Biomechanics of Lumbar Spine

The spine as a whole is made up of vertebral segments classified into regions: cervical spine, vertebral thoracic spine, lumbar spine.

Main function of spine: to \[ \frac{3}{4} \text{ to } \frac{1}{4} \] from head to trunk to pelvis. The lumbar region is subjected to greater loads than rest of spine and is also a source of pain for a large percentage of the population.

Functional unit: the motion segment is comprised of adjacent vertebrae along with the intervening soft tissue (see fig.), portion: vertebral bodies, intervertebral disc, two long ligaments portion: vertebral arches, intervertebral joints, transverse \( \frac{3}{4} \) spinous processes \( \frac{3}{4} \) ligaments portion: spinal cord, intervertebral nerve roots.

**FIG. 10-1**
Anteroposterior (A) and lateral (B) roentgenograms of the lumbar spine. One motion segment, the functional unit of the spine, is indicated.

**FIG. 10-2**
Schematic representation of a motion segment in the lumbar spine (sagittal view). Anterior portion: 1, posterior longitudinal ligament; 2, anterior longitudinal ligament; 3, vertebral body; 4, cartilaginous end plate; 5, intervertebral disc; 6, intervertebral foramen with nerve root. Posterior portion: 7, ligamentum flavum; 8, spinous process; 9, intervertebral joint formed by the superior and inferior facets (the capsular ligament is not shown); 10, supraspinous ligament; 11, interspinous ligament; 12, transverse process (the intertransverse ligament is not shown); 13, arch; 14, vertebral canal (the spinal cord is not depicted).
Anterior portion of motion segment in more detail.

Vertebral bodies - largest in lumbar area - designed mainly to sustain loads.

Intervertebral disc - see Fig ( ).

NP - a fluid mass made up of colloidal gel rich in GAG's (recall from cartilage chapter).

AF is fibroid cartilage with bundles of collagen fibers arranged in a criss-cross pattern of annular fibers. These fibers make a 30° angle with the vertebral bodies and 120° angle with each other (see Fig ). This arrangement allows high bending and torsional loads to be sustained cartilaginous end plate is which separates NP from AF.

Disc is normal loaded from a combination of compression, bending, and torsion. There is an internal pressure built up in disc.

**FIG. 11-11**

Schematic drawings of an intervertebral disc showing the criss-cross arrangement of its fibers. A. Concentric layers of the annulus fibrosus are depicted as cut away to show the alternating orientation of the collagen fibers. B. The layers of the annular fibers are oriented at a 30° angle to the vertebral body and at 120° angles to each other.

from both ligaments (loads) and extra loading from muscles; external loads (loads). This internal pressure tends to separate the vertebral bodies and cause tension in the annular fibers and longitudinal ligaments. The NP acts (uniform pressure throughout the NP). This tends to provide a cushion to distribute the loads. Also there is a tendency for the disc as a whole to act to some degree elastically to store energy.

Unloaded disc - data from Nachemson (1970) done on cadavers. Prestress of disc from ligaments ~ 10 N/cm² →

Loaded disc - data from Nachemson (1975) (see Fig.) - For a given external stress (__) on the motion segment from above, the recorded compressive stresses were highest in the NP (__) and lower in the AF (__). However the bulging of the disc creates stresses laterally in the AF of ~ with age - disc degeneration (see Fig.)

**FIG. 10-4**

Distribution of stress in a cross-section of a lumbar disc under compressive loading. The compressive stress is highest in the nucleus pulposus, 1.5 times the externally applied load (F) per unit area. By contrast, the compressive stress on the annulus fibrosus is only approximately 0.5 times the externally applied load. This part of the disc bears predominantly tensile stress, which is four to five times greater than the externally applied load per unit area. *Adapted with permission from Nachemson, A. (1975). Towards a better understanding of back pain: A review of the mechanics of the lumbar disc. Rheumatol Rehabil, 14, 129.*
Posterior portion of motion segment

This portion determines the motion of the motion segment. Articulations between vertebrae guide this motion. This is determined by the orientation of the ___. Note there are 2 facets—one on each side laterally. (See ____) Motion allowed:

- Cervical spine: flex/ext, lat flex/ext, left/right rotation
- Thoracic spine: lateral flex/ext, rotation, some flex/ext
- Lumbar spine: flex/ext, lat flex/ext, rotation

Facets also bear some of the load (up to ___). This load on facets is highest in (1) hyperextension and (2) forward flexion coupled with ___

Shear loads are especially important in controlling spinal column stability in extreme hyperextension—the facets ___, forward displacement of the vertebral and subsequent spinal cord damage.

Transverse and spinous processes serve as muscle attachment sites—These ___ provide ___ stability to the spine. ___ provide ___ stability to the spine. Most of these ligaments are predominantly collagen fibers (like other loopy ligaments) and such are very resistant to elongation. However just posterior to the spinal cord is highly elastic. (Recall previous discussion of ligaments) Its constant tension (it never goes slack) prestresses the disc. Also transfer tensile loads as well (which would tend to separate the vertebrae from one another) and ligaments also guide and restrict spinal motion in general.
Range of Motion of an individual motion segment is small. This motion does not occur independently for one motion segment compared to another. Spinal movements are always a combined action of several motion segments. Also, these combined spinal movements are further combined with and joint motions.

There are generally six degrees of freedom (df = 6) for these motion segments — rotations + translations.

ICR technique (in sagittal plane) shows normal ICR to lie (see Fig ).

RMs at any given motion segment are generally less than and depend on the level of the spine and the plane of movement (see Fig. Data of White & Panjabi).

( Lateral flex/ext generally less than 10°)

FIG. 10-8

Instant center pathway for a normal cadaver spine (A) and a cadaver spine with moderate disc degeneration (B). Instant centers were determined for 3° intervals of motion from maximum extension to maximum flexion. In the normal spine, all instant centers fell within a small area in the disc. In the degenerated spine, the centers were displaced, and hence the surface motion was abnormal. Reprinted with permission from Gertzbein, S.D., et al. (1985). Centrodle patterns and segmental instability in degenerative disc disease. Spine, 10, 257.
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**FIG. 10-7**

- Flexion-extension
- Lateral flexion
- Rotation

 Movements of rotation, lateral bending, and flexion occur at the same time.

1. Main movements include flexion, extension, lateral bending, and rotation.
2. At full flexion, the ligaments become taut and provide the necessary moment to control the downward motion. The flexor muscle gets greater control over flexion at full flexion, which is something that other studies have shown, but previous studies have not.

Skeletal muscle: Erector spinae.
Electromyography of the quadratus lumborum (QL) and erector spinae superficial (ES-s) and deep (ES-d) muscles. Wire electrodes were inserted in QL and ES-d, surface electrodes were used for ES-s. Five positions (a-e) of trunk flexion are depicted. In full nonforced trunk flexion (e), the ES-d activity is silent, however, the ES-s and QL are very active to counterbalance the trunk flexion movement. (Courtesy of Eva Andersson, M.D., Ph.D., Karolinska Institute, Stockholm, Sweden.)

Also, some direct measurements have been taken (both in vivo and in vitro) and some static analyses are possible from them. Also - some forces and moments have been recorded from these analyses and 3-D analyses of the trunk movement were done. These measurements usually involve pressure measurements in the disc; by way of the skin, and in the longitudinal ligaments and the behavior of the discs, longobdile, standing posture has been described as a curving in the sagittal plane, prima.
in thoracic region and ______ in lumbar region contribute to the spring-like behavior of the spine and allow the spine to withstand greater loads than if it were straight. However, are crucial to the stability of the spine. In cadavers where muscles were removed it only took a load of ______ to buckle the spine (Lucas & Brester, 1961). (See Fig)

When standing—normal sacral angle should be about ______ (See Fig) Pelvic tilt to either side of this value tends to increase muscle activity and thereby joint forces.

FIG. 10-14

Effect of pelvic tilting on the inclination of the base of the sacrum to the transverse plane (sacral angle) during upright standing. A, Tilting the pelvis backward reduces the sacral angle and flattens the lumbar spine. B, During relaxed standing, the sacral angle is approximately 30°. C, Tilting the pelvis forward increases the sacral angle and accentuates the lumbar lordosis.
other static postures

Lying flat  see Fig
standing
 unsupported sitting upright
standing with forward lean
 unsupported sitting with forward lean

Disc pressures increase Data from Nachemson

see Fig about sitting upright
with proper lumbar lordosis vs
slouching with lordosis reduced.
when slouching the moment arm
of superimposed body weight is
increased, thus requiring more
erector spinae muscle force and
hence greater disc compressive forces
(joint forces).

Supported sitting (Fig )
Reclining the backrest is good
and adding a properly placed lumbar
support. These tend to reduce disc
pressure (data from Andersson)

Data from two studies using intradiscal pressure measurements. The relative loads on the third and fourth lumbar discs measured in vivo in various body positions are compared with the load during upright standing, depicted as 100%. Adapted with permission from Nachemson, A. (1975). Towards a better understanding of back pain: A review of the mechanics of the lumbar disc. Rheumatol Rehabil, 14, 129 and from Wilke, H.J., Neef, P., Caimi, M., et al. (1999). New in vivo measurements of pressures in the intervertebral disc in daily life. Spine, 24, 755.
Influence of backrest inclination and back support on loads of the lumbar spine, in terms of pressure in the third lumbar disc, during supported sitting. A, Backrest inclination is 90° and disc pressure is at a maximum. B, Addition of a lumbar support decreases the disc pressure. C, Backward inclination of the backrest is 110°, but with no lumbar support it produces less disc pressure. D, Addition of a lumbar support with this degree of backrest inclination further decreases the pressure. E, Shifting the support to the thoracic region pushes the upper body forward, moving the lumbar spine toward kyphosis and increasing the disc pressure. Adapted with permission from Andersson, G.B.J., Ortengren, R., Nachemson, A., et al. (1974). Lumbar disc pressure and myoelectric back muscle activity during sitting. 1. Studies on an experimental chair. Scand J Rehabil Med, 6, 104.

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Generally, disc pressures are low when lying down—however, with people with back problems—to reduce disc pressure further, one should flex the hips to reduce the passive tension in the psoas muscle which reduces the amount this muscle pulls on the lumbar spine. Otherwise— one should lay on one's side with hips somewhat flexed. (See Fig. 10-18b) with added traction when necessary to reduce pressure even further.

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Handout for Wiktorin & Nordin problem

Muscles are not the only source of extensor moments when lifting—discs can provide some (see Fig. 10-18b) and can also provide extensor moments.
The forward-bent position produces a bending moment on the lumbar spine. The moment is a product of the force produced by the weight of the upper body (W) and the lever arm of the force (L_w). The forward inclination of the upper body subjects the disc to increased tensile and compressive stresses. The annulus bulges on the compressive side and the nucleus is shifted posteriorly.

A, When a person assumes a supine position with legs straight, the pull of the vertebral portion of the psoas muscle produces some loads on the lumbar spine. B, When the hips and knees are bent and supported, the psoas muscle relaxes and the loads on the lumbar spine decrease.
9.2. Loads on the L5 Disc during Bedmaking

In this example, the loads on the lumbar spine at the level of L5 during bedmaking are calculated. The example allows a comparison of the loads on the L5 disc during bedmaking with the upper body upright and with the upper body bent forward.

Problems

9.2A. How large is the forward-bending moment (M) on the L5 disc when the individual stands upright (Figure 9.2A) and bends forward (Figure 9.2B) while making a bed? The necessary data for solving the problem can be obtained from the figures.

9.2B. How large a force (E) must the erector spinae muscles exert in each case to counteract the forward-bending moment? The moment arm for the erector spinae muscle force is 0.05 m.

9.2C. How large will the compressive force (C) and the shear force (S) on the L5 disc be in the two cases? The angle of inclination of the L5 disc to the horizontal plane is 30° with the upper body upright (Figure 9.2A) and 70° with the upper body bent forward (Figure 9.2B). The line of application of the erector spinae muscle force is perpendicular to the disc inclination.

Figure 9.2. An individual makes a bed with the upper body upright (Figure A) and bent forward (Figure B). The weight of the head and trunk is 560 N, and that of the arms is 60 N. The moment arms of the two forces relative to the center of motion at the L5 disc are 0.17 m and 0.18 m, respectively (Figure A), and 0.31 m and 0.67 m, respectively (Figure B).
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9.2

\[ M = 60(14\text{ft}) + 400(17) = \boxed{} \]

\[ \Sigma M = 0 \Rightarrow M - Ed = 0 \]

\[ E = \frac{M}{d} = \frac{70.8 \text{N.m}}{0.05 \text{m}} = \boxed{} \]

\[ \Sigma F_x = 0 \]

\[ R_c - E - 400 \cos 30^\circ - 60 \cos 60^\circ = 0 \]

\[ R_c = E + (400 + 60) \cos 30^\circ \]

\[ = 1576 + 460 \cos 30^\circ = 1974.37\text{N} \]

\[ \Sigma F_y = 0 \]

\[ R_c \sin 30^\circ - 60 \sin 30^\circ = 0 \]

\[ R_c = (400 + 60) \sin 30^\circ = \boxed{} \]

Learn how ... TO LIFT PROPERLY

To keep those kinks out of your back!

1. SQUAT DOWN
2. BEND KNEES
3. BACK STRAIGHT
4. ARMS CLOSE
5. KEEP LOAD CLOSE