and morbidity.

In unstable patients with suspected major mediastinal injuries, especially in the presence of large or continuing intrathoracic bleeding, initial thoracic incisions are advisable. This usually implies a median sternotomy, but if the wound is on the left and a proximal left subclavian artery is suspected, an anterolateral thoracotomy is performed. Anterolateral thoracotomy is performed on the side of injury in patients with massive intrathoracic bleeding if sternal splitting instruments are not immediately available.

Oblique cervical and horizontal clavicular incisions often provide adequate exposure without the added risk and morbidity of thoracotomy. One of these incisions is appropriate in stable patients with cervical, periclavicular, or supramanubrial wounds without evidence of deep mediastinal penetration or intrathoracic hemorrhage. A wide operative field is essential, however, and extension to a thoracic incision is made without hesitation.

The oblique cervical incision provides adequate exposure for most cervical wounds without evidence of mediastinal penetration. In the series of Flint et al, this incision provided adequate exposure for the control and repair of 84 percent of internal jugular vein and 76 percent of common carotid injuries. Lateral extension with resection of the medial half of the clavicle is sometimes necessary for additional exposure. Using this extension, satisfactory access was obtained in more than 90 percent of patients with common carotid and internal jugular injuries. If difficulty with proximal exposure is encountered during the dissection of either common carotid artery, a midsternal extension is made.

The horizontal clavicular incision is initially used in stable patients with periclavicular or supramanubrial wounds and suspected mediastinal penetration but without notable intrathoracic bleeding. Eighty-seven percent of subclavian vein injuries, 75 percent of innominate vein injuries, and 60 percent of subclavian artery injuries were successfully repaired by Flint and associates using this incision.

If possible, complete proximal and distal vascular control should precede dissection into the immediate area of suspected injury and the tamponading hematoma. If exposure is inadequate during the dissection of either proximal common carotid artery or the right subclavian artery, a midsternal extension should be made without hesitation. If proximal exposure is inadequate during the transclavicular dissection of the left subclavian artery, a left anterolateral thoracotomy is performed and, if additional exposure is required, midsternal extension forms a musculoskeletal flap.

The repair of the vascular injury, once isolated, seldom presents a major problem and can usually be accomplished by lateral arteriography or end-to-end anastomosis. When graft interposition is required, autogenous material is preferred. The use of shunts or extracorporal circulation to maintain cerebral flow should be considered if flow is reduced in more than one of the vessels supplying the brain. Vascular reconstruction is desirable, but because of the rich collateral circulation, single arterial ligations can usually be safely performed when survival depends on early completion of the operation. Measurement of "stump" pressures may be helpful in predicting the consequences of major arterial ligations. Venous ligation usually results in minimal morbidity and may be indicated when optimal repair is not possible, although both innominate veins should not be ligated.

Larynx and Trachea. The signs and symptoms of laryngeal and tracheal injuries include respiratory distress, hoarseness, hemoptysis, and subcutaneous emphysema. Subcutaneous air is not diagnostic of such an injury since air may enter through the skin wound or be due to an injury of the esophagus, bronchus, or lung.

Whenever laryngeal or tracheal injury produces difficulty breathing in the emergency room, a tracheostomy is performed before transfer of the patient to the operating suite. If the patient is hoarse or the wound is near the thyroid or larynx, indirect laryngoscopy is performed preoperatively, when feasible, to evaluate the larynx and function of the recurrent laryngeal nerves.

Clean lacerations of the trachea or larynx are closed using synthetic absorbable suture such as Dexon or Vicryl. These materials result in less frequent problems with chronic granulation tissue postoperatively. Tracheal wounds can more often be primarily repaired than was previously thought. If a tracheostomy is not also performed, an endotracheal tube is usually indicated for several days postoperatively to ensure an adequate airway. A tracheostomy may be required instead of or in addition to primary repair, depending on the site and size of the defect and the magnitude of associated injuries. Patients with laryngeal injuries should have normal anatomy reconstructed as accurately as possible to lessen subsequent airway and speech difficulties. If a tracheostomy is required, it is maintained until healing is complete and laryngeal or tracheal edema has subsided, usually 4 to 8 days.

Pharynx and Esophagus. The clinical findings suggesting pharyngeal or esophageal injury are hematemesis, dysphagia, and subcutaneous emphysema. Preoperative contrast studies are sometimes helpful to locate the site of injury but cannot be relied upon to exclude the presence of an injury.

After adequate debridement, injuries of the pharynx and esophagus usually may be primarily repaired using an inner layer of absorbable sutures such as Vicryl or Dexon and an outer layer of silk, cotton, or Prolene. If a small esophageal injury is suspected, but cannot be demonstrated during exploration, an anesthetic mask may be applied to the nose and mouth and positive pressure exerted while the wound is filled with saline solution. Bubbles may disclose the point of injury. It is vital to drain all such wounds, because infections and salivary leaks are potential complications. If there is massive loss of esophageal tissue, as with a close-range shotgun blast, it may be necessary to perform a cutaneous esophagostomy for feeding purposes and a cutaneous pharyngostomy for salivary drainage. A secondary reconstruction will be required after initial healing is complete. A small plastic nasogastric tube is used for feeding for 8 to 10 days following major esophageal injuries, unless a gastrostomy is deemed preferable.

Nerve Injuries. A preoperative neurologic examination is performed, whenever possible, to identify injured nerves. The brachial plexus, deep cervical plexus, phrenic nerves, and the cranial nerves are systematically tested. The vagus and recurrent laryngeal nerves can be evaluated by examining the vocal cords. A hypoglossal or spinal accessory nerve injury is particularly easy to miss unless a preoperative neurologic examination is performed. An associated head injury or alcoholic intoxication often impedes an adequate neurologic examination. Whenever possible, severed or lacerated nerves are debrided and repaired primarily using interrupted fine silk sutures on the perineurium.

Salivary Glands. The diagnosis of salivary gland injury is usually made during operative exploration but, if suspected preoperatively, may be made with sialography. Debridement, hemostasis, and simple drainage provide effective treatment. In the absence of ductal obstruction, a salivary fistula rarely occurs after injury to the gland substance. When the major duct is injured, it may be repaired with fine silk over a ureteral catheter stent. The catheter should be removed after repair is completed. When repair is not feasible because of the patient's condition or for some other compelling reason, the duct may be ligated and the gland allowed to atrophy, or the duct may be reimplanted in the mucosa at a later time. If a salivary fistula does occur postoperatively and fails to close spontaneously, irradiation usually arrests salivary flow, but is not advisable in children or young adults.

When the parotid gland is involved, the major facial nerve branches should be identified and, if injured, repaired. Primary repair has a better prognosis for nerve function than does delayed repair, unless there is gross bacterial contamination or massive loss of tissue.

Miscellaneous Injuries. Thyroid injuries require only debridement of devitalized tissue, hemostasis, and adequate drainage. The thoracic duct may be injured with wounds near the left innominate-jugular venous bifurcation. Repair of the duct is not feasible because of its friability, but simple ligation is adequate. The duct may divide immediately before entering the vein or there may be tributaries from the head and arm and multiple ligations may be required for lymphostasis. The area should be thoroughly dried and inspected before closing, because a large collection of lymph may occur postoperatively from even a small leak. If lymph does accumulate, incision and drainage with the application of a bulky pressure dressing for a few days will usually effect closure of the lymphatic fistula, Injured right thoracic ducts, though less frequent, are treated similarly.

Abdominal Trauma

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The incidence of abdominal trauma increases each year. About 5 million persons in the USA are injured early in automobile accidents, and many of these injuries are abdominal. Blunt abdominal trauma generally leads to higher mortality rates than penetrating wounds and presents greater problems in diagnosis. The spleen, liver, kidneys, and bowel are the most frequently injured abdominal viscera. In a review of several series of blunt abdominal trauma the frequency of injury was determined (see Table 6-3).

Table 6-3. Frequency of Injury in Abdominal Trauma

Viscera injured	*Frequency, %*
Spleen	26.2
Kidneys	24.2
Intestines	16.2
Liver	15.6
Abdominal wall	3.6
Retroperitoneal hematoma	2.7
Mesentery	2.5
Pancreas	1.4
Diaphragm	1.1

Evaluation of Blunt Trauma

The greatest difficulty in the management of blunt abdominal trauma is in the diagnosis. This is largely due to masking of abdominal injury by associated injuries. The most frequently associated injuries are head trauma, chest trauma, and fractures. Often the patient is unconscious because of alcoholism, drug abuse, shock, or associated head injury. Another misleading factor in diagnosis, often not recognized, is that relatively trivial injuries may rupture abdominal viscera. The index of suspicion must be high, even in cases of supposedly minor abdominal trauma, if diagnostic errors are to be avoided.

Clinical Manifestations. The evaluation of the patient with blunt abdominal trauma begins with a careful history and physical examination. The knowledge of the mechanism of injury is frequently helpful in discerning the likelihood of abdominal injury. Factors such as rapid deceleration, impaling forces, and seat belt restrainers make abdominal viscera prone to injury. Physical examination in the alert patient is the most reliable predictor of injury, and yet this will be misleading as either a false-positive or false-negative examination in 10 to 20 percent of patients. The entire patient must be examined as well as the abdomen because of the high incidence of associated trauma. Fitzgerald et al have reported extra-abdominal injuries in 97 percent of patients with abdominal injuries who were dead on arrival at the hospital and in 70 percent of those admitted alive. When the diagnosis is doubtful, one must often depend on repeated physical examinations alone, done at frequent intervals by the same examiner, to decide whether the patient requires laparotomy.

Abdominal pain and tenderness are the most frequent findings. Abdominal rigidity, or involuntary guarding, is the most helpful sign, and even when present alone, warrants exploratory laparotomy. Patients with an altered state of consciousness resulting from closed head injuries, alcoholism, or drug abuse frequently do not demonstrate the classic physical findings. Hinton, in 1929, recommended a period of watchful waiting before exploration because of fear of uncontrollable hemorrhage and infection, as well as the difficulty of performing the necessary surgical procedures under adverse conditions. There is no excuse for this course today, and a policy of watchful waiting frequently may be disastrous. Fitzgerald et al reported no deaths of patients who had exploratory laparotomy without a finding of intraabdominal injury. However, three deaths in their series occurred from intraabdominal hemorrhage because abdominal injury was masked by associated head injuries. The absence of any mortality for negative abdominal exploration for suspected abdominal trauma has been reported from several trauma centers.

In patients with blunt abdominal trauma, determinations of alterations in blood pressure are often useful. It was found that a valuable sign of continuing intraabdominal hemorrhage was transient elevation of the blood pressure to normal levels for a few minutes followed by return to hypotensive levels with rapid infusion of 500 to 1.000 mL of Ringer's lactate solution. Patients who are hypotensive from minimal blood loss or from neurogenic shock usually do not behave in this manner. The Ringer's lactate solution generally is infused over a period of 15 to 20 minutes while other measures, such as blood typing and cross matching, are being carried out. Postural hypotension, when the patient assumes the erect position, is another useful sign of continuing intraabdominal bleeding.

Diagnostic Procedures. Whereas history and physical examination remain the most reliable diagnostic modalities, other diagnostic aids will frequently confirm clinical suspicions. In general, laboratory determinations do not offer much help in the young, previously healthy traumatized patient.

Berman et al state that if the leukocyte count is greater than 15.000 following abdominal trauma, a ruptured solid viscus is likely, especially if other findings are compatible with that diagnosis. Williams and Zollinger, however, have not found the leukocyte count to be so helpful.

Sudden acute blood loss may not be adequately reflected by early hemograms; hence, a normal hemoglobin and hematocrit shortly after injury may be misleading. Serum glucose and creatinine determination may be helpful in elderly patients suspected of having diabetes or renal insufficiency. Whereas serum electrolytes are rarely diagnostic, the serum potassium level is extremely important if operation is contemplated. Unrecognized hypokalemia may lead to disastrous consequences. A serum amylase level, when elevated, is a relatively reliable predictor of intraabdominal injury although not always an indication for operative intervention. In addition to being elevated with pancreatic injury, abnormal amylase levels are also seen in injuries to the duodenum and upper small bowel. Leakage of the amylase-containing fluid is rapidly absorbed into the blood from the peritoneal cavity.

Studies of urinary sediment are useful, since hematuria may indicate injury to the genitourinary tract. If the patient with abdominal injury cannot void, catheterization should be done to obtain urine for examination. Catheterization is contraindicated prior to obtaining an urethrogram, if there is a scrotal hematoma, perineal hematoma, or a drop of blood at the tip of the male meatus. In these instances injury to the urethra is suspected and additional damage may be done if a catheter is inserted.

Levin tubes are inserted in all patients sustaining blunt abdominal trauma. The stomach contents are aspirated and the aspirate is examined for the presence of blood. In addition, a Levin tube provides for decompression of the stomach, prevents gastric dilatation, and prevents aspiration with the induction of anesthesia. The instillation of 30 to 60 mL of antacid in the Levin tube will further minimize the ravages of aspiration, should it occur, by neutralizing the stomach contents.

Blood-gas determinations should be obtained in all multiple injured patients and, in particular, those patients with a history of chronic pulmonary disease, chest injuries, or possible aspiration.

Radiologic Findings. For patients who have sustained severe abdominal injury and in whom other clinical signs obviously point to such injury, radiography, for diagnosis, may dangerously delay surgical intervention. However, for about one-third of patients with stable vital signs and questionable diagnoses of intraabdominal injury, x-ray studies may be helpful. Radiography is of least aid in injury to solid viscera, notably the liver, spleen, and pancreas.

When a patient is suspected of having intraabdominal injuries, upright films of the chest should be made, in addition to supine films of the abdomen. Occasionally additional information may be obtained from lateral and left lateral decubitus films. Skeletal parts are checked for fractures or dislocations. Examinations of the soft tissues may give information concerning alterations of size, shape, or position of many viscera. Pneumoperitoneum may be diagnosed with the patient in the erect or lateral decubitus positions. Indirect evidence of solid viscera rupture with secondary hemorrhage may be presumed by an increase in density in the region, by displacement of neighboring viscera, or by accumulation of fluid between the gas shadows of bowel loops. If a gastric, duodenal, or upper jejunal rupture is suspected, the appearance of pneumoperitoneum may be facilitated by injecting 750 to 1.000 mL of air into the nasogastric tube, after which the patients sits in a semierect position for 10 minutes before an upright chest film or left lateral decubitus film of the abdomen is made. Films should also be made prior to the air injection for purposes of comparison if the patient's condition permits.

Another study which may be useful is examination of the upper gastrointestinal tract by x-ray after ingestion of a water-soluble opaque medium, which may indicate injury of the stomach, duodenum, or upper small bowel. The use of barium mixtures for this is dangerous, since a severe peritoneal reaction is caused by barium if it leaks through a perforation in the gastrointestinal tract. This is especially true if there is fecal contamination in the peritoneal cavity from concomitant colon injury.

Intravenous pyelograms should be done if feasible for patients with hematuria or other evidence of genitourinary injury, not only to establish the nature of the injury, but also to determine if both kidneys are functioning prior to surgical intervention in case an injured kidney must be removed. It is important to note that occasional renal injuries are not detected by intravenous pyelography and, if clinically suspected, may be better confirmed by arteriography. If arteriography is contemplated, the intravenous pyelogram and cystogram can be obtained at the conclusion of the angiogram, thereby eliminating one study and conserving time. If necessary, intravenous pyelograms may be done during the surgical procedure to determine the presence of a functional kidney on one side before removing the other kidney.

Cystograms may also be useful for diagnosing bladder injury or perforation from blunt abdominal trauma, but normal cystograms do not rule out bladder injury.

Paracentesis. Needle abdominal paracentesis is a useful diagnostic aid only for those cases of abdominal trauma in which, after physical examination, the examiner continues to suspect intraabdominal hemorrhage. The abdominal tap has been particularly useful as a diagnostic adjunct for comatose patients with head injury in whom adequate physical examination of the abdomen is not possible. A review of this procedure shows a diagnostic accuracy of 95 percent with positive paracentesis. A negative tap is not definitive, particularly if other elements of the physical examination indicate other reasons for exploring the abdomen. In female patients with suspected intraabdominal hemorrhage, culdocentesis may be positive for blood when abdominal taps are negative.

The technique is well described by Drapanas and McDonald. The abdomen is surgically cleansed with pHisoHex or an iodinated compound. An 18-gauge short-bevel spinal needle is attached to a syringe and inserted through the abdominal wall after prior infiltration of the site of tap with a local anesthetic agent. Suction is applied to the syringe as the needle is slowly advanced into the abdomen at the sites illustrated. Return of a minimum of 0.1 mL of nonclotting blood constitutes a positive tap. Occasionally, an intraabdominal blood vessel may be entered, but this blood will clot and differentiate if from blood obtained from the free peritoneal cavity. Bilateral flank taps are as reliable as four-quadrant taps and may be more reliable if only small amounts of blood are present. Puncture of the rectus abdominis sheath anteriorly should be avoided to prevent a rectus abdominis sheath hematoma from injury to the epigastric vessels and to diminish the chance of the needle's penetrating the bowel, since gas-filled loops of bowel tend to float anteriorly in the abdomen containing fluid or blood. Actually, the danger of penetrating the intestine is slight; several studies have shown that penetration with an 18-gauge needle is harmless, as a hole in the bowel seals of quite rapidly with no leakage. Other technical considerations include the following:

1. Areas of abdominal scars or other points of possible bowel fixation to the abdominal wall should be avoided.

2. The direction of the needle inside the abdominal cavity should be changed only by withdrawing the point of the needle just superficially to the peritoneum, redirecting the needle, and reintroducing it into the peritoneal cavity.

3. Peritoneal taps should be avoided in the presence of markedly distended bowel, because abnormally elevated intraluminal pressure may cause continued leakage.

Paracentesis is simple and quick with relatively few complications. A positive needle tap is quite accurate. The major drawback is the high percentage of false-negative results.

Peritoneal Lavage. Because of the poor reliability of paracentesis, if nonclotting blood is not aspirated, other procedures have been developed to detect intraabdominal injury. Canizaro et al described in 1964 the use of intraperitoneal saline infusions in animals. Root et al described in 1965 the technique of peritoneal lavage in human beings and subsequently reported a series of 304 patients with a 96 percent accuracy. A recent review of this procedure has proved peritoneal lavage to be a safe and reliable adjunctive procedure for evaluating patients with blunt abdominal trauma. The indications for this technique are patients with closed head injuries, altered consciousness, spinal cord injuries, equivocal abdominal findings, and negative needle paracentesis. It is not recommended for patients with gunshot wounds to the lower chest or abdomen, stab wounds to the back, multiple abdominal procedures, dilated bowel, late pregnancy, or positive needle paracentesis.

Several techniques are currently described. The Lazarus-Nelson approach utilizes a small Teflon catheter inserted over a previously placed flexible guide wire. The technique popularized by Perry selects a point in the lower midline below the umbilicus approximately one-third of the distance between that and the pubic symphysis. After decompression of the urinary bladder, the skin is cleansed and prepared with an iodinated antiseptic solution. A weal is raised with 1% lidocaine with epinephrine and the skin incised with a #11 scalpel. A standard peritoneal dialysis catheter is inserted, and the trocar advanced carefully until it just penetrates the peritoneum. An alternative and perhaps safer method is to incise the abdominal wall to the peritoneum and insert the trocar under direct vision. Once the peritoneum is penetrated, the trocar is removed and the dialysis catheter advanced toward the pelvis. A syringe is then attached to the catheter and the peritoneal cavity is aspirated.

Nonclotting blood will often be aspirated through the larger catheter in spite of a negative needle paracentesis. If no blood is aspirated, a liter of balanced salt solution (Ringer's lactate) is rapidly infused into the peritoneal cavity over 5 to 10 minutes. For children and small adults 10 to 15 mL/kg is used. The patient is then turned from side to side in order to further mix the blood and fluid. If other injuries such as pelvic or long bone fractures are present, this step is eliminated.

The empty intravenous-fluid bottle is lowered and the fluid siphoned out of the peritoneal cavity. A sample is sent to the laboratory for quantitative analysis. In addition to obtaining red cell and white cell counts, it is important to determine the presence or absence of amylase, bile, or bacteria. Some have recommended colorimetric methods, but these do not appear to be as accurate as quantitative analysis of the fluid. The criteria for positive peritoneal lavage include the following determination: gross blood in lavage fluid; greater than 100.000 RBC/mm^3. To a lesser extent, greater than 500 WBC/mm^3, elevated amylase level, presence of bile or bacteria in the aspirate are significant.

It must be emphasized that the lavage is very inaccurate in indicating retroperitoneal injuries. Unless the posterior peritoneum has been torn or considerable time has elapsed between the injury and lavage, most pancreatic injuries are not detected. The same is true for duodenal, urologic, and major vessel injuries which are retroperitoneal. Diaphragmatic injuries likewise are rarely detected by peritoneal lavage. Complications occur frequently enough that lavage is not recommended for every patient suspected of abdominal injury. However, a negative lavage may spare the patient an exploratory celiotomy.

Arteriography. Selective arteriography is another available aid to the diagnosis of blunt abdominal trauma. This procedure, advocated by Freeark, employs percutaneous retrograde arteriography by the Seldinger method. Depending upon the skill of the technician, selective catheterization of celiac, mesenteric, or renal vessels may be performed. The arteriogram provides visualization of the arteries supplying the abdominal viscera and pelvis. A film taken several minutes after injection can be used as an excretory urogram.

Arteriography is useful in assessing renal artery injury and is routinely employed if a kidney is not promptly visualized with intravenous pyelography. Intimal tears, aortic occlusion, and traumatic aneurysm are often seen in conjunction with seat belt injuries and are occasionally associated with serious lumbosacral trauma.

When continued pelvic bleeding occurs with extension into the retroperitoneal space secondary to pelvic fractures, arteriography may be beneficial in localizing the site of bleeding. Additionally, vasospastic agents may be employed to control hemorrhage. Hemostatic agents as well as autologous clot may be embolized to control bleeding.

Again, it must be emphasized that time should not be wasted on adjunctive procedures when surgical intervention is indicated.

Scintiscanning. Both liver and splenic scanning have been described in conjunction with blunt abdominal trauma. This technique primarily is limited to those patients whose diagnoses are uncertain and whose conditions remain stable. The radionuclide most frequently used is ^{99m}Tc sulfur colloid. Most series reporting results of this technique are small and emphasize the relative inaccuracy of the examination.

A filling defect representing a parenchymal hematoma frequently is seen with damage to the spleen or liver. In addition, displacement, increased size, and mottled appearance of the spleen may increase the suspicion of splenic trauma. Filling defects also may indicate cysts, abscesses, infarcts, or tumors secondary to trauma.

Other Procedures. Newer, noninvasive modalities, such as sonography and computerized tomography, are emerging and have a definite place in the diagnostic armamentarium. Federle et al have recently described the benefits of computerized tomography in a series of 200 patients with blunt abdominal trauma. They reported no false-positive or false-negative CT interpretations and felt it was highly sensitive and specific for a wide variety of intraperitoneal and retroperitoneal traumatic lesions. Additional studies evaluating the CT scan will be forthcoming and will help elucidate its place in the evaluation of the patient with blunt abdominal trauma. Although some authors are now recommending laparoscopy, this technique as well as needleoscopy provide a less than complete examination and cannot be recommended at this time for the multiply injured patient.

Penetrating Trauma

Stab Wounds

Diagnosis of penetrating injuries of the abdomen does not usually present the difficult problem often posed by blunt abdominal trauma. Three methods of management have evolved: (1) routine exploration of all patients with abdominal stab wounds, (2) selective management, or (3) exploration following demonstration of peritoneal cavity and/or visceral injury.

Before 1960 there was little controversy, since essentially all surgeons agreed that penetrating trauma to the abdomen required exploratory celiotomy to rule out visceral injury. This agreement was first challenged by Shaftan in 1960, who recommended exploratory celiotomy only for patients with physical evidence of injury due to penetrating abdominal trauma and observation in the hospital for those without evidence of visceral injury. The major controversy now revolves around the following issues, which assume paramount importance:

1. How reliable are the various diagnostic criteria for visceral injury?

2. What is the effect of delayed celiotomy on the complication and fatality rate among patients who have no clinical manifestations of visceral injury after penetrating trauma, but who subsequently develop such manifestations.

3. Does negative celiotomy cause significant morbidity and mortality?

Most clinicians who favor mandatory celiotomy for all patients who have sustained possible abdominal trauma cite the unreliability of physical examination of the abdomen in detecting visceral injury. This point of view is supported by Bull and Mathewson, who found that 23 percent of 78 patients with significant intraabdominal injury confirmed at celiotomy and due to penetrating abdominal wounds had no physical signs preoperatively. In contrast, 18 percent of 100 patients with possible penetrating injuries in whom the peritoneal cavity was not entered did have physical findings suggestive of visceral injury.

In spite of the fact that there is virtually no mortality associated with negative celiotomy, most series report postoperative complications in the range of 10 to 20 percent. A recent review of 175 negative celiotomies performed at Parkland Memorial Hospital revealed a readmission rate of 2 percent for small bowel obstruction. Because of the high incidence of negative celiotomy following routine exploration, most trauma centers have abandoned this approach.

Selective management of abdominal stab wounds is new recommended by many authors. Following clinical assessment, the decision to perform exploratory celiotomy is based on the following factors: (1) physical signs of peritoneal injury; (2) unexplained shock; (3) loss of bowel sounds; (4) evisceration of a viscus; (5) evidence of blood in the stomach, bladder, or rectum; and (6) evidence of visceral injury such as pneumoperitoneum or visceral displacement on x-ray films. Occasionally, other diagnostic studies are employed, including intravenous pyelography, cystography, arteriography, needle paracentesis, or peritoneal lavage. In the absence of any indication of visceral injury, these patients are admitted to the hospital for a 24- to 48-hour period of observation. They are reevaluated frequently, preferably by the same observer. If the patient's condition deteriorates, or changes significantly, exploratory celiotomy is performed. Nance and Cohn reported a reduction in the percentage of negative celiotomies following selective management from 53 percent to 11 percent; 4.8 percent of 210 patients initially observed subsequently required an operation when manifestations of visceral injury developed. This delay in surgical treatment caused no mortality or significant morbidity.

An alternative approach other than routine exploration or selective management involves adjunctive methods that help determine whether penetration of the peritoneal cavity has occurred. The decision to operate is based upon confirmation of peritoneal penetration and/or visceral injury. Cornell et al have described the diagnostic injection of radiopaque contrast material. Following aseptic preparation of the wound site, a small catheter is inserted into the wound and held tightly by a purse-string suture; 50 to 100 mL of contrast media is injected; and anteroposterior, lateral, and oblique films of the abdomen are obtained. Contrast media seen within the peritoneal cavity is an indication of peritoneal penetration. Objections to this technique are the following:

1. Some patients are hypertensive to the contrast material.

2. Injection of this material may be quite painful, thereby masking further evaluation.

3. The incidence of false-positive and false-negative results is as high as 15 to 25 percent in some series.

4. The technique is impractical for multiple stab wounds.

Local exploration is another modality that may provide useful information. The abdominal wall is prepared with an antiseptic agent. Using local anesthesia, the wound is opened sufficiently to visualize the complete course and depth of the tract. Often with adequate light, instruments, assistance, and exposure, it is obvious that a wound thought to have penetrated the peritoneal cavity is actually superficial and not damaging to the viscera. These patients are managed by simple drainage and outpatient follow-up if other injuries do not require hospitalization. Local wound exploration must involve more than simple instrument-probing to determine penetration. This blind probing may be misleading, since a tortuous wound tract may allow passage of the probe for only a short distance, creating a false impression of nonpenetration. If the end of the tract cannot be visualized or the peritoneum is penetrated, local exploration is considered positive. This technique is equally useful for stab wounds of the back, although the thickness of the paraspinous muscles may prevent visualization of the end of the wound tract. Frequently, innocuous, small stab wounds of the back significantly damage such retroperitoneal structures as the inferior vena cava, ureter, pancreas, or duodenum. A recent review of over 300 abdominal stab wounds by the authors indicated that nearly 20 percent of the patients could be discharged from the emergency room without hospital admission based on a negative local exploration that clearly demonstrated the end of the tract.

The abdominal viscera are at risk to injury with stab wounds of the lower chest as well as the abdomen. The diaphragmatic excursion with maximal inspiration and expiration reaches the elevation as high as the fourth to fifth intercostal space anteriorly. Wounds at or below this level are therefore evaluated for abdominal injury as well.

If the stab wound to the chest is located below the fifth intercostal space and medial to the anterior axillary line and there is no obvious indication for operation, peritoneal lavage is performed. If lavage is negative, the patient is admitted to the hospital and observed for 24 to 48 hours. If lavage is positive, operation is performed.

Patients with stab wounds of the abdomen located medial to the anterior axillary line are evaluated clinically. If there is no indication for operation, local exploration is performed. If the end of the tract is not visualized or the peritoneum has been penetrated but the abdominal physical findings are considered negative, lavage is similarly performed. Since lavage is unpredictable in determining retroperitoneal injuries, this method of management is limited to lower chest and abdominal wounds that are located between the two anterior axillary lines. Whereas these wounds have previously been treated by routine celiotomy, a review of 123 patients treated in this manner successfully reduced the incidence of negative celiotomies from 25.6 percent to 4.1 percent; 70 percent of the patients in this series were spared operative procedures, while 2.3 percent of the 88 patients initially observed were subsequently operated upon, but did not suffer any ill effects from delayed surgical treatment.

Patients with posterior wounds lateral to the anterior axillary line are not lavaged because of this method's unreliability with retroperitoneal injuries. In many centers these wounds are treated according to the criteria for selective management; other institutions recommend operative intervention to rule out visceral injury.

Since lower chest wounds may penetrate the diaphragm, it is important to evacuate air and blood from the pleural space with chest tubes prior to celiotomy. Although a pneumothorax may not be indicated by x-ray or physical examination, prophylactic insertion of an anterior chest tube will decrease the danger of a tension pneumothorax developing during induction of anesthesia and subsequent abdominal exploration.

Gunshot Wounds

The incidence of visceral injury in patients with abdominal gunshot wounds is at least 90 percent, as compared with 30 to 40 percent in patients with abdominal stab wounds. There is an eighthfold to tenfold difference in mortality rates associated with gunshot wounds when compared with stab wounds.

It is not possible to predict the path of a missile by merely observing the entrance and exit wounds or connecting a line between an entrance wound and the appearance of a bullet on the x-ray film. These missiles may bounce, tumble, ricochet, and embolize.

Extraperitoneal gunshot wounds may produce intraabdominal injury by blast effect. In a report by Edwards and Gaspard, 14 percent of 35 patients sustaining gunshot wounds to the abdomen without penetration of the peritoneal cavity sustained at least one visceral injury.

Any bullet passing in proximity to the peritoneal cavity requires exploratory celiotomy. This includes all wounds of the lower chest and abdomen, flank, and back. Approximately 25 percent of lower chest wounds will produce intraabdominal injury. Celiotomy is recommended for patients with entrance wounds below the fifth intercostal space or entrance wounds above that area in which either the exit wound or missile is seen below the fifth intercostal space. If the patient's condition permits, anterior, posterior, and lateral films of the abdomen should be made to locate the missile. Selective management, the use of radiopaque material, local exploration, or peritoneal lavage are not recommended. A recent review of 59 gunshot wound patients all of whom were taken to the operating room in spite of a negative physical examination and negative peritoneal lavage had a 25 percent incidence of visceral injury. Injuries not detected by either modality included the colon, diaphragm, kidney, pancreas, and aorta.

Once the diagnosis of intraabdominal injury is established and resuscitation instituted, the abdomen is explored. A long midline incision is preferred for the following reasons:

1. It may be made much more rapidly than other incisions, a matter of vital importance when attempting rapid control of exsanguinating hemorrhage.

2. It gives wide access to all parts of the abdomen, which transverse incisions do not.

3. It may be readily extended into either side of the thorax in case of combined thoracoabdominal injury or when better abdominal exposure is required.

4. It may be rapidly closed, which is of great importance in decreasing the anesthesia and operative time in gravely injured patients.

Management of Patients With Exsanguinating Abdominal Hemorrhage. With improvement of prehospital care, more patients are arriving at the hospital in extremis. Frequently this condition is due to massive intraabdominal hemorrhage that is refractory to standard resuscitative measures. Ledgerwood and associates have advocated performing preliminary left thoracotomy and temporary thoracic aortic occlusion prior to opening the abdomen in patients with massive hemoperitoneum, tense abdominal distension, and persistent hypotension. The descending thoracic aorta is quickly and bluntly dissected circumferentially and occluded by a straight vascular clamp just above the diaphragm.

Once the abdomen is opened, the aortic clamp can be slowly released following stabilization of the patient, and proximal control gained at a lower level. A medium or large Richardson retractor may be used to obtain rapid temporary occlusion of the abdominal aorta just below the diaphragm. The lesser curvature of the stomach is pulled inferiorly and the flat surface of the retractor blade is compressed firmly against the abdominal aorta, thus occluding it against the vertebra just beneath the diaphragm.

With effective control of massive hemorrhage, resuscitation can be successfully completed, ensuring continuous perfusion to the heart and brain and minimizing the possibility of sudden cardiac arrest.

Stomach

Injuries to the stomach from blunt trauma are infrequent, perhaps because of a relative lack of fixation of the stomach and its protected position. However, penetrating injuries of the stomach from gunshot wounds occur frequently.

Diagnosis. The diagnosis of gastric injury is generally suspected from the course of the penetrating object, and, at times, additional suspicion of gastric injury arises from the presence of bloody fluid aspirated from the Levin tube. Generally, wounds of the anterior stomach wall are easily seen at laparotomy. Because of the possibility of missing posterior stomach wall wounds, it is important in all cases of proved or possible gastric injury to open the lesser sac through the gastrocolic omentum. This permits the entire posterior aspect of the stomach to be searched for injury. The points of attachment of the greater and lesser omenta on the greater and lesser curvatures of the stomach, respectively, should also be carefully inspected. If a hematoma is noted at the mesenteric attachment, it should be evacuated and the stomach wall at that site carefully inspected for injury of that part of the wall located between the leaves of the greater or lesser omentum.

Treatment. Gastric wounds are repaired by first placing a continuous locked 2-0 suture through all layers of the gastric wall (Vicryl or Dexon suture material may be preferable to chromic catgut); a purse-string suture in the stomach does not provide adequate hemostasis. The hemostatic stitch is very important to control extensive bleeding that may occur from the rich submucosal network of blood vessels in the stomach. After this inner layer closure, an outer inverting row of interrupted non-absorbable mattress sutures of the Lembert or Halsted type is placed. The outer row of sutures provides adequate serosal approximation of the stomach wall, seals off readily, and prevents leaks. These sutures in the outer layer should not be through-and-through, as is the first row of sutures, but should extend through the seromuscular coat and the submucosal layer of the stomach. Wounds of the stomach are not drained externally, since they are unlikely to leak, as duodenal wounds may. However, it is very important to suction the peritoneal cavity, with special attention to the subhepatic and subphrenic spaces and the lesser sac, so that all food particles and gastric juice spilled into these areas are removed.

After operation for a gastric wound, nasogastric tube suction should be maintained for several days until active peristalsis resumes and the danger of postoperative gastric dilatation passes. The gastric aspirate should be observed for excessive bleeding, which may occur if the hemostatic suture line is inadequate. If bleeding is brisk or persists, the patient should be immediately reexplored to control the gastric bleeding point. After peristalsis resumes, gastric aspiration is discontinued and the patient is started on clear liquids in the usual fashion and advanced to a normal diet over the next few days.

Complications. Complications that may develop after stomach injury are hemorrhage from, or leakage of, the suture line and development of subhepatic, subphrenic, or lesser sac abscesses secondary to spilling of contaminated gastric contents. Development of such abscesses is suspected after gastric wounds in patients who fail to do well postoperatively and who have unexplainable fever for more than a few days. If contamination seems heavy, the skin and subcutaneous tissue should be left open until the wound appears clean.

Duodenum

Injuries to the duodenum and small bowel comprise about one-quarter of blunt and penetrating abdominal trauma. In 1947, Lauritzen reported the mortality rate of retroperitoneal duodenal perforation as approximately 60 percent and related it to the difficulty in establishing an early diagnosis. Burrus et al in 1961, reported a series of 86 duodenal injuries with an overall mortality of 26 percent.

Mortality rates for duodenal injuries have steadily decreased and are directly proportional to the number and severity of associated injuries as well as the time between injury and treatment. Lucas and Legderwood reported a mortality rate of 40 percent in patients who were not operated upon in the first 24 hours after injury, in contrast to a mortality of only 11 percent among those operated upon within less than 24 hours. The improving mortality rate among patients with duodenal injuries is indicated by four series of duodenal wounds reported since 1978. The total number of patients in these series was 677 and the mortality rates ranged from 10.5 to 14 percent. The mortality rate for simple stab wounds involving only the duodenum should be significantly less than 5 percent, while the mortality for severe blunt trauma or shotgun wounds to the duodenum ranges from about 35 to more than 50 percent, especially when such trauma is combined with serious pancreatic injuries.

Diagnosis. The diagnosis of blunt trauma to the duodenum and small bowel is considerably more difficult than that of penetrating trauma to these organs. With duodenal or small bowel trauma, all of the characteristic signs of injury to abdominal viscera may be minimal or absent for several reasons: (1) The injury of the duodenum following blunt trauma is frequently retroperitoneal, so that duodenal contents leak into the retroperitoneal area, rather than into the free peritoneal cavity. (2) Duodenal and small bowel fluid may cause minimal contamination and may not lead to early signs of bacterial peritonitis, as occurs following colon injury. (3) The pH of the small bowel contents is frequently nearly neutral and, thus, produces only slight chemical irritation of the peritoneum. This is not true of injuries of the intraperitoneal duodenum, in which duodenal fluid freely flows into the peritoneal cavity. The highly alkaline pH of this fluid causes immediate chemical irritation of the peritoneum and physical signs of such irritation.

Injuries of the duodenum or upper small bowel should be suspected in any patient who receives a blow to the upper abdomen or lower chest, such as from a steering wheel. Testicular pain should raise suspicion of a retroperitoneal duodenal rupture. Also, pain referred to the shoulders, chest, and back may be associated with perforation of the duodenum and small intestine.

Several diagnostic aids may be helpful in determining rupture of the duodenum or small bowel. First, needle paracentesis of the abdomen, especially in the right gutter region or in the upper quadrants, may be helpful if blood, bile, or abnormal amounts of small bowel content are aspirated. Plain radiographs of the abdomen are helpful and may be diagnostic, but absence of free intraperitoneal air does not rule out bowel perforation. Retroperitoneal rupture of the duodenum is not often diagnosed by x-ray. However, the diagnosis may be based on detection of a large accumulation of air about the right kidney or along the psoas muscle margins. After x-ray films of the abdomen and upright chest films are made to search for intraabdominal air collections, it is helpful to inject air through the nasogastric tube to produce or enlarge these air collection so they are more readily detectable. The accuracy of radiographic studies may also be increased by giving the patient a water-soluble radiopaque contrast medium orally and making abdominal x-ray films to detect leakage of the medium from the duodenum or small bowel. Such diagnostic procedures are unnecessary if other clinical signs indicate the need for exploratory laparotomy. Federle et al have recently shown that computerized tomography may be useful in the diagnosis of intraabdominal trauma, especially in the retroperitoneal area, where ruptures of the third and fourth portions of the duodenum are likely to occur.

When laparotomy is done for suspected intraabdominal injury, duodenal lesions are often missed, especially retroperitoneal lesions of the third or fourth portions of the duodenum. This is due to superficial observation, inadequate exposure, and lack of persistence on the part of the surgeon. It has been reported that duodenal perforations have been missed initially in 33 to 50 percent of the various reported series of retroperitoneal duodenal injuries. To avoid overlooking duodenal trauma and contributing to the high mortality from duodenal wounds, it is important to inspect the entire duodenum during abdominal exploration for trauma. This is especially true if a retroperitoneal hematoma is noted near the duodenum or if there is crepitation or bile-stained fluid along the lateral margins of the duodenum retroperitoneally. If these signs are noted or if the duodenum is contused, it should be widely mobilized by the Kocher maneuver, incising the peritoneum along its lateral margins, so that the duodenum is completely mobilized along with the head of the pancreas. Thus, small areas of perforation in the retroperitoneal aspect of the duodenum may be seen. Often retroperitoneal wounds of the duodenum that were missed at initial exploration are not recognized until several days later when bile-stained fluid drains from the abdominal wound of a patient who has continued to do poorly postoperatively. The following signs, in addition to those mentioned previously, indicate careful exploration of the duodenum and the retroduodenal area: elevation of the posterior peritoneum with a glassy edema; petechiae or fat necrosis over the ascending and transverse colon or mesocolon; retroperitoneal phlegmon; hematoma over the head of the pancreas extending into the base of the mesocolon; fat necrosis of the retroperitoneal tissues; and/or discoloration of retroperitoneal tissues - dark from hemorrhage, grayish from suppuration, or yellowish from bile.

The third and fourth portions of the duodenum may be exposed by mobilizing the cecum, right colon, hepatic flexure of the colon, and mesenteries of these organs up to and including the ligament of Treitz, carrying the dissection of the mesocolon along the attachment at the root of the small bowel mesentery.

Treatment. The local treatment of the duodenal perforation itself depends more on the size of the perforation than any other single factor. In general, an attempt is made to close the duodenal perforation if this can be done without decreasing the lumen of the duodenum. This closure is carried out with a continuous locking 3-0 suture through all layers of the duodenal wall (preferably using Vicryl or Dexon suture material) followed by an outer layer of nonabsorbable interrupted mattress sutures in the seromuscular layer of the duodenum. After this, the duodenum is carefully palpated to exclude stenosis. If the perforation is so large that simple closure will cause a stricture of the duodenum, consideration should be given to (1) complete division of the duodenum and an end-to-end anastomosis or (2) division of the duodenum, closure of both ends, and gastroenterostomy.

Kobold and Thal first reported a method of managing large duodenal defects that previously might have required one of the above techniques of duodenal division. Their method consists of using a retrocolic loop of proximal jejunum which is sutured over a large defect in the duodenum, with an inner row of absorbable sutures taken between the torn edge of the duodenum and the seromuscular layer of the jejunum and an outer layer of nonabsorbable mattress sutures taken between the seromuscular coats of the duodenum and the jejunum. Animal studies, as well as clinical usage, have shown the feasibility of this "patching" technique in managing large duodenal defects.

Large duodenal wounds and duodenal wounds that have dehisced also have been managed by anastomosis of the open end or the side of a defunctionalized Roux en Y loop of proximal jejunum over the duodenal defect.

If the region of the ampulla is involved in a duodenal injury, the common bile duct should be identified by insertion of a T tube, since reimplantation of the common duct sometimes may be necessary. Approximately 75 to 80 percent of all duodenal injuries can be closed by debridement of the wound edges and simple suture. However, for the other 20 to 25 percent, one of the reparative procedures described above recommended by Cleveland and Waddell is used. Rarely, even a pancreaticoduodenectomy may be necessary to manage extensive devitalizing trauma to the duodenum and periampullary region, especially when such injuries are combined with severe pancreatic trauma and it is difficult to control bleeding (see the section Combined Duodenum and Pancreatic Injuries).

Very severe injuries of the duodenum or combined severe injuries of the pancreas and duodenum may be treated by a Berne duodenal "diverticulization" procedure instead of by pancreatoduodenal resection unless the destruction and devitalization of the pancreas and duodenum is too extensive. The duodenal diverticulization procedure was first described by Berne and associates in 1960. This operation consists of diversion of the alimentary stream away from the injured duodenum and pancreatic head. This is achieved by removing the gastric antrum, closing the duodenal stump, and performing a Billroth II gastrojejunostomy and vagotomy. The duodenal laceration is closed with interrupted monofilament, nonabsorbable sutures and the duodenum is decompressed with a tube duodenostomy to reduce the possibility of disruption of the duodenal suture line from increased pressure within the duodenal stump. The tube duodenostomy is performed by inserting a #12 or #14 French straight rubber catheter into the lateral duodenal wall through a stab wound, securing the tube with a purse-string suture. The area of the combined pancreatic and duodenal injuries is then extensively drained with several large Penrose drains and a soft suction drain. The biliary tract is drained by inserting a T tube into the common duct or be performing a tube cholecystostomy. In 1974, Berne and associates reported the use of this operation in the treatment of 50 patients with severe pancreatic and duodenal injuries with a mortality rate of only 16 percent, which is gratifying low for patients with such grave injuries. Even though duodenal and pancreatic fistulas may develop in patients undergoing the Berne duodenal diverticulization procedure, these lesions are generally well tolerated since they are, in effect, end rather than lateral fistulas because the gastric contents are diverted from the duodenum and pancreas. In the experience reported by Berne and associates, there were seven duodenal fistulas and five pancreatic fistulas among their 50 patients, but all closed spontaneously.

An alternative method for diverting the gastric contents from severe duodenal injuries was recently reported by Vaughan and associates. This procedure consists of repair of the duodenal wound, followed by a gastrotomy on the greater curvature of the antrum of the stomach in a site selected for gastrojejunostomy. Through this opening, the pylorus is closed with sutures of chromic catgut (or Vicryl suture). Gastrojejunostomy, side-to-side, is then accomplished. These surgeons used this procedure in 75 patients selected form 175 consecutive patients who had duodenal trauma. The mortality was 19 percent and the rate of fistula formation was 5 percent among the patients treated by pyloric exclusion and gastrojejunostomy, in contrast to a 14 percent mortality rate and a 2 percent fistulization rate in the entire series of 175 patients. The mortality and fistulization rates were somewhat higher in the pyloric exclusion group probably because these patients had more severe duodenal injuries. Two of the three patients who developed duodenal fistulas after pyloric exclusion had spontaneous closure of the fistula and the remaining patient required surgical closure. Vaughan and associates note that in other series of duodenal injuries the rate of lateral duodenal fistula formation has ranged between 6 and 14 percent regardless of the type of closure. This compares very favorably with the 2 percent overall fistulization rate in their series of 175 patients with duodenal injuries. Kelly and associates have performed the same type of pyloric exclusion with gastrojejunostomy but have stapled across the pylorus instead of using the chromic sutures employed by Vaughan and associates to close the pylorus

Prevention of Duodenal Fistulization after Duodenal Trauma. Various surgeons suggest that duodenal fistulas can be prevented by prolonged decompression of the duodenum after closure of the wound. This may be especially indicated in more severe injuries of the duodenum and can be accomplished in several ways. Snyder and associates performed duodenal tube decompression in 53 percent of the 190 of their patients with duodenal injuries who had duodenorrhaphies. The reasons for duodenal decompression in their series was difficult to determine retrospectively, but were probably related to the surgeon's subjective impression of the severity of the duodenal wound. In this series, duodenal fistulas developed in 9 percent and caused death in 4 percent of those who had duodenal decompression. A review of their patients did not allow comment on the efficacy of tube duodenostomy in the prevention of fistulas. However, they did state that the morbidity and mortality might have been greater if tube decompression had not been used. These results suggest that decompression is not a complete safeguard against fistula formation. Sone and Fabian reported a series of 321 patients with duodenal wounds and the most recent 237 were all managed with duodenal decompression via a gastrostomy tube and twin jejunostomy tubes (one passing *retrograde* into the duodenum). Only one duodenal fistula (0.5 percent) occurred in 210 surviving patients. In contrast, failure to decompress the duodenum was associated with an 8 percent leak rate. Thus, tube decompression of the duodenum is a reasonable and probably effective adjunct in the management of selected duodenal wounds. However, decompression is not an effective substitute for careful reconstructions of severe duodenal injuries.

Reliance on an abdominal drain in the management of duodenal trauma has varied considerably, although several reports suggest that routine drainage of the duodenal suture line may favor fistula formation. However, other clinical analyses have reached the opposite conclusion and use of a drain has been urged to provide a tract for discharge of intestinal contents if a duodenal leak occurs. Objective data about drainage of duodenal wounds are lacking, and the argument remains unsettled about whether a soft rubber drain should or should not be used. Probably in the opinion of most surgeons drainage is considered advisable.

Postoperative Care. After repair of duodenal injuries, gastroduodenal decompression with a nasogastric or gastrostomy tube is usually continued for about 5 to 7 days to protect the suture lines. If fistulas form, gastroduodenal decompression should be continued for prolonged periods, and a sump drain should be inserted into the drain site for continuous active suction of the fistulous tract. This is done to prevent the possible spread of duodenal fluid throughout the peritoneal cavity, to promote collapse and healing of the fistulous tract, to prevent digestion of the skin by duodenal fluid draining onto the skin, and to aid calculation and replacement of fluid and electrolyte losses from the fistula. Also, when a duodenal fistula develops, the patient is placed on central intravenous hyperalimentation according to the principles of Dudrick and associates, which are discussed in Chap 2. This regimen maintains excellent nutrition and may reduce the volume of gastrointestinal secretions.

Occasionally, the duodenal fistula does not spontaneously close despite adequate nonoperative treatment with intravenous hyperalimentation and sump drainage. In such cases, when a reasonable trial of conservative treatment has been made and the patient is in optimal condition for reoperation, the abdomen is opened and completely explored to rule out distal bowel obstruction which may be causing the fistula to persist. The fistula is exposed at its origin from the duodenum, and a Roux en Y defunctionalized limb of proximal jejunum is brought up to the fistula and anastomosed to it. This anastomosis may use either the end or the side (after closing the end of the jejunal limb) of the defunctionalized jejunum. This procedure permanently diverts the fistula drainage internally and is very effective in treating persistent duodenal fistulas.

Intramural Hematoma

Intramural hematoma of the duodenum is usually due to blunt abdominal trauma, including child abuse, which causes rupture of intramural duodenal blood vessels with formation of a dark, sausage-shaped mass in the submucosal layer of the duodenal wall. This hematoma may cause partial or complete duodenal obstruction, but the obstruction is usually partial. The patient has signs of a high small bowel obstruction, with nausea and vomiting associated with upper abdominal pain and tenderness, and sometimes a suggestion of a right upper quadrant mass on palpation of the abdomen. Plain films of the abdomen may show an ill-defined right upper quadrant mass and obliteration of the right psoas shadow. Felson and Levin have shown that an upper gastrointestinal tract series is almost diagnostic, showing dilatation of the duodenal lumen with the appearance of a "coiled spring" in the second and third portions of the duodenum due to the crowding of the valvulae conniventes by the hematoma. The serum amylase level may be elevated. An intraduodenal hematoma may also occur spontaneously in patients on anticoagulants.

Woolley and associates state that traditionally the recommended treatment for intramural duodenal hematoma has been surgical. The most common operation has been simple evacuation of the hematoma; however, gastroenterostomy as well as duodenal resection has been performed. Izant and Drucker in 1964 suggested that most infants and children with intramural duodenal hematomas could be successfully treated without surgical intervention. Nonsurgical treatment of these patients consists of cessation of oral intake, nasogastric suction, and intravenous replacement of fluids and electrolytes. Holgerson and Bishop in 1977 reported on nine patients with intramural duodenal hematomas, only one of whom was operated on. It is now increasingly evident that when there is no indication of bowel perforation, most patients with this condition will respond to the conservative treatment noted above.

Small Bowel

Injuries to the small bowel are more common than injuries to the duodenum or colon. Eighty percent of bowel injuries occur between the duodenojejunal junction and the terminal ileum, with approximately 10 percent each in the duodenum and the large intestine. The usual mechanism of small bowel injury from blunt trauma is the crushing of the small bowel against the vertebral column. Rupture of the small bowel is also caused by shearing and tearing forces applied to the abdomen, and rarely by sudden elevation of the intraluminal pressure of the bowel with bursting from such sudden high pressure. Williams and Sargent have experimentally shown that rupture due to sudden elevation of pressure within the bowel is quite unusual.

In exploring the abdomen for injuries to the small bowel, it is important to inspect minutely the entire circumference of the small bowel and its attached mesentery from the ligament of Treitz to the ileocecal valve. The bowel may be completely transected in one or more places by blunt trauma with or without severe injury to the mesentery and its blood supply; at times, the mesentery may be torn from a segment of bowel, thus depriving the bowel of its blood supply. Penetrating trauma to the small bowel from a gunshot wound or stab wound is common, although, surprisingly, it has been noted at times that in patients with a stab wound of the abdomen, the small bowel has been spared. This is probably because the great mobility of the small bowel allows it to slide away from the knife, a much less likely occurrence with gunshot wounds than with stab wounds.

Treatment. Small, single perforations of the small bowel may be closed safely with a single layer of interrupted nonabsorbable mattress sutures that include and invert the seromuscular and submucosal coats of the bowel. A hemostatic stitch, as required for stomach wounds, is not necessary for small bowel injuries, because the small bowel does not tend to continue bleeding from the submucosal plexus, as does the stomach. However, individual bleeders should be ligated with fine suture material. An advantage of a single-layer closure is its rapidity of performance, which is important in patients in precarious condition after multiple trauma.

Two small perforations of the bowel which are very close together may often be repaired by converting the wounds into one and closing the resulting defect as a single linear wound. This type of repair does not constrict the lumen of the bowel as much as two separate lines of suture placed close together and is more secure. Multiple perforations of the small bowel may occur after injury from shotgun pellets. Each one of these injuries should be carefully sought out and closed with interrupted rows of nonabsorbable mattress sutures.

Long linear lacerations of the small bowel lumen also should be closed with a single row of nonabsorbable sutures after ligating any persistent bleeders with small nonabsorbable sutures. Longitudinal lacerations may be closed in a longitudinal direction or transversely according to the Heineke-Mikulicz principle.

Small bowel injuries produced by high-velocity missiles cause severe contusions of tissue surrounding the actual perforation. Because the contusion is a site of potential tissue necrosis and bowel leakage caused by thrombosis of vessels in the area of blast injury, it should be debrided. The debridement should extend into viable bowel where active bleeding is obtained.

If the wound is too large or is long and longitudinal, the bowel may not be adequately closed without loss of lumen, and the damaged segment should be resected. Also, if there are multiple wounds in a short segment of bowel, it is much safer and easier to resect the injured segment than to attempt to suture each of the closely spaced wounds, with resulting impairment of the bowel lumen and blood supply and subsequent obstruction and/or necrosis and leakage. Perforations or lacerations to the mesenteric border, unless they are quite small, are difficult to repair and frequently are associated with vascular impairment. They also should be managed by resection of the involved bowel if an adequate closure cannot be obtained without interference with blood supply. Bowel transections should be reanastomosed after debriding contused and damaged bowel on either side of the wound back to normal intestine that has a good blood supply. Careful attention should be given to leaving uninjured mesentery adjacent to the suture line of the reanastomosis. Extensive segments of bowel may be avulsed from the mesentery adjacent to the suture line of the reanastomosis. Extensive segments of bowel may be avulsed from the mesentery, so that the bowel loses its blood supply. All the necrotic or potentially necrotic bowel and injured mesentery must be resected and an end-to-end anastomosis made between uninjured bowel attached to uninjured mesentery.

Contusions of the small bowel should be assumed to be larger than is apparent. Such injuries are dangerous, since they may lead to subsequent necrosis and perforation. Contusions up to 1 cm in diameter may be turned in with a row of fine nonabsorbable mattress sutures. Larger contusions should be resected.

Postoperative care of patients with wounds of the small bowel includes maintenance of nasogastric suction and low oral intake until adequate bowel activity returns. Also, these patients are usually maintained on broad-spectrum parenteral antibiotics begun preoperatively and continued through the early postoperative period. Leakage from suture lines and intestinal obstruction rarely occur if small bowel wounds are properly managed. In the report of Giddings and McDaniel concerning wounds of the jejunum and ileum during World War II, leakage from suture lines occurred in only 1 percent and intestinal obstruction in 1.7 percent in a series of 1.168 patients with small bowel injuries, most of whom had multiple visceral injuries. Again, extracellular fluid volume deficits should be replaced in patients with small bowel injuries, with adequate amounts of balanced salt solution given during the surgical procedure and in the postoperative period to maintain sufficient urine volume and prevent extracellular fluid volume deficit.

Colon Injuries

The morbidity and mortality from acute injuries to the colon and rectum have been significantly reduced by an aggressive surgical approach. This has been largely influenced by the experiences of military surgeons during World War II and the Korean conflict. In the American Civil War, wounds of the abdomen carried a mortality rate of approximately 90 percent; it was not until the Boer War that the mortality rate of 80 percent of cases treated conservatively was thought to be excessive and active intervention was viewed more favorably. During this time, the fatalities from wounds of the colon eventually dropped to less than 60 percent. In World War II, an impressive improvement in the mortality from wounds of the colon was noted. This was due to several factors including improved methods of triage and transportation, effective replacement of blood and fluid, and early surgical intervention combined with ancillary use of antibiotics.

The mortality rate for wounds of the colon of 37 percent in World War II was reduced to approximately 15 percent during the action in Korea. The majority of military surgeons treating acute injuries of the colon tended to exteriorize the wound as an artificial anus to prevent further soilage of the peritoneal cavity. This approach to these particular wounds was dully carried over into civilian practice and reflected in the subsequent reduction in mortality and morbidity. In the later phase of the Korean conflict, however, some modification of the aggressive technique was noted in that small, primary wounds treated early were handled by primary closure without exteriorization.

Acute wounds of the colon which occur in a civilian environment exhibit features that may modify the indications for exteriorization of the wound. The types of injury usually noted in a military situation resulted from either high-velocity missiles or fragmentation missiles in which there was massive destruction of tissue and usually gross soilage of the peritoneal cavity. In the civilian environment, the wounds more often are caused by low-velocity missiles and usually are unassociated with massive destruction of surrounding organs and tissue. The time from wounding to initial treatment in the civilian situation is generally somewhat less than that noted during military conflict. Similarly, associated injuries occurring in civilian accidents do not tend to be so numerous nor so massive as those in a military environment, and this has a definite influence on morbidity and mortality.

Etiology. Acute injuries of the colon and rectum may be divided into penetrating wounds and wounds resulting from blunt trauma. In the former group, accidental colon injuries may be the result of industrial accidents involving explosions resulting in impalement, penetrating injuries from flying objects, or blast injuries. These injuries may be either the direct result of explosives or the result of accidents involving sources of greatly compressed air. External acts of violence constitute an important source of injuries to the colon, and these are generally penetrating injuries caused by guns or knives or, on rarer occasions, blunt abdominal trauma. Wounds of the rectum, particularly, may be the result of instrumentation during the process of sigmoidoscopy or the administration of enemas. There may also be perforations of the colo-rectum by foreign bodies which pass through the alimentary canal into the colon. Inadvertent penetration of the colon or rectum may occur during difficult operations; this is especially true of operations in the pelvis for severe neoplastic or inflammatory disease. Falls resulting in impalement upon sharp objects may produce wounds of the rectum. Automobile accidents and other forms of blunt trauma may produce acute injuries to the colon and rectum.

Diagnosis. A systemic diagnostic approach to problems of abdominal trauma is necessary, but specific examinations of the colon and rectum may be necessary to delineate an injury. This is particularly pertinent in those instances in which instrumentation is the cause of suspected perforation of the rectum or colon. Rectal examination and sigmoidoscopy should occupy a prominent place in the examination of these patients. Diagnostic abdominal x-ray studies should be employed to determine if there is a perforated colon with leakage of air into the free peritoneal cavity. Anteroposterior and lateral decubitus views are particularly helpful in these instances. Contrast studies of the colon should be employed rarely and cautiously in view of the high morbidity and mortality associated with leakage of barium and feces into the free peritoneal cavity. Aqueous opaque media, such as Gastrografin, are preferable when penetration of the colon is suspected.

Treatment. The general principles of management of patients with abdominal trauma apply to those patients who have acute injuries of the colon. It is important that the time from wounding to definitive operation be as short as possible, and aggressive replacement of fluid and blood losses should be undertaken at once. Preoperatively, penicillin and tetracycline should be started in all patients suspected of having penetrating injuries of the colorectum. Two million units of aqueous penicillin and 0.5 g of tetracycline are added to the intravenous solution.

These patients are explored through a midline incision in order to allow access to all parts of the abdominal cavity. A thorough and complete exploration of all abdominal viscera is made, for the morbidity and mortality vary directly with the number of associated injuries. Bleeding should be controlled as rapidly as possible and immediate efforts made to reduce peritoneal soilage from any penetrating wound of an abdominal viscus. The specific care of the wound of the colon should be approached by noting the anatomic differences between the intraperitoneal and extraperitoneal large intestine. Particular attention must be paid to the type of wound, its location, the amount of tissue destruction, the presence of associated injuries, and the time from wounding to definitive care.

Wounds of the intraperitoneal colon may be divided into two groups: First, small primary wounds located on the antimesenteric border which are seen quite early, in which there is minimal tissue destruction, and minimal or no peritoneal soiling. These wounds, especially of the left colon and in the absence of associated injuries of other abdominal viscera, may often be adequately managed by a primary two-layer closure. The mucosa is approximated with a running lock suture of 3-0 chromic catgut, and the seromuscular layers are closed with interrupted #50 cotton sutures, the Lembert technique. Second, wounds of the right colon, containing liquid feces, are less amenable to this type of primary closure, for often gross and extensive peritoneal soiling follows the colon penetration. High-velocity missile wounds should rarely, if ever, be closed primarily, for tissue destruction is often excessive and may not be readily apparent. The injured area should be extensively debrided.

A *less well accepted* modification of primary closure in which the repaired colon wound is exteriorized and then returned to the abdominal cavity, usually about 10 to 14 days later, has been reported by several groups of surgeons. If the repaired colon wound fails to heal after exteriorization, it is converted to a colostomy and managed in the usual manner, otherwise the patient is returned to the operating room and, under general anesthesia, the repaired and well-healed segment of bowel is freed up and dropped back into the peritoneal cavity. In general, the colon wounds managed by exteriorization-repair are somewhat more severe than those managed by simple primary closure. Flint and associates have classified colon injuries into three stages and this classification has been used to determine the type of repair that is most appropriate for a particular stage. These stages are:

Stage 1 - isolated colonic injuries with minimal contamination or blood loss, without vascular compromise of the colon, and managed within 8 hours of injury (these injuries are most suitable for primary repair).

Stage 2 - colonic injuries associated with other intraabdominal injuries managed within 12 hours of trauma and not associated with heavy contamination, severe blood loss, or prolonged hypotension (exteriorization-repair is generally confined to this stage).

Stage 3 - injuries that involve different segments of the colon far removed from each other or injuries associated with devascularization of the colon, severe blood loss (more than 5.000 mL of blood transfused intraoperatively), prolonged hypotension (systolic BP < 80 mmHg for more than 15 minutes), heavy fecal contamination, or a significant delay (more than 24 hours) in treatment (these wounds should routinely be managed by exteriorization as a colostomy or by primary repair and a proximal venting colostomy).

Favorable experiences with *selective* use of exteriorization-repair have recently been reported by Lou and associates and by Dang and associates. In 65 to 75 percent of the patients in these series the colon wound healed and could be returned to the peritoneal cavity after several days. The mortality rates were zero and the colon-related morbidity rates were 18 percent in both of these experiences. These two series consisted of a total of 88 patients who had exteriorization-repairs. Probably less than 15 percent of patients with colon injuries can be treated in this manner. It is important to emphasize that if exteriorization-repair is used a generous opening must be made in the abdominal wall to permit exteriorization of the repaired wound without obstruction of the colon.

Acute injuries of the intraperitoneal colon resulting from high-velocity missiles which are associated with extensive destruction of tissues or which are large and ragged in nature and are located near or involve the mesenteric border should not be closed primarily. If located in the ascending, transverse, or descending colon, the wound may be exteriorized as a colostomy. Similarly, if the time from wounding to definitive care is relatively long, allowing seeding of the peritoneal cavity with a large number of bacteria, some type of colostomy should be performed either as a wound exteriorization or as a proximal diverting colostomy. Primary closure of the distal wounds is then permissible. Although a loop colostomy may be done for expediency, a completely diverting double-barrel colostomy is favored. It is preferable to open the loop colostomy immediately, usually with the cautery, and secure early, complete fecal diversion. This is performed in the operating room after all the wounds are closed and dressed. When there are associated massive injuries to other viscera, although the colon wound itself might fulfill the indications for primary closure, a colostomy is indicated. In some instances, there may be massive injury of the cecum or of the ileocecal area, in which case it will be necessary to resect the injured bowel and do an ileotransverse colostomy. This is preferable to an ileostomy and, with suitable antibiotic coverage and intraluminal antibiotics, is an adequate procedure.

Localized minor wounds of the right colon and cecum which do not produce extensive destruction of the large bowel and are not associated with massive soilage or serious injury to other viscera may often be managed by primary closure and appendicostomy. In these instances, after debridement and careful closure of the laceration of the cecum, tube appendicostomy is performed to decompress this segment. Seromuscular sutures are placed about the base of the appendix and secured to the lateral parietal peritoneum in order to prevent intraperitoneal leakage about the area of tube insertion. By this technique, suitable decompression of the cecum and right colon may be obtained, and removal of the tube appendicostomy permits the vent to close spontaneously. This route may also be used for intraluminal installation of neomycin or kanamycin solutions, which may offer some protection from bacterial invasion of the suture line.

The extraperitoneal perforations of the rectum must be evaluated under the same principles employed for colon injuries within the peritoneal cavity. If clean lacerations with minimal spillage are seen early, primary bowel repair may be indicated if the wound is accessible. Presacral drains should then be inserted. Associated perineal wounds should be debrided and, if grossly contaminated, left open. If debridement is adequate and these wounds are clean, they may be closed with drainage. Any damage to the anal sphincter may be repaired at this time. When a perineal wound is present but not penetrating the colon, it should be debrided widely and if not grossly contaminated then may be closed with drainage. Where there is no perineal wound but there is significant tissue destruction about the extraperitoneal rectum, presacral drainage should be instituted.

For all injuries of the rectum, complete diversion of the fecal stream is mandatory and can be accomplished by constructing a proximal double-barrel colostomy. Even in those instances where the rectal wound has been closed and diverting colostomy performed, presacral drainage is necessary.

Drainage of the retrorectal area is extremely important. This can be established by making a curvilinear incision in the posterior perianal area, incising the anococcygeal ligament, and bluntly dissecting into the presacral space. Two Penrose drains will usually suffice, but with extensive injuries, it may be necessary to utilize sump drainage for a few days.

Lavenson and Cohen, on the basis of their experience in the Vietnam conflict, strongly recommend removal of all feces from the distal rectum. This is accomplished by irrigating copious amounts of saline solution through the defunctionalized segment until the return is clear. They report a significant decrease in mortality and complication rates when utilizing this technique. Military injuries are generally associated with higher-velocity missiles and cause more fecal contamination and blast injury to surrounding pelvic tissue. In civilian injuries, distal irrigation may not be as important, as evidenced by Trunkey and Shires, who report a lower morbidity and mortality rate in their series, in which distal irrigation was not employed but adequate drainage and diversion were used.

Serious perineal injuries are treated in a similar manner. Even in the absence of rectal injury, sepsis can be avoided by early fecal diversion. Failure to recognize this potential problem may lead to extensive soft tissue infections extending from the knee to the axilla, with potential involvement of the anterior and posterior abdominal wall.

Early closure of the colostomy is indicated in patients who have completely recovered and have no distal colon injury. It is desirable to close the simple colostomy in 2 or 3 weeks. Prior to closure, both limbs of the colon should be visualized radiographically to assure that no lesion persists. Mechanical and bacterial cleansing of the colon is effected preoperatively.

Liver

Injury to the liver is suspected in all patients with penetrating or blunt trauma that involves the lower chest and upper abdomen. Among patients with penetrating abdominal trauma, the liver is second only to the small bowel as the organ most commonly injured; among those with blunt trauma, the liver is second only to the spleen as the most commonly injured organ. About 80 percent of liver injuries occur as a result of penetrating trauma from stab wounds or gunshot wounds; only 15 to 20 percent occur from blunt trauma. In recent years, the incidence of stab wounds has diminished while the incidence of gunshot wounds, especially those caused by higher-velocity and larger-caliber missiles, and blunt trauma has increased. These changes in the types of liver injuries, the more rapid transport of patients with hepatic trauma to treatment facilities, and better resuscitation methods have caused an increase in the severity of liver injuries that are likely to confront the surgeon.

Early exploration, prompt replacement of blood and use of balanced electrolyte solution, antibiotics, proper choice of surgical treatment, and adequate drainage are all factors that have led to increased survival rates. The average overall mortality rate of patients with hepatic trauma is about 13 to 15 percent. However, this rate is directly related to the severity of the liver injury and the presence of associated visceral trauma. The mortality rate of stab wounds to the liver without associated organ injury is only about 1 percent. When significant liver trauma is associated with injuries of more than five other intraabdominal organs, or when major hepatic resection is required to control the bleeding, the mortality rate rises to about 45 to 50 percent.

Treatment. After initial resuscitation and diagnostic maneuvers, patients with suspected hepatic injuries are rapidly moved to the operating room. The entire abdomen and chest are "prepped" and draped, and a long upper midline abdominal incision is made. Sources of bleeding from the liver and abdomen are quickly appraised, and temporary control of the bleeding is obtained by manual compression or packs placed over the bleeding sites and by temporary occlusion of appropriate major vessels. Digital compression of the hepatic artery and portal vein to occlude temporarily the blood flow to the liver (the Pringle maneuver) may control or slow hepatic hemorrhage in some patients, but more often it is necessary to combine the Pringle maneuver with compression packs placed over the liver injury to control hemorrhage effectively. There is general agreement that, in the normothermic liver, blood flow to the liver can be completely occluded for about 15 minutes without causing any hepatocellular damage. If it is necessary to occlude the hepatic blood supply for more than 15 minutes, the vascular occlusion can be briefly interrupted every 10 or 15 minutes to allow short periods of uninterrupted hepatic blood flow. In a small, uncontrolled clinical experience with 22 patients who had complex hepatic injuries, Pachter and Spencer gave an intravenous bolus of methylprednisolone (30 to 40 mg/kg) before hepatic inflow occlusion. This use of steroids may have been responsible for increasing tolerance to inflow occlusion beyond 20 minutes in 82 percent of their patients and beyond 30 minutes in 45 percent; however, it is emphasized that this is an uncontrolled observation. In addition, Pachter and Spencer used 2 liters of iced Ringer's lactate solution intraperitoneally to induce some degree of hepatic hypothermia. Again, this method of protection against warm ischemia was not adequately evaluated, since an intrahepatic temperature probe was not used to confirm the achievement of local hepatic hypothermia.

Definitive treatment of liver injuries may be accomplished by drainage alone, suture or hemostatic maneuvers and drainage, or variations of hepatic resection or resectional debridement.

Drainage Alone. Hepatic hemorrhage ceases spontaneously by the time the abdomen is opened or stopped soon after compression of the bleeding site in about half of patients with liver injuries. In such patients, the only treatment necessary is adequate drainage of the injury. Suturing of nonbleeding liver injuries is unnecessary. This is emphasized by Trunkey, Shires, and McClelland and by Lucas and Legderwood who reported no rebleeding among several hundred patients with liver injuries that stopped bleeding spontaneously or soon after temporary pack compression. Suturing of nonbleeding liver wounds may cause bleeding and needlessly traumatizes hepatic tissue.

In the opinion of essentially all surgeons who manage large numbers of hepatic injuries, these injuries should be drained externally. It is probable that a combination of Penrose drains and sump suction drains should be used to obtain optimal drainage. Large, 1-in-wide Penrose drains should be brought out posterolaterally, as dependently as possible, through an abdominal stab wound to achieve the best drainage by gravity. It is very important to make an adequate opening in the abdominal wall, sufficient to admit at least two fingers, to assure optimal function of the Penrose drains. Otherwise, the drains act as plugs rather than drains. Adequate drainage of the perihepatic space in patients with liver injuries greatly reduces formation of infected collections of bile, blood, and tissue fluid in the subphrenic and subhepatic spaces. While dependent gravity drainage with large Penrose drains may be more reliable than nondependent, suction drainage, in recent years it has become apparent that a combination of Penrose and suction drains may provide optimal evacuation of the perihepatic spaces. The Silastic suction drains now available are generally very effective in providing aspiration drainage. It is probably preferable to bring suction drains through small stab wounds in the abdominal wall that are separate from the Penrose drainage site. Usually, the Penrose drains can be brought through the stab wound at the tip of, or just below, the 12th rib. However, in large patients with more extensive liver wounds, it may be preferable to resect the lateral half or two-thirds of the right 12th rib to achieve more effective gravity drainage. The Penrose drains are left in place 5 to 10 days, thereafter being slowly removed over a 3-day period. Only at this time is a firm, fibrinous tract formed about the drains which ensures adequate external drainage of the material that accumulates in the abdomen after the drain is removed. Suction drains generally should remain in place until each drain is aspirating less than 24 to 30 mL of fluid daily, following which these drains are removed.

Suture, Hemostatic Techniques, and Drainage. Bleeding persists despite temporary compression packing of the injury site in approximately half of patients with liver injuries. Definitive hemostasis of persistently bleeding liver injuries usually can be achieved by liver sutures. Simple interrupted sutures are placed 2 cm from the wound margins, using 2-0 or 0 chromic sutures swaged onto a 2-inch blunt tipped "liver needle". This allows gentle but firm approximation of the wound edges, thereby stopping most bleeding that originates from the outer 2 cm of the liver parenchyma immediately beneath the hepatic capsule. Larger wounds may require placement of figure-of-8 liver sutures to prevent cutting through the liver capsule. Passage of the suture through buttressing material such as Surgicel, Gelfoam, or omentum is seldom needed if the sutures are placed 2 cm from the margin of the injury and tied gently. However, if a bolster is needed, it is preferable to use a vascularized pedicle of omentum instead of foreign material. Trunkey, Shires, and McClelland have abandoned the techniques previously described using interlocking mattress sutures for hemostasis. These authors now recommend direct suture ligation of the bleeding vessel as an attempt to reduce the chance of strangulation and subsequent necrosis by mattress sutures.

Recently, microcrystalline collagen powder (Avitene) has been reported to be successful in controlling bleeding from liver wounds. Unlike other material such as Gelfoam, Avitene can be left in liver wounds without inciting significant foreign body reaction.

The use of liver sutures to obtain hemostasis from both the entrance and exit sites of long gunshot tracts in the liver is controversial. However, Lucas and Ledgerwood state that this technique was successfully used in several of their patients who otherwise would have required extensive surgery. Placement of the liver sutures at both ends of the bullet tract stops bleeding arising from the subcapsular area, which is the usual source. During their 5-year prospective review, Lucas and Ledgerwood found that only one patient developed an intrahepatic abscess following the use of this technique, and no patients developed hemobilia after closure of both ends of a long gunshot tract. They noted that continued bleeding which persists after closure of both ends of the tract is usually identified at the initial operation by blood oozing between the liver sutures or by an increase in the size of the liver within 10 minutes after placement of the sutures. If the persistently bleeding tract is short and close to an accessible surface of the liver, hemostasis can be achieved by limited wedge reaction or by resectional debridement incorporating the tract as part of the debridement. Persistently active bleeding from deep bilobar tracts that do not lend themselves to resectional debridement is best controlled either by ligation of an appropriate branch of the hepatic artery or by tractotomy and ligation of the intraparenchymal bleeding vessel. However, tractotomy may cause further bleeding, and for this reason, ligation of one of the main hepatic artery branches is preferable, since it usually stops arterial bleeding from deep tracts and is likely to cause less morbidity than tractotomy.

Ligation of an appropriate major branch of the hepatic artery (ie, the right or left branch) is a safe and effective means for controlling liver bleeding in patients with active arterial hemorrhage from wounds that do not permit suture ligature or wedge resection and in whom bleeding stops with temporary hepatic artery occlusion. Mays reported achieving liver hemostasis in 15 of 16 patients who underwent ligation of hepatic artery branches. Lucas and Ledgerwood did not find ligation of major branches of the hepatic artery as effective in arresting hemorrhage as Mays did, possibly because some of these patients were bleeding from major venous injuries. It is suggested that the right or left hepatic artery should not be ligated if a simple temporary compression pack or suturing of a bleeding injury controls the hemorrhage. However, if compression or suturing does not control bleeding and temporary occlusion of the hepatic artery branch supplying the injured area of the liver does not stop hemorrhage, then the appropriate major hepatic artery branch should be ligated, especially if the alternative treatment is hepatic resection.

Flint and Polk recently reviewed their large experience with hepatic artery ligation in the management of liver trauma. Critical reanalysis of their results showed that hepatic artery ligation was actually required in only 12.4 percent of their 540 patients with liver trauma rather than in the 17 percent who actually had this procedure. They also point out that the unrealistic expectation that hepatic artery ligation would control venous bleeding undoubtedly led to late recognition of hepatic and portal vein injuries in patients who continued to bleed after hepatic artery ligation. In their present approach to bleeding liver lacerations, Flint and Polk initially pack the liver wound and manually compress the liver while restoring blood volume and controlling other bleeding sites. Preparations for compression of the porta (ie, the Pringle maneuver) are made and the packs are removed. If bleeding recurs, the porta is occluded temporarily with a vascular clamp. If hemorrhage continues after the Pringle maneuver, the wound is repacked and a search is made for hepatic *venous* injury. When porta compression controls hemorrhage, the laceration is gently explored for specific bleeding sites amenable to suture ligation. If this is not feasible, the lobar branch of the hepatic artery and portal vein are exposed and sequentially occluded. The arterial or venous branch giving rise to the bleeding is then ligated. After this, devitalized liver tissue is debrided and the area is drained. The use of a pedicle of omentum as an autogenous pack to control hemorrhage in major hepatic injuries has recently been recommended by Stone and Lamb and by Pachter and Spencer. The omental pedicle provides the necessary bulk to fill a traumatic crevice in the liver so as to obstruct further hemorrhage without causing pressure necrosis of the surrounding hepatic parenchyma. In large liver wounds, this viable pack of omentum may eliminate dead space as well as tamponading venous oozing from the liver.

Resection. Resectional debridement or limited wedge resection is recommended to control bleeding from ragged liver injuries that may be caused by shotgun wounds, high-velocity rifle wounds, and severe blunt injuries. Limited resectional debridement of shattered liver tissue usually achieves hemostasis from such injuries effectively and safely. The margins of resectional debridement should be 2 or 3 cm beyond the point of injury, and bleeding during debridement is controlled by digital parenchymal constriction and/or temporary occlusion of the inflow of blood to the liver at the porta hepatis. The liver parenchyma is separated bluntly by finger fracture, a metal suction tip, or a scalpel handle. Vessels and bile ducts are secured by individual suture ligation or by metal hemoclips as these structures are encountered. It is not necessary to oppose the margins of the resection with interrupted liver sutures if bleeding from the resected surface is controlled. If such hemostasis is not achieved, the omental pack referred to above may be employed.

Anatomic hepatic lobectomy to control bleeding, especially from the right lobe, is preferably reserved for patients in whom (1) hepatic suturing is unsuccessful; (2) resectional debridement or hepatotomy with intraparenchymal hemostasis is precluded by the anatomic location of the injury; (3) occlusion of the hepatic artery fails to control hemorrhage. Although resectional debridement or sublobar hepatic resection may be required in about 4 or 5 percent of all patients with liver injuries, no more than 2 or 3 percent require anatomic, lobar resection to control hemorrhage. Although resectional debridement or sublobar hepatic resection may be required in about 4 or 5 percent of all patients with liver injuries, no more than 2 or 3 percent require anatomic, lobar resection to control hemorrhage. Most of the few patients with liver injuries who require major hepatic lobectomies to control bleeding have massive, shattering injuries of the liver, injuries of the retrohepatic vena cava, or injuries to the major hepatic veins at or near the junction with the vena cava. If it becomes apparent that major lobar resection is necessary, the hepatic bleeding is temporarily controlled by manual compression of packs placed over the liver wound and by a Pringle maneuver while the midline abdominal incision is extended by performing a median sternotomy.

A median sternotomy is much more quickly and easily made and closed than a right thoracoabdominal incision, causes considerably less diaphragmatic injury, provides much easier access to the vena cava and hepatic veins, permits easier insertion of a retrohepatic vena caval shunt if this is required, and causes less postoperative pain and pulmonary morbidity that a right thoracoabdominal incision.

After wide exposure is obtained by the median sternotomy extension of the midline abdominal incision, Rumel tourniquets are placed about the vena cava superior and inferior to the liver. The superior tape is placed about the vena cava superior to the central tendon of the diaphragm after this portion of the vena cava is exposed by opening the pericardium. These tapes permit temporary occlusion of the vena cava for insertion of a retrohepatic intracaval shunt if vascular isolation of the liver is required during hepatic lobectomy because of major retrohepatic vena cava or major hepatic vein injury near where these veins enter the vena cava. The hepatic artery, portal vein, and bile ducts supplying the lobe to be resected are then suture-ligated and divided. After this, hepatic resection can be done by dividing Glisson's capsule with a cautery along the line appropriate for the lobe being removed. The lobe is removed by fracturing through the liver substance along the line of resection with the thumb and forefinger or with the tip of a Poole metal abdominal suction tube from which the guard has been removed. As the blood vessels and bile ducts are encountered within the liver, they are isolated by passing a right-angle clamp around them and are then ligated and divided. After the larger vessels and ducts are suture-ligated, the smaller ones are secured with metal hemoclips. No attempt is made to secure the hepatic veins at their junction with the retrohepatic vena cava before beginning the resection; instead, it is much easier and safer to isolate and suture-ligate or oversew the appropriate major hepatic veins as they are encountered posteriorly during the liver resection. The resection begins anteriorly and progresses posteriorly toward the right or left side of the vena cava, keeping to the right or left of the middle hepatic vein (depending upon whether a right or left lobectomy is being done). The middle hepatic vein demarcates the right from the left lobe of the liver and passes in a line from the middle of the gallbladder bed posteriorly to the midportion of the retrohepatic vena cava. The hepatic veins and other large vascular structures must be oversewn, since simple ligatures on these large structures often slip off and cause catastrophic bleeding.

The Lin hepatic compression clamp may be very helpful in performing resections. With the use of this clamp, there is considerable reduction in blood loss and operating time, but its availability should not cause a broadening of the strict indications for liver resection for trauma. The clamp can be used for resecting the liver only when the liver has been severely shattered and devitalized without injury to the retrohepatic vena cava or the major hepatic veins near the junction with the vena cava.

Vascular Isolation. Vascular isolation may be required in a highly selective group of patients with liver injuries. This technique allows the surgeon to control bleeding from and to repair retrohepatic vena caval or major hepatic venous injuries. Vascular isolation of the liver is attained by using one of two techniques. The first of these techniques employs occlusive vascular clamps placed across the aorta just below the diaphragm, on the porta hepatis, and across the inferior vena cava above and below the liver. This technique may be associated with cardiac dysrhythmias and renal insufficiency. The second technique for obtaining vascular isolation of the liver was first described and reported by Schrock and associates and further successful experience with this method was reported by Yellin and associates. When this technique is used, retrohepatic vena caval and hepatic venous isolation is attained by inserting a #36 endotracheal tube with an inflatable balloon near the caudal end via the right atrial appendage of the heart. The tube is then passed down the retrophepatic cava and shunts blood around the liver from the lower portion of the body to the right heart. Control of vascular inflow to the liver is obtained by placing a Rumel tourniquet or vascular clamp on the port hepatis. The introduction of the intracaval shunt via the right atrial appendage is most expeditiously done through a median sternotomy. Also, it is suggested that three equidistant "guy" sutures should be placed in the right atrial wall somewhat outside the atrial purse-string suture before making the atrial opening in the center of the purse-string suture to insert the shunt tube. These guy sutures are then spread apart and held up by assistants as the atrium is opened; this greatly facilitates insertion of the shunt by stabilization of the atrial wall. Defore and associates reported survival of 7 of 15 patients with major vena caval or hepatic vein injuries following vascular isolation and introduction of an intracaval shunt as described. Nevertheless, this technique is difficult and somewhat dangerous to perform and should be used only when it is certain that the vena caval and/or hepatic vein injuries are severe enough that bleeding can be controlled in no other way. In the latter instance, the shunt may be lifesaving. It is also emphasized that the results with the shunt probably can be improved if it is used promptly as soon as it becomes apparent that no other method will achieve hemostasis. In some experiences reporting poor results with the shunt, its use may have been delayed too long and the massive transfusion required in the interim may have led to an intractable coagulopathy. In reviewing 60 patients from several institutions in whom the shunt was used, Walt found a survival rate of 20 percent and very probably most of these patients would not have survived without the shunt.

Another method for controlling hemorrhage from the retrohepatic vena cava or major hepatic veins has been described by the authors. If the major venous laceration is in such a position in the suprahepatic vena cava or the extrahepatic portion of the hepatic veins, a Foley catheter may be quickly inserted into the exposed laceration. The balloon of the Foley catheter is then inflated and gently pulled up against the wall of the vena cava or hepatic vein to occlude the laceration, arrest the hemorrhage, and thus permit repair of the venous laceration with relatively good exposure and little blood loss.

It is again emphasized that these methods should not be used except by a skillful and experienced surgeon in whose judgment exsanguination will occur unless vascular isolation is carried out. If such is not the case, the temporary use of gauze packing to control intractable hemorrhage may still be indicated. A recent experience with the use of packs to control hemorrhage in patients with hepatic trauma was reported by Feliciano and associates. These surgeons used intraabdominal gauze packing for hepatic tamponade in 10 patients with continued hepatic parenchymal oozing despite all attempts at surgical control of extensive injuries. The packing was removed at relaparotomy in four patients and through abdominal drain sites in five. Nine of the ten patients survived and there were no cases of rebleeding after removal of the packing. The packs were removed from these 10 patients when their hemodynamic status was satisfactory, bleeding seemed to be under control, and other systemic problems did not preclude another general anesthetic to remove the packs. The packs were removed from 8 hours to 10 days (average: 5.2 days) after the last operation to control hepatic hemorrhage. Feliciano and associates note that reoperation to remove the packs is not necessary, but a "second-look" operation is valuable since it permits further debridement of nonviable tissue, irrigation of the subphrenic and subhepatic spaces, and insertion of clean perihepatic drains. A warning must be given against indiscriminate packing as a primary treatment for liver injuries, as was often done with catastrophic results many years ago. In this regard, Feliciano and associates state that packing is a valuable adjunct for controlling hepatic hemorrhage in *highly selected* patients with the following characteristics: (1) coagulopathy after hepatotomy or selective hepatic artery ligation; (2) coagulopathy before a needed lobectomy can be done; (3) extensive subcapsular hematoma; and (4) extensive bilobar injuries.

Subcapsular Hematoma. The treatment of subcapsular hematomas of the liver is somewhat controversial. Left alone, these may (2) resolve spontaneously; (2) expand and burst with delayed intraperitoneal bleeding; (3) cause an hepatic abscess; or (4) decompress into the biliary tree and cause hemobilia. The risk of inducing massive hemorrhage, at times uncontrollable, accompanies attempts at incision and evacuation.

Richie and Fonkalsrud reported a series of subcapsular hematoma patients who were treated nonoperatively. They emphasize that severe bleeding may result in some patients in whom hematomas of the liver are unroofed, and they further noted that since some hematomas are centrally located within the liver, they often do not lend themselves to resection or control by hepatic artery ligation. These authors recommend performing an emergency liver scan on patients with probable blunt hepatic trauma who do not have persistent hemorrhage or shock and who do not have other indications for immediate laparotomy, such as positive needle paracentesis of the abdomen or positive peritoneal lavage. If the patient's condition remains stable, and a subcapsular hematoma is seen on liver scan, they recommend close observation of the patient in the hospital by means of frequent physical examinations, serial hematocrit determinations, and performance of liver function tests. The status of the hematoma is appraised by serial liver scans to be certain it is resolving and not increasing in size. Geis and associates have also recently reported a successful experience with the treatment of subcapsular and intrahepatic hematomas, These authors emphasize that serious sequelae of these lesions may occur approximately 1 to 28 days after injury. They also pointed out that one-quarter of their 16 patients with intrahepatic hematomas had palpable livers and all of these had large hematomas visualized by hepatic scan. Furthermore, three of the four with *large* hematomas had complications. Thus, they caution that a *palpable* liver is an ominous sign that indicates a large hematoma and a very high incidence of serious complications. Other recent favorable experiences with the nonoperative management of subcapsular hematomas of the liver have been reported by Cheatham and associates and by Lambeth and Rubin.

Emergency hepatic arteriography for patients in stable condition with probable subcapsular or intrahepatic hematomas due to blunt trauma is probably preferable to emergency scanning. Arteriography more definitely delineates the size and location of a subcapsular or intrahepatic hematoma, indicates whether there is persistent intrahepatic or extrahepatic hemorrhage, and may show the source and severity of the bleeding.

Another notable advantage of hepatic arteriography in some stable patients with intrahepatic hematomas is that this technique can be used therapeutically as well as diagnostically. If a site of arterial hemorrhage is visualized arteriographically, the hemorrhage may be stopped nonoperatively and atraumatically by embolizing several 2-mm^2 pieces of Gelfoam through the hepatic arterial catheter. These emboli obstruct the bleeding site and prevent further bleeding.

Hemobilia. Hemobilia is caused by arterial hemorrhage into the biliary tract after liver trauma; classically it presents with a triad of findings consisting of upper or lower gastrointestinal hemorrhage, obstructing jaundice, and colicky abdominal pain. In the past, the standard treatment for this condition consisted of hepatic resection or hepatotomy with direct exposure and suture ligation of the bleeding artery. Such treatment is often associated with considerable blood loss and high operative mortality and morbidity. There are now several reports of successful management of traumatic hemobilia by ligation of the hepatic arteries supplying the involved lobe of the liver. Also, in 1976, Walter and associates first reported successful control of hemobilia by hepatic artery catheter embolization. Since that time, Heimbach and his colleagues and Perlberger have also successfully treated traumatic hemobilia with angiographic embolization.

Complications. Major nonfatal complications occur in approximately 20 percent of patients with liver injuries. Since the thorax is involved in many hepatic injuries, there is a high incidence of pulmonary complications. Also, the incidence of intraabdominal and perihepatic abscesses ranges from 4.5 to 20 percent. The probability of such abscess formation increases with more complex injuries of the liver and with the presence of associated colon injuries.

Patients with major lobar resections may be expected to have some postoperative bilirubin elevation, probably secondary to transient biliary obstruction by blood clots and temporary hepatic insufficiency (due to shock, loss of hepatic mass, operative trauma, and occasionally, postoperative sepsis). Hyperbilirubinemia usually disappears within about 3 weeks, with no further surgical treatment required for the relief of jaundice. Liver function studies generally show hepatic impairment but usually return to normal after several weeks. Glucose metabolism is altered after resection, and in the early postoperative period it may be necessary to give the patient supplemental glucose solutions. Studies indicate that survival is possible with only 20 percent of the normal hepatic mass, and that within 1 to 2 years, most of the resected hepatic tissue is replaced by hepatic regeneration.

Although Merendino and associates, and Perry and LaFave suggested the T-tube drainage of the common bile duct should be carried out after hepatic resections, reports by

Lucas and Walt and by Pinkerton and associates suggest that septic complications and bleeding from gastroduodenal stress ulcers are significantly increased by T-tube drainage. Lucas and Walt, in a well-controlled prospective study, supported the position that effective biliary decompression is not achieved by the T tube and that drainage of the common duct may increase the incidence of complications in patients with hepatic trauma, especially those due to infection and bile duct obstruction (ie, jaundice, cholangitis, and bile duct stricture).

Gallblader

Although perforations of the gallbladder due to blunt trauma are very unusual, penetrating abdominal trauma frequently causes gallbladder injuries. Penetrating or avulsion injuries of the gallbladder are best managed by cholecystectomy, but in unstable patients with other severe injuries, when, in the surgeon's judgment, cholecystectomy is inadvisable, a tube cholecystostomy should be done, with placement of drains around the gallbladder and the subhepatic space. In general, simple suture of a gallbladder perforation is not recommended because of the probability of bile leakage. After about 4 weeks, if a patient who has had a tube cholecystostomy is doing well, a cholangiogram is performed through the cholecystostomy tube, and if this shows that the gallbladder and biliary ducts are normal, with free flow of contrast material into the duodenum, the cholecystostomy tube can be removed. Routine cholecystectomy after removal of the cholecystostomy tube in patients who have sustained gallbladder trauma is unnecessary, but it is probably advisable to perform an oral cholecystogram several months after injury to determine the status of the gallbladder.

Extrahepatic Biliary Tree

Penetrating Injuries

The diagnosis of penetrating injuries of the extrahepatic biliary tree usually presents no problem as compared with the diagnosis of blunt trauma of the biliary tree, which may be difficult unless intraabdominal hemorrhage occurs. When the hepatic artery and portal vein are involved, the mortality rate is inordinately high because of massive hemorrhage which may be virtually impossible to control before irreversible hypoxic damage occurs to the brain and myocardium. Probably most patients with injuries to the extrahepatic biliary tree and one of the major vessels in the hepatoduodenal ligament do not survive to come to surgical exploration. This is especially true when the wounding agent is a large-caliber, high-velocity missile. In contrast, wounds of the gallbladder, which are seen frequently after penetrating abdominal trauma, have a low mortality rate and are not so commonly associated with injuries to the major vessels in the hepatoduodenal ligament.

While opening the abdomen, blood and bile seen issuing from the subhepatic region indicate possible injury to the biliary tree. At times, the amount of bile, blood, or contusion may be minimal, and the gallbladder, cystic duct, and hepatoduodenal structures must be carefully inspected to evaluate the significance of any subserosal hematoma or bile staining. If the patient has survived to be surgically explored, generally no massive bleeding from the subhepatic region will be noted initially. However, many times in obtaining exposure of the hepatoduodenal ligament structures, clots which have formed and tamponaded major bleeding sites may be dislodged, with recurrence of vigorous bleeding from the portal vein, hepatic artery, or their branches, which are so frequently injured when the bile ducts are injured.

Generally, the hemorrhage may be immediately arrested by placing the fingers in the foramen of Winslow and compressing the hepatoduodenal ligament (the Pringle maneuver). Following this, after removing the free blood and obtaining good exposure while maintaining finger tamponade as above, more definitive control of the hemorrhage may be obtained by placing vascular or rubbershod clamps across all the structures in the hepatoduodenal ligament. One clamp should be placed as far distal as possible on the hepatoduodenal ligament, and this maneuver is aided by dividing the lateral serosal reflection of the duodenum and reflecting the duodenum and head of the pancreas medially. Another clamp is then placed on the hepatoduodenal ligament through the foramen of Winslow as near the liver hilus as possible.

After hemorrhage is controlled, the serosa of the hepatoduodenal ligament at the site of the hematoma formation is incised, and the disruption of the portal vein or hepatic artery is visualized by rapidly dissecting out these structures. When the defects in the major vessels are located, repair is carried out with 5-0 arterial sutures using the general principles and techniques of vascular surgery. The vascular repair should be done only after careful exposure of the defect, but also with dispatch, since the *known* safe occlusion period of hepatic vascular inflow is only 15 to 20 minutes unless the patient is under hypothermia. As noted in the section on liver trauma, it may be possible to extend this period by giving an intravenous bolus of methylprednisolone according to Pachter and Spencer.

The management of blunt and penetrating injuries of the extrahepatic biliary tree was recently reviewed by Busuttil and associates who treated 21 patients with severe injuries to the porta hepatis over a 10-year period. Fourteen of these patients had bile duct injuries, eight had complete transection of the common duct, and five had a tangential or incomplete disruption with a portion of the duct wall remaining intact. Five of the eight patients who had complete transection had primary end-to-end repair with T-tube stenting, while three underwent primary Roux en Y choledochojejunostomy. All patients with *incomplete* disruptions had primary repairs with or without T-tube stenting. Of the five patients with *complete* disruptions who had primary end-to-end anastomosis of the bile duct with T-tube stenting, all required secondary biliary tract reconstruction of some type because of subsequent bile duct stricture. In contrast, no patient with *complete* transection treated by means of a primary Roux en Y choledochojejunostomy or choledochoduodenostomy required reoperation.

Busuttil and associates state that the most important factor in determining how to manage the bile duct injury depends on whether or not the duct is completely or incompletely transected. From their experience, *complete* transection almost always ends with stricture if the duct is primarily repaired end-to-end, but has a favorable outcome if some type of duct-enteric anastomosis is done. These findings were reported by Belzer some years ago when he showed that an *incomplete* ductal injury could be successfully repaired by duct anastomosis or patch (vein or gallbladder graft); however, a *complete* division, when mobilized for primary anastomosis or patch, almost always ended in stricture. Also, Longmire recommended duct-enteric anastomosis as the best method for the early treatment of injuries to the extrahepatic bile ducts.

Busuttil and his colleagues further state that if the duct has been perforated or *incompletely* divided, primary repair *can* be successfully performed. There seems to be no definitive evidence that the presence or absence of a T-tube stent makes any difference in the rate of success in these cases. However, Busuttil and associates believe that a T-tube stent should not be used if the duct is of small caliber.

If the patient is in poor condition and cannot tolerate a prolonged procedure for definitive repair of the bile duct, then the defects of the biliary duct may be repaired by simple bridging with a T tube fixed in place with a suture at either end of the ductal defect; secondary repair can then be done as soon as the patient can tolerate it. If possible, however, definitive repair should be done, since recurrent strictures are more likely after the more difficult secondary repairs of the bile ducts.

If the gallbladder and cystic duct are intact, the biliary-enteric bypass to repair a ductal injury also may be done between the gallbladder and jejunum with ligation of the distal and proximal limbs of the damaged common duct. Also, it may be more expedient at times to use a simple loop of jejunum instead of a Roux en Y limb to perform the bypass procedure.

Blunt Trauma

Blunt trauma to the biliary tree deserves separate discussion, not because the surgical management differs, but because of its relative rarity and difficulty of diagnosis. Soderstrom and associates reported that through December, 1979, there were 101 patients with gallbladder injuries due to blunt abdominal trauma reported in the English language literature. This included 31 patients from their own experience; these 31 patients represented 2.1 percent of 1.349 patients who had blunt intraabdominal injuries from 1973 through 1979 at the Maryland Institute for Emergency medical Services System. According to Carmichael, complete division of the common duct by blunt trauma was reported in 34 cases from the time this was first described in 1861 up to 1978. The usual means of closed injury to the extrahepatic biliary tree is a shearing force applied to the common duct. Rydell states that impingement of the bile duct between the vertebral column and a crushing force applied to the abdominal wall does not play a major role in these ductal injures.

When blunt trauma to the biliary tree is severe enough to result in a free flow of bile into the peritoneal cavity, the characteristic picture of bile peritonitis occurs. According to Sturmer and Wilt, the usual history reveals a crushing injury to the right upper quadrant, the epigastrium, or the lower part of the chest, which results in severe pain and is followed by shock. The shock is seldom of more than a few hours' duration. Generally during this period, the diagnosis of probable intraabdominal injury may be established by signs of peritoneal irritation, such as abdominal rigidity and guarding. Bile or non-clotting blood may be found on peritoneal tap or lavage. Shock is usually secondary to the marked outpouring of extracellular fluid into the peritoneal cavity due to the chemical irritation of the peritoneum by bile. The initial chemical peritonitis caused by bile may be followed shortly after by bacterial peritonitis. If biliary leakage is minimal, shock may be of relatively short duration or may be absent, and abdominal signs initially may be slight. This may be followed by the recovery and well-being of the patient, which may last for periods up to 5 or 10 days. However, the onset of jaundice on about the third day is a fairly constant sign. The appearance of clay-colored stools and the presence of bile in the urine may be noticed from about the second to the fifth day after injury of the duct. Carmichael reported that of 12 deaths due to common duct avulsion, delay in surgical treatment ranged from several hours to 9 months, with an average delay of 40 days, while the delay in treatment of the 22 survivors following common bile duct avulsion averaged 9 days.

A considerable gradual increase in abdominal size occurs during the first 10 days that may be unattended by the usual signs of peritonitis in patients with bile duct rupture. This increasing abdominal girth is accompanied by progressive signs of extracellular fluid volume deficit and by evidence of infection, such as rising temperature and leukocytosis. In the reported cases of transection of the common duct, the site of transection was uniformly in the retroduodenal area of the superior margin of the pancreas, thus indicating the importance of extensive medial reflection of the duodenum to explore the retroperitoneal duodenum as well as the distal common duct and pancreas in patients undergoing laparotomy for blunt abdominal trauma.

In reviewing the surgical treatment of the 34 patients reported to have blunt injuries of the common bile duct, Carmichael notes that nine of the earlier patients were treated by simple external drainage and seven of these nine patients died. Of the two survivors of simple drainage, choledochoduodenostomy was required for stricture two and one-half months after injury in one and a primary repair of a stricture was done later in the other. Thus, simple drainage is unwise because of the high mortality and high stricture rate with this method of treatment. Many surgeons recommend primary end-to-end repair of the divided duct over a T-tube stent. However, in the review by Carmichael, it is stated that among the ten patients who had primary end-to-end repairs, three developed strictures and one of these died with cholangitis and cirrhosis. Moreover, T-tube stents were used in the initial repair of the duct in all three of the patients who developed strictures after end-to-end reconstruction. Longmire has stated that primary repair of the common duct should be attempted only if there is an adequate lumen, no inflammation, and a short injured segment of the duct. Carmichael advocates choledochoduodenostomy when the distal duct is unsuitable for primary repair or is missing. Of eight choledochoduodenostomies in his review, all did well except one, who required a cholecystojejunostomy to reestablish bile flow. No duodenal fistulas occurred. Choledochojejunostomy with or without a Roux en Y jejunal limb was done in six patients and all of these did well. Finally, Carmichael reported that cholecystoenterostomy was done in seven cases, with ligation of the distal bile duct. This operation was associated with one death and two revisions.

Thus, Carmichael concluded that the most successful procedures in reconstruction of the avulsed common bile duct are Roux en Y choledochojejunostomy or choledochoduodenostomy. Choledochojejunostomy offers a better exposure if a future operation is required, a tension-free anastomosis, and a technically easier mucosa-to-mucosa anastomosis. Also, this procedure avoids the lateral duodenal fistula that may occur after choledochoduodenostomy.

The postoperative therapy of biliary tract injuries, in which bile peritonitis is an important complicating feature, should include adequate replacement of extracellular fluid volume deficits, which may require intravenous infusion of several liters of balanced salt solutions in 24 hours. These solutions should be given as soon as possible preoperatively and continued throughout the surgical procedure and postoperatively to avoid extracellular fluid volume deficit. Broad-spectrum antibiotics should be given before the surgical procedure and continued during the operation and for several days after, until the changes of sepsis diminish.

The overall mortality in the collected series of common duct injuries reported by Carmichael was 35 percent; however, the mortality from biliary tract injuries probably should be below 5 or 10 percent if they are discovered early and treated appropriately.

Portal Vein

Approximately 90 percent of portal vein injuries occur because of penetrating trauma. They are frequently associated with other visceral injuries, most commonly to the inferior vena cava, liver, pancreas, and stomach. Mattox and associates recently reported a survival rate of 50 percent in their series of 22 patients with portal vein injuries. Lateral venorrhaphy, if possible, is the preferred method of treatment. Mattox suggests performing a portacaval or mesocaval shunt as an alternative treatment of portal vein injury if suture repair is impossible and the patient's general condition is stable. In contrast, Fish reported that four of five patients who had portacaval shunts for portal vein reconstruction after trauma developed hepatic decompensation or encephalopathy, whereas those complications were not observed in patients undergoing portal vein ligation.

The insertion of an autogenous vein graft to bridge the defect in the portal vein (using the left common iliac vein, left renal vein, or a paneled saphenous vein graft) may be preferable to a portacaval shunt if the patient's condition is stable and the proximal and distal ends of the injured vein are suitable for the insertion of a graft. This procedure should prevent portal hypertension or hepatic deterioration that may occur if the vein is ligated. However, if associated injuries are severe, then ligation of the portal vein may make it possible to save the patient. Even though portal vein ligation may cause portal hypertension, interruption of the vein is compatible with the patient's survival in about 80 percent of the cases. It should, of course, be emphasized that in those with associated hepatic arterial injuries, a good repair of the hepatic artery must be achieved before accepting treatment of portal vein injuries by ligation. It has been reported recently that 80 percent of 20 patients survived portal vein ligation when lateral venorrhaphy was not possible. However, because of obstruction to portal outflow, acute splanchnic *hypervolemia* develops simultaneously with peripheral *hypovolemia.* Patients have died of such splanchnic pooling after portal vein ligation. Since appreciating this problem, these patients have been followed closely with either central venous or pulmonary artery pressure measurements to maintain a functionally normal peripheral blood volume. This may require overtransfusion of a volume of blood almost equal to the patient's own normal blood volume.

Pancreas

Travers described the first pancreatic injury found in an intoxicated woman who was struck by a stage coach wheel in England in 1827. About two-thirds of pancreatic injuries are caused by penetrating and one-third from blunt trauma.

Diagnosis. Diagnosis of pancreatic injuries is based upon a complete history, including the mechanism of injury, thorough physical examination, serum amylase level, and adequate visualization of the pancreas at surgical exploration.

Following isolated blunt pancreatic trauma, symptoms are often mild and delayed and physical signs may be absent or minimal. Usually, however, there is at least mild upper abdominal tenderness, but in the absence of a history of significant trauma or severe symptoms, this sign may be overlooked. Injuries to retroperitoneal organs such as the pancreas may not produce clinical findings of loss of bowel sounds, tenderness, guarding, or spasm for several hours.

Serum Amylase Determination. Over 25 years ago, Matthewson and Halter advocated routine serum amylase determinations in patients sustaining blunt trauma and emphasized that pancreatic injury was more common than had been previously appreciated. Serum amylase elevation alone is not an indication for exploratory celiotomy. If signs of peritonitis are present (such as spasm, tenderness, and absent bowel sounds), then a celiotomy is performed. Unrecognized severe pancreatic injury can be a fatal lesion, particularly when it is accompanied by disruption of pancreatic tissue and leakage of pancreatic juice.

Many patients have been found to have an elevated serum amylase level but negative abdominal findings. These patients are closely observed for evidence of peritonitis or until the amylase level returns to normal. An amylase determination is performed on peritoneal lavage fluid, but the elevation is more often due to small bowel injury than to pancreatic injury.

Amylase determinations may be misleading. Olsen stated that 33 percent of patients with hyperamylasemia had no significant intraabdominal trauma, and no patient in his series with hyperamylasemia had significant intraabdominal injury without other evidence of trauma. He reemphasized that hyperamylasemia alone without any other evidence of visceral injury is not an indication for exploratory celiotomy. Serum amylase is not a reliable indicator of pancreatic injury.

In 400 patients sustaining pancreatic trauma and managed at Parkland Memorial Hospital, only 20 percent had preoperative elevation of the serum amylase following penetrating trauma, but 65 percent had an elevation following blunt trauma. Sometimes the serum amylase is elevated in less than 2 hours following injury, but the longer the delay from injury to surgery, the more likely an elevation. With complete transection of the pancreas, over 70 percent have an elevation.

Though these various reports show that it is unwise to perform exploratory celiotomy on the basis of elevated amylase levels alone, nevertheless, the detection of hyperamylasemia in asymptomatic patients who have sustained abdominal trauma cannot simply be dismissed. These patients are admitted to the hospital and closely observed. Plain abdominal x-ray films may show evidence of retroperitoneal trauma. This is suspected when there is obliteration of the psoas margin, retroperitoneal air along a psoas margin or around the upper pole of the right kidney, or displacement of the stomach. Upper gastrointestinal studies with water-soluble media may show leakage of contrast media from the retroperitoneal duodenal area. Serial sonographic studies of the upper abdomen, when strongly positive, may also indicate pancreatic or other retroperitoneal exploratory celiotomy in patients with blunt abdominal trauma who have asymptomatic hyperamylasemia.

As more experience is gained with endoscopic retrograde pancreatography, it is possible that this technique may have a role in the diagnosis of pancreatic injury. Computed tomography of the abdomen may become the most specific method of diagnosing organ injury preoperatively, particularly following blunt trauma. It should not take the place of a good physical examination or close follow-up observation.

Surgical Exploration. When preoperative diagnostic studies indicate a probability of pancreatic injury, it is necessary to visualize the entire pancreas. The head of the pancreas and the duodenum are completely mobilized to the midline by performing a Kocher maneuver. The gastrocolic omentum is also divided in order to enter the lesser sac and view the entire body of the pancreas.

Any retroperitoneal hematoma in the upper part of the abdomen or a peripancreatic hematoma should be considered presumptive evidence of pancreatic injury and should be explored. Over 60 percent of patients sustaining penetrating trauma have an associated retroperitoneal injury.

Associated Injuries. Isolated pancreatic injury is rare following penetrating trauma but occurs in 20 percent of blunt injuries. Associated injuries are usually more obvious indications for surgical exploration than suspected pancreatic injury. Death and serious complications are frequent in pancreatic trauma but are rarely caused by the pancreatic injury. Although the pancreas is a vascular organ, it is not often responsible for uncontrollable hemorrhage. When profuse bleeding occurs from the pancreatic area, the pancreas is mobilized and the superior mesenteric and the splenic vessels, the aorta, and the vena cava are inspected, since they are often the source of severe hemorrhage. Because of the location of the pancreas, injuries to the liver and the stomach are frequent.

Management of Pancreatic Injuries. After bleeding from the pancreas or from adjacent major blood vessels is controlled, the extent of the pancreatic injury is determined. Simple pancreatic contusions without capsular or ductal disruption and without persistent hemorrhage require no suturing or debridement. These injuries are drained with a sump and Penrose drains placed directly at the site of the pancreatic contusion and brought out along a short, direct tract at the tip of the twelfth rib. The drains are left in place for 10 days, since moderate drainage may not occur during the first week following injury. Lack of drainage to such areas of unrecognized capsular injury may lead to complications associated with intraabdominal collections of pancreatic secretions such as pseudocysts, pancreatic abscesses, and lesser-sac abscesses. Simple drainage is a satisfactory method of management in 75 percent of patients sustaining either stab or gunshot wounds.

Distal Pancreatectomy. The most effective method of treatment for pancreatic injuries with obvious disruption of the pancreatic duct in the body or tail of the gland is distal pancreatectomy. This is performed at the point where the main duct is injured, and allows removal of the traumatized and devitalized tissue.

When performing a distal pancreatectomy, sutures are placed in the superior and inferior borders of the pancreas approximately 1.5 to 2 cm from the edge. This, along with isolation of splenic vessels during distal pancreatectomy, prevents unnecessary blood loss and probably provides better visualization. In resecting the distal pancreas, the cut edge is beveled in a fish-mouth fashion. This enables a better closure of the proximal end of the pancreas. The transected duct of Wirsung in the remaining proximal gland is ligated with a transfixion suture of fine monofilament, nonabsorbable material such as Prolene, to discourage fistula formation. The cut surface of the transected proximal pancreas is oversewn with interrupted, interlocking mattress sutures, which facilitate hemostasis. Recently, the auto stapler has been used with excellent results. This method of management provides excellent hemostasis and prevents fistula formation. The stump of the pancreas is extensively drained with a sump and large Penrose drain.

Most patients sustaining a stab or gunshot wound do not require surgical resection. A conservative approach in the absence of proven ductal injury results in a low mortality. Liberal use of resective debridement for only possible ductal injury contributes to a higher mortality. Simple drainage of the pancreas is the treatment of choice for most penetrating injuries, particularly in the unstable patient. Approximately 25 percent of patients undergoing a distal pancreatectomy develop an intraabdominal abscess.

Distal Pancreatectomy with Roux en Y Anastomosis. This technique of placing a Roux en Y limb to the end of the proximal pancreas is utilized in patients undergoing primary distal pancreatectomy for severe blunt trauma when there is much contusion and edema of the remaining pancreatic head. In these cases, the surgeon may anticipate that there will be significant obstruction in the proximal ductal system, leading to persistent leakage of pancreatic secretions from the end of the transected pancreas, if the pancreatic duct and stump are simply oversewn and drained instead of being implanted in a defunctionalized Roux en Y limb of jejunum. This procedure, reserved for the infrequent severely injured head and body of pancreas secondary to blunt trauma, is not indicated following penetrating trauma.

Roux en Y Pancreaticojejunostomy. Several methods of treating pancreatic transection have been described. For the pancreas completely transected over the superior mesenteric vessels and to the right of these vessels, a Roux en Y anastomosis suturing both ends of the pancreas to the defunctionalized limb has proved satisfactory. This treatment has been recommended by Jones and Shires for treatment of injuries which require removal of 80 percent or more of the pancreas. Transections of less magnitude are treated by simple distal pancreatectomy. A Roux en Y anastomosis to the distal pancreas with oversew of the end of the proximal segment is the usual method of management, particularly if the spleen is not injured. A less frequently utilized technique is a Roux en Y anastomosis to both ends of the severed pancreas. Both methods leave all functioning pancreatic tissue, thereby avoiding the possibility of pancreatic insufficiency or diabetes. The risk of injury to the underlying splenic vessels is less with this mode of treatment than with resection. The possibility of fistula and pseudocyst formation is also minimized.

The Roux en Y anastomosis is accomplished using permanent sutures placed approximately 1 cm apart in a single-layer anastomosis. Once this anastomosis is accomplished, a drainage tract is established with Penrose and sump drains. Unless the completely severed pancreatic duct is managed with definitive surgery, a pseudocyst or fistula will almost always result. A Roux en Y anastomosis to one fragment of the severed pancreas is little more time consuming than resection of the distal fragment, which requires a splenectomy.

If location of the pancreatic injury suggests the possibility of injury to the intrapancreatic portion of the common bile duct, a needle cholangiogram is performed or the common bile duct is opened in its supraduodenal position and a cholangiogram obtained. If a partial tear of the distal intrapancreatic common duct has occurred, but some ductal continuity remains, a T tube is inserted for decompression.

Anterior Roux en Y Pancreaticojejunostomy. A Roux en Y pancreaticojejunostomy may be placed to the anterior surface of the pancreas over the injury in selected cases. This method of treatment has been satisfactory only if the posterior pancreatic capsule is intact. If the posterior pancreatic capsule is broken, drainage will continue into the retroperitoneal space rather than into the Roux en Y limb and result in abscess, pseudocyst, or fistula formation. Similar complications occur if the Roux en Y limb is sutured to the posterior surface of the pancreas if the injury involves the anterior capsule.

Combined Duodenum and Pancreatic Injuries

Approximately 20 percent of pancreatic injuries are associated with duodenal trauma. The mortality for combined pancreaticoduodenal trauma is 25 percent, mostly from associated injuries.

These injuries are usually managed by drainage of the pancreas and suture of the duodenum. A duodenostomy tube may be inserted, but it is difficult to demonstrate that this decreases morbidity or mortality.

Pyloric exclusion has been used by Vaughan et al resulting in only a 5 percent duodenal fistula rate. Berne diverticulization has been advocated for moderately severe injuries and pancreaticoduodenectomy for the most extensive injuries.

Pancreaticoduodenectomy. Prior to performing a pancreaticoduodenectomy the presence of a pancreatic ductal injury should be verified. This may be accomplished by either duodenotomy, cannulation of the pancreatic duct, and pancreatogram, or intraoperative retrograde pancreatography. The common duct is identified and proved to be intact by operative cholangiogram. An alternate method of determining ductal injury is by mobilizing the tail of the pancreas and performing a pancreatogram through the distal pancreatic duct. Hemostatic sutures are placed 1.5 to 2 cm into the superior and inferior portions of the pancreas prior to incising the tail. If the common bile duct and major duct system are intact and the duodenal injury can be closed, then a pancreaticoduodenectomy is usually not indicated.

Indications for pancreaticoduodenectomy include rupture of the duodenum and head of the pancreas, avulsion of the common duct from the duodenum with avascular duodenal wall, and stellate fracture with bleeding from a crushing injury of the head of the pancreas. This procedure also is indicated for combined injuries to the head of the pancreas and duodenum with destruction of both to control hemorrhage, remove devitalized tissue, and restore ductal continuity. The overall condition of the patient and associated injuries must be considered prior to submitting the patient to several more hours of surgery. There are times when this procedure is necessary, but they are rare, particularly if the duodenum is intact. Complications following pancreaticoduodenectomy are common. Thus mortality rate of this procedure must be low to justify its use if any other form of management can be employed. The average mortality rate for patients treated with the Whipple procedure continues to be about 30 percent with some series reporting as high as 50 to 60 percent. This high mortality rate is frequently due to associated injuries, particularly vascular injuries, and it is probable that some of these patients would have died if a pancreaticoduodenectomy had not been done.

In addition to fistula formation and abscesses, marginal ulceration with upper gastrointestinal bleeding has occurred following pancreaticoduodenectomy in which a vagotomy or subtotal gastric resection was not performed. Symptoms of dumping, diabetes, and weight loss with diarrhea have occurred following pancraticoduodenectomy for trauma. Postoperative bleeding following pancraticoduodenectomy with bleeding into the intestinal tract from the site of the pancreaticojejunostomy demonstrated by arteriographic studies requiring reoperation has occurred.

Complications. Complications following pancreatic trauma include fistula, pancreatic abscesses, vascular necrosis with hemorrhage from the drain site, pseudocyst formation, and intestinal fistula secondary to suture line breakdown from pancreatic juice activation.

Fistula. Most pancreatic fistulas are minor and close within a period of 1 month. Major pancreatic fistulas have been arbitrarily defined as those which drain longer than 1 month. The serum amylase level is frequently elevated while the fistula is present, probably because of transperitoneal absorption. Almost all pancreatic fistulas will eventually close spontaneously; therefore treatment is mainly conservative. Attention must be given to preventing autodigestion of the surrounding skin.

The use of Stomahesive provides an excellent method for managing the drainage from pancreatic or other types of gastrointestinal fistulas. An opening is made in the Stomahesive sheet just large enough to permit drains from the fistula tract to pass through. Stomahesive securely adheres to the skin for several days before it must be replaced and is virtually nonallergenic. A gas-sterilized polyethylene bag with adherent backing and a "drainable stoma" at the bottom is applied so that it adheres to the Stomahesive sheet rather than to the patient's skin. The Penrose drains, if these are still in place, are completely contained within the bag, and the suction catheter in the fistula tract exits through the drainable stoma in the bag. Leakage is prevented by placing rubber bands around the suction catheter and the polyethylene bag in order to make a tight seal where the catheter passes through the stoma. This method protects the skin, isolates the drains from outside infection, and permits accurate measurement of fluid loss from the fistula.

Many patients with pancreatic fistulas can continue oral intake of food, especially if the fistula drains less than 500 to 600 mL each day and the volume does not increase significantly when the patient eats. In the presence of large-volume pancreatic fistulas, it is preferable to institute intravenous hyperalimentation. Intravenous hyperalimentation has two beneficial effects on such patients: (1) It maintains excellent nutrition and nitrogen balance without stimulating the pancreas, as do oral feedings; and (2) intravenous hyperalimentation can significantly reduce the volume of pancreatic exocrine secretion (by one-half or more).

Pseudocyst. A pancreatic pseudocyst is a cyst whose wall of inflammatory fibrous tissue does not contain epithelium but is made of those structures surrounding the region of the pancreas in the retroperitoneum. The most frequent symptoms associated with a pancreatic pseudocyst are an abdominal mass, pain, nausea, and vomiting. The serum amylase level is usually elevated for a prolonged period of time during this illness. Diagnosis is by sonography or computed tomography. The pseudocyst rarely resolves spontaneously. Pancreatic pseudocyst is now a rare complication following pancreatic trauma if the pancreas has been explored and managed appropriately, such management including adequate drainage with a sump and Penrose drains. The preferred method of draining pancreatic pseudocysts is internally by either cyst gastrostomy or Roux en Y cyst jejunostomy.

Sepsis. Intraabdominal abscess is a common complication following multiple abdominal trauma and is the second most common cause of death. Although pancreatic fistulas rarely cause death, they occasionally give rise to lesser-sac abscesses and subphrenic abscess. Subphrenic abscess is frequently associated with injuries to the liver, spleen, and colon. The location of a right or left subdiaphragmatic abscess is predictable in most patients depending on whether the associated injury was to the spleen or to the liver. A lesser-sac abscess may contribute to either sepsis or retroperitoneal bleeding and death. Cultures of the abscess grow a predominance of mixed gram-negative organisms; however, staphylococci and enterococci may often be present. The serum amylase level is not consistently elevated in patients with a pancreatic or lesser-sac abscess.

The method of management of pancreatic abscesses consists of adequate debridement and drainage, frequently with gastrostomy and feeding jejunostomy. Hemorrhagic pancreatitis may present with massive bleeding from the drain tract, probably from erosion of ligated retroperitoneal vessels.

Mortality. The mortality rate caused by pancreatic injury is quite variable and is chiefly related to hemorrhage from adjacent major blood vessels. The mortality following stab wounds is 7 percent, gunshot wounds 18 percent, and blunt trauma 18 percent.

Early surgical intervention in both blunt and penetrating abdominal trauma, meticulous abdominal examination of all organs, and an aggressive approach to pancreatic injuries, including resection when indicated, are essential if the mortality rate is to be lowered. Jones and Shires reported a decrease in mortality due to blunt trauma to the pancreas from 37 percent in 1965 to an overall 16 percent in 1970. The mortality for isolated pancreatic injury was less than 1 percent. Thus, a conservative approach is indicated for most pancreatic injuries, resulting in shorter operating time and less blood loss for the unstable patient with multiple injuries.

Spleen

The spleen is the abdominal organ most frequently injured by blunt trauma: such injuries to the spleen represent approximately one-quarter of all blunt injuries of the abdominal viscera. The spleen also is often injured by penetrating abdominal trauma and is frequently associated with blunt and penetrating thoracoabdominal injuries.

Diagnosis. The diagnosis of splenic injury is usually easily made with penetrating trauma but is often more difficult in patients sustaining blunt trauma. The clinical manifestations are the systemic symptoms and signs of hemorrhage and local evidence of peritoneal irritation in the region of the spleen. Only about 30 to 40 percent of patients with splenic injury present with a systolic blood pressure below 100 mmHg. However, many patients with splenic trauma may develop hypotension and tachycardia when assuming the sitting position. A tender abdomen with guarding and distension is apparent in only about 50 to 60 percent of those patients with splenic rupture.

A history of injury, which may be seemingly slight, followed by abdominal pain, predominantly in the left upper quadrant, left should pain, and syncope is very significant. Often the left shoulder pain, or Kehr's sign, occurs only when the patient is in a supine or head-down position. This is caused by irritation of the inferior surface of the left side of the diaphragm by free blood or blood clots. Elevation of the foot of the bed or pressure in the left subcostal region may occasionally reproduce pain at the top of the left should. Ballance's sign, which refers to fixed dullness to percussion in the left flank and dullness in the right flank that disappears on change of position of the patient, thus indicating large quantities of clot in the perisplenic region and free blood in the remainder of the peritoneal cavity, may be helpful in establishing the diagnosis. Whereas a decreased or falling hematocrit, leucocytosis of more than 15.000, x-ray findings such as fractures of the left lower ribs, gastric displacement, loss of splenic outline, and splinting or elevation of the left diaphragm are useful diagnostic findings, they are frequently absent.

Abdominal paracentesis and diagnostic peritoneal lavage are extremely helpful in establishing the diagnosis in doubtful cases, particularly in patients whose sensibility is obtunded by other injuries. In patients with splenic trauma the incidence of false-negative diagnostic peritoneal lavage is reported, in repeated series, to be less than 1 percent.

Radionuclide scans are used with increasing frequency to detect splenic injury and to follow patients who are treated by either nonoperative therapy or one of the many splenic preservation procedures. Computerized tomography is now available as a diagnostic aid. It appears to be an accurate, simple way to diagnose subcapsular hematomas and more extensive transcapsular lacerations. Jeffrey et al reported correct interpretation in 49 of the first 50 patients studied with 28 true-negatives and 21 of 22 true-positives being identified.

Delayed rupture of the spleen was first described by Baudet in 1902, and the asymptomatic interval between abdominal injury and rupture of the spleen is known as the latent period of Baudet. It was postulated that bleeding appeared several days after injury because (1) a subcapsular splenic hematoma gradually increased in size until it caused a delayed rupture of the splenic capsule and intraperitoneal hemorrhage or (2) there was initial bleeding from a splenic laceration which ceased spontaneously but began again in several days or weeks when the perisplenic hematoma became dislodged. This concept has been challenged by Olsen and Polley and by Benjamin and associates. These authors report a rate of delayed rupture of the spleen of less than 1 percent in over 600 patients. They suggest that delayed splenic rupture is an unusual occurrence and that the 15 percent incidence reported in older papers actually represents a delay in diagnosis rather than a delayed rupture in those patients.

Treatment. King and Shumacker in 1952 reported that all five patients under 6 months who had splenectomies developed meningitis or overwhelming septicemia. Two of these five patients died. This observation stimulated further investigation followed by considerable confusion and contradictory remarks into the relationship between splenectomy and what was later termed *overwhelming postsplenectomy infection* (OPSI). This syndrome is characterized by an abrupt onset of overwhelming sepsis, massive bacteremia, usually pneumococcal, followed by early death.

Eraklis and Filler report a mortality rate of 0.8 percent in 342 patients under age 16 who had splenectomy for trauma. Singer reviewed 23 series from the literature including 2.795 patients. The risk of sepsis was 1.45 percent in the 688 patients (300 adults) who had splenectomy for trauma. Only 4 of these patients died for a mortality rate of 0.58 percent. This has been compared with the general population where a death rate due to sepsis is estimated at 0.01 percent. This comparison is not accurate as the two groups are dissimilar by virtue of the fact the former group have all sustained some type of trauma and undergone an operative procedure which is not accounted for in the control group.

O'Neal and McDonald recently reported a mortality rate of 2.7 percent in a series of 256 adult patients. There were no fatalities in the 115 patients with splenectomy for trauma. All of the deaths in this series occurred in patients whose spleen was removed in conjunction with other nontraumatic elective procedures or patients with proven malignancies.

In spite of the fact the literature supporting this syndrome in the adult trauma patient is a bit weak, but nevertheless stimulated by these and many other reports describing the immunologic abnormalities and pathophysiology of the overwhelming sepsis syndrome, a more conservative approach has evolved concerning the management of splenic trauma. Nonoperative therapy in the pediatric age group has been advocated by Aronson et al, Ein et al, and others. This approach has several distressing aspects. In assessing the patient with multiple trauma one cannot assume the spleen is the only injured organ, hence other injuries may be missed in as many as 30 percent of patients. Nonoperative therapy requires a prolonged hospitalization which is generally accomplished in an intensive care unit. Other drawbacks include a prolonged convalescence, increased hospital cost, and risk and complications associated with repeated blood transfusions, such as delayed autoimmune disease.

A more rational approach to the problem is splenic preservation in carefully selected patients at the time of operation. The procedures include: (1) no therapy for nonbleeding capsular lacerations; (2) application of microfibrillar collagen or other hemostatic agents to minor lacerations with minimal bleeding; (3) suture repair of more extensive injuries; (4) partial splenectomy for splenic injuries which do not involve the hilus. Contraindications to splenic salvage procedures as recommended by Traub include: (1) patient instability secondary to major associated injuries; (2) splenic avulsion or extensive fragmentation; (3) extensive hilar vascular injury; (4) failure to attain splenic hemostasis. Relative contraindications include significant peritoneal contamination from concomitant bowel injury and rupture of a diseased spleen.

Increasing experimental data and clinical evidence indicate that an intact spleen is required to produce important opsonic antibodies which are necessary for optimal function of the macrophage system and production of immunoglobulins. Sepsis is a rather frequent occurrence following splenectomy for certain hematologic disorders, many of which have diffuse reticuloendothelial abnormalities. Many of these patients, however, receive various forms of therapy that alter immunity and response to infection.

Splenectomy is still a safe procedure and the indicated procedure of choice in many patients.

Operative Technique. (See Chap 33). Although drainage of the splenic bed following elective splenectomy is controversial, there is little question that drainage should be employed when splenectomy is performed under emergency conditions. The incidence of drain tract infections and subphrenic abscesses has been reported to be as high as 25 to 50 percent when drains were used, in contrast to 5 to 12 percent when drains were not employed. Many of these infections, however, were related to the presence of associated injuries, usually in the gastrointestinal tract, or to the immunologic defects often present in patients requiring splenectomies for conditions other than trauma, and not to the drains per se. The routine use of drains following splenectomy for trauma is supported by the series reported by Naylor and Shires. These authors reported an incidence of subphrenic abscess of only 3.4 percent in 408 patients undergoing splenectomy for trauma. Among the 72 patients who had splenectomy for trauma involving the spleen alone, there were no subphrenic abscesses and an incidence of drain tract infection of only 1.3 percent.

Thus, while it cannot be proved that drainage of the splenic bed after splenectomy for trauma reduces the incidence of subphrenic collections, it is most probable that drainage in such cases does not increase the incidence of subphrenic abscess. Also in those instances of splenic injury in which there is any question of associated pancreatic or gastric trauma, drainage of the splenic bed may prevent complications that could arise if such unrecognized injuries were not drained. Even those authors who incriminate the usage of splenic bed drains report no higher incidences of subphrenic abscess or other infections if the drains are removed before the sixth postsplenectomy day.

Another area of controversy is the issue of prophylactic antibiotics in the postsplenectomized patient, particularly in the pediatric age group. Most authors advocate prophylactic penicillin therapy until at least age five years, but it has been recommended that protection be extended into the teenage years, and isolated reports suggest indefinite protection. The use of long-term antibiotics is not without untoward effects, such as drug sensitivity, bacterial resistance, and suppression of natural immunologic defenses. Patient compliance over a long period of time is very poor. Patients who have undergone splenectomy are advised to contact their physician at the first sign of any febrile illness.

Pneumococcal vaccination is usually recommended following splenectomy. This should protect against 80 percent of the pneumococcal strains leading to sepsis. It must be stressed, however, that although pneumococcus is the most prevalent offending organism, the syndrome can be caused by other organisms such as meningococcus and *Haemophilus influenzae.*

Mortality. Factors contributing to mortality following splenic injury include (1) associated injury, (2) mechanism of injury, (3) presence of shock on admission to hospital, and (4) advanced age. Naylor and associates reported an overall mortality rate of 11.2 percent in their series of 408 patients, which compares favorably with that in other reports.

Retroperitoneal Hematoma

The management of traumatic retroperitoneal hematoma is a controversial problem. The most common cause of retroperitoneal hemorrhage, according to Baylis et and according to the experience at Parkland Memorial Hospital, is pelvic fracture, which accounts for about 60 percent of all traumatic retroperitoneal hematomas. The diagnosis of retroperitoneal hematoma is most difficult following blunt, nonpenetrating trauma to the abdomen, and should be suspected in any patient following trauma who has signs and symptoms of hemorrhagic shock but no obvious source of hemorrhage. Hemorrhage within the retroperitoneal area may be massive and may exceed 2.000 mL of blood. Experimental data have shown that as much as 4.000 mL of fluids can extravasate into the retroperitoneal space under pressure equal to that in the pelvic vessels.

Diagnosis. Abdominal pain occurs in approximately 60 percent of patients, and back pain in about 25 percent. The abdominal pain is usually vague and generalized but is occasionally localized over the hematoma. Local or generalized tenderness is present in about two-thirds of the patients, and shock occurs in approximately 40 percent. Occasionally, a tender mass is palpable through the abdomen or in the flanks, and in some cases, rectal examination will reveal a boggy mass anterior or posterior to the rectum. Dullness to percussion over the flanks or the abdomen which does not vary with changing positions of the patient has been recorded in some instances. At times, discoloration of the flanks from retroperitoneal hemorrhage has been noted after the lapse of a few hours (Grey Turner's sign). Progressive decrease in the hemoglobin and hematocrit is a consistent finding, and hematuria is found in 80 percent of patients. Hematuria may represent the first clue to the development of a retroperitoneal hematoma.

Somewhat more than half the patients produce free, nonclotting blood on diagnostic paracentesis or lavage of the abdomen; this blood is generally related to the presence of both retroperitoneal and intraabdominal hemorrhage. However, if the retroperitoneal hematoma which occurs without intraperitoneal hemorrhage is large enough to yield a so-called false-positive peritoneal tap or lavage from retroperitoneal hemorrhage alone, then the hematoma itself may require abdominal exploration to search for the persistent source of the retroperitoneal bleeding.

Radiography according to Baylis et al, has been valuable in several respects; approximately two-thirds of the patients with peritoneal hematoma have had fractures of the pelvis, and other x-ray findings have included obliteration of the psoas shadow in 30 percent, abdominal mass in 5 percent, and paralytic ileus in 8 percent. Also, displaced bowel-gas shadows and fractured vertebrae have been noted. Baylis et al also noted that in one patient a pelvic phlebolith was displaced by an expanding retroperitoneal hematoma. Intravenous pyelograms and/or retrograde cystograms are routinely obtained in all patients with suspected retroperitoneal hematomas, if the patient's condition is stable enough to have these studies performed. Arteriography has also been helpful in establishing the diagnosis of retroperitoneal injury. In the patient whose condition is deteriorating, however, immediate exploration is performed without obtaining such studies, in order to attempt rapid control of progressive bleeding. Most retroperitoneal hematomas from pelvic fractures will tamponade themselves within a short time, and the patient's condition will remain stable and the hematocrit normal, perhaps after transfusion of several units of blood.

Treatment. It has been recommended by some that retroperitoneal hematomas not be explored at the time of operation. This nonexploration is considered poor practice, an opinion based on experience which indicates that nonoperative treatment of retroperitoneal hematomas (with the exception of retroperitoneal hematoma secondary to pelvic fracture) has led to an excessive mortality from continued or recurrent hemorrhage from injured retroperitoneal vessels such as the vena cava, aorta, lumbar veins, or renal veins. In addition, it is felt that nonexploration of retroperitoneal hematomas adjacent to partially extraperitoneal bowel is dangerous because of the possibility of missing a perforation in the bowel's extraperitoneal portion (eg, duodenum). Consequently, it is recommended to explore all retroperitoneal hematomas discovered during celiotomy for the source of bleeding, as well as for associated injuries to the bowel, kidney, ureter, bladder, etc. This is done regardless of the size at the time of exploration. This policy has not been associated with any complications arising solely from such exploration.

Warnings have been made that if a small hematoma which is not enlarging is disturbed, uncontrollable bleeding may occur. However, it is felt that if such bleeding is to occur, it is best for it to take place at the time of the surgical procedure rather than postoperatively. If major vessels are not explored at the time that hematomas occur near them, major and sometimes fatal postoperative bleeding may occur. Present-day vascular surgical techniques obviate the fear of incurring massive hemorrhage as a contraindication to exploring retroperitoneal hematomas. This is with the sole exception of the treatment of large retroperitoneal hematomas due to pelvic fracture.

In massive retroperitoneal hematomas following pelvic fractures, it is often impossible adequately to control multiple small bleeding points. Consequently, it is advisable not to explore this type of massive pelvic hematoma (for fear of causing bleeding which may be very difficult to control) unless the hemorrhage from the fracture site fails spontaneously to tamponade itself and exsanguination threatens. However, spontaneous tamponade usually occurs. When not exploring this hematomas, it is important to be certain that there is no injury to the distal aorta, common iliac, or external iliac vessels.

Seavers et al advise that the ligation in continuity of one or both hypogastric arteries may, at times, control persistent bleeding in the pelvic retroperitoneal space from pelvic fractures which cannot be controlled by any other means. This will often control the venous bleeding from this source, also. Certainly it is preferable to locate a single vessel which is bleeding and either ligate or repair it, than blindly to ligate the hypogastric arteries. Recent studies now indicate that infusion of vasospastic drugs or the embolization of autologous clots or hemostatic agents may be beneficial in controlling this type of hemorrhage. On rare occasions it may be necessary to pack the pelvis with large lap packs for 24 to 48 in order to achieve hemostasis.

Inferior Vena Cava

Inferior vena caval injuries associated with penetrating abdominal wounds are being seen with increasing frequency. It has been reported that 1 in every 50 gunshot wounds and 1 in every 300 knife wounds of the abdomen will injure the vena cava. These are serious injuries: one-third of the patients die before reaching the hospital, and up to half the remaining persons will die during hospitalization. Most deaths occur from bleeding because of the inherent difficulties in controlling injuries of large veins, but significant wounds of other structures, especially in the retroperitoneum, are common and often adversely affect therapeutic efforts.

Etiology and Distribution. Most injuries of the inferior vena cava are caused by gunshot wounds, but stab wounds or blunt trauma may also be involved. Simple penetrating wounds produced by knives and low-velocity missiles are less lethal than those wounds caused by shotguns, high-velocity bullets, and especially blunt trauma. Widespread serious damage to other structures, particularly liver and major arteries and veins, are likely to result from shotgun wounds and blunt trauma to the abdomen and lower part of the chest.

The infrarenal vena cava is most susceptible and most often injured. The level of injury is a major determinant of survival, and injuries of the suprarenal, intrahepatic vena cava are extremely dangerous, especially when accompanied by wounds of hepatic and renal veins. Difficulties in exposure and control are invariably encountered, and adjunctive measures are often necessary.

Diagnosis. Injuries of the inferior vena cava should be considered in all cases of penetrating wounds of the abdomen and lower part of the chest. Because of the vagaries of the trajectory of bullets, innocent-appearing small-caliber wounds may produce serious damage to retroperitoneal structures, without intraabdominal organ injury. Patients who have suffered stab wounds of the back or lower part of the chest may also harbor unsuspected caval injuries.

One of the major determinants of survival of these patients is the presence of hemorrhagic shock on admission. This is often a clue that despite the absence of identifying physical findings, major vascular injuries are present. Hemoperitoneum, hemothorax, subcutaneous blood staining from retroperitoneal bleeding, and evidence of distal vena caval obstruction may be helpful in diagnosis.

Except for direct venous studies with contrast media, radiographic examination is rarely specific. Routine x-ray studies, including anteroposterior and lateral films of the chest and abdomen, are useful and are recommended, but in a patient in unstable condition these should be obtained in the operating room as preparations for surgery are in progress. It is usually best not to delay surgery for elaborate studies if firm indications for exploration exist.

Treatment. As alluded to in the discussion of other vascular injuries, associated injuries are common and are a major factor in survival of these patients. Prior to exploration, resuscitation and attention to other problems often are important. An adequate airway must be obtained, volume and blood deficits repaired, and fractures stabilized. Vena caval injuries which require clamping may reduce the effectiveness of using lower-extremity veins for fluid administration, and at least one large-bore catheter should be placed into the upper-extremity venous system. This line is best reserved for blood and fluid administration, and should not be used for primary anesthetic manipulations.

Thoracotomy may be required, especially in patients with suprarenal caval injuries. If transatrial intracaval shunts are needed, a median sternotomy offers good exposure for this maneuver as well as for control of associated hepatic injuries.

Abdominal exploration is performed through a midline incision which can be extended as required, and median sternotomy can be added if necessary. Rapid abdominal exploration will usually expose major injuries and establish priorities of repair. It is usually wise to control the bleeding, pause, and complete volume and blood restoration before definitive repairs are begun. Attempts to complete bowel repair while bleeding persists from other injuries often extend the hypotensive episode and increase blood loss.

Centrally located retroperitoneal hematomas above the pelvis often harbor significant injuries, and usually are explored. Damage to other retroperitoneal structures is common (79 percent) and not always evident without formal exploration. The size or stability of the hematoma does not offer reliable evidence as to the presence or absence of significant injuries. Continued bleeding from the vena caval injury, however, is ominous. Patients actively bleeding at the time of operation have a very high mortality rate, especially if the vena caval injury is at or above the renal arteries and veins.

Initial control of bleeding can usually be obtained with pressure and packs. Occasionally temporary occlusion of the abdominal aorta at the diaphragmatic hiatus is useful in reducing blood loss from high caval injuries. Exposure of the inferior vena cava is obtained by reflecting medially the right colon, duodenum, and pancreas. Direct tamponade, manually or with sponge sticks, is usually effective in controlling bleeding. Simple lacerations or punctures are most common, but transections, avulsion, or multiple lacerations may be encountered, and control may be very difficult in the last group.

Simple lacerations can be controlled with gentle digital pressure and sutured by simply passing the needle under the occluding finger. In some cases the edge of the wound can be held gently in apposition with vascular forceps or blunt Allis clamps while repair is effected. Balloon catheter tamponade has also been employed for control of these wounds. Partial occlusion with vascular clamps is a useful technique and can be instituted after the initial use of other maneuvers. These simple tangential wounds usually can be repaired without injury to lumbar veins, but occasionally ligation of gonadal and lumbar tributaries is required.

Transections may be repaired by end-to-end vascular surgical techniques after mobilizing the vena cava. If there are multiple caval wounds requiring complicated repairs, or if repair poses an undue risk in a patient with multiple injuries, infrarenal ligation is preferable. In most cases construction of venous grafts is not required, and the time and effort necessary to perform these repairs may increase the operative morbidity and mortality.

Wounds at or above the renal veins are difficult to expose and repair. If bleeding from behind the liver is encountered and is not easily identified as coming from a laceration of the anterior cava wall below the caudate lobe, an intracaval shunt may be needed. The liver can be rotated medially after division of supporting ligaments, and if intrahepatic vena cava or combined hepatic vein lacerations are present, the shunt can be inserted as described by Schrock et al. The transatrial approach is easier than inserting the shunt from the infrarenal vena cava, and is very useful in managing these extremely dangerous wounds. A large chest tube (34 to 38 Fr) with a proximal side hole is inserted through the atrial appendage, and the tip is placed near the orifices of the renal veins. Umbilical tapes encircling the inferior vena cava within the pericardium and above the renal veins secure the catheter. The side hole in the catheter is placed at a level to permit the return of blood via the tube into the right atrium.

This shunt, occasionally combined with temporary occlusion of the portal triad, will usually allow sufficient control of bleeding to effect repairs. This technique is rarely required.

Unlike injuries of the infrarenal cava, most wounds above the renal veins should be repaired. Ligation of the inferior vena cava at this level produces serious complications. Some survivors have been reported, and those were usually in operations uncomplicated by hypotension, shock, or multiple injuries.

Those vascular procedures used in other areas are effective in repairing the suprarenal vena cava. Simple venorrhaphy often may suffice, but patch graft angioplasty or anastomosis may be needed. If graft interposition is required, autogenous venous grafts obtained from the infrarenal cava or iliac vein are preferred. Concomitant repair of hepatic vein injuries can be effected, but in some cases ligation may be preferable.

These repairs can usually be completed within 30 minutes, a period of ischemia well tolerated by the normothermic liver. Regional hypothermia may be induced with iced saline solution by irrigation techniques, thus conferring further protection of the liver during more prolonged ischemia.

Complications. In patients with isolated wounds of the inferior vena cava, repair is usually effective and complications are few. In these patients, two episodes of ileofemoral venous thrombosis have been encountered, and an additional patient had a pulmonary embolus. Pancreatitis has also been encountered, and recurrent retroperitoneal bleeding occurred in one patient.

The mortality in patients with isolated inferior vena caval injuries was 11 percent in the present series, but 67 percent of the patients with one or more major vessel injuries died. All the patient with inferior vena caval wounds at or above the renal veins had significant associated injuries, usually liver and bowel, occasionally pancreas, stomach, and lung. The mortality is high in this group of patients, especially if the inferior vena cava is actively bleeding at surgery.

Female Reproductive Organs

Injuries to the female reproductive organs are infrequently seen following either blunt or penetrating trauma to the abdomen. A series reported by Quast and Jordan revealed only 27 patients with gynecologic injuries in a 16-year period at their hospital. Two of those injuries resulted from blunt trauma with rupture of the uterus in patients who were in the immediate postpartum period. These are apparently the only cases recorded of rupture of the nonpregnant uterus. The remaining injuries were penetrating wounds. An enlarged uterus was present in 10 of their patients. Six patients were pregnant, two had large uterine myomas, and two were in the postpartum period. No cases of rupture of an unenlarged uterus by blunt trauma have been recorded, however. Rupture of the pregnant uterus due to blunt trauma is rare, but has occurred in a number of instances. Of blunt and penetrating wounds to the female reproductive tract, 90 percent involve the uterine corpus, and 10 percent involve the remaining adnexa.

Treatment. The signs and symptoms from a ruptured pregnant uterus are those of abrupt and massive intraperitoneal hemorrhage. Associated with these findings are generalized abdominal pain and tenderness, abdominal distension, ileus, and the absence of fetal heart sounds and movements. If the patient arrives at the hospital alive (which is not often the case), immediate blood volume and extracellular fluid replacement must be instituted through several large-bore intravenous catheters, preferably placed in the upper extremities, since there may be an interference with venous return from lower extremities of these patients. Urgent celiotomy is necessary to control hemorrhage, even though the patient may still be in shock at the time, since the only means of controlling the shock is to stop the hemorrhage. Probably the only anesthesia which will be required is assisted respiration with 100% oxygen administered through an endotracheal tube. Other agents may be added if and when shock abates. The treatment of choice is evacuation of the uterus, closure of the disruption with large chromic catgut sutures, and thorough peritoneal toilet with removal of all blood and foreign tissue.

Wounds of the uterus and adnexa are repaired by figure-of-eight chromic catgut sutures without drainage in most instances, although in occasional patients hysterectomy is indicated, as in injury of the lower uterine segment and major uterine vessels caused by high-velocity missiles. In these instances, hysterectomy is preferable to an attempted suture repair, since repair may cause stenosis of the cervical canal with resultant hematometra and dystocia. Also, hysterectomy for lower-uterine-segment injuries is indicated to obtain proper control of bleeding vessels and to help rule out uretheral injury at the point where the ureter and uterine artery are in juxtaposition.

It is wise to leave the vaginal cuff partially open following hysterectomy for trauma, because of the likelihood of vaginal cuff or cul-de-sac abscess formation, especially if there is appreciable blast injury or concomitant colon injury. If abscesses occur and the vaginal cuff has been left open, it is usually a relatively simple matter to drain the abscess with a finger inserted through the vagina into the open cuff. If gross fecal contamination is present from colon injury, the cuff should be left open and a Penrose drain led out of the vagina from the cul-de-sac. This drain may be secured to the vaginal cuff by a single small chromic catgut suture.

If massive uncontrollable or recurrent bleeding occurs following trauma to the female pelvic organs, it may be rapidly and adequately controlled by bilateral in-continuity ligations of the hypogastric arteries with nonabsorbable suture material. This will not often be required, but should be borne in mind as a very helpful and possibly lifesaving procedure.

Following injury to the pregnant uterus, the loss of the fetus is quite high. Quast and Jordan reported a salvage of only 1 of 10 pregnancies. One patient who was pregnant at the time of a tangential knife injury of the uterus had a uterine repair for penetrating trauma and subsequently delivered the child uneventfully per vagina.

Other instances have been reported in which penetrating uterine injury during pregnancy has been repaired with ensuing normal delivery. Quast and Jordan found that 81 percent of their patients with uterine injuries during pregnancy delivered subsequently per vagina with no difficulty. The cesarean section rate was 19 percent. Of the patients they followed after uterine injury, all who were in the childbearing age subsequently were able to conceive children. In this group, the abortion rate for these later pregnancies was 16 percent, with no apparent cause found.

By far the majority of pregnant patients with uterine injuries will abort shortly after the injury, frequently requiring curettage to control bleeding after spontaneous abortion. Others will require elective emptying of the uterine contents at the time of celiotomy in order to secure adequate hemostasis and uterine repair. Intravenous oxytocin should be given in such instances to aid in uterine contraction and hemostasis after hysterotomy.

Abdominal Wall

Injury to the abdominal wall without peritoneal injury is often difficult to diagnose. Muscular guarding and rigidity are frequently present, and it may be impossible to rule out intraabdominal injury from a hematoma of the abdominal wall. Such hematomas are usually due to rupture of the rectus abdominis or the epigastric artery by direct trauma or severe muscular exertion. The epigastric artery may be injured also by penetrating trauma, so that a hemoperitoneum results. The patient may become hypotensive from such an injury because of the severe intraperitoneal bleeding which sometimes occurs.

The mass from the rectus abdominis hematoma is below the umbilicus in over 80 percent of the cases. To distinguish this mass from intraperitoneal masses, the patient should be required to raise his head against resistance; the mass should disappear if it is intraperitoneal and remain the same if it is in the abdominal wall. This sign is not completely reliable, and if adjunctive diagnostic aids such as paracentesis and lavage are equivocal, then abdominal celiotomy should be performed.