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Biomechanics of the Spine: A case study on the fourth and fifth lumbar vertebrae

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Abstract

The spine's lumbar and sacral regions are critical in load-bearing activities typical in daily life and sports, such as lifting and carrying heavy objects. These activities subject the spine to complex biomechanical forces—namely compression, tension, and shear—particularly impacting the lumbar vertebrae. Understanding these forces is crucial for developing preventive strategies against injuries and enhancing physical performance. This case study aims to elucidate the biomechanical dynamics at play in the lumbar and sacral vertebrae under various loading conditions to identify the causes of injuries and devise methods to minimize their occurrence through improved lifting techniques. The research employed advanced biomechanical analysis, including the use of the DWATBAK computer model, to measure spinal forces during physical activities. This case study focused on the impact of shear forces and the resultant stresses during weightlifting, integrating anthropometric measurements to determine safe and effective lifting postures Present findings highlight the necessity of maintaining the natural curvature of the lumbar spine to decrease injury risk. Carrying loads close to the body's center was shown to significantly reduce spinal stress, particularly in the lower lumbar region. The case study delineated how specific postures could alleviate the risk of shearing forces that primarily affect the fourth and fifth lumbar vertebrae. Adopting correct lifting postures is imperative to prevent spinal injuries in the lumbar and sacral areas. The study emphasizes incorporating biomechanical insights into training regimes to improve safety and efficacy in activities involving heavy lifting.

Keywords: *biomechanics, lumbar vertebrae, spine*

Introduction

In our current era, where daily loads on individuals are increasing, the spine emerges as a crucial element requiring a precise understanding of its mechanisms and the forces affecting it to avoid potential injuries and to improve physical performance. The spine serves as a center for load bearing in the human body, consisting of vertebrae arranged in a way that allows for significant flexibility and support (Hanan Murad Marzouk & Hoda Badawi Shabib, 2023). The main forces impacting the spine discussed in this study include compression, tension, and shear. Continuous exposure to these forces without proper biomechanical planning can lead to complex injuries, particularly between the fourth and fifth lumbar vertebrae, necessitating in-depth research to understand these mechanisms and develop strategies for injury prevention. This case study aims to explore the biomechanical mechanisms of the spine, especially in the lumbar and sacral regions, which endure significant stress during activities such as lifting and carrying. More precisely, we aimed to investigate how the lumbar and sacral vertebrae are affected by different forces during daily activities, especially during weightlifting, and to identify the factors leading to injuries and how to minimize their occurrence through proper techniques and appropriate lifting postures. Additional goal was to understand how external loads affect the lumbar joint and the extent to which weight and the upper body's center impact the stability and safety of the spine.

By understanding the dynamics affecting the spine, effective strategies can be developed to reduce the risk of injuries

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and enhance individuals' physical performance (Davis, 2020). This research not only highlights the necessary precautions for lifters but also provides doctors and therapists with valuable information about the biomechanical adaptations required for spinal patient.

Based on these goals and methodology, the present case study strives to make significant contributions to the field of occupational health and safety and improve training and sports performance standards, reflecting the importance of biomechanical studies in maintaining the musculoskeletal system's health.

Methodology

Accurate biomechanical analyses were used to measure the forces affecting the spine during various activities, focusing on shear forces and the stresses resulting from lifting and carrying. The study relies on detailed biomechanical analysis that includes the use of computer models (such as DWATBAK) to analyze loads and evaluate performance, and measuring the forces impacting the spine during various activities. Additionally, the study employs anthropometric measurements to determine the safest and most effective postures during lifting.

This methodology allows for a comprehensive examination of how different forces impact the spine under simulated conditions, providing insights into optimal lifting techniques that can reduce the risk of injury. By using computer models, researchers can simulate a wide range of activities and scenarios, which helps in understanding the biomechanical stresses that occur on the spine and thus informing better practices and preventive measures. The incorporation of anthropometric data ensures that the findings are applicable to different body sizes and shapes, enhancing the practical application of the research outcomes in real-world settings.

Analysis

The three directions that force is applied to human tissue are compression, tension, and cutting (as shown in Figure 1). The curvature that exists in the spine, the nature of its S-shaped formation, and the various pressures to which it is exposed are one aspect of the variables to which it is exposed. The spine in vertebral compression and shear force, and torsion is a type of cut. This discussion is about the mechanics of the lumbar vertebrae. Shear force is defined as the force that acts in a direction parallel to the surface of the spine, as slippage can occur. Between the fourth point and the other are the fifth lumbar vertebrae, due to their vulgar formation and the force and shape that are affected by this area.

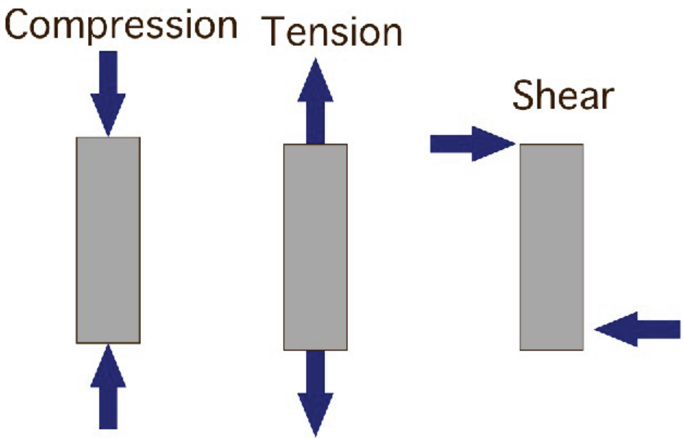

FIGURE 1. Terms used for strength trends

Mechanical Impacts:

1. Weightlifting and Its Effect: Lifting a weight centered on the upper part of the body and arms creates significant pressure on the lumbar vertebrae. This pressure generates a large torque around these vertebrae, necessitating considerable force to maintain balance and support. (Jones & Raasch, 2011)

2. Rotation Around the Cartilage: The cartilage located between the fourth and fifth lumbar vertebrae acts as the rotation center for this force, The muscular line of the spinal pelvic region is very close to the joint's rotation center, approximately 6-7 cm away, thus these muscles must exert a collective force to lift the spine. (Bauer & Paulus, 2020)

3. Muscular and Ligament Stress: The illustration also shows how the muscle line pulls the lumbar vertebrae together, creating pressure between them. This concept might be hard to visualize, but when the body's base is actually grounded the lower lumbar vertebrae are "pushed up" from below and pulled downwards by the muscles, generating significant compression forces again for lifting heavy weights. (Toyooka et al., 2019)

Additionally, there is a torque wanting to rotate the lifted weight towards the front side (clockwise direction in the illustration), along with the weight and load of the upper body during the descent of the weight (gravity pull). A component of this force involves cutting through the fourth and fifth lumbar cartilages. This force could pose a threat to slippage or particularly more severe injuries (Nachemson et al., 1986).

Anatomy of the Vertebrae and Causes of Injury
Understanding the Spinal Structure

- Complexity of Spinal Anatomy: The spinal column is highly complex and understanding it is not straightforward (Susan Hill & Translated by Hassan Hadi Al-Ziyadi and others, 2014) . Maintaining the natural curvature of the lumbar vertebrae (bending) is essential for spinal health.
- Mechanism of Injuries: Discussing the mechanics behind these injuries is crucial. The affected area typically involves the muscle line and various ligaments that connect the vertebrae to each other (from one segment to another) as illustrated in Figure 2. The muscle action line should be visible, and these components work to counteract the narrative force, which means the vertebrae are subjected to two forces acting in opposite directions, thereby attempting to create a balance between the force exerted and the impact on spinal operations.
- Types of Forces: Scientists and experts identify two main types of forces affecting the spine: shearing, which occurs when carrying heavy weights. The closer the upper body moves horizontally with the effect of the moving weight, the more significant is the actual impact on the joint between the fourth and fifth lumbar vertebrae and the strength of the muscle ligament (John McLester & Peter St. Pierre, 2008). This influencing force includes the effects of muscles and the ligament strength which causes the actual "infection" or damage to the fourth and fifth lumbar vertebrae (Panjabi & White, 1980).

Ligament Strength Visibility

- Visibility of Ligament Strength: The strength of the ligaments does not show clearly if you maintain the natural curvature of your lumbar spine. The spinal muscles create an opposing torque to extend your trunk, an element of this significant muscular force causes neutralization or reduction of the shearing force resulting from carrying a weight and the body mass.
- Muscle Forces: The muscular force is mostly parallel to the spine but also acts to pull back to resist forward movement. Many trainers believe that shearing force on the back does not occur unless the force impacting it is substantial. Although this may not be particularly intuitive, it is accurate that muscular forces compensate for the weight's impact (force) of the load and the upper body mechanically. Furthermore, these bends in the spine help absorb shocks without further injury when straight to respond to the forces impacting them in the same way (Tsuchida et al., 2022).

Common Injuries During High-Energy Activities

- Soft Tissue and Ligament Injuries: Injuries to soft tissues and ligaments are among the most common during activities requiring high friction and energy, such as collisions in basketball. Excessive tension or stress in the tissues or longitudinal ligaments can lead to tears or bone failures, as occurs when a ligament pulls a piece of the bone away from its attachment site (Susan J. Hall, 2007) (Predel et al., 2017) .

What happens when you bend backward? Understanding the spinal flexion and its effects.

1. Backward Bending (Extension):
    - Studies incorporating the analysis of electrical activity in the spine show that when the lumbar region is fully flexed forward (rounded forward), the contribution of the muscles to the required torque is significantly reduced, with the supportive force primarily generated by the ligaments. This state allows you to "turn off" your muscles, letting the ligaments bear the weight, which is not ideal.
2. Implications of Full Lumbar Flexion:
    - A well-trained athlete, though strong and adaptable, does not have sufficient ligament strength to counteract the shearing forces alone—the overlapping ligaments imply that they contribute significantly to the shearing component. During lumbar flexion, the angle at which these ligaments are pulled. Carrying a weight with full spinal bending leads to a phenomenon known as myoelectric silence (reduced muscle tension due to the relaxation and flexion relaxation phenomena), with all joints remaining static (O'Neill et al., 2022).
3. Muscle Inactivity and Ligament Recruitment:
    - It is observed that the definition in the lower back remains unchanged; then, the ligaments are recruited to contribute to the anterior shearing force which sometimes exceeds (1000 N) (Kamegaya, 2016) .

Common Misconceptions in Weightlifting:

1. Postural Misconceptions:
    - Most novice weightlifters (and even the more experienced ones) believe that their shoulders should be behind the bar, and their posture should be as straight as possible (McGill & Norman, 1987). This natural inclination aims to reduce the shearing force affecting the back, but this mechanical posture is incorrect.

Proper Training Focus:

Training should always focus on reassuring young athletes that having a flat back is not the same as having a straight back. A natural curve in the back, the state of the natural spine, should be maintained. Thus, the weight should be kept as close to the vertical axis as possible.

Biomechanical Analysis of Lifting and Its Impact on the Quadriceps and Spine

Part One: Range of Motion

- First Phase: This encompasses the first 60 degrees of motion, focusing primarily on the anterior bending of the leg.
- Second Phase: This includes an additional 25 degrees of bending, intensifying the movement's complexity and the precision needed to perform it safely.

Part Two: Biomechanical Analysis

- Detailed Analysis: The biomechanical analysis of lifts that pose risks to the quadriceps offers a detailed view. The ability to study the forces impacting the spine is invaluable for understanding the real risk of spinal injuries. This analysis is based on a program and numbers that simulate the condition of this crucial and fundamental part of human movement and the specific risks some lifts pose to the cervical vertebrae.
- Use of DWATBAK Program: The commercial computer model known as DWATBAK (Richardson, 2002) is utilized in the field of biomechanics. It mainly focuses on the spine, the central pillar in all lifting and carrying tasks, helping many researchers, doctors, and health and safety officials to minimize the occurrence of back injuries.

Program Specifications:

- Model Functionality: The program is designed for ease of use with a static model, meaning it calculates the torque due to loads and weights around the body's joints without motion. Because it computes non-dynamic forces in static (stationary) situations, the muscle torque must be exactly equal in strength but opposite in direction to maintain the correct posture since no injury occurs (Nachemson et al., 1986).
- Model Limitations: Such models cannot be used if the loads are unstable or mobile. Given that the process of lifting high weights is inherently risky and perilous at the outset, the program features relatively slow lifting, and the values it producer (Norman et al., 1998) are close to the actual forces affecting the spine. The model must also assume average measurements.

Implications for Training and Safety:

- Risk Assessment: By simulating real-life conditions and measuring forces accurately, the program helps in preparing individuals for safe lifting techniques that prevent undue stress on the spine, particularly protecting the cervical vertebrae.
- Safety Protocols: The static nature of the model ensures that trainers and health professionals can develop lifting strategies that avoid dynamic or unexpected loads, which are more likely to cause injuries.

Assumptions and Limitations:

- Assumption of Average Measurements: The model assumes average measurements for body parts, crucial for assessing the deep anatomy of the spine and ligaments based on MRI studies. A test conducted on a six-foot man (198 cm) weighing 200 pounds (90 kg) showed that although the pressure and loading values for a lighter individual are not significantly less, the weight of the load, not the body weight, is the dominant factor in calculations.
- Introduction of a 300-pound Load: A load of 300 pounds (136 kg) was introduced, and using this heavy-weight lifting model provides accurate values for the force impacting the spine. Despite some limitations, the model offers useful data for weightlifting when utilized correctly.

Computational Benefits:

- Spinal Posture and Force Calculation: The computer program is advantageous as it allows you to set loads either in a position of normal spine or fully flexible spine. The program then calculates the forces based on whether the muscles or ligaments bear this weight (load). The arm's torque (distance from a turning point) of muscles and ligaments is essentially the same in both cases, significantly influencing the shearing force.
- Figures and Graphical Representation: Figure (2) below show the lifting posture for weight (alignment of the normal spine and complete curvature) and the computer model measurements of the same postures, with "force arrows" representing the weight of the load. Acceptable values also appear on the tape graph. As shown above, these include (3433 N) pressure (also the upper limit of strength 6376 N as maximum allowed) and (500 N) for shearing (also with a maximum of (1000 N).

The Minor Difference Between the Two States in Lifting

The slight difference between the two scenarios is that adopting the correct mechanical posture for your back during snatch lifting, with less than maximum effort, involves moving your trunk slightly more horizontally and lowering your shoulders. This action increases torque, requiring the balance of the correct mechanical position. The significant difference between these two forces is that they impact the cervical spine area due to the collective shearing force. In the correct form of snatch, the proper biomechanical performance would only involve a shearing force of (699 N), which is below the maximum. However, the shearing force affecting the flexible back is (3799 N), equivalent to (775 pounds). Given that the computer program is designed for correct usage, the narrative force value for this lift is literally "below the level." A (600 pounds) load was entered into the program. The correct lifting values were pressure (17000 N), equivalent to (3500 pounds), and shearing (1200 N), equivalent to (240 pounds). Therefore, when lifting a quad weight of (600 pounds) properly as a narrative force, it is only 20% above what sports medicine scientists indicate as the maximum. With the incorrect spine posture, however, the pressure is 18300 N and the shearing force large (6700 N). This condition poses a risk to the spin (Kattoju et al., 2023, Hambali et al., 2019).

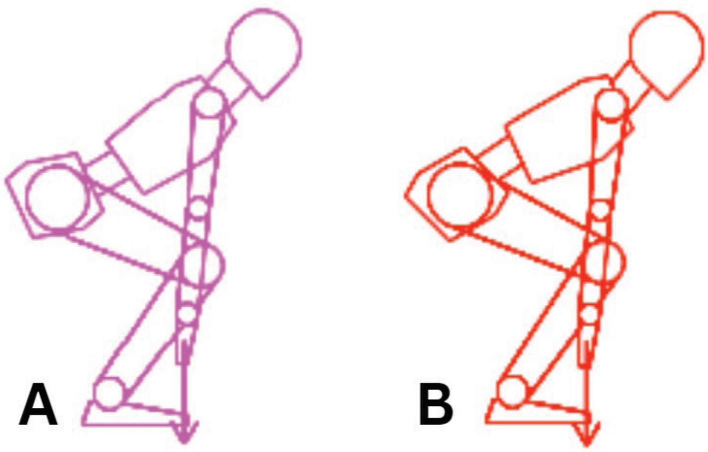

FIGURE 2. The model A represents inappropriate position and the B model represents the correct shape with the elasticity of the spine in the cotton area.

Importance of Proper Lifting Techniques

The illustration above shows the positioning of the spine at the back with the stretching force approximately 6 cm (Moramarco et al., 2010) away, which necessitates resisting the torque generated by the body's weights in addition to any external load. This explains why it is advisable to lift and carry heavy objects close to the trunk, emphasizing the importance of proper lifting techniques to minimize the risk of back injuries. Proper posture, especially keeping heavy loads close to the body's center, significantly reduces the stress on the spine, particularly in activities requiring heavy lifting (Labaj, 2014).

Causes and Treatment of Individual Lumbar Vertebrae Pain

Causes of Lumbar Vertebrae Pain

Lumbar vertebrae pain is one of the most severe and challenging types of pain for humans, with numerous underlying causes. Here are some of the main reasons for individual cases of lumbar vertebrae pain:

1. Severe Psychological Stress: One of the primary causes of lumbar vertebrae pain is severe psychological stress, which can lead to back muscle strain, spasms, and lower back cramps. These pains often do not respond to conventional treatment.
2. Inflammation and Infections: Back inflammation, bone abscesses, or meningitis can also cause lumbar pain.
3. Mechanical Usage of the Back: The way the back is used in daily activities can affect the lumbar area, leading to issues like disc slippage. This can be treated conservatively with rest and physical therapy sessions if mild, or may require surgical intervention if severe and significantly painful.
4. Gastrointestinal Diseases: Diseases such as gallbladder issues, pancreatitis, neuromas, and duodenal ulcers can also lead to lumbar pain.
5. Osteoporosis: Osteoporosis is a critical cause of structural damage to the lumbar vertebrae and severe pain.
6. Degenerative Disc Disease: The most significant cause of spinal damage and lumbar disc herniation is spinal stenosis, which results in intense pain in the lumbar vertebrae. This can be compounded by conditions like rheumatism or psoriatic arthritis, and fibromuscular inflammation associated with insufficient sleep or inadequate rest and intestinal arthritis (Saraswati et al., 2022).

Treatment for Lumbar Vertebrae Pain

The treatment for lumbar vertebrae pain involves several approaches depending on the severity and the underlying cause:

1. Complete Rest: Doctors often prescribe complete bed rest for a period of one to two weeks in a fully relaxed posture, using warm compresses, gentle massage, and avoiding carrying any weight exceeding 40-50 Newtons.
2. Medication: Pain relievers and anti-inflammatory drugs are

commonly used, and sometimes sedatives are prescribed.
3. Physical Therapy: This may include specific exercises, thermal or electrical therapy, and hydrotherapy to help relieve pain and restore function.
4. Surgical Intervention: In severe cases affecting mobility and causing intense pain, surgical intervention may be necessary to treat the disc slippage.
5. Lifestyle Adjustments: Modifications in daily activities to reduce the mechanical use of the back can prevent the aggravation of lumbar area issues.

Conclusion

The loads experienced by an individual on the spine are crucially linked, with the impact of the load and weights focused on the fourth and fifth lumbar vertebrae. Anatomical knowledge of the movement of the spine plays a significant role in preventing injuries. Adopting the correct mechanical posture when carrying a specific weight clearly influences injury prevention. Increasing the effectiveness of muscles and ligaments significantly contributes to avoiding injuries or complications. Weights should be carried close to the body to reduce additional loads, pinpoint the lumbar sacral area, and prevent injuries. Learning the causes of injuries, avoiding them, and their rehabilitation are essential.

Understanding the mechanical and metaphysical aspects of the athlete and the coach contributes to creating a positive environment in reducing injury occurrences. There is a need to focus on knowledge in mechanical, anatomical, and physical aspects to define loads. Training for athletes engaged in weightlifting and other sports influences the risk of injuries. Conducting clinical examinations and understanding the anatomical aspects of the spine thereby knowing the extent to which strength training can be endured when carrying weights, whether dynamic or static.

There is a need for rehabilitation exercises to consider the possibility of developing balanced muscle work for all muscles surrounding the operations, stabilizing, counteracting to assist, and assisting. There is a need to study and rehabilitate sports injuries according to the correct mechanical performance for each sport. Each sport has a different muscular structure from one to another and plays a significant role in adopting a model for muscular and kinetic performance. Knowing the weak and anatomical aspects of muscles, ligaments, and bones has a positive effect in reducing the occurrence of injuries when progressing in training loads.

These conclusions and recommendations emphasize the importance of proper technique, anatomical understanding, and preventive strategies to enhance safety and effectiveness in lifting practices, thereby reducing the risk of spine-related injuries. It is crucial to integrate these insights into training regimes and rehabilitation programs to ensure athletes can perform safely and effectively.

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