

the **CrossFit** JOURNAL ARTICLES

Spine Mechanics for Lifters

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Anyone who has watched CrossFit instructional videos and read *CrossFit Journal* articles focusing on lifting technique will know the importance of maintaining a straight torso with normal lumbar curvatures. This month I want to briefly discuss lumbar spinal anatomy and mechanics.

I believe that being able to express mechanical concepts (such as different postures during lifting) in numbers provides the strongest possible support for coaching points. Therefore, I have also included a quantitative analysis of the deadlift using a biomechanical computer model.

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.

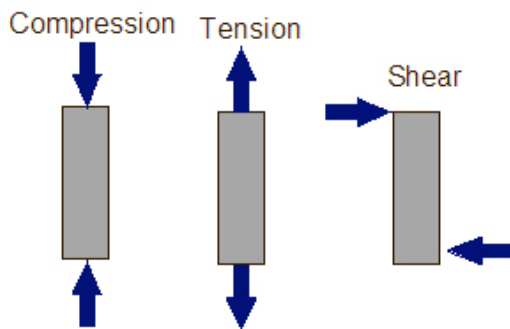


Figure 1. Terminology for directions of force.

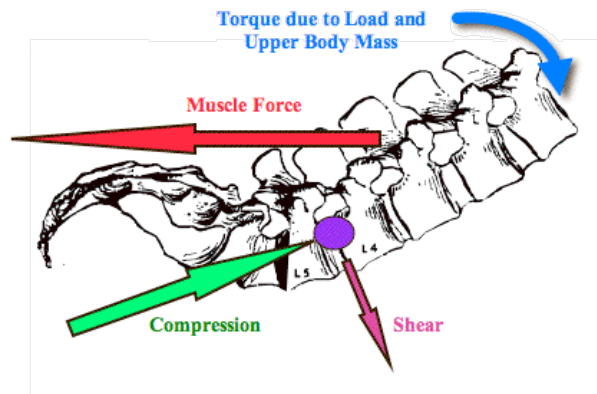


Figure 2. Torque and forces acting on the lumbar spine.

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 (2.4 to 2.8 inches) and hence these muscles must pull

Spine Mechanics for Lifters (continued...)

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 lifted 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.

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 determines 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

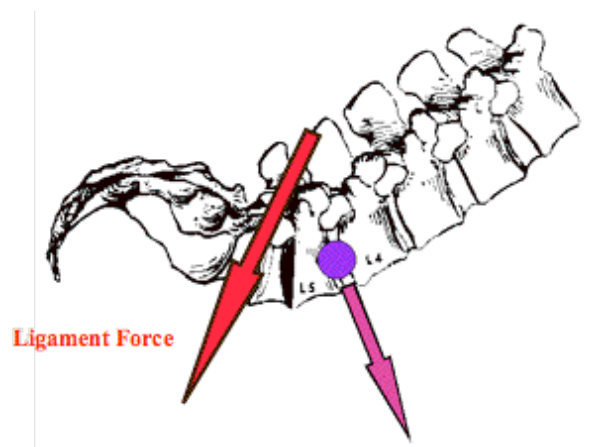


Figure 3. Force from interspinous ligaments contributes to joint shear in the lumbar spine.

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. This is what Mark Rippetoe explains in the video “Deadlift Alignment, Part 1” on the CrossFit.com website on September 11, 2007, when he says “Remember, 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.

Deadlift Alignment
Video



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 CrossFitter 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

Spine Mechanics for Lifters (continued...)

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.

In the deadlift alignment video, Rippetoe states that 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 (body and limb size and shape) 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. (See [Rippetoe's article](#) on the deadlift for an excellent discussion of proper deadlift form for all body types.)

Biomechanical analysis of the deadlift

As I said at the beginning, 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 loads. 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.

Another reason to model the deadlift is that the model is 2-dimensional (fore-aft plane, also known as the sagittal plane) and the deadlift movement occurs in that plane. So 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 was established by NIOSH (National Institute for Occupational Safety and Health) in 1981. This is around 760 pounds of force (3,433 Newtons, to be precise). 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 (approximately 4,000 pounds-force) 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 (approximately 100 pounds-force) as a safe limit and 1,000 Newtons (200 pounds-force) 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.

Spine Mechanics for Lifters (continued...)

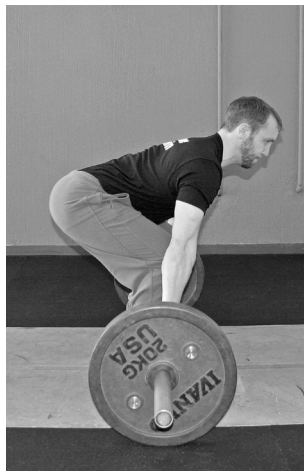


Figure 4



Figure 5



Figure 6

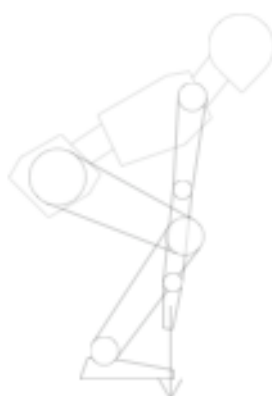


Figure 7

Figures 4 and 5 show the two deadlift postures (normal spinal alignment and full flexion), and figures 6 and 7 show the computer model's mannequins of the same two postures, with "force arrows" that represent the load weight. Figure 7 shows 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 show a deadlift with acceptable spine position, and figures 5, 7, and 9 show a deadlift with a fully flexed spine. I used the limb angles to enter values for the model in figure 4 into the program to create the mannequin shown in figure 6. The photo of the poor lift (figure 5) is just an example of what a lift with a fully

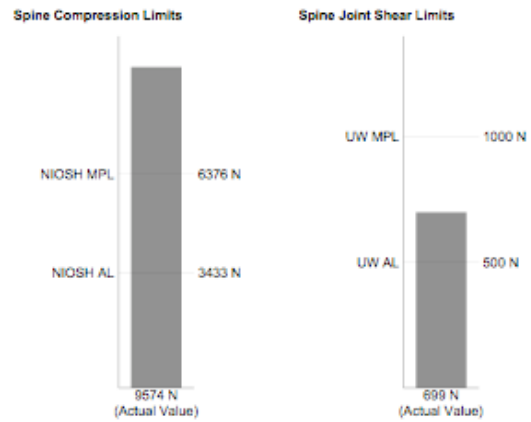


Figure 8

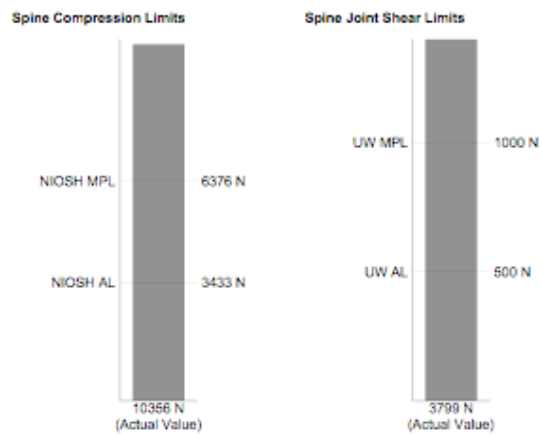


Figure 9

flexed spine looks like. In the program, I just chose the fully flexed option in and adjusted the hands to be at the same level for the starting position. The two mannequins 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 required 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 (142 pounds-force), which is even below an occupational maximal limit. However, the joint shear

Spine Mechanics for Lifters (continued...)

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.

Believe it or not, the top right figure is a photo of a deadlift from a university biomechanics text I am currently reviewing for the publishers. This is a good text for biomechanics and the photo is part of a sequence of photos used by the authors to discuss lifts for specific movement patterns. But, my goodness, what an example! No wonder Mark Rippetoe emphasized the need for good form in last month's *CrossFit Journal*. And if any of you felt he was overstating the fact that poor form is common—and that even big flaws are overlooked even by the so-called experts—doubt no longer. It is clearly represented in this photo.

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. So, as you may have heard before, form matters.



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.

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