CHAPTER OBJECTIVES

At the completion of this chapter, the reader will be able to do the following:

✓ Define energy in the context of production of injury.
✓ Describe the association between the laws of motion, energy, and the kinematics of trauma.
✓ Describe the relationship of injury and energy exchange to speed.
✓ Discuss energy exchange and the production of cavitation.
✓ Given the description of a motor vehicle crash, use kinematics to predict the likely injury pattern for an unrestrained occupant.
✓ Associate the principles of energy exchange with the pathophysiology of injury to the head, spine, thorax, abdomen, and extremities resulting from that exchange.
✓ Describe the specific injuries and their causes as related to interior and exterior vehicle damage.
✓ Describe the function of restraint systems for vehicle occupants.
✓ Relate the laws of motion and energy to mechanisms other than motor vehicle crashes (e.g. blasts, falls).
✓ Describe the five phases of blast injury and the injuries produced in each phase.
✓ Describe the differences in the production of injury with low-, medium-, and high-energy weapons.
✓ Discuss the relationship of the frontal surface of an impacting object to energy exchange and injury production.
✓ Integrate principles of the kinematics of trauma into patient assessment.
✓ Describe the recommended card and procedure for documenting TCCC care on the battlefield.
You and your partner are dispatched to a two-car collision. The day is warm and sunny. The scene is secured by law enforcement when you arrive.

On arrival, you confirm that there are only two cars involved. The first car is in the ditch on the right side of the road and has impacted a tree at the passenger-side door. There are bullet holes in the left-front door. At least three holes are visible to you. There are two occupants in the vehicle.

The other car veered off the left side of the road and hit a utility pole, centered between the two headlights. There are two people in that car. It is an old vehicle without air bags. There is a bent steering wheel, and, there is a bull’s-eye fracture of the windshield on the driver’s side. As you look into the car on the passenger side, you find an indentation in the lower part of the passenger-side dash. None of the passengers in either vehicle are wearing a safety belt. You are dealing with four injured patients—two in each car—and all have remained in the cars.

You are the senior EMT-paramedic on the scene. It is your responsibility to assess the patients and assign priority for transportation. Take the patients one at a time and describe them based on the kinematics.

**How would you describe each patient based upon the kinematics?**

**What injuries do you expect to find?**

Unexpected traumatic injuries are responsible for more than 169,000 deaths in the United States each year. Vehicle collisions accounted for more than 37,000 deaths and more than 4 million injured persons in 2008. This problem is not limited to the United States; other countries have an equal frequency of vehicular trauma, although the vehicles may be different. Penetrating trauma from guns is very high in the United States. In 2006, there were almost 31,000 deaths from firearms. Of these, over 13,000 were homicides. In 2008, there were over 78,000 nonfatal firearm injuries reported. Blast injuries are a major cause of injuries in many countries, whereas penetrating injuries from knives are prominent in others. Successful management of trauma patients depends on identification of injuries or potential injuries and the use of good assessment skills. It is frequently difficult to determine the exact injury produced, but understanding the potential for injury and the potential for significant blood loss will allow the critical-thinking process of the provider to recognize this likelihood and make appropriate triage, management, and transportation decisions.

The management of any patient begins (after initial resuscitation) with the history of the patient’s injury. In trauma, the history is the story of the impact and the energy exchange that resulted from this impact. An understanding of the energy exchange process will lead to the suspicion of 95% of the potential injuries.

When the provider, at any level of care, does not understand the principles of kinematics or the mechanisms involved, injuries may be missed. An understanding of these principles will increase the level of suspicion based on the pattern of injuries likely associated with the survey of the scene on arrival. This information and the suspected injuries can be used to properly assess the patient on the scene and can be transmitted to the physicians and nurses in the emergency department (ED). At the scene and en route, these suspected injuries can be managed to provide the most appropriate patient care and “do no further harm.”

Injuries that are not obvious but are still severe can be fatal if they are not managed at the scene and en route to the trauma center or appropriate hospital. Knowing where to look and how to assess for injuries is as important as knowing what to do after finding injuries. A complete, accurate history of a traumatic incident and proper interpretation of this data will provide such information. Most of a patient’s injuries can be predicted by a proper survey of the scene, even before examining the patient.

This chapter discusses the general principles and mechanical principles involved in the kinematics of trauma, and the sections on the regional effects of blunt and penetrating trauma address local injury pathophysiology. The general principles are the laws of physics that govern energy exchange and the general effects of the energy exchange. Mechanical principles address the interaction of the human body with the components of the crash for blunt trauma (e.g., motor vehicles, three- and two-wheeled vehicles, and falls), penetrating trauma, and blasts. A crash is the energy exchange that occurs when an object with energy, usually something solid, impacts the human body. It is not only the collision of a motor vehicle, but also the crash of a falling body onto the pavement, the impact of a bullet on the external and internal tissues of the body, and
the overpressure and debris of a blast. All of these involve energy exchange, all result in injury, all involve potentially life-threatening conditions, and all require the correct management by a knowledgeable and insightful prehospital care provider.

## General Principles

A traumatic event is divided into three phases: precrash, crash, and postcrash. Again, the term crash does not necessarily mean a vehicular crash. The crash of a vehicle into a pedestrian, a missile (bullet) into the abdomen, and a construction worker striking the asphalt after a fall are all examples of a crash. In each case, energy is exchanged between a moving object and the tissue of the human body or between the moving human body and a stationary object.

The precrash phase includes all of the events that preceded the incident. Conditions that are present before the incident, but important in the management of the patient’s injuries, are assessed as part of the precrash history. These include such things as a patient’s acute or pre-existing medical conditions (and medications to treat those conditions), ingestion of recreational substances (illegal and prescription drugs, alcohol, etc.), and a patient’s state of mind. Typically, young trauma patients do not have chronic illnesses. With older patients, however, medical conditions that are present before the trauma event can cause serious complications in the prehospital assessment and management of the patient and can significantly influence the outcome. For example, the elderly driver of a vehicle that has struck a utility pole may have chest pain indicative of a myocardial infarction (heart attack). Did the driver hit the utility pole and have a heart attack, or did he have a heart attack and then strike the utility pole? Does the patient take medication (e.g. beta blocker) that will prevent elevation of the pulse in shock? Most of these conditions not only directly influence the assessment and management strategies discussed in Chapters 4 and 5, but are important in overall patient care as well, even if they do not necessarily influence the kinematics of the crash.

The crash phase begins at the time of impact between one moving object and a second object. The second object can be moving or stationary and can be either an object or a person. Three impacts occur in most vehicular crashes: (1) the impact of the two objects; (2) the impact of the occupants into the vehicle; and (3) the impact of the vital organs inside the occupants. For example, when a vehicle strikes a tree, the first impact is the collision of the vehicle with the tree. The second impact is the occupant of the vehicle striking the steering wheel or windshield. If the patient is restrained, an impact occurs between the occupant and the seat belt. The third impact is between the patient’s internal organs and his or her chest wall, abdominal wall, or skull. (In a fall, only the second and third impacts are involved.)

The direction in which the energy exchange occurs, the amount of energy that is exchanged, and the effect that these forces have on the patient are all important considerations as assessment begins.

During the postcrash phase the information gathered about the crash and precrash phases is used to assess and manage a patient. This phase begins as soon as the energy from the crash is absorbed. The onset of the complications from life-threatening trauma can be slow or fast (or these complications can be prevented or significantly reduced), depending in part on the care provided at the scene and en route to the hospital. In the postcrash phase, the understanding of the kinematics of trauma, the index of suspicion regarding injuries, and strong assessment skills all become crucial to the patient outcome.

Simply stated, the precrash phase is the prevention phase. The crash phase is that portion of the traumatic event that involves the exchange of energy or the Kinematics (mechanics of energy). Lastly, the postcrash is the patient care phase.

To understand the effects of the forces that produce bodily injury, the prehospital care provider needs first to understand two components—energy exchange and human anatomy. For example, in a motor vehicle crash (MVC), what does the scene look like? Who hit what and at what speed? How long was the stopping time? Were the victims using appropriate restraint devices such as seat belts? Did the air bag deploy? Were the children restrained properly in seats, or were they unrestrained and thrown about the vehicle? Were occupants thrown from the vehicle? Did they strike objects? If so, how many objects and what was the nature of those objects? These and many other questions must be answered if the prehospital care provider is to understand the exchange of forces that took place and translate this information into a prediction of injuries and appropriate patient care.

The process of surveying the scene to determine what forces and motion were involved and what injuries might have resulted from those forces is called kinematics. Because kinematics is based on fundamental principles of physics, an understanding of the pertinent laws of physics is necessary.

### Energy

The initial component in obtaining a history is to evaluate the events that occurred at the time of the crash (Figure 4-1), to estimate the energy that was exchanged with the human body, and to make a gross approximation of the specific conditions that resulted.

### Laws of Energy and Motion

Newton’s first law of motion states that a body at rest will remain at rest and a body in motion will remain in motion unless acted on by an outside force. The skier in Figure 4-2...
was stationary until the energy from gravity moved him down the slope. Once in motion, although he leaves the ground, he will remain in motion until he hits something or returns to the ground and comes to a stop.

As previously mentioned, in any collision, when the body of the potential patient is in motion, there are three collisions: 1) the vehicle hitting an object, moving or stationary; 2) the potential patient hitting the inside of the vehicle, crashing into an object, or being struck by energy in an explosion; and 3) the internal organs interacting with the walls of a compartment of the body or being torn loose from their supporting structures. An example is a person sitting in the front seat of a vehicle. When the vehicle hits a tree and stops, the unrestrained person continues in motion—at the same rate of speed—until he or she hits the steering column, dashboard, and windshield. The impact with these objects stops the forward motion of the torso or head, but the internal organs of the person remain in motion until the organs hit the inside of the chest wall, abdominal wall, or skull, halting the forward motion.

The law of conservation of energy combined with Newton’s second law of motion describes that energy cannot be created or destroyed but can be changed in form. The motion of the vehicle is a form of energy. To start the vehicle, gasoline explodes within the cylinder of the engine. This moves the pistons. The motion of the pistons is transferred by a set of gears to the wheels, which grasp the road as they turn and impart motion to the vehicle. To stop the vehicle, the energy of its motion must be changed to another form, such as heating up the brakes or crashing into an object and bending the frame. When a driver brakes, the energy of motion is converted into the heat of friction (thermal energy) by the brake pads on the brake drums/disk and by the tires on the roadway. The vehicle decelerates.

Just as the mechanical energy of a vehicle that crashes into a wall is dissipated by the bending of the frame or other parts of the vehicle (Figure 4-3), the energy of motion of the organs and the structures inside of the body must be dissipated as these organs stop their forward motion. The same concepts apply to the human body when it is stationary and comes into contact and interacts with an object in motion such as a knife, a bullet, or a baseball bat.

Kinetic energy is a function of an object’s mass and velocity. Although they are not exactly the same, a victim’s weight is used to represent his or her mass. Likewise, speed is used to represent velocity (which really is speed and direction). The
relationship between weight and speed as it affects kinetic energy is as follows:

**Kinetic energy = One-half the mass times the velocity squared**

\[ KE = \frac{1}{2}mv^2 \]

Thus, the kinetic energy involved when a 150-lb (68-kg) person travels at 30 mph (48 km/hr) is calculated as follows:

\[ KE = \frac{150}{2} \times 30^2 \]

\[ KE = 67,500 \text{ units} \]

For the purpose of this discussion, no specific physical unit of measure (e.g. foot-pounds, joules) is used. The units are used merely to illustrate how this formula affects the change in the amount of energy. As just shown, a 150-lb (68-kg) person travelling at 30 mph (48 km/hr) would have 67,500 units of energy that has to be converted to another form when he or she stops. This change takes the form of damage to the vehicle and injury to the person in it, unless the energy dissipation can take some less harmful form, such as on a seat belt or into an air bag.

Which factor in the formula, however, has the greatest effect on the amount of kinetic energy produced: mass or velocity? Consider adding 10 lbs to the 150-lb person travelling at 30 mph (48 km/hr) in the prior example now making the mass equal to 160 lbs (72 kg):

\[ KE = \frac{160}{2} \times 30^2 \]

\[ KE = 72,000 \text{ units} \]

As the mass has increased, so has the amount of kinetic energy.

Finally, returning to this same example of a 150-lb (68-kg) person, instead of increasing the mass by 10, if the speed is increased by 10 mph (16 km/hr), the kinetic energy is as follows:

\[ KE = \frac{150}{2} \times 40^2 \]

\[ KE = 120,000 \text{ units} \]

These calculations demonstrate that increasing the velocity (speed) increases the kinetic energy much more than increasing the mass. Much more energy exchange will occur (and, therefore, produce greater injury to either the occupant or the vehicle or both) in a high-speed crash than in a crash at a slower speed. The velocity is exponential and the mass is linear; this is critical even when there is a great mass disparity between two objects.

**Mass \times \text{ acceleration} = \text{ force} = \text{ mass} \times \text{ deceleration}**

Force (energy) is required to put a structure into motion. This force (energy) is required to create a specific speed. The speed imparted is dependent on the weight (mass) of the structure. Once this energy is passed on to the structure and it is placed in motion, the motion will remain until the energy is given up (Newton’s first law of motion). This loss of energy will place other components in motion (tissue particles) or be lost as heat (dissipated into the brake disks on the wheels). An example of this process is the gun and the patient. In the chamber of the gun is a cartridge that contains gunpowder. If this gunpowder is ignited, it burns rapidly creating energy that pushes the bullet out of the barrel at a great speed. This speed is equivalent to the weight of the bullet and the amount of energy produced by the burning of the gunpowder or force. To slow down (Newton’s first law of motion), the bullet must give up its energy into the structure that it hits. This will produce an explosion in the tissue that is equal to the explosion that occurred in the chamber of the gun when the initial speed was given to the bullet. The same phenomenon occurs in the moving automobile, the patient falling from a building, or the explosion of an improvised explosive device (IED).

Another important factor in a crash is the **stopping distance**. The shorter the stopping distance and the quicker the rate of that stop, the more energy transferred to the patient and the more damage or injury that is done to the patient. A vehicle that stops against a brick wall or one that stops when the brakes are applied dissipates the same amount of energy, just in a different manner. The rate of energy exchange (into the vehicle body or into the brake disks) is different and occurs over a different distance. In the first instance, the energy is absorbed in a very short distance and amount of time by the bending of the frame of the vehicle. In the latter case, the energy is absorbed over a longer distance and period of time by the heat of the brakes. The forward motion of the occupant of the vehicle (energy) is absorbed in the first instance by damage to the soft tissue and bones of the occupant. In the latter case, the energy is dissipated, along with the energy of the vehicle, into the brakes.

This inverse relationship between stopping distance and injury also applies to falls. A person has a better chance of surviving a fall if he or she lands on a compressible surface, such as deep, powdery snow. The same fall terminating on a hard surface, such as concrete, can produce more severe injuries. The compressible material (i.e. the snow) increases the stopping distance and absorbs at least some of the energy rather than allowing all of the energy to be absorbed by the body. The result is decreased injury and damage to the body. This principle also applies to other types of crashes. In addition, an unrestrained driver will be more severely injured than a restrained driver. The restraint system, rather than the body, will absorb a significant portion of the energy transfer.

Therefore, once an object is in motion and has energy in the form of motion, in order for it to come to a complete rest, the object must lose all of its energy by converting the energy to another form or transferring it to another object. For exam-
The energy exchange from a moving vehicle to a pedestrian crushes tissue and imparts speed and energy to the pedestrian to knock the victim away from the point of impact. Injury to the patient can occur at the point of impact as the pedestrian is hit by the vehicle and as the pedestrian is thrown to the ground or into another vehicle.

**Energy Exchange between a Solid Object and the Human Body**

When the human body collides with a solid object, the number of body tissue particles that are impacted by the solid object determines the amount of energy exchange that takes place. This transfer of energy produces the amount of damage (injury) that occurs to the patient. The number of tissue particles affected is determined by (1) the density (particles per volume) of the tissue and (2) the size of the contact area of the impact.

**Density**

The denser a tissue is (measured in particles per volume), the greater the number of particles that will be hit by a moving object and, therefore, the greater the rate and the total amount of energy exchanged. Driving a fist into a feather pillow and driving a fist at the same speed into a brick wall will produce different effects on the hand. The fist absorbs more energy colliding with the dense brick wall than with the less dense feather pillow (Figure 4-5).

Simplistically, the body has three different types of tissue densities: *air density* (much of the lung and some portions of the intestine), *water density* (muscle and most solid organs; e.g. liver, spleen), and *solid density* (bone). Therefore, the amount of energy exchange (with resultant injury) will depend on which type of organ is impacted.

**Contact Area**

Wind exerts pressure on a hand when it is extended out of the window of a moving vehicle. When the palm of the hand is horizontal and parallel to the direction of the flow through the wind, some backward pressure is exerted on the front of the hand (fingers) as the particles of air strike the hand. Rotating the hand 90 degrees to a vertical position places a larger surface area into the wind; thus, more air particles make contact with the hand, increasing the amount of force on it.

For trauma events, the impact surface area can be modified by any change in the impact surface area. Examples of this effect on the human body include the front of an automobile, a baseball bat, rifle bullet or shotgun. The automobile’s front surface contacts a large portion of the victim. A baseball bat contacts a smaller area and a bullet contacts a very small area. The amount of energy exchange that would produce damage to the patient depends then on the energy of the object and the density of the tissue in the pathway of the energy exchange.
If all of the impact energy is in a small area and this force exceeds the resistance of the skin, the object is forced through the skin. This is the definition of **penetrating trauma**. If the force is spread out over a larger area and the skin is not penetrated then it fits the definition of **blunt trauma**. In either instance, a cavity in the patient is created by the force of the impacting object. Even with something like a bullet, the impact surface area can be different based on such factors as bullet size, its motion (tumble) within the body, deformation (“mushroom”), and fragmentation.

**Cavitation**

The basic mechanics of energy exchange are relatively simple. The impact on the tissue particles accelerates those tissue particles away from the point of impact. These tissues then become moving objects themselves and crash into other tissue particles, producing a “falling domino” effect. A common game that provides a visual effect of cavitation is pool. The cue ball is driven down the length of a pool table by the force of the muscles in the arm. The cue ball crashes into the racked balls at the other end of the table. The energy from the arm into the cue ball is thus transferred onto each of the racked balls (Figure 4-6). The cue ball gives up its energy to the other balls. The other balls began to move while the cue ball, which has lost its energy, slows or even stops. The other balls take on this energy as motion and move away from the impact point. A cavity has been created where the rack of balls once was. The same kind of energy exchange occurs when a bowling ball rolls down the alley, hitting the set of pins at the other end. The result of this energy exchange is a cavity. This sort of energy exchange occurs in both blunt and penetrating trauma.

Similarly, when a solid object strikes the human body or when the human body is in motion and strikes a stationary object, the tissue particles of the human body are knocked out of their normal position, creating a hole or cavity. Thus, this process is called **cavitation**.

Two types of cavities are created:

1. A temporary cavity is caused by the stretching of the tissues that occurs at the time of impact. Because of the elastic properties of the body’s tissues, some or all of the contents of the temporary cavity return to their previous position. The size, shape, and portions of the cavity that become part of the permanent damage depend on the tissue type, the elasticity of the tissue, and how much rebound of tissue occurs. This extent of this cavity is usually not visible when theprehospital or hospital provider examines the patient, even seconds after the impact.

![Figure 4-6](image-url)
2. A permanent cavity is left after the temporary cavity collapses and is the visible part of the tissue destruction. In addition, there is a crush cavity that is produced by the direct impact of the object on the tissue. Both of these can be seen when the patient is examined (Figure 4-7).

The amount of the temporary cavity that remains as a permanent cavity is related to the elasticity (stretch ability) of the tissue involved. For example, forcefully swinging a baseball bat into a steel drum leaves a dent, or cavity, in its side. Swinging the same baseball bat with the same force into a mass of foam rubber of similar size and shape will leave no dent once the bat is removed (Figure 4-8). The difference is elasticity—the foam rubber is more elastic than the steel drum. The human body is more like the foam rubber than the steel drum. If a person punches a fist into another person’s abdomen, he or she would feel the fist go in. However, when the person pulls the fist away, a dent is not left. Similarly, a baseball bat swung into the chest will leave no obvious cavity in the thoracic wall, but it would cause damage, both from direct contact and the cavity created by the energy exchange. The history of the incident and its interpretation will provide the information needed to determine the potential size of the temporary cavity at the time of impact. The organs or the structures involved predict injuries.

When the trigger of a loaded gun is pulled, the firing pin strikes the cap and produces an explosion in the cartridge. The energy created by this explosion is exchanged onto the bullet, which speeds from the muzzle of the weapon. The bullet now has energy, or force (acceleration × mass = force). Once such force is imparted, the bullet cannot slow down until acted on by an outside force (Newton’s first law of motion). In order for the bullet to stop inside the human body, an explosion must occur within the tissues that is equivalent to the explosion in the weapon (acceleration × mass = force = mass × deceleration) (Figure 4-9). This explosion is the result of energy exchange accelerating the tissue particles out of their normal position, creating a cavity.

**Blunt and Penetrating Trauma**

Trauma is generally classified as either blunt or penetrating. However, the energy exchange and the injury produced are similar in both types of trauma. Cavitation occurs in both; only the type and direction are different. The only real difference is penetration of the skin. If an object’s entire energy is concentrated on one small area of skin, the skin likely will tear, and the object will enter the body and create a more concentrated energy exchange along the pathway. This can result in greater destructive power to one area. A larger object whose energy is dispersed over a much larger area of
skin may not penetrate the skin. The damage will be distributed over a larger area of the body, and the injury pattern will be less localized. An example is difference in the impact of a large truck into a pedestrian versus a gunshot impact (Figure 4-10).

The cavitation in blunt trauma is frequently only a temporary cavity and is directed away from the point of impact. Penetrating trauma creates both a permanent and a temporary cavity. The temporary cavity that is created will spread away from the pathway of this missile in both frontal and lateral directions.

**Blunt Trauma**

**Mechanical Principles**

This section is divided into two major parts. The mechanical and structural effects on the vehicle of a crash are discussed first, and then the internal effects on the organs and body structures are addressed. Both are important and must be understood to properly assess the trauma patient and the potential injuries that exist after the crash.

The on-scene observations of the probable circumstances that led to a crash resulting in blunt trauma provide clues as to the severity of the injuries and the potential organs involved. The factors to assess are: (1) direction of the impact; (2) external damage to the vehicle (type and severity); and (3) internal damage (e.g., occupant-compartment intrusion, steering wheel/column bending, windshield bull's-eye fractures, mirror damage, dashboard knee impacts).

In blunt trauma, two forces are involved in the impact: shear and compression, both of which may result in cavitation. *Shear* is the result of one organ or structure (or part of an organ or structure) changing speed faster than another organ or structure (or part of an organ or structure). This difference in acceleration (or deceleration) causes the parts to separate and tear. *Compression* is the result of an organ or structure (or part of an organ or structure) being directly squeezed between other organs or structures. Injury can result from any type of impact, such as MVCs (vehicle or motorcycle), pedestrian collisions with vehicles, falls, sports injuries, or blast injuries. All of these mechanisms are discussed separately, followed by the results of this energy exchange on the specific anatomy in each of the body regions.

As discussed previously in this chapter, three collisions occur in blunt trauma. The first is the collision of the vehicle into another object. The second is the collision that occurs when the potential patient strikes the inside of the vehicular passenger compartment, strikes the ground at the end of a fall, or is struck by the force created in an explosion. The third is when the structures within the various regions of the body (head, chest, abdomen, etc.) strike the wall of that region or are torn (shear force) from their attachment within this com-
Motor Vehicle Crashes

Many forms of blunt trauma occur, but MVCs (including motorcycle crashes) are the most common. In 2008, 86% of fatalities were vehicle occupants. The remaining 14% were pedestrians, cyclists, and other nonoccupants, as reported by the National Highway Traffic Safety Administration (NHTSA).6

MVCs can be divided into the following five types:

1. Frontal impact
2. Rear impact
3. Lateral impact
4. Rotational impact
5. Rollover7

Although each pattern has variations, accurate identification of the five patterns will provide insight into other, similar types of crashes.

In MVCs and other rapid-deceleration mechanisms (e.g. snowmobiles and motorcycles), in boating crashes, and in falls from heights, three collisions occur: (1) the vehicle collides with an object or with another vehicle; (2) the unrestrained occupant collides with the inside of the vehicle; and (3) the occupant’s internal organs collide with one another or with the wall of the compartment that contains them.

An example is a vehicle hitting a tree. The first collision occurs when the vehicle strikes the tree. The vehicle stops but the unrestrained driver keeps moving forward (consistent with Newton’s first law of motion). The second collision occurs when the driver hits the steering wheel, windshield and/or some other part of the occupant compartment. Now, the driver’s torso stops moving forward, but many internal organs keep moving (Newton’s first law again) until they strike another organ or cavity wall or are suddenly stopped by a ligament, fascia, vessel, or muscle. This is the third collision.

One method to estimate the potential for injury to the occupant is to look at the vehicle and determine which of the five types of collisions occurred, the energy exchange involved, and the direction of the impact. The occupant receives the same type of force as the vehicle from the same direction as the vehicle. The amount of force exchanged with the occupant, however, may be somewhat reduced by absorption of energy by the vehicle.

Frontal Impact.

In Figure 4-11, for example, the vehicle has hit a utility pole in the center of the car. The impact point stopped its forward motion, but the rest of the car continued forward until the energy was absorbed by the bending of the car. The same type of motion occurs to the driver resulting in injury. The stable steering column is impacted by the chest, perhaps in the center of the sternum. Just as the car continued in forward motion, significantly deforming the front of the vehicle, so too will the driver’s chest. As the sternum stops forward motion against the dash, the posterior thoracic wall continues until the energy is absorbed by the bending and possible fracture of the ribs. This process will also crush the heart and the lungs trapped between the sternum and the vertebral column and the posterior thoracic wall.

The amount of damage to the vehicle indicates the approximate speed of the vehicle at the time of impact. The greater the intrusion into the body of the vehicle, the greater is the speed at the time of impact. The greater the vehicle speed, the greater the energy exchange and the more likely the occupants are to be injured.

Although the vehicle suddenly ceases to move forward in a frontal impact, the occupant continues to move and will follow one of two possible paths: either up-and-over or down-and-under.

The use of a seat belt and the deployment of an air bag or restraint system will absorb some or most of the energy, thus reducing the injury to the victim. For clarity and simplicity of discussion, the occupant is these examples will be assumed to be without restraint.

Up-and-Over Path. In this sequence, the body’s forward motion carries it up and over the steering wheel (Figure 14-12). The head is usually the lead body portion striking the windshield, windshield frame, or roof. The head then stops its forward motion. The torso continues in motion until its energy/force is absorbed along the spine. The cervical spine is the least protected segment of the spine. The chest or abdomen then collides with the steering column, depending on the position of the torso. Impact of the chest into the steering column produces thoracic cage, cardiac, lung, and aortic...
injuries (see Regional Effects of Blunt Trauma). Impact of the abdomen into the steering column can compress and crush the solid organs, produce overpressure injuries (especially to the diaphragm), and rupture of the hollow organs. The kidneys, spleen, and liver are also subject to shear injury as the abdomen strikes the steering wheel and abruptly stops. An organ may be torn from its normal anatomic restraints and supporting tissues. For example, the continued forward motion of the kidneys after the vertebral column has stopped moving produces shear along the attachment of the organs at their blood supply. The aorta and vena cava are tethered tightly to the posterior abdominal wall and vertebral column. The continued forward motion of the kidneys can stretch the renal vessels to the point of rupture (Figure 4-13). A similar action may tear the aorta in the chest as the unattached arch becomes the tightly adhered descending aorta (Figure 4-14).

Down-and-Under Path. In a down-and-under path, the occupant moves forward, downward, and out of the seat into the dashboard (Figure 4-15). The importance of understanding kinematics is illustrated by the injuries produced to the lower extremity in this pathway. Because many of the injuries are difficult to identify, an understanding of the mechanism of injury is very important.

The foot, if planted on the floor panel or on the brake pedal with a straight knee, can twist as the continued torso motion angulates and fractures the ankle joint. More often, however, the knees are already bent, and the force is not directed to the ankle. Therefore, the knees strike the dashboard.

The knee has two possible impact points against the dashboard, the tibia and the femur (Figure 4-16A). If the tibia hits the dashboard and stops first, the femur remains in motion and overrides it. A dislocated knee, with torn ligaments, tendons, and other supporting structures, can result. Because the popliteal artery lies close to the knee joint, dislocation of the joint is frequently associated with injury to the vessel. The artery can be completely disrupted or the lining alone (intima) may be damaged (Figure 4-16B). In either case, a blood clot may form in the injured vessel, resulting in significantly decreased blood flow to the leg tissues below the knee. Early recognition of the knee injury and the potential for vascular injury will alert the physicians to the need for assessment of the vessel in this area.

Early identification and treatment of such a popliteal artery injury significantly decreases the complications of distal limb ischemia. Perfusion to this tissue needs to be re-established within about 6 hours. Delays could occur because the prehospital care provider failed to consider the kinematics of the injury or overlooked important clues during assessment of the patient.

Although most of these patients have evidence of injury to the knee, an imprint on the dashboard where the knee impacted is a key indicator that significant energy was
focused on this joint and adjacent structures (Figure 4-17). Further investigation is needed in the hospital to better eliminate the possible injuries.

When the femur is the point of impact, the energy is absorbed on the bone shaft, which can then break (Figure 4-18). The continued forward motion of the pelvis onto the femur that remains intact can override the femoral head, resulting in a posterior dislocation of the acetabular joint (Figure 4-19).

After the knees and legs stop their forward motion, the upper body will bend forward into the steering column or dashboard. The unrestrained victim may then sustain many of the same injuries described previously for the up-and-over pathway.

Recognizing these potential injuries and relaying the information to the ED physicians can result in long-term benefits to the patient.

**Rear Impact**

Rear-impact collisions occur when a slower-moving or stationary vehicle is struck from behind by a vehicle moving at a faster rate of speed. For ease of understanding, the more rapidly moving vehicle is called the “bullet vehicle” and the slower-moving or stopped object is called the “target vehicle.” In such collisions, the energy of the bullet vehicle at the moment of impact is converted to acceleration of the target...
vehicle and damage results to both vehicles. The greater the difference in the momentum of the two vehicles, the greater the force of the initial impact and the more energy is available to create damage and acceleration.

During a rear-impact collision, the target vehicle in front is accelerated forward. Everything that is attached to the frame will also move forward at the same rate of speed. This includes the seats in which the occupants are riding. The unattached objects in the vehicle, including the occupants, will begin forward motion only after something in contact with the frame begins to transmit the energy of the frame motion to these objects or occupants. As an example, the torso is accelerated by the back of the seat after some of the energy has been absorbed by the springs in the seats. If the headrest is improperly positioned behind and below the occiput of the head, the head will

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**FIGURE 4-15** The occupant and the vehicle travel forward together. The vehicle stops, and the unrestrained occupant continues forward until something stops that motion.

**FIGURE 4-16** A. The knee has two possible impact points in a motor vehicle crash: the femur and the tibia. B. The popliteal artery lies close to the joint, tightly tied to the femur above and tibia below. Separation of these two bones stretches, kinks, and tears the artery.

**FIGURE 4-17** The impact point of the knee on the dashboard indicates both a down-and-under pathway and a significant absorption of energy along the lower extremity.

**FIGURE 4-18** When the femur is the point of impact, the energy is absorbed on the bone shaft, which can then break.

**FIGURE 4-19** The continued forward motion of the pelvis onto the femur can override the femur’s head, resulting in a posterior dislocation of the acetabular joint.
begin its forward motion after the torso, resulting in hyperextension of the neck. Shear and stretching of the ligaments and other support structures, especially in the anterior part of the neck, can result in injury (Figure 4-20A).

If the headrest is properly positioned, the head moves at approximately the same time as the torso without hyperextension (Figures 4-20B, 4-21). If the target vehicle is allowed to move forward without interference until it slows to a stop, the occupant will probably not suffer significant injury because most of the body’s motion is supported by the seat, similar to an astronaut launching into orbit.

However, if the vehicle strikes another vehicle or object or if the driver slams on the brakes and stops suddenly, the occupants will continue forward, following the characteristic pattern of a frontal-impact collision. The collision then involves two impacts—rear and frontal. The double impact increases the likelihood of injury.

**Lateral Impact**

Lateral-impact mechanisms come into play when the vehicle is involved in an intersection (“T-bone”) collision or when the vehicle veers off the road and impacts sideways a utility pole, tree, or other obstacle on the roadside. If the collision is at an intersection, the target vehicle is accelerated from the impact in the direction away from the force created by the bullet vehicle. The side of the vehicle or the door that is struck is thrust against the side of the occupant. The occupants may then be injured as they are accelerated laterally (Figure 4-22) or as the passenger compartment is bent inward by the door’s projection (Figure 4-23). Injury caused by the

If it can be proved that the victim’s headrest was not properly positioned when the neck injury occurred, some courts consider reducing the liability of the party at fault in the crash on the grounds that the victim’s negligence contributed to the injuries (contributory negligence). Similar measures have been considered in cases of failure to use occupant restraints. Elderly patients have a high frequency of injury.25

**FIGURE 4-20** A. A rear-impact collision forces the torso forward. If the headrest is improperly positioned, the head is hyperextended over the top of the headrest. B. If the headrest is up, the head moves with the torso, and neck injury is prevented.

**FIGURE 4-21** Head rests.

**FIGURE 4-22** Lateral impact of the vehicle pushes the entire vehicle into the unrestrained passenger. A restrained passenger moves laterally with the vehicle.

**FIGURE 4-23** Intrusion of the side panels into the passenger compartment provides another source of injury.
vehicle’s movement is less severe if the occupant is restrained and moves with the initial motion of the vehicle.²

Five body regions can sustain injury in a lateral impact:

1. **Clavicle.** The clavicle can be compressed and fractured if the force is against the shoulder (Figure 4-24). 
2. **Chest.** Compression of the thoracic wall inward can result in fractured ribs, pulmonary contusion, or compression injury of the solid organs beneath the rib cage, as well as overpressure injuries (e.g., pneumothorax) (Figure 4-24B). Shear injuries of the aorta can result from the lateral acceleration (25% of aortic shear injuries occur in lateral-impact collisions).¹⁰,¹¹,¹²
3. **Abdomen and pelvis.** The intrusion compresses and fractures the pelvis and pushes the head of the femur through the acetabulum (Figure 4-24C). Occupants on the driver’s side are vulnerable to spleen injuries because the spleen is on the left side of the body, whereas those on the passenger side are more likely to receive an injury to the liver.
4. **Neck.** The torso can move out from under the head in lateral collisions as well as in rear impacts. The attachment point of the head is posterior and inferior to the center of gravity of the head. Therefore, the motion of the head in relationship to the neck is lateral flexion and rotation. The contralateral side of the spine will be opened (distraction) and the ipsilateral side compressed. This can fracture the vertebrae or more likely produce jumped facets and possible dislocation as well as spinal cord injury (Figure 4-25).
5. **Head.** The head can impact the frame of the door.

**Near-side impacts produce more injuries than far-side impacts.**

**Rotational Impact**

Rotational-impact collisions occur when one corner of a vehicle strikes an immovable object, the corner of another vehicle, or a vehicle moving slower or in the opposite direction of the first vehicle. Following Newton’s first law of motion, this corner of the vehicle will stop while the rest of the vehicle continues its forward motion until all its energy is completely transformed.

Rotational-impact collisions result in injuries that are a combination of those seen in frontal impacts and lateral collisions. The victim continues to move forward and then is hit by the side of the vehicle (as in a lateral collision) as the vehicle rotates around the point of impact (Figure 4-26). More severe injuries are seen in the victim closest to the point of impact.

**Rollover**

During a rollover, a vehicle may undergo several impacts at many different angles, as may the unrestrained occupant’s body and internal organs (Figure 4-27). Injury and damage

**FIGURE 4-24**  A. Compression of the shoulder against the clavicle produces midshaft fractures of this bone. B. Compression against the lateral chest and abdominal wall can fracture ribs and injure the underlying spleen, liver, and kidney. C. Lateral impact on the femur pushes the head through the acetabulum or fractures the pelvis.
can occur with each of these impacts. In rollover collisions, a restrained occupant often sustains shearing-type injuries because of the significant forces created by a rolling vehicle. The forces are similar to the forces of a spinning carnival ride. Although the occupants are held securely by restraints, the internal organs still move and can tear at the connecting tissue areas. More serious injuries result from being unrestrained. In many cases, the occupants are ejected from the vehicle as it rolls and are either crushed as the vehicle rolls over them or sustain injuries from the impact with the ground. If the occupants are ejected onto the roadway, they can be struck by oncoming traffic. The NHTSA reports that in crashes involving fatalities in the year 2008, 77% of occupants who were totally ejected from a vehicle were killed.\textsuperscript{13}

**Vehicle Incompatibility**

The type of vehicles involved in the crash plays a significant role in the potential for injury and death to the occupants. For example, in a lateral impact between two cars that lack air bags, the occupants of the car struck on its lateral aspect are 5.6 times more likely to die than the occupants in the vehicle striking that car. This can be largely explained by the relative lack of protection on the side of a car compared with the large amount of deformation that can occur to the front end of a vehicle before there is intrusion into the passenger compartment. However, when the vehicle that is struck in a lateral collision (by a car) is a sport utility vehicle (SUV),

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**FIGURE 4-25** The center of gravity of the skull is anterior and superior to its pivot point between the skull and cervical spine. During a lateral impact, when the torso is rapidly accelerated out from under the head, the head turns toward the point of impact, in both lateral and anterior-posterior angles. Such motion separates the vertebral bodies from the side of opposite impact and rotates them apart. Jumped facets, ligaments, tears, and lateral compression fractures result.

**FIGURE 4-26** The victim in a rotational-impact crash first moves forward and then laterally as the vehicle pivots around the impact point.

**FIGURE 4-27** During a rollover, the unrestrained occupant can be wholly or partially ejected out of the vehicle or can bounce around inside the vehicle. This action produces multiple and somewhat unpredictable injuries that are usually severe.
van, or pickup truck rather than a car, the risk of death to occupants is almost the same for all vehicles involved. Thus, SUVs, vans, and pickup trucks provide additional protection to their occupants because the passenger compartment sits higher off the ground than that of a car, and the occupants sustain less of a direct blow in a lateral impact.

More serious injuries and a greatly increased risk of death to vehicle occupants have been documented when a car is struck on its lateral aspect by a van, SUV, or pickup. In a lateral-impact collision between a van and a car, the occupants of the car struck broadside are 13 times more likely to die than those in the van. If the striking vehicle is a pickup truck or SUV, the occupants of the car struck broadside are 25 to 30 times more likely to die than those in the pickup truck or SUV. This tremendous disparity results from the higher center of gravity and increased mass of the van, SUV, or pickup truck. Knowledge of vehicle types in which occupants were located in a crash may lead the prehospital care provider to have a higher index of suspicion for serious injury.

**Occupant Protective and Restraining Systems**

**Seat Belts.** In the injury patterns described previously, the victims were assumed to be unrestrained. The NHTSA reported that, in 2008, only 17% of occupants were unrestrained compared with 67% in a 1999 NHTSA report. Ejection from vehicles accounted for approximately 25% of the 44,000 vehicular deaths in 2002. About 77% of passenger vehicle occupants who were totally ejected were killed; 1 in 13 ejection victims sustained a spine fracture. After ejection from a vehicle, the body is subjected to a second impact as the body strikes the ground (or another object) outside the vehicle. This second impact can result in injuries that are even more severe than the initial impact. The risk of death for ejected victims is six times greater than for those who are not ejected. Clearly, seat belts save lives.

The NHTSA reports that 49 states and the District of Columbia have safety-belt legislation. From 2004 through 2008, more than 75,000 lives were saved by the use of these restraining devices. The NHTSA estimates that over 255,000 lives have been saved in the United States alone since 1975. Also, the NHTSA reports that over 13,000 lives were saved by seat belts in the United States in 2008 and that if all occupants wore restraints, the total lives saved would have been more than 17,000.

What occurs when the victims are restrained? If a seat belt is positioned properly, the pressure of the impact is absorbed by the pelvis and the chest, resulting in few, if any, serious injuries (Figure 4-28). The proper use of restraints transfers the force of the impact from the patient’s body to the restraint belts and restraint system. With restraints, the chance of receiving life-threatening injuries is greatly reduced.

Seat belts must be worn properly to be effective. An improperly worn belt may not protect against injury in the event of a crash, and it may even cause injury. When lap belts are worn loosely or are strapped above the pelvis, compression injuries of the soft abdominal organs can occur. Injuries of the soft intra-abdominal organs (spleen, liver, and pancreas) result from compression between the seat belt and the posterior abdominal wall (Figure 4-29). Increased intra-abdominal pressure can cause diaphragmatic rupture and herniation of abdominal organs. Lap belts should also not be worn alone but in combination with a
Anterior compression fractures of the lumbar spine can occur as the upper and lower parts of the torso pivot over the lap belt, especially in the restrained twelfth thoracic (T12), first lumbar (L1), and second lumbar (L2) vertebrae. Many occupants of vehicles still place the diagonal strap under the arm and not over the shoulder, risking serious injury.

As mandatory laws on seat belt use are passed and enforced, the overall severity of injuries decreases, and the number of fatal crashes is significantly reduced.

Air Bags. Air bags (in addition to seat belts) provide supplemental protection to the occupant of a vehicle. Originally, front-seat driver and passenger air bag systems were designed to cushion the forward motion of only the front-seat occupants. The air bags absorb energy slowly by increasing the body’s stopping distance. They are extremely effective in the first collision of frontal and near-frontal impacts (the 65% to 70% of crashes that occur within 30 degrees of the headlights). However, air bags deflate immediately after the impact and, therefore, are not effective in multiple-impact or rear-impact collisions. An air bag deploys and deflates within 0.5 second. As the vehicle veers into the path of an oncoming vehicle or off the road into a tree after the initial impact, no air bag protection is left. Side air bags do add to the protection of occupants.

When air bags deploy, they can produce minor but noticeable injuries that the prehospital care provider needs to manage. These include abrasions of the arms, chest, and face (Figure 4-30); foreign bodies to the face and eyes; and injuries caused by the occupant’s eyeglasses (Figure 4-31). Air bags that do not deploy can still be dangerous to both the patient and the prehospital care provider (Figure 4-32). Air bags can be deactivated by an extrication specialist trained to do so properly and safely. Such deactivation should not delay patient care or extrication of the critical patient.

Air bags pose a significant hazard to infants and children if the child is either unrestrained or placed in a rear-facing child seat in the front-passenger compartment. Of the over 290 deaths from air-bag deployments, almost 70% were passengers in the front seat, and 90 of those were infants or children.
Motorcycle Crashes

Motorcycle crashes account for a significant number of the motor vehicle deaths each year. While the laws of physics for motorcycle crashes are the same, the mechanism of injury varies from automobile and truck crashes. This variance occurs in each of the following types of impacts: head-on, angular, and ejection. An additional factor that leads to increased death, disability, and injury is the lack of structural framework around the biker that is present in other motor vehicles.

Head-on Impact

A head-on collision into a solid object stops the forward motion of a motorcycle (Figure 4-33). Because the motorcycle’s center of gravity is above and behind the front axle, which is the pivot point in such a collision, the motorcycle will tip forward, and the rider will crash into the handlebars. The rider may receive injuries to the head, chest, abdomen, or pelvis, depending on which part of the anatomy strikes the handlebars. If the rider’s feet remain on the pegs of the motorcycle and the thighs hit the handlebars, the forward motion will be absorbed by the midshaft of the femur, usually resulting in bilateral femoral fractures (Figure 4-34). “Open-book” pelvic fractures are a common result of the interaction between the biker’s pelvis and the handlebars.

Angular Impact

In an angular-impact collision, the motorcycle hits an object at an angle. The motorcycle will then collapse on the rider or cause the rider to be crushed between the motorcycle and the object that was struck. Injuries to the upper or lower extremities can occur, resulting in fractures and extensive soft tissue injury (Figure 4-35). Injuries can also occur to organs of the abdominal cavity as a result of energy exchange.

Ejection Impact

Because of the lack of restraint, the rider is susceptible to ejection. The rider will continue in flight until the head, arms, chest, abdomen, or legs strike another object, such as a motor vehicle, a telephone pole, or the road. Injury will occur at the point of impact and will radiate to the rest of the body as the energy is absorbed.

Injury Prevention

Many riders do not use proper protection. Protection for motorcyclists includes boots, leather clothing, and helmets. Of the three, the helmet affords the best protection. It is built similar to the skull: strong and supportive externally and energy-absorbent internally. The helmet’s structure absorbs much of the impact, thereby decreasing injury to the face, skull, and brain. Failure to use helmets has been shown to increase head injuries by more than 300%. The helmet provides only minimal protection for the neck but does not cause neck injuries. Mandatory helmet laws work. For example, Louisiana had a 60% reduction in head injuries in the first 6 years after passing a helmet law. Most states that have passed mandatory helmet legislation have found an associated reduction in motorcycle incidents.

“Laying the bike down” is a protective maneuver used by bikers to separate them from the motorcycle in an impending crash (Figure 4-36). The rider turns the motorcycle sideways and drags the inside leg on the ground. This action slows the rider more than the motorcycle so that the motorcycle will move out from under the rider. The rider will then slide along on the pavement but will not be trapped between the motorcycle and any object it hits. These riders usually receive abrasions (“road rash”) and minor fractures but generally avoid the severe injuries associated with the other types of impact, unless they directly strike another object (Figure 4-37).
Pedestrian Injuries

Pedestrian collisions with MVCs have three separate phases, each with its own injury pattern, as follows:

1. The initial impact is to the legs and sometimes the hips (Figure 4-38A).
2. The torso rolls onto the hood of the vehicle (and may strike the windshield) (Figure 4-38B).
3. The victim falls off the vehicle and onto the ground, usually headfirst, with possible cervical spine trauma (Figure 4-38C).

The injuries produced in pedestrian crashes vary according to the height of the victim and the height of the vehicle (Figure 4-39). The impact points on a child and an adult standing in front of a car present different anatomical structures to the vehicles. Because they are shorter, children are initially struck higher on the body than adults (Figure 4-40A). The first impact generally occurs when the bumper strikes the child’s legs (above the knees) or pelvis, damaging the femur or pelvic girdle. The second impact occurs almost instantly afterward as the front of the vehicle’s hood continues forward and strikes the child’s thorax. Then, the head and face strike...
FIGURE 4-38  A. *Phase 1.* When a pedestrian is struck by a vehicle, the initial impact is to the legs and sometimes to the hips. B. *Phase 2.* The torso of the pedestrian rolls onto the hood of the vehicle. C. *Phase 3.* The pedestrian falls off the vehicle and hits the ground.

FIGURE 4-39  The injuries resulting from vehicle-pedestrian crashes vary according to the height of the victim and the height of the vehicle.
the front or top of the vehicle’s hood (Figure 4-40B). Because of the child’s smaller size and weight, the child may not be thrown clear of the vehicle, as usually occurs with an adult. Instead, the child may be dragged by the vehicle while partially under the vehicle’s front end (Figure 4-40C). If the child falls to the side, the lower limbs may also be run over by a front wheel. If the child falls backward, ending up completely under the vehicle, almost any injury can occur (e.g., being dragged, struck by projections, or run over by a wheel).

If the foot is planted on the ground at the time of impact, the child will receive energy exchange at the upper leg, hip, and abdomen. This will force the hips and abdomen away from the impact. The upper part of the torso will come along later, as will the planted foot. The energy exchange moving the torso but not the feet will fracture the pelvis and shear the femur, producing severe angulation at the point of impact and possible spine injury as well.

To complicate these injuries further, a child will likely turn toward the car out of curiosity, exposing the anterior body and face to injuries, whereas an adult will attempt to escape and will be hit in the back or the side.

Adults are usually struck first by the vehicle’s bumper in the lower legs, fracturing the tibia and fibula. The collision continues into the pelvis and chest as the victim is impacted. As the victim is impacted by the front of the vehicle’s hood, depending on the height of the hood, the abdomen and thorax are struck by the top of the hood and the windshield. This substantial second strike can result in fractures of the upper femur, pelvis, ribs, and spine, producing intra-abdominal or intrathoracic crush and shear. If the victim’s head strikes the hood or if the victim continues to move up the hood so that the head strikes the windshield, injury to the face, head, and cervical and thoracic spine can occur. If the vehicle has a large frontal area (trucks and SUVs), the entire potential patient is hit simultaneously.

The third impact occurs as the victim is thrown off the vehicle and strikes the pavement. The victim can receive a significant blow on one side of the body, injuring the hip, shoulder, and head. Head injury often occurs when the victim strikes either the vehicle or the pavement. Similarly, because all three impacts produce sudden, violent movement of the torso, neck, and head, an unstable spine fracture may result. After falling, the victim may be struck by a second vehicle travelling next to or behind the first.

As with an adult, any child struck by a vehicle can receive some type of head injury. Because of the sudden, violent forces acting on the head, neck, and torso, cervical spine injuries are high on the suspicion list.

Knowing the specific sequence of multiple impacts in pedestrian versus motor vehicle crashes and understanding the multiple underlying injuries that they can produce are keys to making an initial assessment and determining the appropriate management of a patient.

Falls

Victims of falls can also sustain injury from multiple impacts. An estimation of the height of the fall, the surface on which the victim landed, and the part of the body struck first are important factors to determine since these are indications of the energy involved and, thus, the energy exchange that occurred. Victims who fall from greater heights have a higher incidence of injury because their velocity increases as they fall. Falls from greater than three times the height of the victim are frequently severe. The type of surface on which the victim lands and its degree of compressibility (ability to be deformed by the transfer of energy) also have an effect on stopping distance.

The pattern of injury in falls occurring feet first is called the Don Juan syndrome. Only in the movies can the character Don Juan jump from a high balcony, land on his feet, and
walk painlessly away. In real life, bilateral fractures of the calcaneus (heel bone), compression or shear fractures of the ankles, and distal tibial or fibular fractures are often associated with this syndrome. After the feet land and stop moving, the legs are the next body part to absorb energy. Tibial plateau fractures of the knee, long-bone fractures, and hip fractures can result. The body is compressed by the weight of the head and torso, which are still moving, and can cause compression fractures of the spinal column in the thoracic and lumbar areas. Hyperflexion occurs at each concave bend of the S-shaped spine, producing compression injuries on the concave side and distraction injuries occur on the convex side. This victim is often described as breaking his or her “S.”

If a victim falls forward onto the outstretched hands, the result can be bilateral compression and flexion (Colles’) fractures of the wrists. If the victim did not land on the feet, theprehospital care provider will assess the part of the body that struck first, evaluate the pathway of energy displacement, and determine the injury pattern.

If the falling victim lands on the head with the body almost inline, as often occurs in shallow-water diving injuries, the entire weight and force of the moving torso, pelvis, and legs compress the head and cervical spine. A fracture of the cervical spine is a frequent result, as with the up-and-over pathway of the frontal-impact collision.

Sports Injuries

Severe injury can occur during many sports or recreational activities, such as skiing, diving, baseball, and football. These injuries can be caused by sudden deceleration forces or by excessive compression, twisting, hyperextension, or hyperflexion. In recent years, various sports activities have become available to a wide spectrum of occasional, recreational participants who often lack the necessary training and conditioning or the proper protective equipment. Recreational sports and activities include participants of all ages. Sports such as downhill skiing, waterskier, bicycling, and skateboarding, are all potentially high-velocity activities. Other sports, such as trailbiking, all-terrain vehicle (ATV) riding, and snowmobiling, can produce velocity deceleration, collisions, and impacts similar to motorcycle crashes or MVCs.

The potential injuries of a victim who is in a high-speed collision and then ejected from a skateboard, snowmobile, or bicycle are similar to those sustained when a person is ejected from an automobile at the same speed because the amount of energy is the same. The specific mechanisms of MVCs and motorcycle crashes were described earlier.

The potential mechanisms associated with each sport are too numerous to list in detail. However, the general principles are the same as for MVCs. While assessing the mechanism of injury, the prehospital care provider considers the following questions to assist in the identification of injuries:

- What forces acted on the victim, and how?
- What are the apparent injuries?
- To what object or part of the body was the energy transmitted?
- What other injuries are likely to have been produced by this energy transfer?
- Was protective gear being worn?
- Was there sudden compression, deceleration, or acceleration?
- What injury-producing movements occurred (e.g. hyperflexion, hyperextension, compression, excessive lateral bending)?

When the mechanism of injury involves a high-speed collision between two participants, as in a crash between two skiers, reconstruction of the exact sequence of events from eyewitness accounts is often difficult. In such crashes, the injuries sustained by one skier are often guidelines for examination of the other. In general, which part of one victim struck what part of the other victim and what injury resulted from the energy transfer are important. For example, if one victim sustains an impact fracture of the hip, a part of the other skier’s body must have been struck with substantial force and, therefore, must have sustained a similar high-impact injury. If the second skier’s head struck the first skier’s hip, the prehospital care provider will suspect potentially serious head injury and an unstable spine for the second skier.

Broken or damaged equipment is also an important indicator of injury and must be included in the evaluation of the mechanism of injury. A broken sports helmet is evidence of the magnitude of the force with which it struck. Because skis are made of highly durable material, a broken ski indicates that extreme localized force came to bear, even when the mechanism of injury may appear unimpressive. A snowmobile with a severely dented front end indicates the force with which it struck a tree. The presence of a broken stick after an ice hockey skirmish raises the question of whose body broke it, how, and, specifically, what part of the victim’s body was struck by the stick or fell on it.

Victims of significant crashes who complain of no apparent injuries must be assessed as if severe injuries exist. The steps are as follows:

1. Evaluate the patient for life-threatening injury.
2. Evaluate the patient for mechanism of injury. (What happened and exactly how did it happen?)
3. Determine how the forces that produced injury in one victim may have affected any other person.
4. Determine whether any protective gear was worn (it may have already been removed).
5. Assess damage to the protective equipment. (What are the implications of this damage relative to the patient’s body?)
6. Assess the patient for possible associated injuries.

High-speed falls, collisions, and falls from heights without serious injury are common in many contact sports. The ability of athletes to experience incredible collisions and falls and sustain only minor injury—largely as a result of
impact-absorbing equipment—may be confusing. The potential for injury in sports participants may be overlooked. The principles of kinematics and careful consideration of the exact sequence and mechanism of injury will provide insight into sports collisions in which greater forces than usual came to bear. Kinematics is an essential tool in identifying possible underlying injuries and determining which patients require further evaluation and treatment at a medical facility.

**Regional Effects of Blunt Trauma**

The body can be divided into several regions: head, neck, thorax, abdomen, pelvis, and extremities. Each body region is subdivided into (1) the external part of the body, usually composed of skin, bone, soft tissue, vessels, and nerves, and (2) the internal part of the body, usually vital internal organs. The injuries produced as a result of shear, cavitation, and compression forces are used to provide an overview in each component and region for potential injuries.

**Head**

The only indication that compression and shear injuries have occurred to the patient’s head may be a soft tissue injury to the scalp, a contusion of the scalp, or a bull’s-eye fracture of the windshield (Figure 4-41).

**Compression.** When the body is travelling forward with the head leading the way, as in a frontal vehicular crash or a head-first fall, the head is the first structure to receive the impact and the energy exchange. The continued momentum of the torso then compresses the head. The initial energy exchange occurs on the scalp and the skull. The skull can be compressed and fractured, pushing the broken, bony segments of the skull into the brain (Figure 4-42).

**Shear.** After the skull stops its forward motion, the brain continues to move forward, compressing against the intact or fractured skull with resultant concussion, contusions, or lacerations. The brain is soft and compressible; therefore, its length is shortened. The posterior part of the brain can continue forward, pulling away from the skull, which has already stopped moving. As the brain separates from the skull, stretching or breaking (shearing) of brain tissue itself or any blood vessels in the area occurs (Figure 4-43). Hemorrhage into the epidural, subdural, or subarachnoid space can then result, as well as diffuse axonal injury of the brain. If the brain separates from the spinal cord, it will most likely occur at the brain stem.

**Neck**

**Compression.** The dome of the skull is fairly strong and can absorb the impact of a collision; however, the cervical spine is much more flexible. The continued pressure from the momentum of the torso toward the stationary skull produces angulation or compression (Figure 4-44). Hyperextension or hyperflexion of the neck often results in fracture or dislocation of one or more vertebra and injury to the spinal cord. The result can be jumped (dislocated) facets, potential fractures, spinal cord compression or unstable neck fractures (Figure 4-45). Direct inline compression crushes the bony vertebral bodies. Both angulation and inline compression can result in an unstable spine.

**Shear.** The skull’s center of gravity is anterior and cephalad to the point at which the skull attaches to the bony spine. Therefore, a lateral impact on the torso when the neck is unrestrained will produce lateral flexion and rotation of the neck (see Figure 4-25). Extreme flexion or hyperextension may also cause stretching injuries to the soft tissues of the neck.

**Thorax**

**Compression.** If the impact of a collision is centered on the anterior part of the chest, the sternum will receive the ini-
tial energy exchange. When the sternum stops moving, the posterior thoracic wall (muscles and thoracic spine) and the organs in the thoracic cavity continue to move forward until the organs strike and are compressed against the sternum.

The continued forward motion of the posterior thorax bends the ribs. If the tensile strength of the ribs is exceeded, fractured ribs and a flail chest can develop (Figure 4-46). This is similar to what happens when a vehicle stops suddenly against a dirt embankment (see Figure 4-3). The frame of the vehicle bends, which absorbs some of the energy. The rear of the vehicle continues to move forward until the bending of the frame absorbs all the energy. In the same way, the posterior thoracic wall continues to move until the ribs absorb all the energy.

Compression of the chest wall is common with frontal and lateral impacts and produces an interesting phenomenon called the *paper bag effect*, which may result in a pneumothorax. A
victim instinctively takes a deep breath and holds it just before impact. This closes the glottis, effectively sealing off the lungs. With a significant energy exchange on impact and compression of the chest wall, the lungs may then burst, like a paper bag full of air that is popped (Figure 4-47). The lungs can also become compressed and contused, compromising ventilation.

Compression injuries of the internal structures of the thorax may also include cardiac contusion, which occurs as the heart is compressed between the sternum and the spine and can result in significant dysrythmias. Perhaps a more frequent injury is compression of the lungs leading to pulmonary contusion. Although the clinical consequences may develop over time, immediate loss of the ability of the patient to properly ventilate may occur. Pulmonary contusion can have consequences in the field for the prehospital provider and for the physicians during resuscitation after arrival in the hospital. In situations in which long transport times are required, this condition can play a role en route.

Shear. The heart, ascending aorta, and aortic arch are relatively unrestrained within the thorax. The descending aorta, however, is tightly adhered to the posterior thoracic wall and the vertebral column. The resultant motion of the aorta is similar to holding the flexible tubes of a stethoscope just below where the rigid tubes from the earpiece end and swinging the acoustic head of the stethoscope from side to side. As the skeletal frame stops abruptly in a collision, the heart and the initial segment of the aorta continue their forward motion. The shear forces produced can tear the aorta at the junction of the portion that moves freely with the tightly bound portion (see Figure 4-14).

An aortic tear may result in an immediate, complete transection of the aorta followed by rapid exsanguination. Some aortic tears are only partial, and one or more layers of tissue remain intact. However, the remaining layers are under great pressure, and a traumatic aneurysm often develops, similar to the bubble that can form on a weak part of a tire. The aneurysm can eventually rupture within minutes, hours, or days after the original injury. Approximately 80% of these patients die on the scene at the time of the initial impact. Of the remaining 20%, one-third will die within 6 hours, one-third will die within 24 hours, and one-third will live 3 days or longer. It is important that the prehospital care provider recognizes the potential for such injuries and relays this information to the hospital personnel.

Abdomen

Compression. Internal organs pressed by the vertebral column into the steering wheel or dashboard during a frontal collision may rupture. The effect of this sudden increase in pressure is similar to the effect of placing the internal organ on an anvil and striking it with a hammer. Solid organs frequently injured in this manner include the pancreas, spleen, liver, and kidneys.

Injury may also result from overpressure in the abdomen. The diaphragm is a 1/3-inch thick (5mm) muscle located across the top of the abdomen that separates the abdominal cavity from the thoracic cavity. Its contraction causes the pleural cavity to expand for ventilation. The anterior abdomi-
nal wall comprises two layers of fascia and one very strong muscle. Laterally, there are three muscle layers with associated fascia, and the lumbar spine and its associated muscles provide strength to the posterior abdominal wall. The diaphragm is the weakest of all the walls and structures surrounding the abdominal cavity. It may be torn or ruptured as the intra-abdominal pressure increases (Figure 4-48). This injury has four common consequences, as follows:

1. The “bellows” effect that is usually created by the diaphragm is lost and ventilation is affected.
2. The abdominal organs can enter the thoracic cavity and reduce the space available for lung expansion.
3. The displaced organs can become ischemic from compression of their blood supply.
4. If intra-abdominal hemorrhage is present, the blood can also cause a hemothorax.

Another injury caused by increased abdominal pressure is from sudden retrograde blood flow up the aorta and against the aortic valve. This force against the valve can rupture it. This injury is rare but does exist. It occurs when a collision with the steering wheel or involvement in another type of incident (e.g. ditch or tunnel cave-in) has produced a rapid increase in intra-abdominal pressure. This rapid pressure increase results in a sudden increase of aortic blood pressure. Blood is pushed back (retrograde) against the aortic valve with enough pressure to cause rupture of the valve cusps.

Shear. Injury to the abdominal organs occurs at their points of attachment to the mesentery. During a collision, the forward motion of the body stops, but the organs continue to move forward, causing tears at the points of attachment of organs to the abdominal wall. If the organ is attached by a pedicle (a stalk of tissue), the tear can occur where the pedicle attaches to the organ, where it attaches to the abdominal wall, or anywhere along the length of the pedicle (see Figure 4-13). Organs that can shear this way are the kidneys, small intestine, large intestine, and spleen.

Another type of injury that often occurs during deceleration is laceration of the liver caused by its impact with the ligamentum teres. The liver is suspended from the diaphragm but is only minimally attached to the posterior abdomen near the lumbar vertebrae. The ligamentum teres attaches to the anterior abdominal wall at the umbilicus and to the left lobe of the liver in the midline of the body. (The liver is not a midline structure; it lies more on the right than on the left.) A down-and-under pathway in a frontal impact or a feet-first fall causes the liver to bring the diaphragm with it as it descends into the ligamentum teres (Figure 4-49). The ligamentum teres will fracture or transect the liver, analogous to a cheese slicing cheese.

Pelvic fractures are the result of damage to the external abdomen and may cause injury to the bladder or lacerations of the blood vessels in the pelvic cavity. Approximately 10% of patients with pelvic fractures also have a genitourinary injury.

Pelvic fractures resulting from compression from the side, usually due to a lateral impact collision have two components. One is the compression of the proximal femur into the pelvis which pushes the head of the femur through the acetabulum itself. This frequently produces radiating fractures that involve the entire joint. Further compression of the
Penetrating Trauma

Physics of Penetrating Trauma

The principles of physics discussed earlier are equally important when dealing with penetrating injuries. Again, the kinetic energy that a striking object transfers to body tissue is represented by the following formula:

\[ KE = \frac{1}{2}mv^2 \]

Energy cannot be created or destroyed, but it can be changed in form. This principle is important in understanding penetrating trauma. For example, although a lead bullet is in the brass cartridge casing that is filled with explosive powder, the bullet has no force. However, when the primer explodes, the powder burns, producing rapidly expanding gases that are transformed into force. The bullet then moves out of the gun and toward its target.

According to Newton’s first law of motion, after this force has acted on the missile, the bullet will remain at that speed and force until it is acted on by an outside force. When the bullet hits something, such as a human body, it strikes the individual tissue cells. The energy (speed and mass) of the bullet’s motion is exchanged for the energy that crushes these cells and moves them away (cavitation) from the path of the bullet.

\[ \text{Mass} \times \text{acceleration} = \text{force} = \text{mass} \times \text{deceleration} \]

Factors That Affect the Size of the Frontal Area

The larger the frontal area of the moving missile, the greater is the number of particles that will be hit—therefore, the greater the energy exchange that occurs and the larger the cavity that is created. The size of the frontal surface area of a projectile is influenced by three factors: profile, tumble, and fragmentation. Energy exchange or potential energy exchange can be analyzed based on these factors.

Profile. Profile describes an object’s initial size and whether that size changes at the time of impact. The profile, or frontal area, of an ice pick is much smaller than that of a baseball bat, which in turn is much smaller than that of a truck. A hollow-point bullet flattens and spreads on impact (Figure 4-50). This change enlarges the frontal area so that it hits more tissue particles and produces greater energy exchange. As a result, a larger cavity forms and more injury occurs.

In general, a bullet should remain very aerodynamic as it travels through the air en route to the target. Low resistance while passing through the air (hitting as few air particles as possible) is a good thing. This will allow it to maintain most of its speed. To achieve this, the frontal area is kept small in a conical shape. A lot of drag (resistance to travel) is a bad thing. A good bullet design would have very little drag while passing through the air but much more drag when passing through the body’s tissues. If that missile strikes the skin and becomes deformed, covering a larger area and creating much more drag, then a much greater energy exchange will occur. Therefore, the ideal bullet is designed to keep its shape while in the air and only deform on impact.

Tumble. Tumble describes whether the object turns over and over and assumes a different angle inside the body than the angle it assumed as it entered the body, thus creating more drag inside the body than in the air. A wedge-shaped bullet’s center of gravity is located nearer to the base than to the nose of the bullet. When the nose of the bullet strikes something, it slows rapidly. Momentum continues to carry the base of the bullet forward, with the center of gravity seeking to become the leading point of the bullet. A slightly asymmetrical shape causes an end-over-end motion, or tumble. As the bullet tumbles, the normally horizontal sides of the bullet become its leading edges, thus striking far more par-
Particles than when bullet was in the air (Figure 4-51). More energy exchange is produced, and therefore, greater tissue damage occurs.

**Fragmentation.** Fragmentation describes whether the object breaks up to produce multiple parts or rubble and, therefore, more drag and more energy exchange. There are two types of fragmentation rounds: 1) fragmentation on leaving the weapon, (e.g. shotgun pellets) (Figure 4-52); and 2) fragmentation after entering the body. This can be active or passive fragmentation. Active fragmentation involves a bullet that has an explosive inside it that detonates inside the skin. Bullets with soft noses or vertical cuts in the nose and safety slugs that contain many small fragments to increase body damage by breaking apart on impact are examples of passive fragmentation. The resulting mass of fragments creates a larger frontal area than a single solid bullet, and energy is dispersed rapidly into the tissue. If the missile shatters, it will spread out over a wider area, with two results: (1) more tissue particles will be struck by the larger frontal projection; and (2) the injuries will be distributed over a larger portion of the body because more organs will be struck (Figure 4-53). The multiple pieces of shot from a shotgun blast produce similar results. Shotgun wounds are an excellent example of the fragmentation injury pattern.

**Damage and Energy Levels**

The damage caused in a penetrating injury can be estimated by classifying penetrating objects into three categories according to their energy capacity: low-, medium-, and high-energy weapons.

**Low-Energy Weapons**

Low-energy weapons include hand-driven weapons such as a knife or an ice pick. These missiles produce damage only with their sharp points or cutting edges. Because these are low-velocity injuries, they are usually associated with less secondary trauma (i.e. less cavitation will occur). Injury in these victims can be predicted by tracing the path of the weapon into the body. If the weapon has been removed, the prehospital care provider should try to identify the type of weapon used.

*FIGURE 4-51* Tumble motion of a missile maximizes its damage at 90 degrees.

*FIGURE 4-52* Maximum fragmentation damage is caused by a shotgun.

*FIGURE 4-53* When the missile breaks up into smaller particles, this fragmentation increases its frontal area and increases the energy distribution. (From McSwain NE Jr: Pulmonary chest trauma. In Moylan JA, editor: *Principles of Trauma*, New York, 1992, Gower.)
The gender of the attacker is an important factor in determining the trajectory of a knife. Men tend to thrust with the blade on the thumb side of the hand and with an upward or inward motion, whereas women tend to hold the blade on the little finger side and stab downward (Figure 4-54).

An attacker may stab a victim and then move the knife around inside the body. A simple entrance wound may produce a false sense of security. The entrance wound may be small, but the damage inside may be extensive. The potential scope of the movement of the inserted blade is an area of possible damage (Figure 4-55).

Evaluation of the patient for associated injury is important. For example, the diaphragm can reach as high as the nipple line on deep expiration. A stab wound to the lower chest can injure intra-abdominal as well as intrathoracic structures, and a wound of the upper abdomen may also involve the lower chest.

Penetrating trauma can result from impaled objects such as fence posts and street signs in vehicle crashes and falls, ski poles in snow sports, and handlebar injuries in bicycling.

### Medium-Energy and High-Energy Weapons

Firearms fall into two groups: medium energy and high energy. Medium-energy weapons include handguns and some rifles whose muzzle velocity is 1000 ft/sec. The temporary cavity created by this weapon is three to five times the caliber of the bullet. High energy weapons have muzzle velocity in excess of 2000 ft/sec and significantly greater muzzle energy. They create a temporary cavity 25 times or greater than the caliber of the bullet. It is obvious that as the amount of gunpowder in the cartridge increases and the size of the bullet increases, the speed and mass of the bullet and, therefore, its kinetic energy increase (Figure 4-56A–B). The mass of the bullet is an important, but smaller, component \( KE = \frac{1}{2} m v^2 \). However, the bullet mass is not to be discounted. In the War Between the States, the Kentucky Long rifle 0.55 caliber Minie Ball had almost the same muzzle energy as the modern M16. The mass of the missile becomes more important when considering the damage produced by a 12-gauge shotgun at close range or an Improvised Explosive Device (IED). Additional information is available in the blast chapter of the military edition of PHTLS.

In general, medium-energy and high-energy weapons damage not only the tissue directly in the path of the missile, but also the tissue involved in the temporary cavity on each side of the missile’s path. The variables of missile profile, tumble, and fragmentation influence the rapidity of the
energy exchange and, therefore, the extent and direction of the injury.\(^{[N]}\) The force of the tissue particles moved out of the direct path of the missile compresses and stretches the surrounding tissue (Figure 4-57).

High-energy weapons discharge high-energy missiles (Figure 4-58A–B). Tissue damage is much more extensive with a high-energy penetrating object than with one of medium energy. The vacuum created in the cavity created by this high-speed missile can pull clothing, bacteria, and other debris from the surface into the wound.

A consideration in predicting the damage from a gunshot wound is the range or distance from which the gun (either medium- or high-energy) is fired. Air resistance slows the bullet; therefore, increasing the distance will decrease the energy at the time of impact and will result in less injury. Most shootings are done at close range with handguns, so the probability of serious injury is related to both the anatomy involved and the energy of the weapon rather than loss of kinetic energy.

**High-Energy Weapons**

**Cavitation.** Fackler and Malinowski described the unusual injury pattern of an AK-47. Because of its eccentricity, the bullet tumbles and travels almost at a right angle to the area of entrance. During this tumble action, the rotation carries it over and over so that there are two or sometimes even three (depending on how long the bullet stays in the body) cavitations.\(^{18}\) The very high energy exchange produces the cavitation and a significant amount of damage.

The size of the permanent cavity is associated with the elasticity in the tissue struck by the missile. For example, if the same bullet going the same speed penetrates both muscle and the liver, the results are very different. Muscle has much more elasticity and will expand and return to a relatively small, permanent cavity. On the other hand, the liver has very little elasticity, so it develops fracture lines and a much larger, permanent cavity than the same energy exchange in muscle.\(^{19,20}\)

**Fragmentation.** The combination of high-energy weapon with fragmentation can produce significant damage. If the high-energy missile fragments on impact (which many do not), the initial entrance site may be very large and may have significant soft tissue injury. On the other hand, if the bullet only fragments when it hits a hard structure in the body (such as bone), this large cavitation occurs at this impact point and the bony fragments themselves become part of the damage-producing component. Significant destruction to the bone and nearby organs and vessels may result.\(^{18}\)

Emil Theodor Kocher, a surgeon living at the latter part of the 19th century, was extremely active in the understanding of ballistics and the damage produced by the weapons. He was a strong advocate of not using the “dum-dum” bullet (produced
by the arsenal in Dum Dum, India). The St. Petersburg Declaration of 1868 outlawed explosive projectiles less than 400 grams in weight. This was followed by the Hague Convention of 1899, which outlawed the use of dum-dum bullets in war.

**Anatomy**

**Entrance and Exit Wounds**

Tissue damage will occur at the site of missile entry into the body, along the path of the penetrating object, and on exit from the body. Knowledge of the victim’s position, the attacker’s position, and the weapon used is helpful in determining the path of injury. If the entrance wound and the exit wound can be related, the anatomical structures that would likely be in this pathway can be approximated.

Evaluating wound sites provides valuable information to direct the management of the patient and to relay to the receiving facility. Do two holes in the victim’s abdomen indicate that a single missile entered and exited or that two missiles entered and are both still inside the patient? Did the missile cross the midline (usually causing more severe injury) or remain on the same side? In what direction did the missile travel? What internal organs are likely to have been in its path?

Entrance and exit wounds usually, but not always, produce identifiable injury patterns to soft tissue. Evaluation of the apparent trajectory of a penetrating object is very helpful to the clinician. This information should be given to the physicians in the hospital. On the other hand, prehospital providers (and most physicians) do not have the experience or the expertise of a forensic pathologist; therefore, the assessment of which wound is an entrance and which is an exit is fraught with uncertainty. Such information is solely for patient care to try to gauge the trajectory of the missile and not for legal purposes to determine specifics about the incident. These two issues should not be confused. The provider must have as much information as possible to determine the potential injuries sustained by the patient and to best decide how the patient is to be managed. The legal issues related to the specifics of entrance and exit wounds are best left to others. An entrance wound from a gunshot lies against the underlying tissue, but an exit wound has no support. The former is typically a round or oval wound depending on the entry path, and the latter is

![Figure 4-58](image-url)
usually a stellate (starburst) wound (Figure 4-59). Because the missile is spinning as it enters the skin, it leaves a small area of abrasion (1 to 2 mm in size) that is pink (Figure 4-60). Abrasion is not present on the exit side. If the muzzle was placed directly against the skin at the time of discharge, the expanding gases will enter the tissue and produce crepitus on examination (Figure 4-61). If the muzzle is within 2 to 3 inches (5 to 7 cm), the hot gases that exit will burn the skin; at 2 to 6 inches (5 to 15 cm) the smoke will adhere to the skin; and inside 10 inches (25 cm) the burning cordite particles will tattoo the skin with small (1 to 2 mm) burned areas (Figure 4-62).

**Regional Effects of Penetrating Trauma**

This section discusses the injuries sustained by various parts of the body during penetrating trauma.

**Head**

After a missile penetrates the skull, its energy is distributed within a closed space. Particles accelerating away from the missile are forced against the unyielding skull, which cannot expand as can skin, muscle or even the abdomen. Thus, the brain tissue is compressed against the inside of the skull, producing more injury than would otherwise occur if it could expand freely. It is similar to putting a firecracker in
an apple and then placing the apple in a metal can. When the
firecracker explodes the apple will be destroyed against the
wall of the can. If the forces are strong enough, the skull may
explode from the inside out (Figure 4-63).

A bullet may follow the curvature of the interior of the
skull if it enters at an angle and has insufficient force to exit
the skull. This path can produce significant damage (Figure
4-64). Because of this characteristic, small caliber, medium-
velocity weapons, such as the 0.22-caliber or 0.25-caliber pis-
tol, have been called the “assassin’s weapon.” They go in and
exchange all of their energy into the brain.

**Thorax**

Three major groups of structures are inside the thoracic cav-
ity: the pulmonary system, vascular system, and gastrointes-
tinal tract. This does not include the bone and muscle of the
chest wall. One or more of the anatomic structures of these
systems may be injured by a penetrating object.

**Pulmonary System.** Lung tissue is less dense than blood, solid
organs, or bone; therefore, a penetrating object will hit fewer
particles, exchange less energy and do less damage to lung tis-
sue. Damage to the lungs can be clinically significant (Figure
4-65), but fewer than 15% of patients will require surgical explora-

**Vascular System.** Smaller vessels that are not attached to the
chest wall may be pushed aside without significant damage.
However, larger vessels, such as the aorta and vena cava, are
less mobile because they are tethered to the spine or the heart.
They cannot move aside easily and are more susceptible to
damage.

The myocardium (almost totally muscle) stretches as the
bullet passes through and then contracts, leaving a smaller
defect. The thickness of the muscle may control a low-energy
penetration, such as by a knife, or even a small, medium-
energy 0.22-caliber bullet. This closure can prevent immedi-
ate exsanguination and allow time to transport the victim to
an appropriate facility.

**Gastrointestinal Tract.** The esophagus, the part of the gastro-
intestinal tract that traverses the thoracic cavity, can be pen-
etrated and can leak its contents into the thoracic cavity. The
signs and symptoms of such an injury may be delayed for
several hours or several days.

**Abdomen**
The abdomen contains structures of three types: air-filled,
solid, and bony. Penetration by a low-energy missile may
not cause significant damage; only 30% of knife wounds
penetrating the abdominal cavity require surgical explora-
tion to repair damage. A medium-energy injury (e.g., handgun wound) is more damaging; 85% to 95% require surgical repair. However, in injuries caused by medium-energy missiles, the damage to solid and vascular structures frequently does not produce immediate exsanguination. This enables prehospital care providers to transport the patient to an appropriate facility in time for effective surgical intervention.

Extremities
Penetrating injuries to the extremities can include damage to bones, muscles, nerves, or vessels. When bones are hit, bony fragments become secondary missiles, lacerating surrounding tissue (Figure 4-66). Muscles often expand away from the path of the missile, causing hemorrhage. The missile may penetrate blood vessels, or a near-miss may damage the lining of a blood vessel, causing clotting and obstruction of the vessel within minutes or hours.

Shotgun Wounds
Although shotguns are not high-velocity weapons, they are high-energy weapons and, at close range, they can be more lethal than some of the highest-energy rifles. Handguns and rifles predominantly use rifling (grooves) on the inside of the barrel to spin a single missile in a flight pattern toward the target. In contrast, most shotguns possess a smooth, cylindrical tube barrel that directs a load of missiles in the direction of the target. Devices known as chokes and diverters can be attached to the end of a shotgun barrel to shape and form the column of missiles into specific patterns (e.g., cylindrical or rectangular). Regardless, when a shotgun is fired, a large number of missiles are ejected in a spread, or spray, pattern. The barrels may be shortened (“sawed off”) to prematurely widen the trajectory of the missiles.

Although shotguns may use various types of ammunition, the structure of most shotgun shells is similar. A typical shotgun shell contains gunpowder, wadding, and projectiles. When discharged, all these individual components are propelled from the muzzle and can inflict injury on the victim. Certain types of gunpowder can stipple (“tattoo”) the skin in close-range injuries. Wadding, which is usually lubricated paper, fibers, or plastic used to separate the shot (missiles) from the charge of gunpowder, can provide another source of infection in the wound if not removed. The missiles can vary in size, weight, and composition. A wide variety of missiles are available, from compressed metal powders to birdshot (small metal pellets), buckshot (larger metal pellets), slugs (a single metal missile), and more recently, plastic and rubber alternatives. The average shell is loaded with 1 to 1 1/2 ounces of shot. Fillers that are placed with the shot (polyethylene or polypropylene granules) can become embedded in the superficial layers of the skin.

An average birdshot shell may contain 200 to 2000 pellets, whereas a buckshot shell may contain only 6 to 20 pellets (Figure 4-67). It is important to note that as the size of the buckshot pellets increases, they approach the wounding characteristics of 0.22-caliber missiles in regard to effective range and energy transfer characteristics. Larger or “magnum” shells are also available. These shells may contain more shot and a larger charge of gunpowder or only the larger powder charge to boost the muzzle velocity of the shot.

The type of ammunition used is important in gauging injuries, but the range (distance) at which the patient was shot provides the most important variable when evaluating the shotgun-injury victim. Shotguns eject a large number of
missiles, most of which are spherical. These projectiles are especially susceptible to the effects of air resistance, thereby quickly slowing once they exit the muzzle (Figure 4-68). The effect of air resistance on the projectiles decreases the effective range of the weapon and changes the basic characteristics of the wounds that it generates. Consequently, shotgun wounds have been classified into four major categories: contact, close-range, intermediate-range, and long-range wounds (Figure 4-69).

Contact wounds occur when the muzzle is touching the victim at the time the weapon is discharged. This typically results in circular entrance wounds, which may or may not have soot or an imprint of the muzzle (see Figure 4-61). Searing or burning of the wound edges is common, secondary to the high temperatures and the expansion of hot gases as the missiles exit the muzzle. Some contact wounds may be more stellate (star-shaped) in appearance, caused by the superheated gases from the barrel escaping from the tissue. Contact wounds usually result in widespread tissue damage and are associated with high mortality. The length of a standard shotgun barrel makes it difficult to commit suicide with this weapon, since it is difficult to reach and pull the trigger. Such attempts usually result in a split face without the shot reaching the brain.

Close-range wounds (less than 6 feet), although still typically characterized by circular entrance wounds, will likely have more evidence of soot, gunpowder, or filler stippling around the wound margins than contact wounds. Additionally, abrasions and markings from the impact of the wadding that coincide with the wounds from the missiles may be found. Close-range wounds also create significant damage in the patient; missiles fired from this range still retain sufficient energy to penetrate deep structures and exhibit a slightly wider spread pattern. This increases the extent of injury as missiles travel through soft tissue.

Intermediate-range wounds are characterized by the appearance of satellite pellet holes emerging from the border around a central entrance wound. This pattern is a result of individual pellets spreading from the main column of shot and generally occurs at a range of 6 to 18 feet. These injuries are a mixture of deep, penetrating wounds and superficial wounds and abrasions. Because of the deep, penetrating components of this injury, however, victims may still have a relatively high mortality rate.
Long-range wounds are rarely lethal. These wounds are typically characterized by the classic spread of scattered pellet wounds and result from a range of greater than 18 feet. However, even at these slower velocities, the pellets can cause significant damage to certain sensitive tissues (e.g. eyes). In addition, larger buckshot pellets can retain sufficient velocity to inflict damage to deep structures, even at long range. Theprehospital care provider also needs to consider the cumulative effects of many small missile wounds and their locations, focusing on sensitive tissues. Adequate exposure is essential when examining all patients involved in trauma, and shotgun injuries are no exception.

These varying characteristics need to be taken into account when evaluating injury patterns in patients with shotgun injuries. For example, a single, circular, shotgun wound could represent a contact or close-range injury with birdshot or buckshot in which the missiles have retained a tight column or grouping. Conversely, this may also represent an intermediate-range to long-range injury with a slug or solitary missile. Only detailed examination of the wound will allow differentiation of these injuries that will likely involve significant damage to internal structures despite strikingly different missile characteristics.

Contact and close-range wounds to the chest may result in a large, visually impressive wound resulting in an open pneumothorax, and bowel may eviscerate from such wounds to the abdomen. On occasion, a single pellet from an intermediate-range wound may penetrate deep enough to perforate the bowel, leading eventually to peritonitis, or may damage a major artery, resulting in vascular compromise to an extremity. Alternatively, a patient who exhibits multiple small wounds in a spread pattern may have dozens of entrance wounds. However, none of the missiles may have retained enough energy to penetrate through fascia, let alone produce significant damage to internal structures.

Although immediate patient care must always remain the priority, any information (shell type, suspected range of the patient from the weapon, number of shots fired) thatprehospital care providers can gather from the scene and relay to the receiving facility can assist with appropriate diagnostic evaluation and treatment of the shotgun-injured patient. Furthermore, recognition of various wound types can aid providers in maintaining a high index of suspicion for internal injury regardless of the initial impression of the injury.

### Blast Injuries

#### Injury from Explosions

Explosive devices are the most frequently used weapons in combat and by terrorists. Explosive devices cause human injury by multiple mechanisms, some of which are exceedingly complex. The greatest challenges for clinicians at all levels of care in the aftermath of an explosion are the large numbers of casualties and multiple, penetrating injuries (Figure 4-70).

#### Physics of Blast

Explosions are physical, chemical, or nuclear reactions that result in the almost instantaneous release of large amounts of energy in the form of heat and rapidly expanding, highly compressed gas, capable of projecting fragments at extremely high velocities. The energy associated with an explosion can take multiple forms: kinetic and heat energy in the “blast wave;” kinetic energy of fragments formed by the breakup of the weapon casing and surrounding debris; and electromagnetic energy.

Blast waves can travel at greater than 16,400 feet (5000 meters)/second and are composed of static and dynamic components. The static component (“blast overpressure”) surrounds...
objects in the flow field of the explosion, loading them on all sides with a discontinuous rise in pressure called the “shock front” or “shock wave” up to a “peak overpressure” value. Following the shock front, the overpressure drops down to ambient pressure, and then a partial vacuum is often formed as a result of air being sucked back (Figure 4-71). The dynamic component (“dynamic pressure”) is directional and is experienced as a blast “wind.” The primary significance of the blast wind is that it propels fragments at speeds in excess of several thousand meters per second (faster than standard ballistic weapons such as bullets and shells).24 Whereas the effective range of both the static and dynamic pressure is measured in tens of feet, the fragments accelerated by the dynamic pressure will quickly outpace the blast wave to become the dominant cause of injury out to ranges of thousands of feet.

**Interaction of Blast Waves with the Body**

Blast waves interact with the body and other structures by transmitting energy from the blast wave into the structure. This energy causes the structure to deform in a manner dependent on the strength and the natural period of oscillation of the structure being affected. Changing density interfaces within a structure cause complex re-formations, convergences, and couplings of the transmitted blast waves. This occurs particularly with large density interfaces such as solid tissue to air or liquid (e.g. lung, heart, liver, and bowel).

**Explosion-Related Injuries**

Injuries from explosions are generally classified as primary, secondary, tertiary, quaternary, and quinary after the injury taxonomy described in Department of Defense Directive 6025.21E24 (Figure 4-72, Figure 4-73). Detonation of an explosive device sets off a chain of interactions in the objects and people in its path.21 If an individual is close enough, the initial blast wave increases pressure in the body, causing stress and shear, particularly in gas-filled organs such as the ears, lungs, and (rarely) bowels. These primary blast injuries are more prevalent when the explosion occurs in an enclosed space because the blast wave bounces off surfaces, thus enhancing the destructive potential of the pressure waves.25 Immediate death from pulmonary barotrauma (blast lung) occurs more often in enclosed-space than in open-air bombings.26, 27, 28 Most (95%) explosion injuries in Iraq and Afghanistan occur in open-space explosions.29 The most common form of primary blast injury is tympanic membrane rupture.30, 31 Tympanic membrane rupture, which may occur at pressures as low as 5 psi,32, 33 is often the only significant overpressure injury experienced. The next major injury occurs at less than 40 psi, a threshold known to be associated with pulmonary injuries including pneumothorax, air embolism, interstitial and subcutaneous emphysema, and pneumomediastinum.34 Data from burned soldiers from Operation Iraqi Freedom (OIF) confirm that tympanic membrane rupture is not predictive of lung injury.

The shock front of the blast wave quickly dissipates and is followed by the blast wind, which propels fragments to create multiple penetrating injuries. Although these are termed secondary injuries, they are usually the predominant wounding agent.23 The blast wind also propels large objects into people or people onto hard surfaces (whole or partial body translocation), creating blunt (tertiary blast) injuries; this category of injury also includes crush injuries caused by structural collapse.34 Heat, flames, gas, and smoke generated during explosions cause quaternary injuries that include burns, inhalation injury, and asphyxiation.25 Quinary injuries are produced when bacteria, chemicals, or radioactive materials are added to the explosive device and released upon detonation.
Injury from Fragments

Conventional explosive weapons are designed to maximize damage caused by fragments. With initial velocities of many thousands of feet per second, the distance that fragments may be thrown for a 50-lb (23-kg) bomb will be well over 1000 feet (0.3 km), whereas the lethal radius of the blast overpressure is approximately 50 feet (15 meters). The developers of both military and terrorist weapons, therefore, design weapons to maximize fragmentation injury so as to significantly increase the damage radius of a free-field explosive.

Very few explosive devices cause injury solely by blast overpressure, and serious primary blast injury is relatively rare compared to the predominant numbers of secondary and tertiary injuries. Thus, few patients have injuries dominated by primary blast effects. The entire array of explosion-related injuries is often referred to en masse as “blast injuries,” leading to major confusion as to what constitutes a blast injury. Because energy from the blast wave dissipates rapidly, most explosive devices are constructed to cause damage primarily from fragments. These may be primary fragments generated through the breakup of the casing surrounding the explosive or secondary fragments created from debris in the surrounding environment. Regardless of whether the fragments are created from shattered munitions casing, flying debris, or embedded objects that terrorists often pack into homemade bombs, they exponentially increase the range and lethality of explosives and are the primary cause of explosion-related injury.

Multi-Etiology Injury

In addition to the direct effects of an explosion, healthcare providers must be mindful of the other causes of injury from attacks with explosions. For instance, an IED that targets a
vehicle may result in minimal initial damage to the vehicle occupants. However, the vehicle itself may be displaced vertically or vectored off course resulting in occupant blunt trauma from collision, from flipping upside down as part of the vertical displacement process, or from rollover, for instance, down an embankment or culvert. In these circumstances, occupants sustain injury based on the mechanisms previously described for blunt trauma. In the military setting, a vehicle’s occupants may be afforded some protection from blunt injury by virtue of their body armor. Furthermore, the occupants of a vehicle disabled following an IED attack may be attacked with gunfire as they exit the vehicle and are subject to ambush, thus potentially becoming victims of penetrating injury.

Using Kinematics in Assessment

The assessment of a trauma patient must involve knowledge of kinematics. For example, a driver who hits the steering wheel (blunt trauma) will have a large cavity in the anterior chest at the time of impact; however, the chest rapidly returns to, or near to, its original shape as the driver rebounds from the steering wheel. If two prehospital care providers examine the patient separately—one who understands kinematics and another who does not—the one without knowledge of kinematics will be concerned only with the bruise visible on the patient’s chest. The prehospital care provider who understands kinematics will recognize that a large cavity was present at the time of impact, that the ribs had to bend in for the cavity to form, and that the heart, lungs, and great vessels were compressed by the formation of the cavity. Therefore, the knowledgeable provider will suspect injury to the heart, lungs, great vessels, and chest wall. The other prehospital care provider will not even be aware of these possibilities.

The knowledgeable prehospital care provider suspecting serious intrathoracic injuries will assess for these potential injuries, manage the patient, and initiate transport more aggressively, rather than react to what otherwise appears to be only a minor, closed, soft-tissue injury. Early identification, adequate understanding, and appropriate treatment of underlying injury will significantly influence whether a patient lives or dies.

SUMMARY

- Integrating the principles of the kinematics of trauma into the assessment of the trauma patient is key to discovering the potential for severe or life-threatening injuries.
- Up to 95% of the injuries can be anticipated by understanding the energy exchange that occurs with the human body at the time of a collision. Knowledge of kinematics allows for injuries that are not immediately apparent to be identified and treated appropriately. Left unsuspected, undetected, and therefore untreated, these injuries contribute significantly to morbidity and mortality resulting from trauma.
- Energy cannot be created or destroyed, only changed in form. The kinetic energy of an object, expressed as a function of both velocity (speed) and mass (weight), is transferred to another object on contact.
- Damage to the object or body tissue impacted is not only a function of the amount of kinetic energy applied to it, but also a function of the tissue’s ability to tolerate the forces applied to it.
- Falls
  - The direction of the impact determines the pattern of and potential for injury: frontal, lateral, rear, rotational, rollover, or angular.
  - Ejection from a car reduces the protection on impact.
- Falls
  - Distance travelled before impact affects the severity of the injury sustained.
  - Energy-absorbing capability of the target at the end of the fall (concrete versus soft snow) affects the severity of the injury.
  - Victim body parts that hit the target and progression of the energy exchange through the victim’s body are important.
- Penetrating trauma
  - The energy varies depending on the primary injuring agent:
  - Low energy—handheld cutting devices
Medium energy—
High energy—
The distance of the victim to the perpetrator and the objects that the bullet might have struck will affect the amount of energy at the time of impact with the body and, therefore, the available energy to be dissipated into the patient to produce damage to the body parts.
Organs in proximity of the pathway of the penetrating object determine the potential life-threatening conditions
The pathway of the penetrating trauma is determined by the wound of entrance and the wound of exit.

Blasts
There are 5 types of injury in a blast:
Primary—over-and-under pressure
Secondary—projectiles (the most common source of injury from blasts)
Tertiary—propulsion of the body into another object
Quaternary—heat and flames
Quinary—Radiation, chemicals, bacteria.

SCENARIO SOLUTION

Patient #1: Driver of the vehicle with side impact. Two bullets traversed the door of the car. The patient has two left-side bullet wounds, one below the ribs and one above the ribs. The patient’s blood pressure was low; therefore, the likely injuries in the chest include pneumothorax, hemothorax, penetration of the heart, and possibly major vessels. Below the ribs, penetration into the abdominal cavity could involve any of the abdominal organs with associated hemorrhage.

Patient #2: Passenger side with side impact of car. Because of the energy exchanged between the door and the occupant, you should suspect injury in all four side impact areas—the shoulder (clavicle), chest wall and the thoracic cavity, the abdominal cavity, and the pelvis. The potential injuries in these areas include: 1) fractured clavicle; 2) fractured ribs (potential flail chest); 3) pulmonary contusions; 4) sheering related to the aorta; 5) pneumothorax; 6) abdomen (fractured liver or spleen); 7) deceleration injury to the kidney; 8) fractured pelvis; and 9) rotational injury of the cervical spine.

Patient #3: Driver of the vehicle. With the bent steering wheel, you suspect an up-and-over pathway at the time of the collision into the pole, with frontal chest impact into the steering wheel and head impact into the windshield. Potential injuries include: 1) myocardial contusion; 2) pneumothorax; 3) flail chest; 4) pulmonary contusion; 5) overpressure injury in the abdomen; 6) fractured liver and spleen; 7) cervical spine fracture; and 8) brain injury.

Patient #4: You suspect down-and-under pathway: 1) fracture of the lower extremities (ankle, shaft of the femur, hip dislocation); 2) facial injuries; and 3) cervical spine injury.

One other additional important assessment to consider: How did the bullet holes get in the first car? Did you search the occupants for weapons?

References


22. American College of Surgeons (ACS) Committee on Trauma: *Advanced trauma life support course*. Chicago, 2002, ACS.


Suggested Reading


American College of Surgeons (ACS) Committee on Trauma: *Advanced trauma life support course*. Chicago, 2002, ACS.


