ISSN 1041-9489

SAFETY BRIEF

April, 2002 Volume 20, No. 2

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Forces and Injuries to the Human Body

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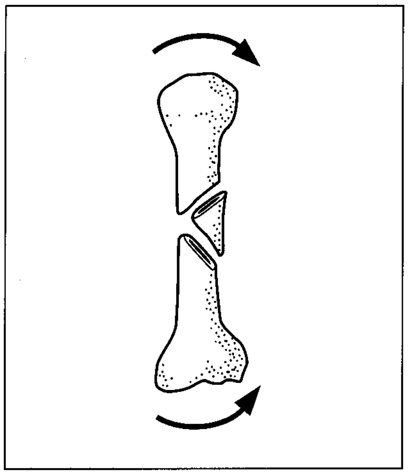

Figure 1 - Bending moment causing a transverse fracture with a butterfly fragment (Modified from Levine[1]).

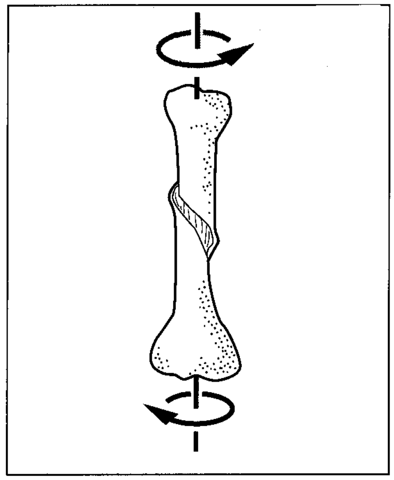

Figure 2 - Torsional, or twisting, moment causing a spiral fracture (Modified from Levine[1]).

A. Introduction

Biomechanics involves the application of mechanical engineering principles to describe forces associated with human movement and injury. The human body contains a number of tissues and organs, which respond in very specific ways to mechanical loading. Consequently, injury patterns observed following a trauma can provide important clues regarding the nature of the forces causing injury. Various aspects of applied forces and their relationship to injury patterns will be discussed including direction, severity, duration, and energetics.

B. Direction of Applied Force

The mechanical response of biological tissues is extremely dependant on the direction of applied loading. This behavior is referred to as material anisotropy. Bone and tendon are two biological materials which exhibit anisotropic behavior.

Bone: The mechanical response of human bone resembles that of wood, a naturally occurring composite material which exhibits anisotropic behavior. The direction of forces applied to bone has a profound effect on the fracture that may result. A bending moment applied to a bone commonly results in a transverse fracture with a butterfly fragment[1] (Figure 1), while a torsional, or twisting, moment results in a spiral fracture[1] (Figure 2).

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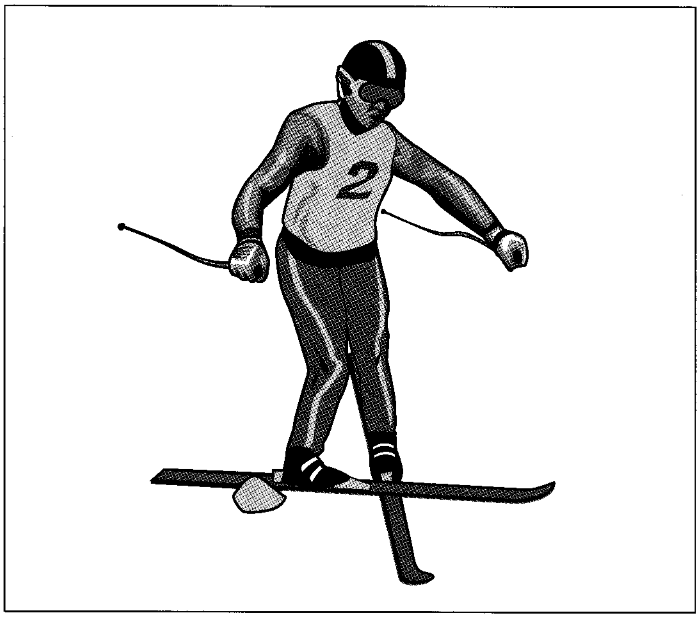

Figure 3 - Skiing accident which may result in a spiral fracture of the tibia

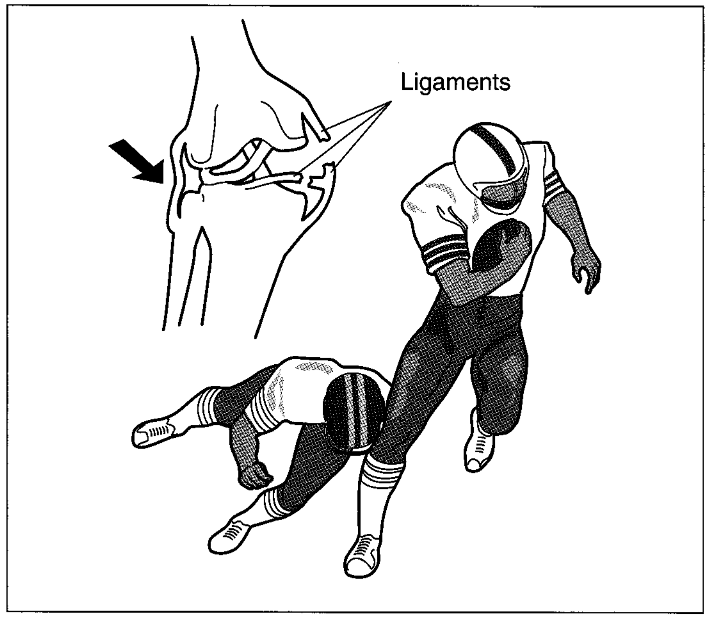

Figure 4 - Sideways tackle causing injuries to knee ligaments (Modified from "Hip and Knee[4].")

In the recent past, spiral fractures of the tibia in the lower leg were common skiing injuries (Figure 3). This spurred the design of ski bindings which prevent excessive torsional loading of the skier's leg, resulting in an 83% reduction in spiral fractures of the tibia[2].

Tendon and Ligament: Connective tissues such as tendons and ligaments are extremely fibrous tissues which serve to transmit tensile loads from muscle to bone in the case of tendons, or from bone to bone in the case of ligaments[3]. The structure of these connective tissues is close to that of rope, with longitudinal fibers. Tendons act across joints, allowing muscle contraction along a line to produce angular joint motion. Tendon injury can be caused by overloading around joints, such as an attempt to catch a heavy falling load on an outstretched arm. Ligaments act to stabilize joint motion and prevent excessive joint motion. Therefore, ligaments can be injured by overloading a joint in an unexpected direction, such as a twisting or sideways loading of the knee. This is common in football injuries to knee ligaments resulting from a sideways tackle, as shown in Figure 4.

Cervical Spine: The human spine is formed by a series of stacked bony components, called vertebrae, surrounding the spinal cord. Vertebral geometry has an effect on the types of injuries observed in different loading directions. Injuries to the neck, or cervical spine, differ greatly depending on whether the neck is loaded in flexion, when the chin bends down towards the chest, or extension, when the head tilts back. If the neck is overloaded in flexion, referred to as hyperflexion, crushing injuries to the front (anterior) portion of the vertebra may result or the vertebra may dislocate, often causing spinal injury (Figure 5). Hyperextension (Figure 6) may be associated with whiplash symptoms, which may result from any of several clinical mechanisms, including direct cervical injury or head rotation[5].

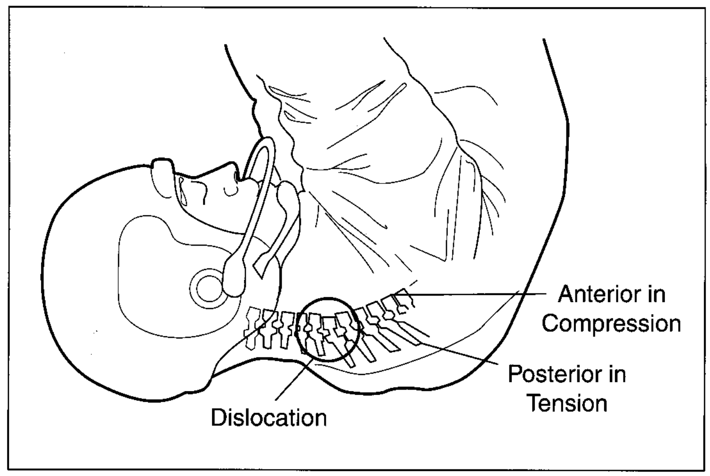

Figure 5 - Neck in Hyperflexion (Modified from McElhaney and Meyers.[5])

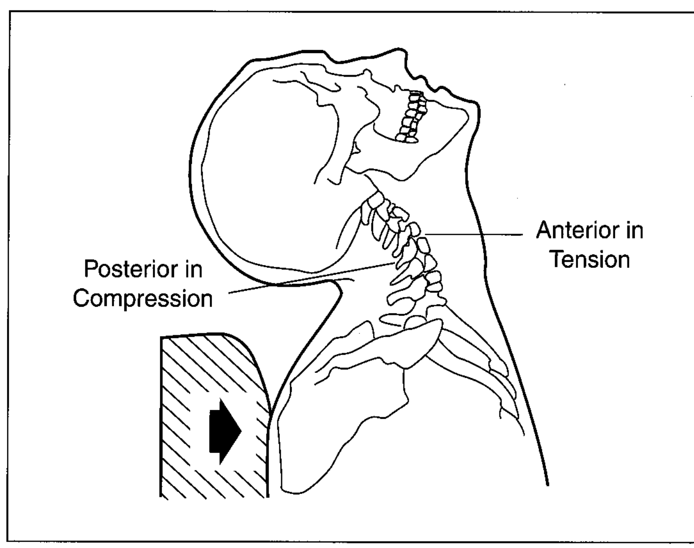

Figure 6 - Neck in Hyperextension (Modified from McElhaney and Meyers.[5])

C. Severity of Applied Force

The severity of trauma required to cause injury varies greatly both within and between individuals. Within an individual, tissue strength varies according to tissue type (muscle vs. bone), location (arm vs. leg), disease state, and age, to name a few factors. The mechanical properties of individual biological tissues vary greatly over the human population[6]. The range of injuries observed in response to a given level of trauma is more variable still. It is this latter fact which makes accident reconstruction such a daunting prospect. A given rear-end automobile collision may injure only one occupant in a particular vehicle, even though the impact velocity and seat belts used are identical for all passengers. Therefore, test results are difficult to apply across different populations. However, tests or surveys performed on large numbers of individuals can allow the investigator to estimate the range of responses most commonly observed in a given situation for that population. One example is the effect of automobile accidents on cervical injury. Based on a study of 5,759 German traffic accidents, front-end automobile collisions resulted in far fewer cervical injuries than did rear-end collisions of the same severity (change in velocity)[7].

D. Duration of Applied Force

The duration over which trauma occurs also has an influence on the resulting injury pattern. Investigators attempting to quantify the relationship of head motion (acceleration) to trauma level have assembled empirical data from human and animal studies and observed that rapid spikes in head acceleration result in less injury than head accelerations sustained over a long period of time. This observation is formally represented in the Head Injury Criterion (HIC) used to assess head injury potential resulting from automobile crash tests[8].

E. Energetics of Applied Force

Traumatic injuries are often concentrated at the areas of contact with surrounding objects. It is sometimes said that we are not hurt from falling, but rather from hitting the ground. Objects which cause a body in motion to come to rest such as the ground under a falling individual, or cause changes in motion such as the interior features of an automobile during a collision, become the sources of contact and, hence, trauma. Mechanical energy is present in a moving body, and this energy must be dissipated by the surrounding environment before the body comes to rest[9]. Dissipating this impact energy is one part of the function of helmets and other protective gear. This impact energy may also be redirected or deflected. When martial artists fall and roll, they are redirecting the energy from the fall into rotational energy of the body, thus minimizing the energy left to cause injury. Helmets with hard shells derive much of their function from redirecting the energy of a collision, as when a baseball glances off a baseball helmet, thereby decreasing the amount of collision energy transferred to the protected body.

As an example, consider the woman falling on her hip sketched in Figure 7. The impact energy will initially be transferred to the hip and arm muscles and bones on the left side of the body on which the woman lands. The injury pattern one might expect to result from such a fall might include fractures of the left leg, hip, and arm. These fractures will dissipate impact energy to some degree.

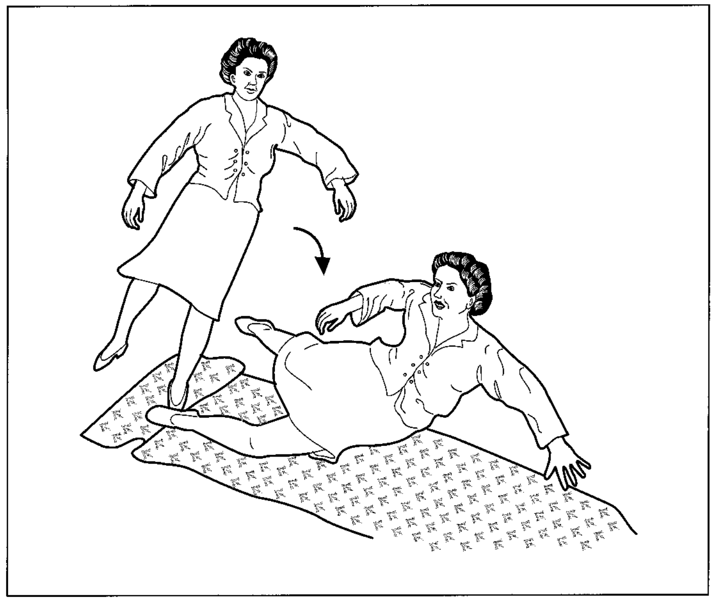

Figure 7 - Woman falling on her left side (Modified from Frankel and Burstein.[9])

An unfortunate aspect of this or any other trauma involving human injury is that little force or energy is required to injure the head. Thus, it would require very little remaining energy to cause damage to the woman's head. In actuality, our limbs, such as the woman's leg and arm, serve as "helmets" to protect our fragile and valuable heads from serious injury. When protective instincts fail to protect the head, as may occur during a fall to the rear, head injury can result. Slip and fall injuries dramatically demonstrate the skeletal injury levels that can arise from falls, even those from a standing height[10].

F. Conclusion

The injury pattern resulting from accidental trauma can provide important information as to the nature of the forces causing injury. In particular, this bulletin has addressed some of the characteristics of applied forces that affect the injury pattern quite dramatically. Force direction, severity, duration, and energetics are all amenable to biomechanical analysis. The determination of these characteristics of the forces causing injury is an important part of accident reconstruction and forensic engineering analysis.

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SAFETY BRIEF

April, 2002 – Volume 20, No. 2

Editor: Paula L. Barnett

Illustrated and Produced by

Triodyne Graphic Communications Group