Weight Training Safety: A Biomechanical Perspective

Everett Harman, PhD, CSCS
U.S. Army Research Institute of Environmental Medicine
Natick, Massachusetts

SAFETY IS OF PARAMOUNT IMPORTANCE in resistance training. Even though improved performance is usually the primary goal of training, it must not be pursued to the exclusion of safety. A conditioning program cannot be effective if it causes an injury that can set back an athlete’s training schedule, team involvement, career, or even end his or her life. Safety goes hand in hand with effective training.

It is the strength and conditioning coach’s responsibility to provide a safe and effective resistance exercise program in a safe training environment. This article provides a biomechanical perspective on weight training safety.

The Back

Back injury can be extremely debilitating, persistent, and difficult to remedy. Thus every effort should be made to avoid such injury. The lower back is particularly susceptible to structural damage.

The spinal column (Figure 1) is made up of several vertebral bones stacked on top of one another and separated by tough fibrous discs filled with shock absorbing gelatinous material. The discs allow considerable bending of the back. Unfortunately, a disc may rupture or deform under stress and thus put pressure on nerves in or near the spinal cord, thus causing pain which may become severe and debilitating.

It has been observed that 85 to 90% of all spinal disc herniations occur at the disc between the lowest two lumbar vertebrae, L4 and L5, or between the lowest lumbar and the top sacral vertebra, L5 and S1 (4). These are the lowest two spinal discs and are located in the region where the spinal column joins with the pelvic girdle. The high percentage of injuries in this area is not surprising, given the extremely high compressive forces on the discs during lifting, which act to squeeze the spinal discs between the adjacent vertebral bodies.

The back is involved directly or indirectly in most lifts because any weight supported in the arms or on the shoulders transmits force to the back. Any time the weight is held further forward than the hips, the lower back muscles must act to either prevent the trunk from tilting for-
ward, control the rate at which it tilts forward, or bring it back upright from a forward tilted position (e.g., squat).

The back muscles act at a great mechanical disadvantage because the horizontal distance from the weight to where the lower back pivots (up to 18 inches) is generally much greater than the distance from the back muscles to the pivot point (about 2 inches). As with an ordinary lever, the closer a force acts to the pivot point, the greater it must be to exert a given torque. Therefore the tensile force on the muscles and tendons can be several times the weight of the bar lifted.

Any acceleration of the bar increases the force even further. Both the force exerted by the weight on the shoulders (directly or through the arms) and the force exerted by the lower back muscles act to compress the spinal discs.

The spinal discs of larger individuals can generally support greater loads than those of smaller people. Also, as people age, the amount of force the spinal discs can withstand decreases dramatically, as evidenced by compressive testing of cadaver spines (4). Discs of people under 40 can typically withstand without damage more than twice the compressive force that would damage discs of people over 60.

The flat back lifting posture has been found to be better overall than a rounded (opposite of arched) back in minimizing L5/S1 compressive forces and ligament strain (2). An arched back (lordosis) has been found to be superior to a round back for avoiding injury to vertebrae, discs, facet joints, ligaments, and muscles of the back. In addition, the low back muscles are capable of exerting considerably higher forces when the back is arched rather than rounded (10).

The spinal column is naturally S-shaped, being rounded in the upper back and arched in the lower back. The wedge-like shape of the vertebral bodies gives the spine its natural curve. However, the intervertebral discs are flat when the back is in its S-shape. When the lower back is rounded, the ventral (toward the belly) edges of the vertebral bodies squeeze the front portions of the spinal discs.

In contrast, extreme arching of the lower back results in squeezing the dorsal (toward the back) portions of the discs. It is believed that such uneven squeezing of the spinal discs increases the risk of disc rupture. Thus, lifting should generally be performed with the lower back in a moderately arched position.

**Intra-abdominal Pressure and Lifting Belts**

When the diaphragm and the deep muscles of the torso contract, pressure is generated within the abdominal cavity. Because the abdomen is mainly composed of fluid and normally contains very little gas, it is virtually incompressible. The abdominal fluids and tissue kept under pressure by surrounding muscle under tension has been described as a "fluid ball" (Figure 2) which aids in supporting the spinal column during lifting. Such support may significantly reduce both the forces required by the erector spinae muscles to perform a lift and the associated disc compressive forces (3, 16).

It has been shown that weight-lifting belts increase intra-abdominal pressure during lifting, and therefore are probably effective in improving lifting safety (9, 12, 13). It has been cautioned, however, that if all lifting is done with a belt, the abdominal muscles that produce intra-abdominal pressure might not get enough training stimulus to develop optimally (9).

It is particularly risky for a person who has become accustomed to wearing a belt to suddenly perform a lift without one because the abdominal musculature might not be capable of generating enough intra-abdominal pressure to significantly reduce erector spinae muscle forces. The resulting excessive disc compressive forces could increase the chance of back injury. Conservative recommendations are,

1. For exercises not stressing the back, do not wear a belt at all.
2. For exercises directly stressing the back, refrain from wearing the belt during lighter sets but wear it for near-maximal and maximal sets. The beltless sets allow the deep abdominal muscles...
that generate intra-abdominal pressure to receive training stimulus without placing excessive compressive forces on the spinal discs.

**The Shoulder**

The shoulder is particularly prone to injury during weight training, due both to its structure and the forces to which it is subjected during lifting. Like the hip, the shoulder is capable of rotating in any direction. Yet whereas the hip is a stable ball and socket joint, the glenoid cavity of the shoulder, which holds the head of the humerus, is not a true socket and is quite loose (Figure 3).

The looseness of the shoulder gives it a wide range of movement. It is so loose that the head of the humerus can actually move 2.5 centimeters (1 inch) out of the glenoid cavity during normal movement (7). Yet the joint's looseness contributes to its vulnerability, as does the close proximity of its bones, muscles, tendons, ligaments, and bursae.

The stability of the shoulder is largely dependent upon ligaments, joint capsules, and muscles. The rotator cuff muscles (supraspinatus, infraspinatus, subscapularis, and teres minor) and the pectorals are particularly instrumental in keeping the ball of the humerus in place (4).

Given the shoulder's great range of motion, it is not unusual for its various structures to impinge upon one another, causing tendinitis as well as inflammation and degeneration of contiguous tissue. High forces during lifting can result in tearing of ligaments, muscles, and tendons. Particular care must be taken when performing the various forms of the bench, incline, and military presses because of the great stresses they place upon the shoulder.

![Figure 3](image) The shoulder has very little bony support and is not a true socket. In contrast, the hip incorporates a deep and firm socket (dotted line).

**The Knee**

The knee is prone to injury because of its location between two long levers, the upper and lower leg. With reference to the body in the anatomical position, flexion and extension about the knee occur almost exclusively in a sagittal plane (Figure 4). Rotation in the frontal and transverse planes is largely prevented by ligamentous and cartilaginous stabilizing structures.

Yet it does not take a great amount of torque about the knee in the frontal plane to cause serious damage. An example of frontal plane torque on the knee is when a football player is hit at mid-leg from the side while his foot is planted firmly on the ground. Fortunately, in lifting, torques occur almost exclusively within the knee's normal plane of rotation.

Of the various components of the knee, the patella and surrounding tissue (Figure 5) are most susceptible to the kinds of forces encountered in resistance training (6). The patella's main function is to hold the quadriceps tendon away from the knee axis, thereby increasing the moment arm of the quadriceps group and its mechanical advantage. The high forces encountered by the patellar tendon during lifting can lead to tendinitis, which is characterized by tenderness and swelling.

**Knee Wraps**

It is not unusual for lifters to use knee wraps during training or competition. The wraps vary from the thin elastic pull-on variety that can be purchased in drug stores to the heavy, specialized wraps sold only through weightlifting supply houses. The use of knee wraps, particularly the heavy ones, is most prevalent among powerlifters.

Very little research has been done on the efficacy of knee wraps. However, a number of professionals working with lifters have noted some detrimental side effects of heavy wraps including skin damage and chondromalacia.
patellae (wearing down and roughening of the posterior surface of the patella) (8).

While there is no available evidence that wraps protect the knee against injury, a recent experiment showed that wraps can improve lifting performance (8). Through a spring effect alone, heavy wraps added an average of 25 lbs to the lifting force. The notion that wraps work only by either stabilizing the knee, lessening the lifter's fear of injury, or providing a kinesthetic cue is incorrect. The wraps actually provide direct help in extending the knee and may therefore be considered an artificial aid to performance.

Based on the spirit of fair play, the lack of evidence that knee wraps prevent injury, and the opinion of a number of health practitioners working with lifters that wraps can actually cause injury, lifters should probably minimize the use of wraps.

### Flexibility and Stretching

Although stretching is frequently recommended for helping to prevent injury, research support is lacking. The small amount of research relating the lack of flexibility to injury has been focused on runners. A study of 583 habitual runners showed that those who regularly stretched before running had no fewer injuries than those who did not stretch (14).

People with relatively high flexibility, either naturally or through stretching, have not been shown to be at lower risk for injury. In fact, high flexibility as well as low flexibility can increase risk. Among 335 male army basic trainees, the most flexible 20% and least flexible 20% had more than twice as many injuries as those of average flexibility (5, 11).

There is some evidence that low flexibility may increase the risk of muscle and tendon injury, while high flexibility may increase the risk for ligament and cartilage injury (1). Tight muscles, which protect cartilage and ligament by limiting the joint range of motion, are susceptible to tearing. Individuals who are naturally loose muscled should not engage in more than mild stretching. Naturally, tight-muscled individuals probably benefit the most from stretching.

The most effective stretching occurs when a muscle is warm. Warming can be accomplished either through exercise or external heating; appropriate clothing allows muscles and tendons to warm up faster in cool weather.

Stretching is probably most important for athletes engaged in sports involving extreme ranges of joint motion, such as gymnastics. The athlete should be flexible enough to move easily through the range of joint motion required by the sport.

### Traumatic Injury

Unfortunately, many weight room injuries are caused by impact. A list of weight equipment related injuries in 1991, compiled by the National Injury Information Clearinghouse in Washington, DC, revealed that more than 70% of the injuries were due to trauma while the rest were largely sprains and strains (17). The most common traumatic injuries were, in descending order of frequency, lacerations, contusions and abrasions, fractures, finger injuries, foot injuries, and facial injuries.

Clearly, the great majority of such injuries are due to carelessness or lapse in attention. While it is impossible to completely control human behavior, proper administration of a weight room can go a long way toward minimizing such injuries. Some basics of a good weight training facility include equipment that is safe and well arranged, a good set of rules that everyone is expected to follow, and instruction for all lifters in both technique and attitude.

### Avoiding Injury During Weight Training

The following steps are recommended to reduce the likelihood of injury during weight training:

- One or more warm-up sets should be performed with relatively light weight, particularly for exercises that heavily involve the shoulder or knee. This stimulates blood flow to the muscles that create the movement, increasing the temperature and pliability of ligaments, tendons, and other structures. Massage may provide additional benefit (20).
- Basic exercises should be performed through a full
range of motion (20). Only specialized supplementary exercises should be performed through limited ranges of motion.

- When a new exercise is introduced to a program or when an athlete resumes lifting after a layoff of 2 or more weeks, relatively light weights should be used.

- Pain in or around the joints should not be ignored. "Working through" pain can lead to chronic injury. Often an athlete can continue lifting by using lighter weights with higher repetitions and/or switching exercises. If pain is severe and persistent, it may be necessary to temporarily suspend all lifting that affects the painful joint and to have the injury examined and medically treated. It is usually not necessary to completely discontinue resistance exercise.

- Maximal lifts should never be attempted without proper preparation, which includes technique instruction and a minimum of several weeks of training in the exercise movement. It is also prudent to cycle into periods of maximal lifting a few times a year at most.

- Post-workout icing of superficial joints under heavy stress may aid in the prevention of injury as well as in recuperation (6, 20).

- The inclusion of supplementary exercises in a workout may help to promote joint stability and balance within the muscles of a group and between those of opposing groups. For example, heavy squats can be accompanied by knee extension and flexion exercises on a weight stack machine (20). Lack of balance between muscles has been cited as a cause of athletic injury. It has been recommended that athletes perform exercise routines that maintain a knee flexion to extension strength ratio of 0.67 to 0.77 at slow speed (60°/sec), 0.80 to 0.91 at medium speed (180°/sec), and 0.95 to 1.11 at fast speed (300°/sec) (15).

- Bouncing at the bottom of squat exercise should be avoided (20) except for specialized exercise routines. The high eccentric force produced during such movements has been identified as a primary cause of muscle injury (19).

- Care must be taken when incorporating plyometrics into a training program. It is generally agreed that athletes should be strong in the squat before beginning a lower body plyometric program. Also, high-intensity plyometrics should not be performed year-round (18).

- During squatting, deviation of the knee from a vertical plane through the foot and hip can place potentially dangerous and unnecessary torques about the knee and should be avoided (20).

- Knee and elbow wraps should only be used with great caution. It has been recommended that, if used at all, they should be limited to the heaviest lifts (20). Heavy and tight wraps can cause joint injury. If used, they should be put on immediately before and removed just after each lift.

- Several variations of an exercise may be performed for more complete muscle development and joint stability (e.g., flat bench press, incline bench press, and decline bench press to train the chest and shoulders) (20).

- Explosive exercises such as cleans, jerks, and snatches should not be attempted without qualified instruction, because minor flaws in technique can place extremely high and potentially destructive forces on muscles, ligaments, and tendons. Correct technique as well as mental concentration must be emphasized.

- Only equipment with a proven record of effectiveness, safety, and reliability should be purchased.

- Exercise equipment should be arranged so as to minimize traffic and the possibility of tripping or collision.

![Figure 5](a) The patella increases the mechanical advantage of the quadriceps muscle group by maintaining the tendon's distance from the knee's axis of rotation (A). (b) Absence of the patella allows the tendon to fall closer to the knee's center of rotation, reducing the mechanical advantage.

October 1994 Strength and Conditioning 59
• A good set of weight room rules and procedures must be established that everyone is expected to follow.

• Technique instruction must be provided, especially for novice lifters or anyone who performs an exercise in a potentially injurious manner.

• Lifters must be educated about the potential for injury.

• Attentiveness must be encouraged among lifters as a means of avoiding injury.

• Athletes whose readiness for a workout is impaired by illness, fatigue, drug/alcohol abuse, or emotional status should be discouraged or even prohibited from using exercise equipment.

■ Conclusions

A biomechanical perspective can be useful for evaluating and improving lifting safety. The information in this article can assist strength and conditioning professionals in providing safe and effective training programs. It must be emphasized, however, that this article is not a comprehensive analysis of resistance training safety.

Topics that warrant further consideration include equipment selection, weight room layout, scheduling, athlete energy level and attitude, and specific lift techniques. Safety must be approached on a variety of fronts; its maintenance requires regular attention. Our goals should be stronger, faster, bigger, and safer.

■ References


---

**Disclaimer:** The views and opinions expressed in this article are those of the author alone and should not be construed as an official Department of the Army position, policy, or decision.