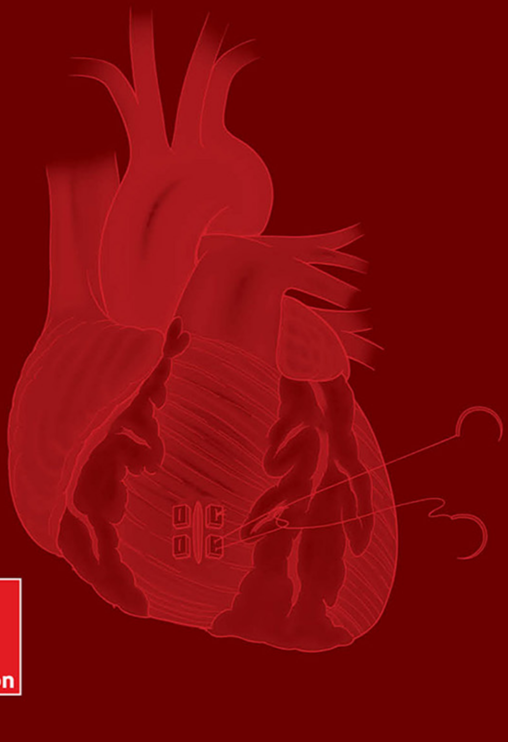
EIGHTH EDITION

TRAUMA



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TRAUMA

Eighth Edition

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The editors of Trauma, Eighth Edition, gratefully dedicate this edition to our five unique “families”:
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Grace S. Rozycki, MD, MBA, David J. Feliciano, Douglas D. Feliciano, JD (DVF);
June Mattox, Kimberly, Dan, Charles, Alex, and Kelsey Toth (KLM);
our trainees, who now dot the globe—our lasting legacy;
our medical schools and academic anchors; our organizations and associations;
our patients, who continue to teach us so much; and our administrative assistants:
Jo Fields (EEM), Karen Lynn and Victoria Dodge (DVF), and Mary Allen (KLM).

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PREFACE

The Eighth Edition of *Trauma* spans more than three decades of development, implementation, and maturation of trauma as an academic discipline. While the term "acute care surgery" has emerged recently, trauma surgeons have always been the go-to surgeon for emergent care, and trauma remains the core. We are very fortunate to have served as editors throughout this period in history, and truly represent the first generation of trauma surgeons in the United States. We experienced the golden age of trauma surgery, during an era in which we did it all: visceral and vascular, torso and extremities. At the outset, virtually all seriously injured patients underwent operative management, primarily based on clinical assessment with the aid of plain x-rays and the venerable diagnostic peritoneal lavage (DPL). Decisions were relatively straightforward since few alternatives existed, and few had the courage to challenge our behavior. By contrast, today the emphasis is on avoiding an operation, and multiple disciplines are involved in the decision making. There is no lack of oversight, monitoring, and data reporting. But the unquestionable benefactor has been the patient, who now survives devastating injuries once considered uniformly lethal. This edition may be the last for us as editors, because we have always believed that to be effective, we must remain active in the trenches to understand the importance of new concepts. While we are all very active in trauma care today, all good things must come to an end.

In the Eighth Edition of *Trauma*, as in the previous editions, we have changed approximately one-third of the authors to ensure the most current knowledge in all topics. In addition, we have expanded our Trauma Atlas, which is designed to provide a quick reference when performing procedures in the ED, OR, or SICU. We are pleased to include a new Trauma Video section, which provides an extensive compilation of technical procedures for the trauma surgeon.

Finally, the editors acknowledge the invaluable assistance of many individuals who have made the Eighth Edition a reality. We are extremely grateful to the authors who have sacrificed their valuable time to share their experience, knowledge, and expertise. The Trauma Video section was generously provided by Demetrios Demetriades and Kenji Inaba, who clearly have seen it all at USC/LA County. Mike de la Flor was persistent and patient in rendering accuracy in the Trauma Atlas. The professional support of McGraw-Hill Education was essential at all levels of publishing; we want to specifically thank Brian Belval, Executive Editor of the Medical Division, and Christie Naglieri, Senior Project Development Editor. And of course, we want to especially recognize the tremendous work of our respective Administrative Assistants: Jo Fields (EEM), Karen Lynn and Victoria Dodge (DVF), and Mary Allen (KLM).

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I

TRAUMA OVERVIEW

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1

Kinematics

Alan B. Marr • Lance E. Stuke • Patrick Greiffenstein

Kinematics (*kn-mtks*) *n*: The science of pure motion, considered without reference to the matter or objects moved or to the force producing or changing the motion. From the Greek *κίνημα*, *κῑνηματ*- a motion (*κῑνεῖν* to move) + -ic suffix.[1]

All injury is related to the interaction of the host and a moving object. That object may be commonplace and tangible, such as a moving vehicle or speeding bullet or more subtle as in the case of the moving particles and molecules involved in injury from heat, blasts, and ionizing radiation. Studying kinematics in relation to trauma uses Newtonian mechanics, the basic laws of physics, and the anatomic and material properties of the human body to explain many of the injuries and injury patterns seen in blunt and penetrating trauma. Injury is related to the energy of the injuring element and the interaction between that element and the victim. Although most patients suffer a unique constellation of injuries with each incident, there are quite definable and understandable energy transfer patterns that result in certain predictable and specific injuries. Knowing the details of a traumatic event may lead the treating physician to further diagnostic efforts to uncover occult but predictable injuries.

This chapter has been organized in a stepwise fashion. First, the basic laws of physics and materials that dictate the interaction between the victim and the injuring element are reviewed. This is followed by a more detailed examination of penetrating and blunt trauma with an effort to dispel some of the common myths about these injury mechanisms. Finally, a synopsis of mechanisms specific to organs and body regions is examined. It is hoped that this will offer the reader a better understanding of specific injury patterns, how they occur, and which injuries may result.

BASIC PRINCIPLES

The goal of studying kinematics in trauma is to help us understand how injuries occur. Understanding the biomechanics of injury may help us prevent and treat these injuries in order to optimize outcomes. It is tempting to believe in the finiteness of the understanding of physics and biomechanics, the sense that all there is to know is already known; however, ever-improving technology is making the experimental study and computer modeling of such phenomena more effective. Therefore, continual reassessment is critical in order to continue to maintain relevance in an ever-changing world. Nevertheless, much of the basis of current understanding has been laid down by the great minds of the past whose insight and understanding, though it might have come from rather humble or mundane observances, has absolute relevance as we examine biomechanics today.

James Prescott Joule, a 19th century English brewer and amateur physicist seeking to optimize the energy needs of his brewing operations, stumbled upon what is now known as the first law of thermodynamics or the law of conservation of energy. It states that, in a closed system, energy can be neither created nor destroyed, only transformed from one state to another.[2] This is in line with *Newton's first law*, which states that an object in motion or at rest will tend to remain in this state unless acted upon by an external force. Thus, kinetic energy, or the energy of motion will be conserved until it is transformed by an external force. When this transformation occurs in the form of transference of energy from one object to another, it can lead to alteration of one or both objects. This is the fundamental principle of traumatic injury.

In order to understand this principle, one must first consider the basic principles of physics. One can divide these principles into two broad groups as follows: principles that describe motion of objects and their interactions, and those that describe the effects of these interactions on the objects themselves. The key principles that describe the former are force, momentum, and impulse. The key elements that describe the latter are stress, strain, and elasticity. First, let us consider momentum (p), which is defined as the product of mass (m) of an object and its speed or velocity (v).

$$p = mv$$

Intuitively, we understand that in order to change an object's momentum, we must typically introduce a force, which will cause the object to either speed up or slow down. When a force causes a change in momentum, it is referred to as impulse. This is a bidirectional exchange, however, where a force causes a change in momentum and, concomitantly, a change in momentum will generate a force.[3]

Newton's second law builds on the first and further defines a force (**F**) to be equal to the product of the mass (m) and acceleration (a).

$$\mathbf{F} = ma$$

The application of a force does not occur instantaneously, but over time. If we multiply both sides of the above equation by time, we get:

$$\int \mathbf{F}dt = ma(t)$$

The product of force and time is known as impulse and multiplying acceleration by time yields velocity. This leads us to *Newton's third law*, which states that for every action there is an equal and opposite reaction.[4] For instance, when two objects of equal velocity and mass strike each other, their velocities are reduced to zero at the moment of impact. Each exerts its force on the other and, because these forces are exactly equal and opposite, the net force is zero. Therefore, the net change in momentum is zero. This means that these two objects would change their direction and "bounce" in opposite directions if each was traveling at the exact same velocity, but in the opposite direction. This occurs only if 100% of the energy could be transferred into changing velocity and none into altering mass.

Interactions in which both momentum and energy are conserved are termed elastic. In real trauma scenarios, collisions are inelastic. Inelastic collisions conserve momentum, but not kinetic energy. In these instances the kinetic energy "does work" in the deformation of materials even to the point where objects can conglomerate and form a single object. This is the hallmark of the inelastic collision. This energy transfer to structures that are deformed in response to a change in their momentum, such as organs and bones, is responsible for the injury sustained by the host.

We can understand the simple basics of these complex interactions using the example of two cars colliding. **Figure 1-1A** represents a head-on collision of two vehicles with equal mass and velocity and, thus, equal kinetic energy and momentum in opposite directions. Thus, the total momentum for the system is 0 prior to the crash and, by the law of conservation of momentum, must be 0 after the crash. Because both cars are traveling in exact opposite directions at exactly the same speed, their momentums will cancel each other out. If the cars were made of a perfectly nondeformable material, all kinetic energy would be exchanged and the cars would bounce in opposite directions at the exact same speed. In reality, however, these vehicles will be deformed by this interaction relative to their velocity on impact. Assuming that both cars come to rest as a single mass of entangled metal (referred to as object C), this change in momentum represents a force, which is equally applied to both cars. Because the final velocity is 0, the final kinetic energy is 0, meaning that all the kinetic energy has been converted to work that stops the other car and causes deformation such as breaking

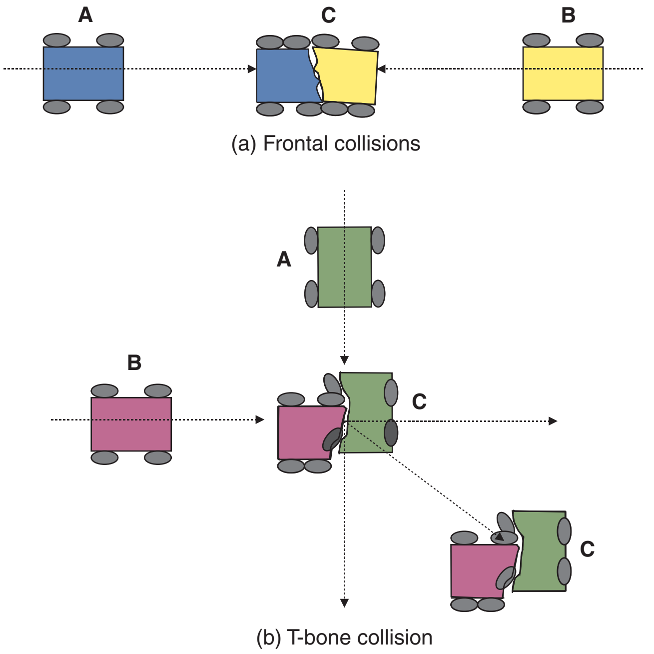

FIGURE 1-1 Energy and momentum available in various motor vehicle crash scenarios. (**A**) Frontal collisions have the greatest change in momentum over the shortest amount of time and hence the highest forces generated. (**B**) T-bone collision. When cars A and B collide their resultant momentum directs them toward their final position C; the individual momentums in the x and y axis are dissipated over a greater time resulting in smaller forces then head-on collision.

glass, bending metal, and causing physical intrusion into the passenger compartment. If the momentum of car A was greater than that of car B by having a greater mass or velocity, the resultant mass C will have momentum the direction of car A prior to impact. As such, the kinetic energy transferred to the occupants of vehicle A will be relatively less than that transferred to car B. This is intuitively accepted as we consider the effects of collisions between a compact car and an SUV with predictable consequences.

In T-bone type crashes the directions of the momentum of cars A and B are perpendicular and momentum is conserved in a third direction, C, Fig. 1-1B. Because kinetic energy is partly conserved in this new momentum, less energy was transferred to the vehicles (or their occupants) and less deformity occurs. In rear-end collisions, the energy exchange is a function of the net difference in momentum, not absolute momentum. The more momentum the conglomerate of the two vehicles (mass C) can conserve, the less energy is transferred into deforming the vehicles A and B and their occupants. In biomechanics as in life, the key to avoiding destruction when two forces meet is to maintain harmony in motion. If such an ideal is impossible to ensure, the next best thing is to protect the essential core of an object by focusing the deformity on nonessential parts. Modern automobile design, taking the lead from automobile racing engineers whose subjects are exposed to extraordinary speeds, involves building impact zones that deform easily on impact and