Biomechanical Analysis of the Deadlift
(aka Spinal Mechanics for Lifters)
Tony Leyland

Mechanical terminology

The three directions in which forces are applied to human tissues are compression, tension, and shear (shown in figure 1). In case you are wondering, bending places one side of the object in compression and the other in shear, and twisting (torsion) is just a type of shear.

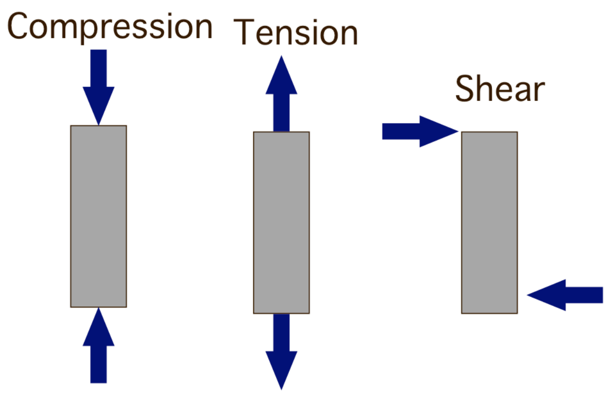

Figure 1. Terminology for directions of force.

For this discussion on lumbar mechanics we do not need to focus on tension as it is as a force that tends to pull a tissue apart and is not relevant to our purposes. Our focus will be on compression and shear. Shear is defined as a force that acts parallel to a surface; in the spine, it can create sliding of one vertebra with respect to another.

Figure 2 is a little busy but it helps illustrate many of the important concepts for this discussion. In a lift such as the deadlift, the weight being lifted and center of mass of the upper body and arms are a relatively long way from the vertebrae, and this creates a huge torque (moment of force) about the lumbar vertebrae. Although the vertebrae are a collection of joints, we can visualize that the disc between lumbar vertebrae 4 and 5 is the center of rotation for this force (the circle in figure 2). The line of action of the spinal erector musculature is a very short distance from the joint center of rotation (6-7 cm) inches) and hence these muscles must pull on the spine with hundreds of pounds of force to lift common loads (and well into the thousands of pounds when performing heavy deadlifts). Figure 2 also shows that the line of action of these muscles pulls the lumbar vertebrae together and creates compression between them. This can be hard to visualize, but when you effectively stabilize your lower body against the ground, the lower lumbar vertebrae are “pushed upward” from below and pulled downward by the muscles. This creates large compressive forces (again into the thousands of pounds when deadlifting).

In addition to creating a torque that wants to rotate the lifter forward (clockwise in the illustration), the load being lifting and weight of the upper body also act downward (gravitational pull). A component of this force acts as shear across the L4-L5 joint. It is this force that can be particularly problematic, as we will soon see.

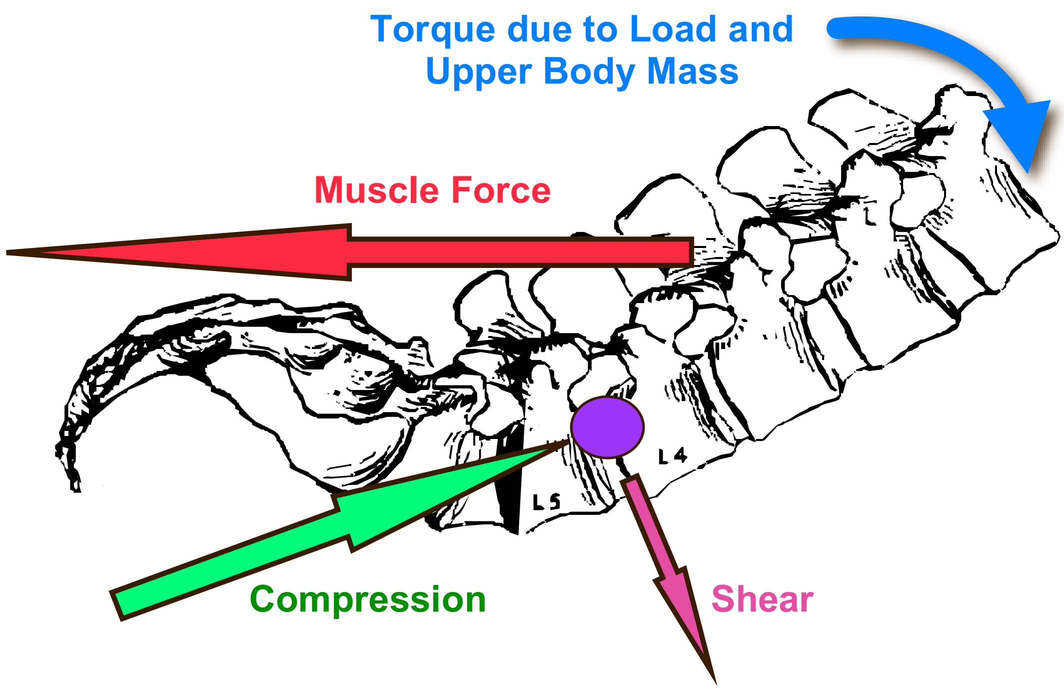

Figure 2. Torque and forces acting on the lumbar spine.

Anatomy of the lumbar spine

The anatomy of the spine is quite complex. However, to understand the need to maintain normal lumbar lordosis (curvature), all we really need to discuss is the line of action of the erector muscles and some of the ligaments that connect the vertebrae to one another (interspinous ligaments). Figure 2 shows the line of action of the muscles and you should be able to see that a component of this force acts to counteract the shear force, that is, it balances out the forces acting across the spine. Dr. Stuart McGill, a world-renowned spinal biomechanist from the University of Waterloo in Ontario, identifies two types of shear. The shear shown in figure 2 is called reaction shear and is the result of gravity pulling the load and the upper body downward. The closer your upper body moves to horizontal, the larger this force will be. However, the true shear on the L4-L5 joint (called the joint shear) is the resultant shear force produced by the sum of the reaction shear and the muscle/ligament shear. It is this value, which includes the effect of muscle/ligament forces, that represents the actual shear experienced at the L4-L5 joint. And it is clearly the true shear on the lumbar spine that will determine whether the spinal loading is manageable, or potentially injurious.

Figure 2 does not show ligament forces because if you maintain the natural curvature of your lumbar spine, the spinal erector musculature will create the opposing torque to extend your trunk as you come up from the lift. And, as shown in the figure, a component of this large muscle force will neutralize the shear produced by the load and body mass. The muscle force is predominantly parallel to the spine but also pulls back to counteract the forward shear. Many coaches will tell you that shear on the back doesn't occur if the back is rigid. This may not be particularly intuitive, but as shown above, it is correct, as the muscle forces offset the shearing effect of the weight (force) of the load and upper body.

So what happens if you do not keep a rigid, straight back? Dr. McGill has shown conclusively with studies analyzing the electrical activity of the spinal erectors that as the lumbar spine becomes fully flexed (rounded forward), the contribution of the muscles to the required torque decreases and the supportive force generated by the ligaments increases. So, in effect, you switch off your muscles and allow your ligaments to support the weight, which is not a good idea. Although the ligaments of a conditioned athlete are going to be strong, they're not *that* strong, and the line of pull of the interspinous lumbar ligaments means they actually add to the shear component. The angle of pull of these ligaments during lumbar flexion is shown in figure 3. In this figure you can see that the muscle force is absent and is therefore unable to help reduce the joint shear. Although the ligaments can counteract the load torque (allowing you to lift with a flexed back), the line of action of the ligament force adds to the joint shear, which becomes very large indeed. The bottom line then is, yes, you can often get away with flexing the spine during a deadlift, but only with a significant risk of damaging the lumbar discs.

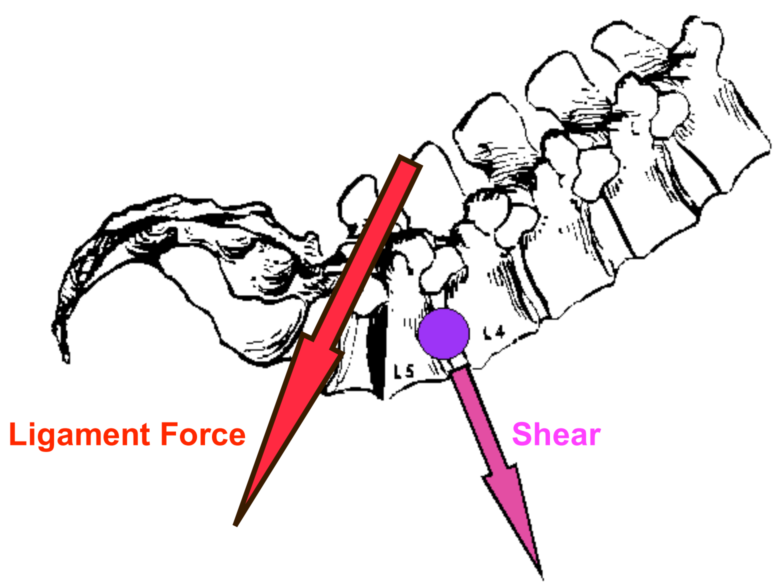

Figure 3. Force from interspinous ligaments contributes to joint shear in the lumbar spine.

Most novice deadlifters (and even some of the more experienced ones) think that their shoulders should be behind the bar and that they should be as upright as possible. This appears to be a natural tendency in an attempt to reduce shear on the back, but, as discussed above, this is a mistaken focus. I am always telling the young athletes I train that a flat back is not the same thing as an upright back. I want a flat, natural spinal posture; it doesn't have to be close to vertical. Your trunk alignment should be decided by your anthropometry (arm. leg and trunk lengths) and you should focus on keeping a natural flat alignment, as a more vertical rounded back will result in more joint shear than a more horizontal flat back.

Biomechanical analysis of the deadlift

As I said at the introductory lecture, if you can put your argument into numbers you can better explain the real danger of bad form. So I modeled the deadlift using a commercially available biomechanical computer modeling program with the not-so-friendly name 4DWATBAK. Most of the literature in the field of spinal biomechanics comes from ergonomics, where researchers, ergonomic consultants, health and safety officials, and union safety committees strive to reduce the incidence of back injuries. Therefore the program I used was developed for ergonomic use.

The model is a static model, which means it calculates the torques due to the load and limb weights about the body's joints with no movement. Because it calculates non-dynamic forces in fixed postures, muscle torques must be of exactly the same magnitude in opposite directions to maintain the posture. Such models cannot be used if loads are accelerating at a reasonable rate, but because the deadlift is a relatively slow lift, the values calculated by the model are close to the actual forces on the spine. The model also has to assume average anthropometry for any given height and weight. By this I mean average leg and trunk lengths and average distances for muscle and ligament lines of action (based on MRI studies conducted to assess the deep anatomy of the spinal muscles and ligaments). I entered the subject as a six-foot, 200-pound male; however, the compression and shear values calculated for a lighter subject are not greatly reduced, as the load weight, rather than body weight, is the dominant factor in the calculations. I entered a load of 300 pounds (136 kg)

Another reason modeling the deadlift will give accurate values of force on the spine is that the model is 2-dimensional sagittal plane and the deadlift movement occurs in that plane. The model would not be useful to model Olympic lifts unless you knew the acceleration of the load, nor could you model any movement with a rotational component in another plane. Despite these limitations, the model will provide useful data for a slow lift in the fore-aft plane.

It is universally agreed in the literature that the spine is well designed to withstand compressive forces. A suggested safe cutoff point of 3,433 Newtons was established by NIOSH (National Institute for Occupational Safety and Health) in 1981. However, this is a standard for an occupational setting where unconditioned workers of all ages and both sexes might have to lift objects. World championship powerlifters can easily generate 20,000+ Newtons of compressive force on their spines with no ill effect. There is much less research on what would, or should, constitute a safe limit for joint shear. The University of Waterloo ergonomic research group has suggested 500 Newtons as a safe limit and 1,000 Newtons as a maximal permissible limit.

The computer program has a feature that allows you to select either a normal spinal posture or a fully flexed spine. The program then calculates the shear forces based on whether the muscles or ligaments are bearing the load. As the moment arm (the distance from rotation point) of the muscle and ligaments are essentially the same in either case, the compressive force does not change with the change in posture.

However, the shear force is greatly affected, as discussed above and shown below in the output values from the program.

Figures 4 and 5 below show two deadlift postures (normal spinal alignment and full flexion), and figures 6 and 7 show the computer model's manikins of the same two postures, with "force arrows" that represent the load weight. Figures 8 and 9 show the program's output of compression and shear forces in graphical bar chart format. It also shows the accepted ergonomic limit values on the bar graph. As discussed above, these are 3,433 N for compression (NIOSH also has an upper limit of 6376 N as a maximal permissible limit), and 500 N for shear (also with a maximal limit of 1000 N).

Figures 4, 6, and 8 are for a deadlift with acceptable spine position, and figures 5, 7, and 9 are for a deadlift with a fully flexed spine. The manikin position in Figure 4 is of a good deadlift using the average anthropometry provided in the program. The actual body alignment for a "good" deadlift will depend on relative leg, arm and trunk lengths . It is not a requirement for a good deadlift that the back is upright. It just has to be straight with a normal lumbar lordosis and the trunk musculature fully activated. The photo of a poor lift in is just an example of what a lift with a fully flexed spine looks like. In the program, For modeling the poor deadlift I just used figure 4 as a starting point and chose the fully flexed option available in the program and adjusted the hands to be at the same level for the starting position. The two manikins look somewhat similar, but if you look at the pelvis and lower spine area, you'll see the crucial difference.

You can see on the graphs that lifting 300 pounds results in a spinal compression of around 10,000 N (about 2,000 pounds-force). The slight difference between the two compression values is because as you round your back in the "poor" deadlift, your trunk moves slightly more horizontal and your shoulders drop lower, meaning more torque is require to balance the posture.

The huge difference between these two lifts though is in the joint shear. In the correct form deadlift, the shear is only 699 N, which is even below an occupational maximal limit. However, the joint shear in the flexed back position is 3799 N (775 pounds-force). Because the computer program is designed for ergonomic use, this shear force value for the poor lift is literally "off the chart".

I also entered a 600-pound deadlift into the program. The values for a correct form lift were: compression 17,000 N (3,500 pounds-force) and shear 1,200 N (240 pounds-force). So even when lifting 600 pounds, with proper form the shear is only 20 percent above what occupational biomechanists suggest as an upper limit in an industrial setting. With the incorrect form of a flexed spine, however, compression is 18,300 N and the shear an amazing 6,700 N. To say this is dangerous to the spine is an understatement.

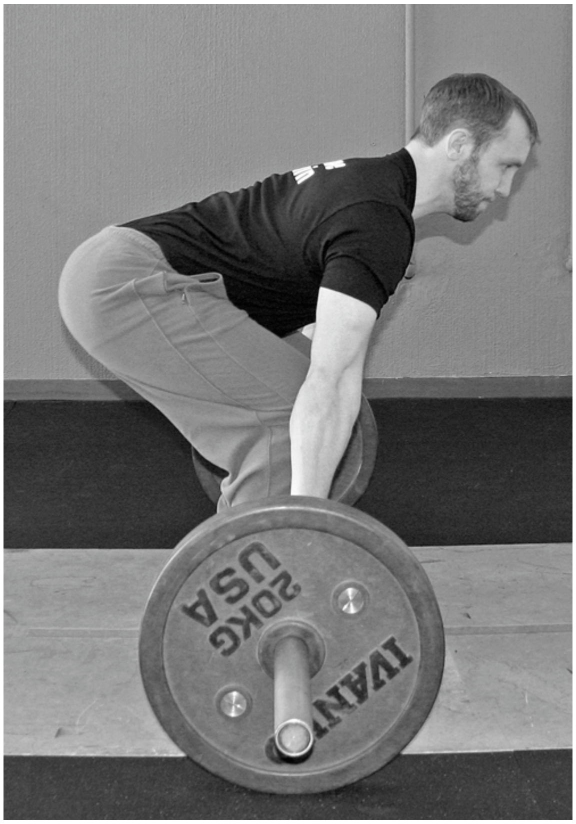

Figure 4. Deadlift (good form)

Figure 5. Deadlift (poor form)

Figure 6. Model of Figure 4 position

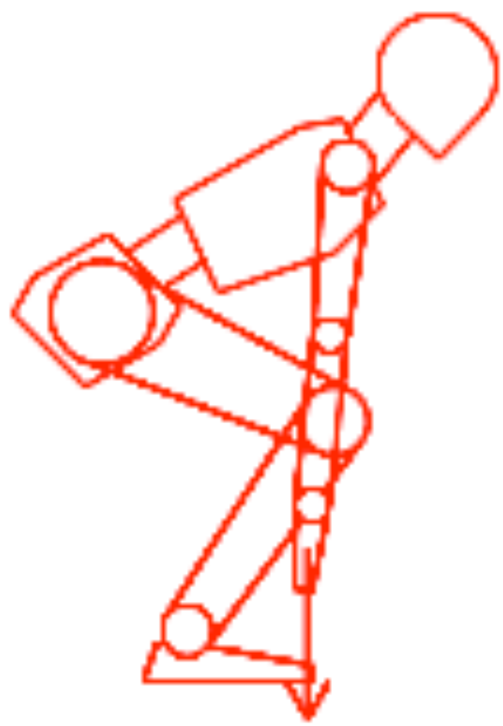

Figure 7. Model of Figure 6 position
but with a flexed lumbar spine

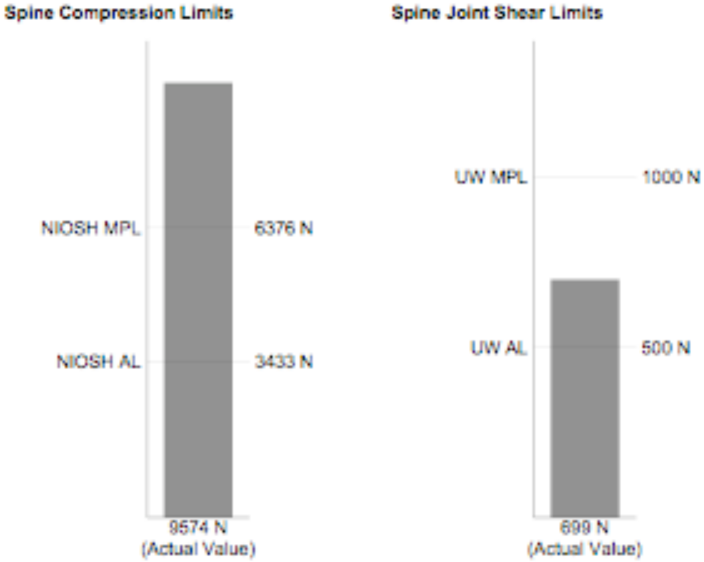

Figure 8. Compression and shear values at L4/L5 for the "good form" deadlift (figure 6).

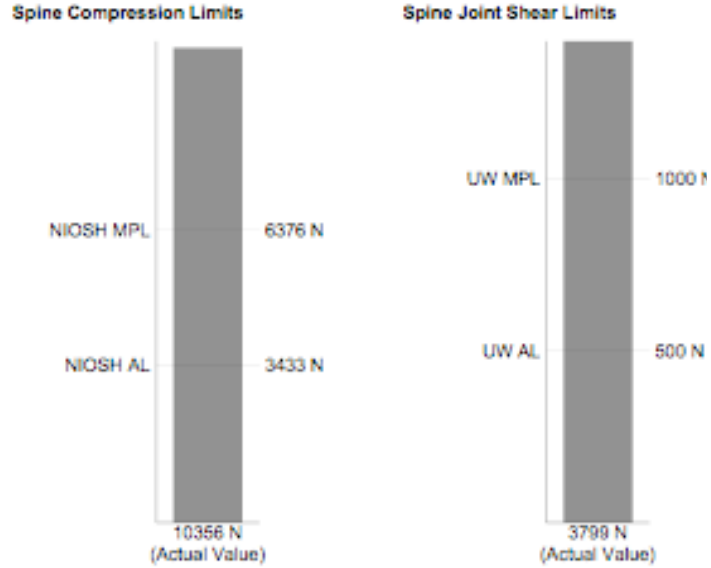

Figure 9. Compression and shear values at L4/L5 for the "poor form" deadlift (figure 7)

The top right figure is a photo of a deadlift I received from the publishers of the course text. I reviewed this text for the publishers. The photo was part of a sequence of photos used by the authors to discuss lifts for specific movement patterns but I do not believe they used it in the final draft.. What a poor example of the deadlift who is apparently a college football player.

Summary

Although I have used the deadlift to quantify the loading on the spine when the lift is performed with natural lumbar lordosis and when it is done with a flexed spine, the concept carries over to all lifts.

The model calculates forces at the L4-L5-l5 vertebrae because 85 to 95 percent of all disc hernias occur either at the L4/L5 or L5/S1 intervertebral discs. This is because the torques on the spine are greatest in the lumbar region and therefore programs are written to analyze this region. However, it is important that your entire spine be rigid and in a natural alignment to protect all the vertebrae and discs.

In summary, a fully flexed spine inactivates back extensors, loads the posterior passive tissues (ligaments), and results in high shearing forces. In contrast a neutral-to-slightly-extended lumbar spine posture disables the interspinous ligaments and reduces joint shear. This analysis emphasizes that correct form is crucial when lifting

Text and computer program cited in this article

McGill, S.M. 2002. *Low Back Disorders: Evidence-Based Prevention and Rehabilitation*. Champaign, IL: Human Kinetics.

4D WATBAK biomechanical computer model, version 2.0.3. 1999. Faculty of Applied Health Sciences, University of Waterloo, Ontario, Canada.