Introduction to Human Factors and Ergonomics 4th Edition

RS BRIDGER

General requirements for humans in systems:

- External forces acting on the human body must not exceed its mechanical tolerance limits.
- Where the exertion of forces on external objects is required, the magnitude of forces must be within the strength and endurance limits of members of the user population.
- The task must be designed to minimize postural load (ALARP)
- Biomechanical risk factors for musculoskeletal injury must be identified and eliminated in the design.

The Body as a Mechanical System

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Function of the Lumbar Spine [2-7]

- Provides a conduit for the spinal cord
- In quadrupeds - acts like a suspension bridge to support the weight of the thorax and the abdominal organs
- In humans - a major part of the axial skeleton - supports the weight of superincumbent body parts
- The key postural adaptation that makes humans truly bipedal

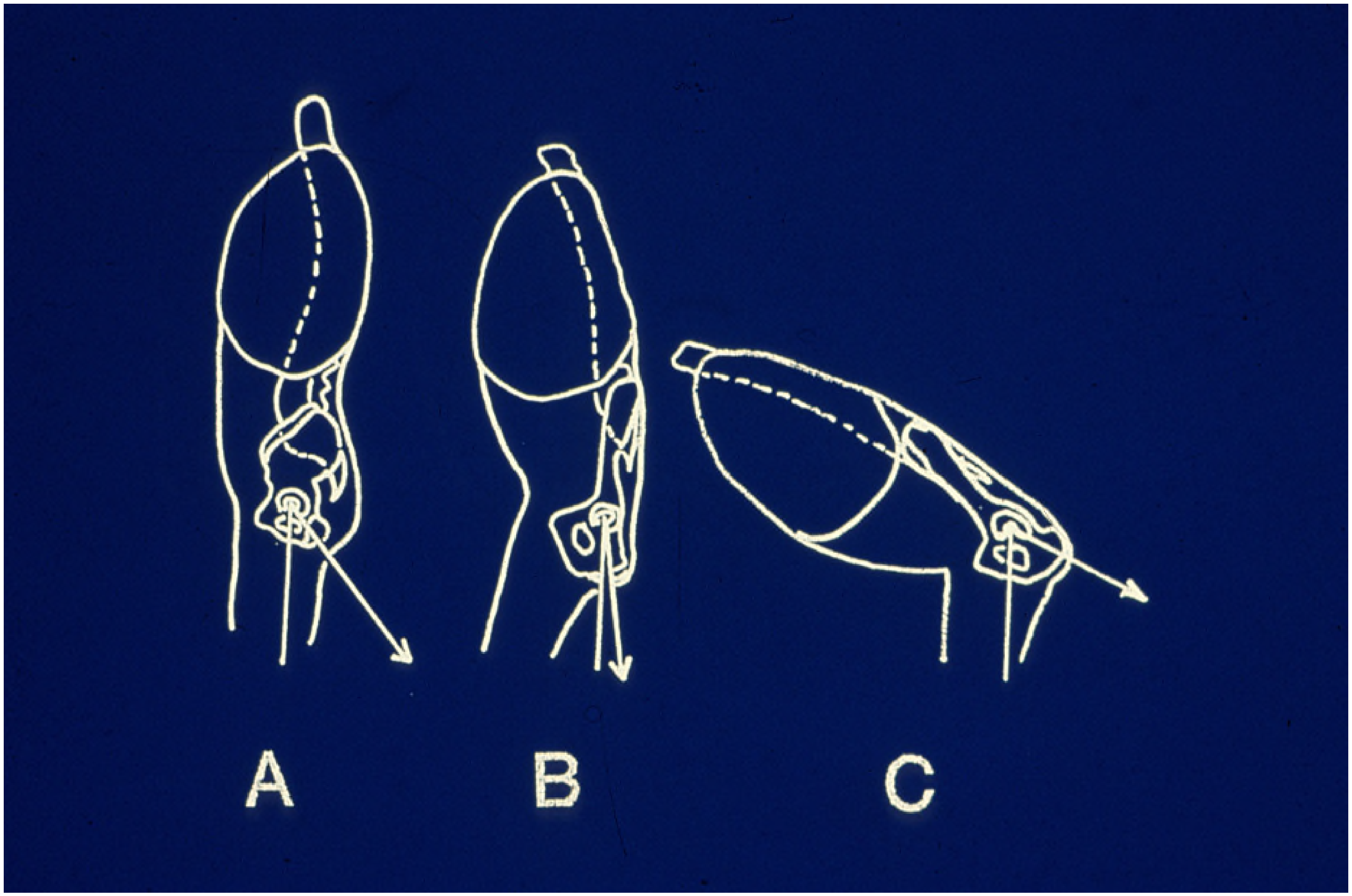
Some Aspects of Spinal Anatomy

- Spine is the axis of the upper body
- Transmits weight of superincumbent body parts to the pelvis
- Conduit for spinal cord
- Consists of 3 columns:
  - Anterior column of 24 vertebrae, not including the sacrum
  - Two posterior columns of stacked articular processes

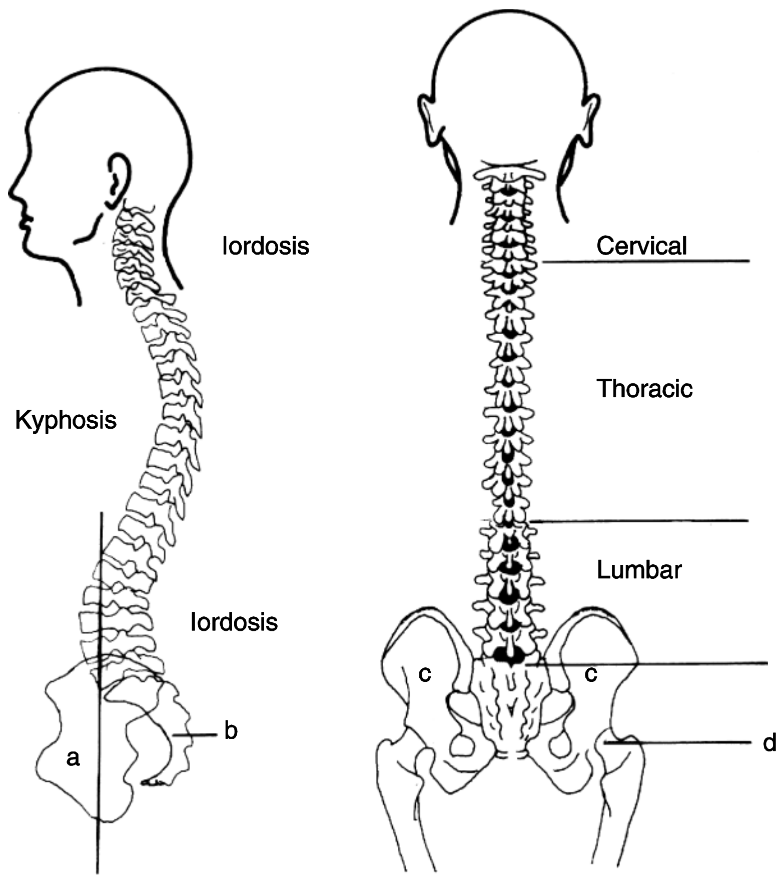
The Standing Posture [42-50]

- Humans unique in their adaptation to standing on two legs
- Extra physiological cost of standing compared to lying down is only 6%
- Functional anatomy of standing in humans:
  - Pelvis tilted anteriorly
  - Lumbar and cervical spines extended to give "S" shape
  - Weight of superincumbent body parts passes through or close to joint centres from head to toe
  - Plantarflexors, iliopsoas, low back, neck extensors and jaw muscles are postural muscles. Low level isometric contraction
  - Body weight is "balanced" on a column of bone
  - The "Tent" analogy
- Natural sitting postures very different from sitting on chairs

The Standing Posture in Human and Other Primates



Spinal Curves



Overall Function of the Spine

- It’s a 3-D jigsaw puzzle that functions like a mast
- Short, deep muscles help to hold the vertebrae together
- Long, superficial muscles make the whole thing move
- The ‘Tent’ analogy and the concept of postural load.

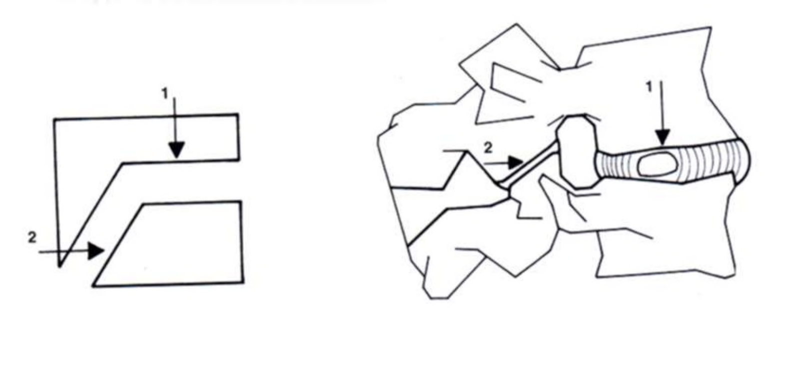
Mechanical Function of a Lumbar Motion Segment

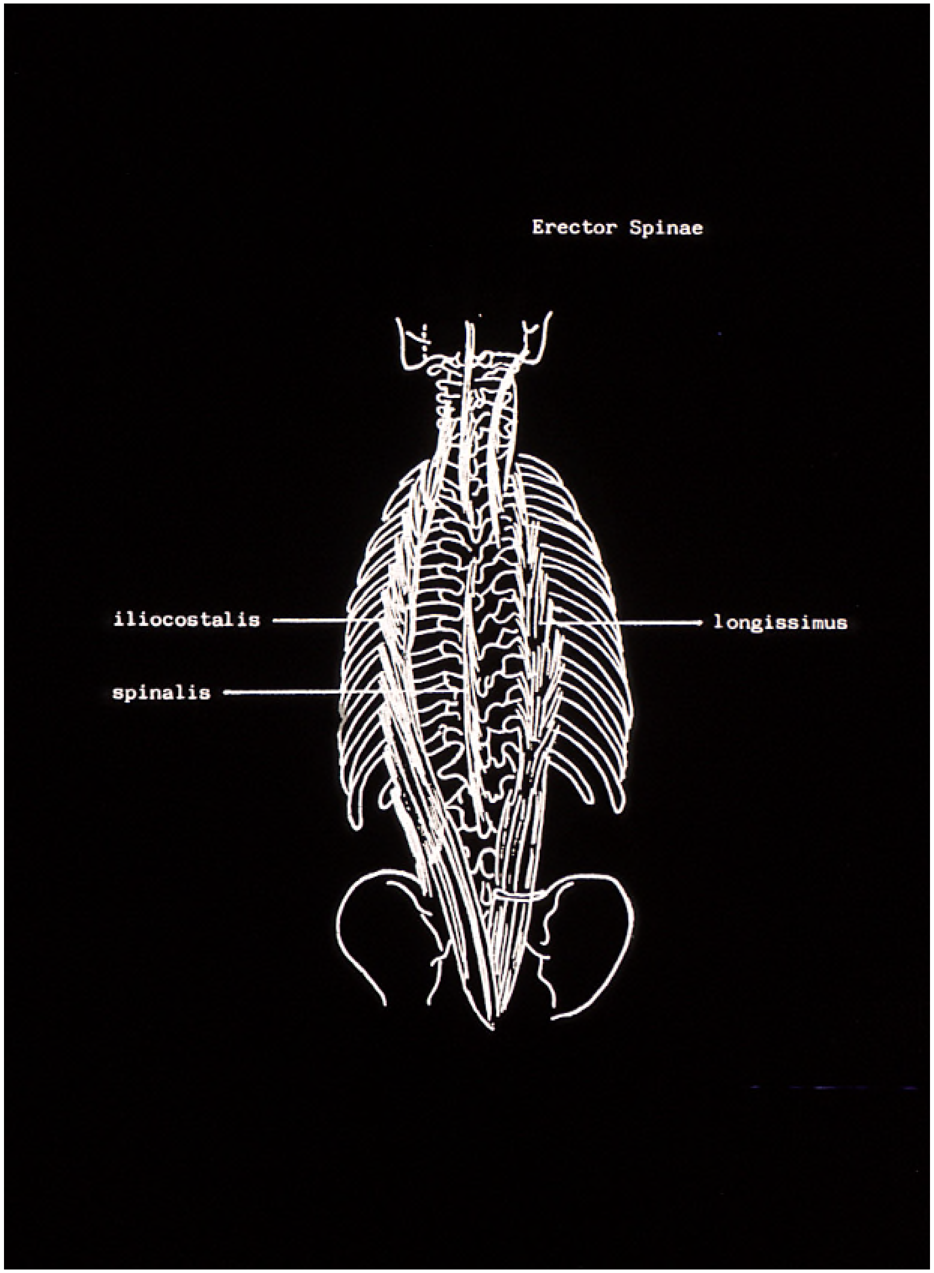
Intervertebral discs are ’spacers’

resist compressive force, providing space for movement in the segment

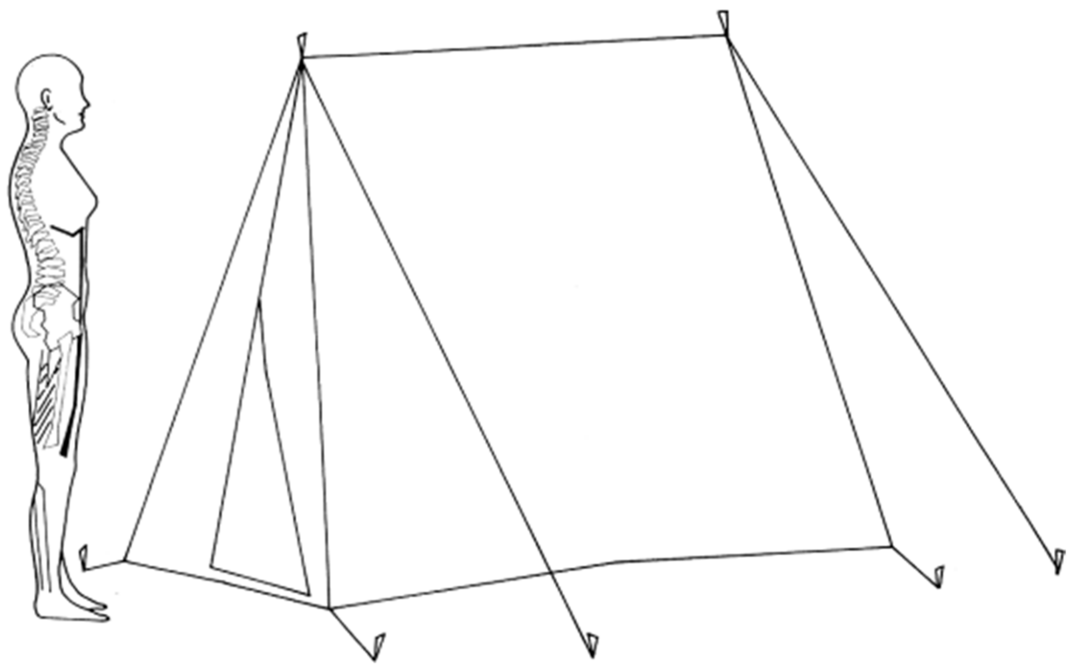
Facet joints resist shear (‘tangential’) force

Vertebral body is a shock absorber

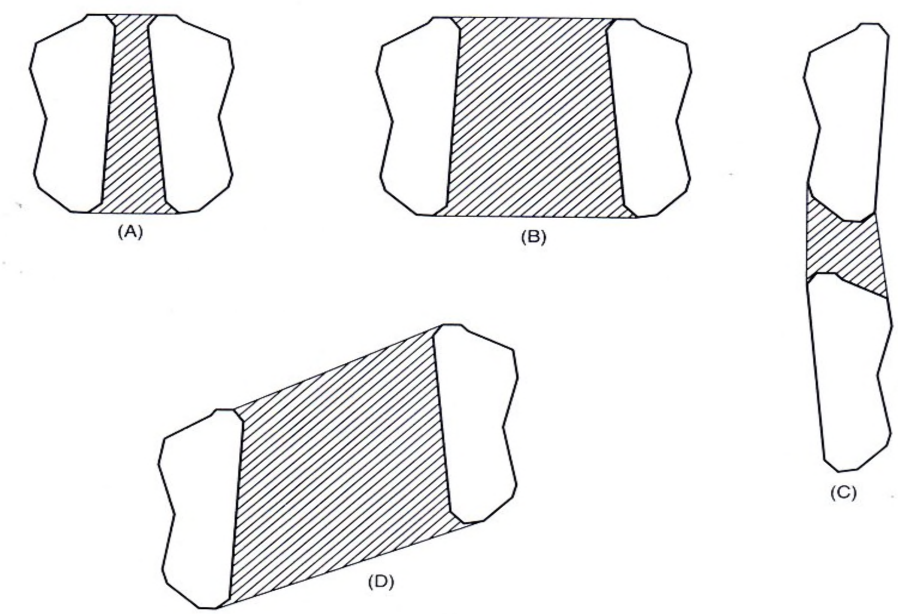


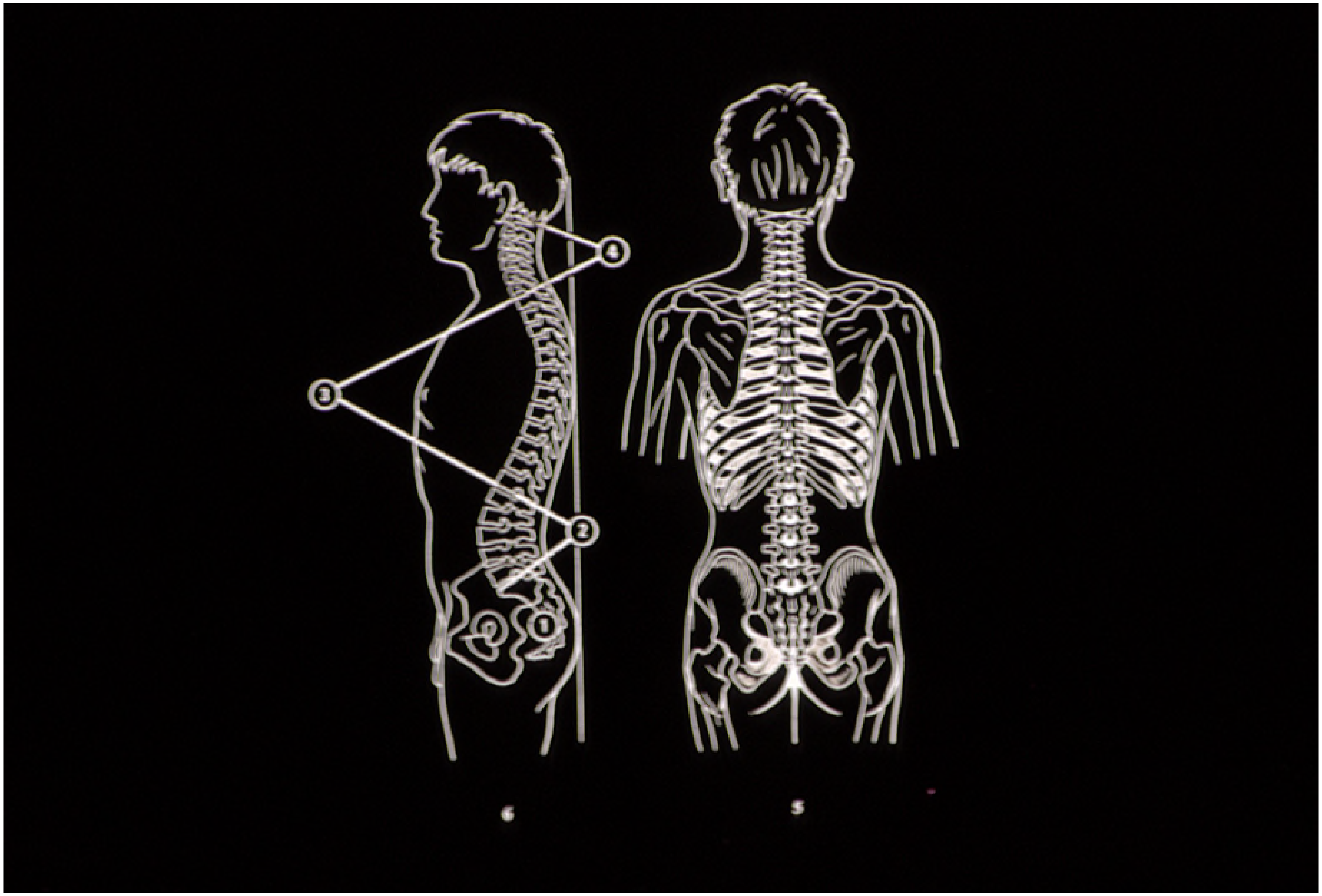

Erector Spinae
iliocostalis
spinalis
longissimus

The Tent Analogy



Base of Support

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3
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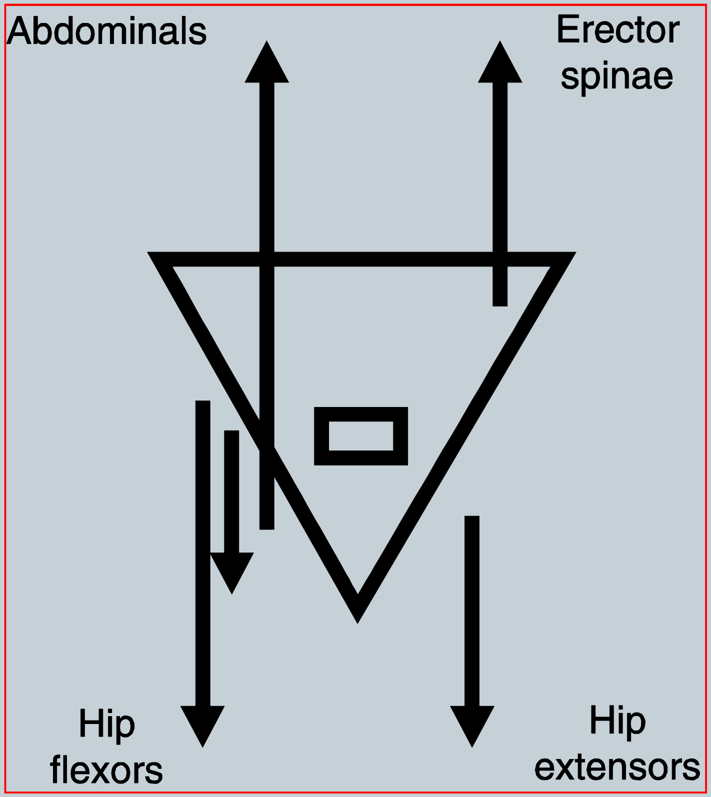
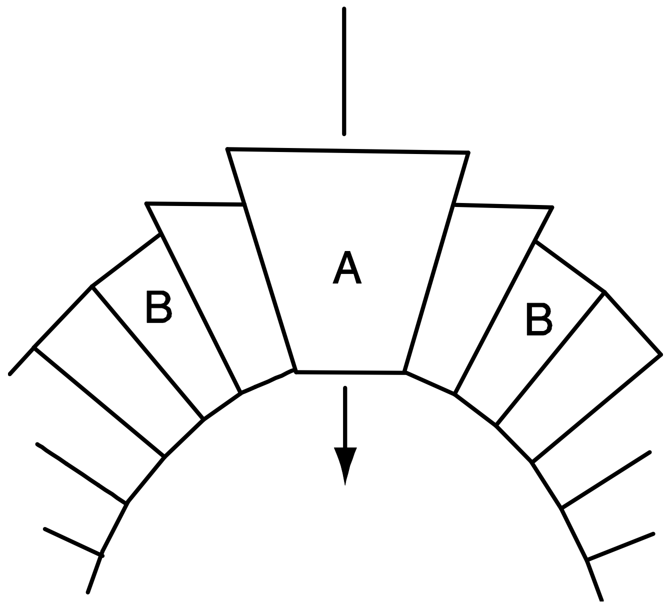
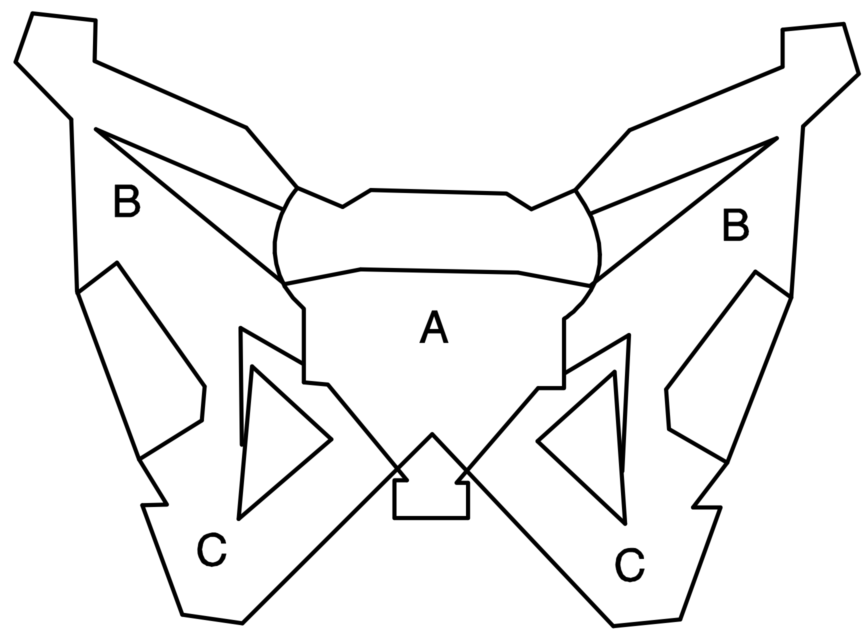
The Lumbo-Pelvic Mechanism

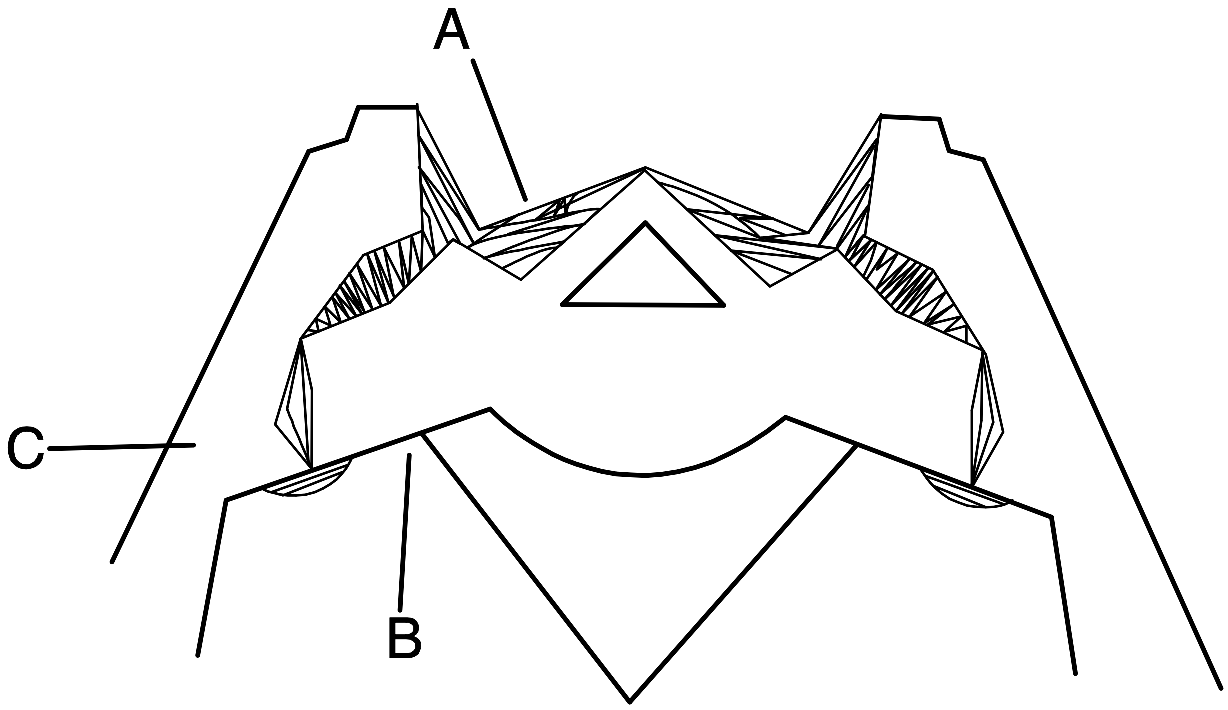


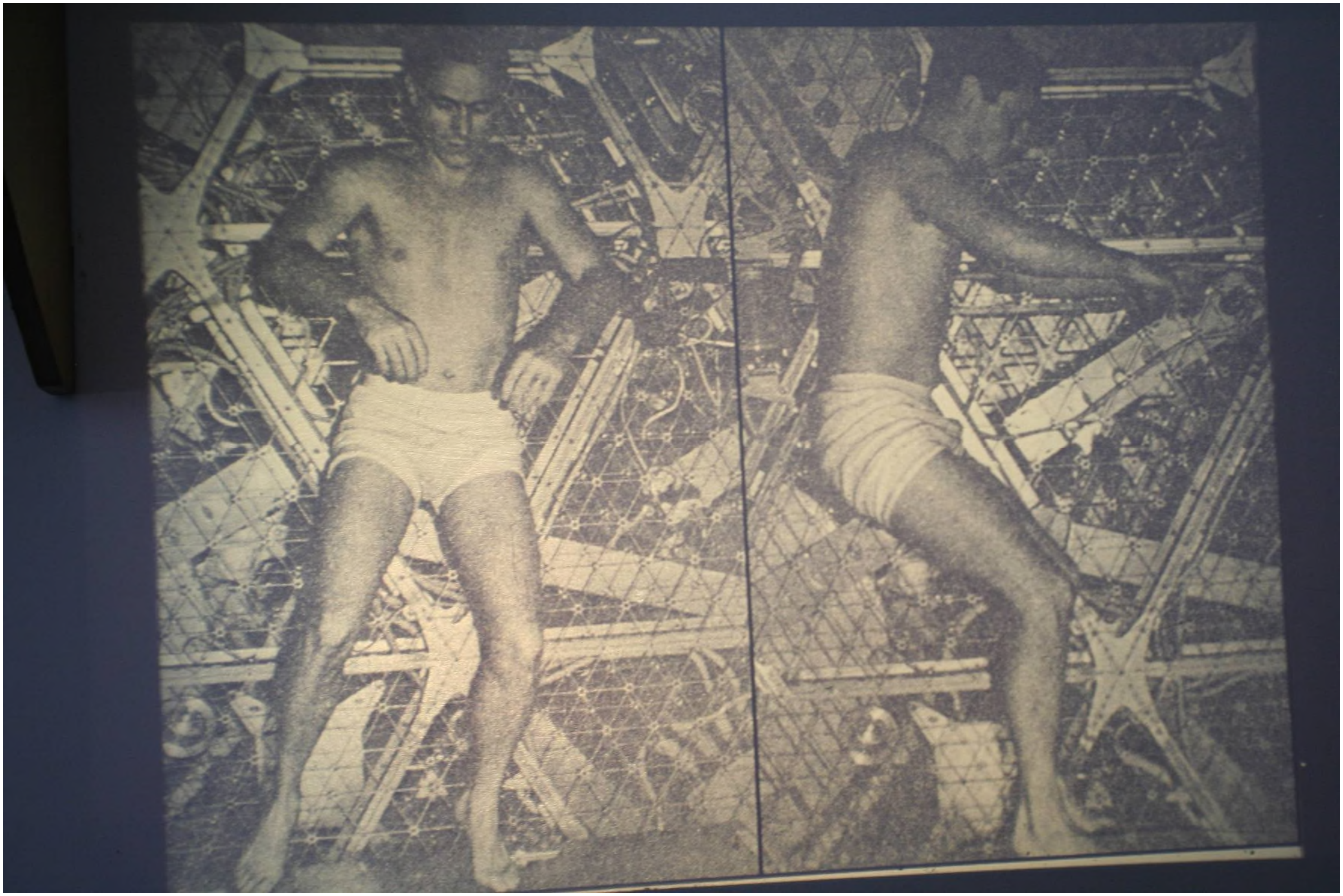
The Pelvis as an Arch



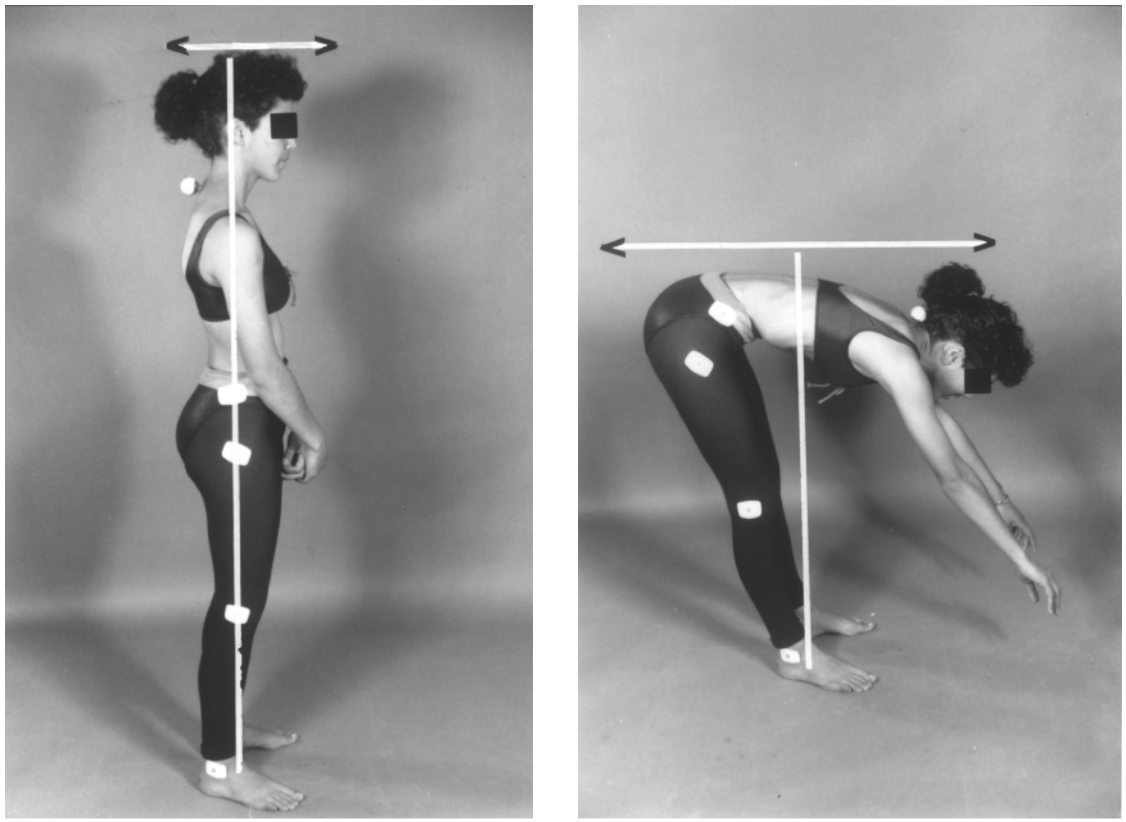


The Sacro-Iliac Joint Viewed From Above



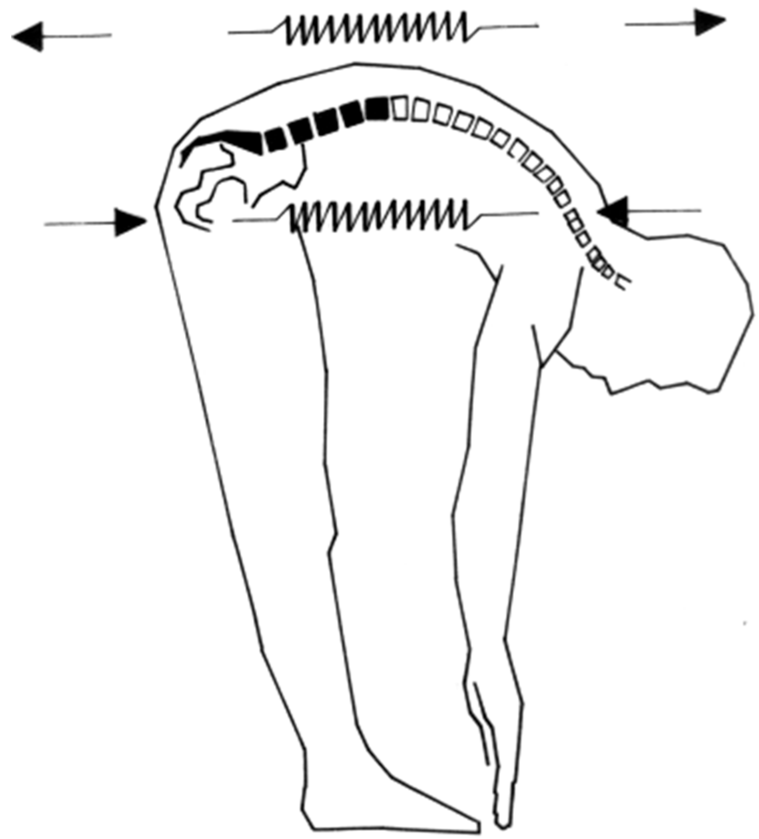


Postural Adaptation



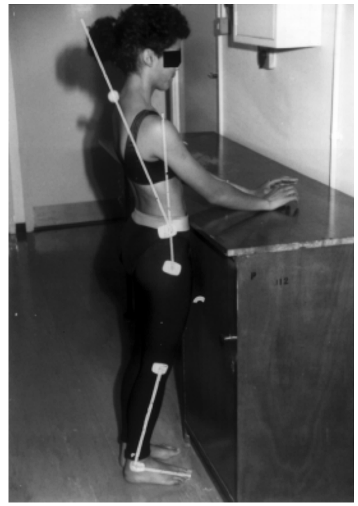
(a) (b)

Postural Adaptation and Tissue Loading

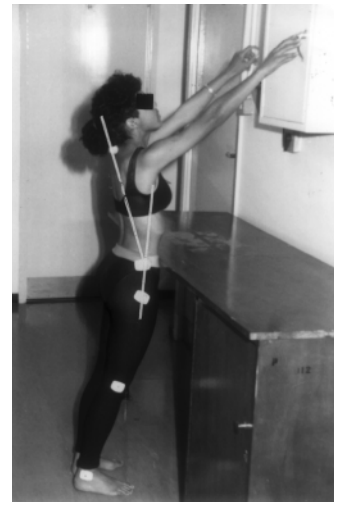


Postural Adaptation at Work

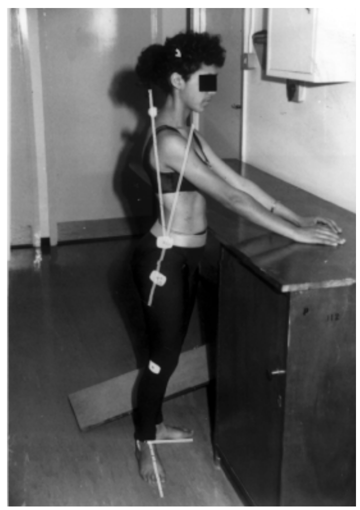
(a)



(b)



(c)



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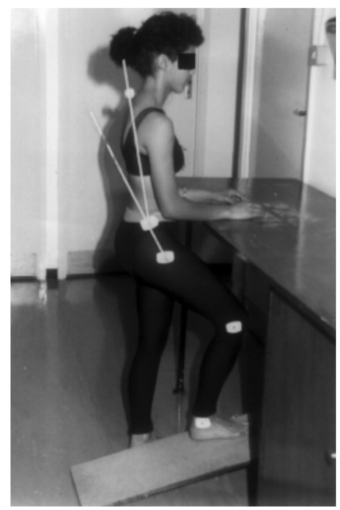
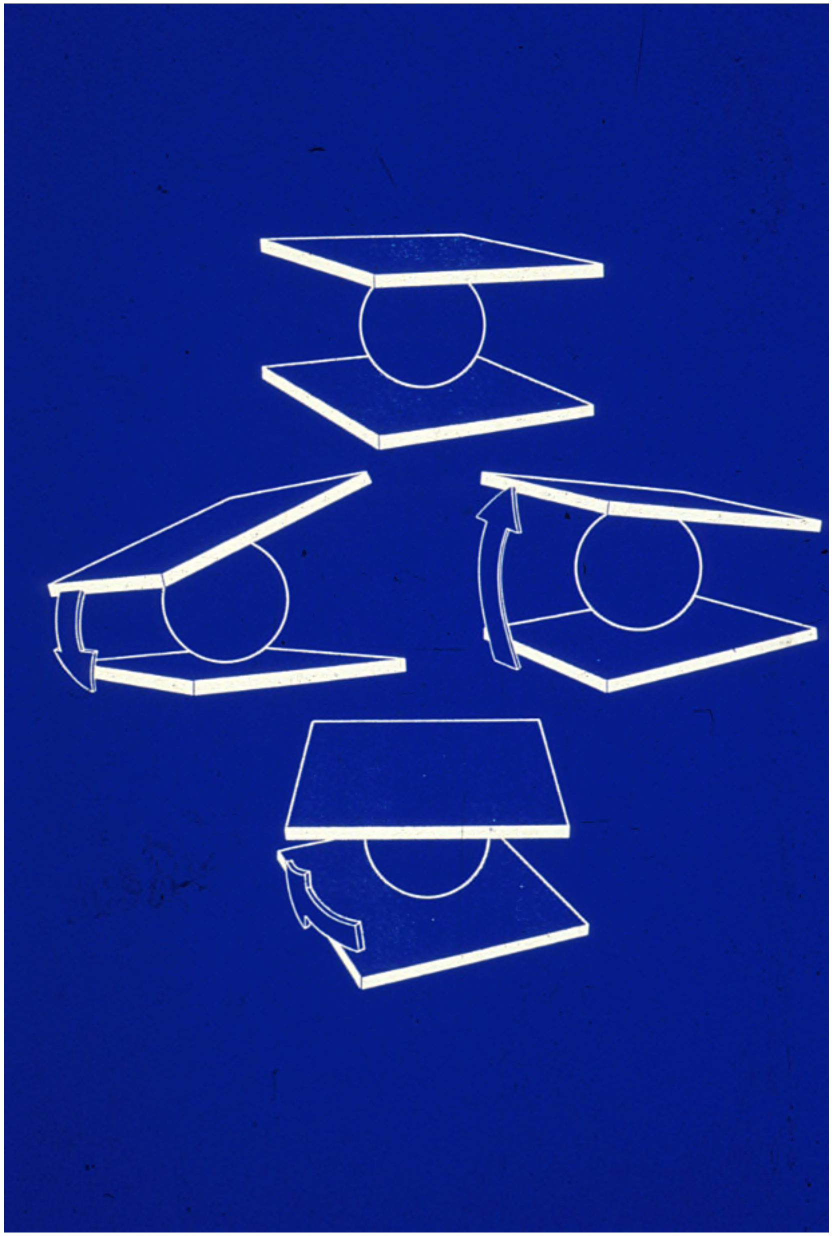


(e)

Intervertebral Discs

- Nucleus pulposus contains proteoglycans in solution
- Surrounded by layers of cartilage like the rings of an onion
- Fibres of the annular layers run obliquely, like the layers of a cross-ply tyre
- Nucleus is under positive osmotic pressure


N
A
a
b



Mechanical Functions of Components

- Vertebrae: to resist the compressive load - but the end plate is the weak link
- Facet joints: to resist the intervertebral shear force (particularly in the lumbar spine)
- Intevertebral discs: to separate the end plates of adjacent vertebrae and thus allow movement between the vertebrae
- Facets also play a role in *limiting* the movement that can take place

Where Does Back Pain Come From?

- Back muscles? Fatigue?
- Facet joints
- Outer rim of posterior annulus
- Sacro-iliac joint
- Nerve roots
- Vascular tissue that is not normally present
- The spinal joints are deep within the body, making it difficult to tell sometimes

Why does the Spine Fail?

- Disease and deformity (Scheurmann's disease, extra lumbar vertebra, congenital weaknesses etc.). People with these conditions are sometimes free of pain, though
- Ageing and degenerative processes
  - Lack of exercise, weak abdominal and back muscles
  - Disc degeneration and loss of "hydration"
  - Shortening of hamstring muscles and decreased mobility increases bending stresses on the spine
- Mechanical Failure: loading increases rate of cell death in the intervertebral discs
- Is chronic LBP "functional" is it a combination of several different factors interacting to produce a painful outcome?

The "Worn Out Lumbar Spine": Some Suggested Features [8-11]

- Degenerated or herniated intervertebral discs
- Osteophyte formation as evidence of abnormal strain responses
- Shnorl's nodes
- Vertebral end plate failure and calus formation
- Osteoarthritis of facet joints
- Spondylosis and spondylolisthesis
- Changes in back muscle biochemistry
- "Ragged red fibres" and increased "fatigue-ability" of back muscles
- Initial injury can lead to a vicious circle of maladaptation leading to further degeneration and loss of function.

Mechanical Failure

- The 3 main sites are:
  - The spine itself, including the ligaments
  - The muscles and their attachments
  - The trunk (hernias)

Mechanical Function of the Lumbar Spine [12-16]

- Vertebral bodies resist most (80%) of the compressive force acting down the spine
- Intervertebral discs also resist compression and allow small movements between vertebrae
- Facet joints protect the discs from shear and torsion
- Intervertebral ligaments prevent excessive bending
- Posture is fundamental to normal functioning - disc pressures increase in forward flexion and decrease in extension as the facet joints take more of the load. Facets may take 70% of compressive force if disc is severely degenerated.

Mechanical Failure of the Lumbar Spine

- Vertebral body is the weak link in the chain - vertebral end plate failure is common in life - evidence of microfractures in most cadaveric specimens
- Damage limit is 60% of SCTL and fatigue limit (under whole body vibration 20-30%).
- Fractures of the pars interarticularis caused by high shear forces and/or lumbar extension cause lumbar vertebra to move forward and down
- Extension and high bending moments cause damage to inferior margin of facet joints. 1-3 degrees of torsion can damage the joint surfaces

Mechanical Failure of the Lumbar Spine [17]

- 70% of spine's resistance to flexion is due to ligaments, rest is from the disc.
- In hyperflexion, the interspinous ligament is the first to go and is wholly or partially ruptered in 20% of cadaveric specimens
- Next to go are the facet joint capsular ligaments, then the disc
- Sustained flexion reduces ligament strength by 40% in 5 minutes and 67% in 1 hour. Ligamentous protection of discs is therefore reduced during subsequent flexions
- Discs are NOT damaged by compressive loading. Torsional loading damages the facet joints long before the disc. Compression , lateral bending and forward bending combined are the only known movements that cause lumbar disc prolapse

Mechanical Failure of the Lumbar Spine[18]

- Mildly degenerated discs may prolapse through existing radial fissures in the annulus
- Severely degenerated discs are too fibrous to prolapse which is why old people don't suffer this injury as often as the middle-aged
- There is a genetic predisposition to disc prolapse
- There is some evidence that sustained flexion lowers the blood supply to the lumbar spine by increasing the hydrostatic resistance to blood flow
- Increased intra-abdominal pressure MAY protect the spine by preventing implosion of the vertebral bodies, particularly the end plates, under sudden compressive loading

Where Does the Pain Come From? A number of possibilities

- Mild reversible backache - no different from any other form of temporary myalgia of mechanical origin
- Pain from the muscles - DeLuca, Biederman - rapid fatigue of back extensors
- Pain in flexion - Snook's theory
- Pain in extension - disc degeneration leads to problems with the facet joints
- Pain in "re-extension" - viscous lengthening of posterior ligaments

Back Pain in the Workplace

- More than 25% of accidents involve handling goods of some kind (HSE)
- Most common cause of low back injury in US is falling, not lifting
- Low back pain accounts for 15% of all Liberty Mutual compensation claims and 23% of costs
- Low back pain more likely in those who regularly lift weights of 3kg. or more in their jobs
- Low back pain less likely in those who occasionally lift weights compared to not at all.
- Lifting is the commonest precipitating event for acute herniated lumbar intervertebral disc - compared to falling, standing, car driving etc.

Lies, Damn lies, Statistics and Costs

- Liberty Mutual insurance company data 1999
- 8.3% of low back claims account for 82.3% of total claim costs for LBP
- A small number of serious injuries last for more than 3 months and so the picture is very skewed
- Interventions need to target high risk areas and high risk people in order to cost-justify themselves
- Blanket preventative efforts are a blunt instrument. They may be morally defensible, but are rarely cost-ineffective
- Screening for cervical cancer as an example of "unhealthy prevention"

Prevalence of Back Pain

- Brattberg et al. 1989.
- Overall prevalence in population is high
- Multiple episodes are the norm
- Prevalence highest in 45-64 yr. age group
- LBP without radiation is the norm
- Prevalence increases with age
- Higher in females than in males
- Miedema et al. (1998). LBP became chronic in 28% of patients (7-year follow-up)

Prevalence of Back Pain

- LeBouef-Yde et al. 1998. 1 yr. Prevalence rises from 7% at 12 yrs to about 50% at 25 whence it levels off up to age 40.
- Prevalence higher in high-income than low-income countries and higher in city than in rural populations
- Prevalence higher in low-income countries in “enclosed workshops”.
- Major problem with all this over-reliance on “yes”/“no” answers and lack of information on severity

Need for a Holistic View

- Evidence that LBP complaints correlate with a variety of other conditions in survey data
    - No. of other pain sites
    - Degree of psychiatric disturbance
    - Response bias depends on personality traits and cultural patterns
    - LBP loss of workdays is associated with compensation claims for other musculoskeletal injury in the last 3 yrs (Daltroy et al. 1997)
- Need to look at the whole person

Safety Propaganda - The Wrong Message

- The spine is easily damaged. Medical treatment can help but the damage has been done
- Bed rest is the best answer when your back hurts - avoid physical activity
- Further investigations, even surgery, may be needed (reinforces the message that the pain is beyond the patient’s control)
- Focus on pain avoidance (implicit message: assumption of normal life must await pain cessation)
- Encourages passivity, discourages coping/adaptation

Safety Propaganda - The Right Message

- Normally, there is no sign of any serious disease
- The spine is strong. Pain is not the same as damage
- Pain is a symptom that your back is not moving as it should be - it's just "out of condition"
- There are a number of treatments that can help - lasting relief depends on you
- Recovery depends on getting you back moving again - the sooner you are back on your feet, the sooner your back will feel better
- Don't let your back rule your life!

Contribution of Psychosocial Factors

- Between them, psychosocial factors account for over 30% of the variance in back pain disability
- Essential to take psychosocial factors into account when carrying out interventions/investigations in the area
- Suggests that psychosocial factors need to be included in the management of occupational low back pain
- COUNTER FATALISTIC BELIEFS!
- BUT……Don't forget about the other 70%!

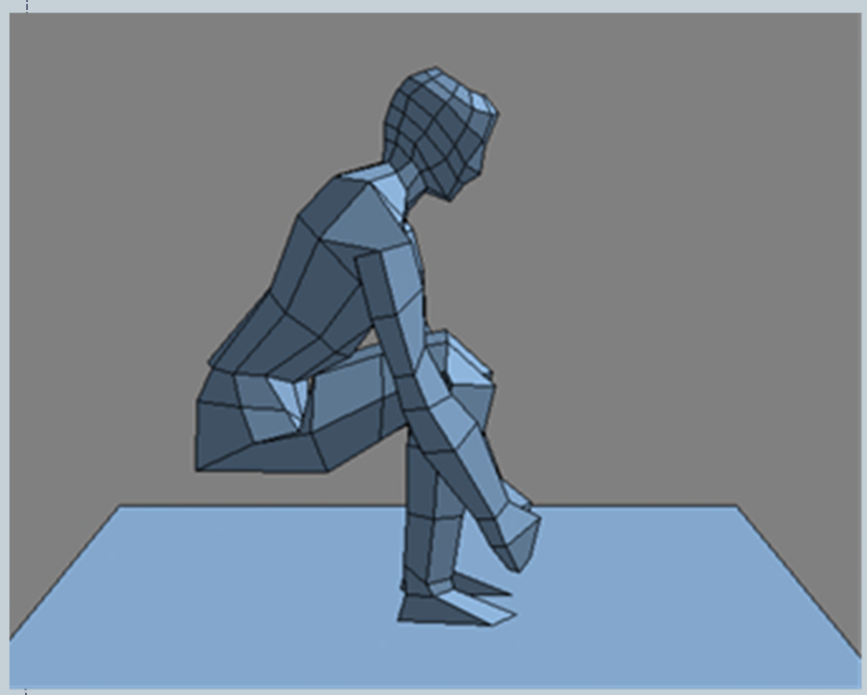
Problems Determining Work-Relatedness

- Mainly cross-sectional studies - can't make causal statements
- Outcomes measured as presence or absence of pain
- Exposure assessments are crude (e.g. job title)
- Lack of evidence of dose-response relationships
- An abundance of confounding variables
- Problems with risk factor epidemiology (plenty of evidence for "risk factors" but we still don't know what causes the disease).
- Odds ratios have enormous confidence intervals (e.g. 1.2-25)
- Possible solutions:
  - Large well-controlled studies across many different sectors
  - Small, tightly focused investigations of high risk areas with interventions and follow-up

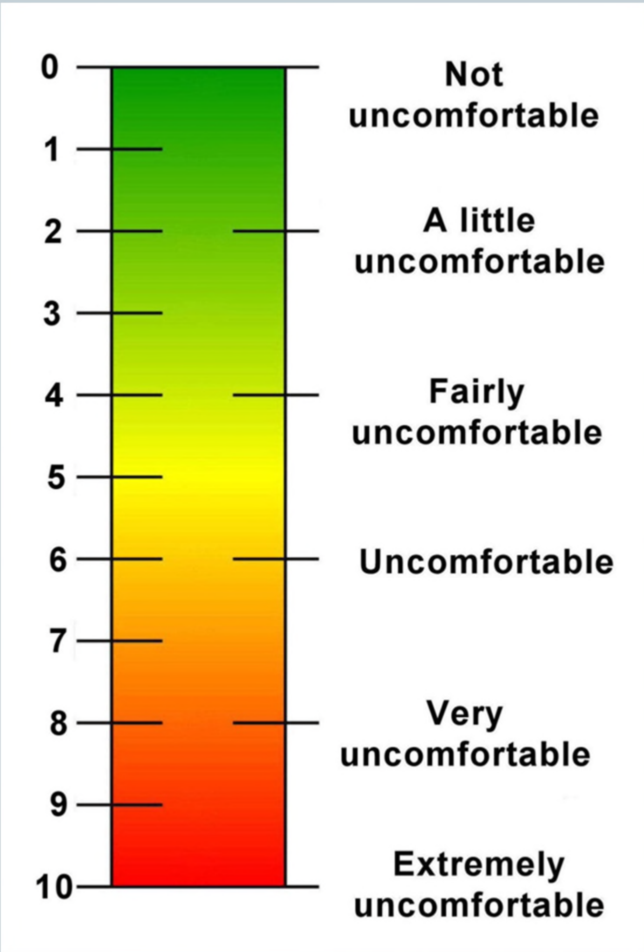
Risk Assessment

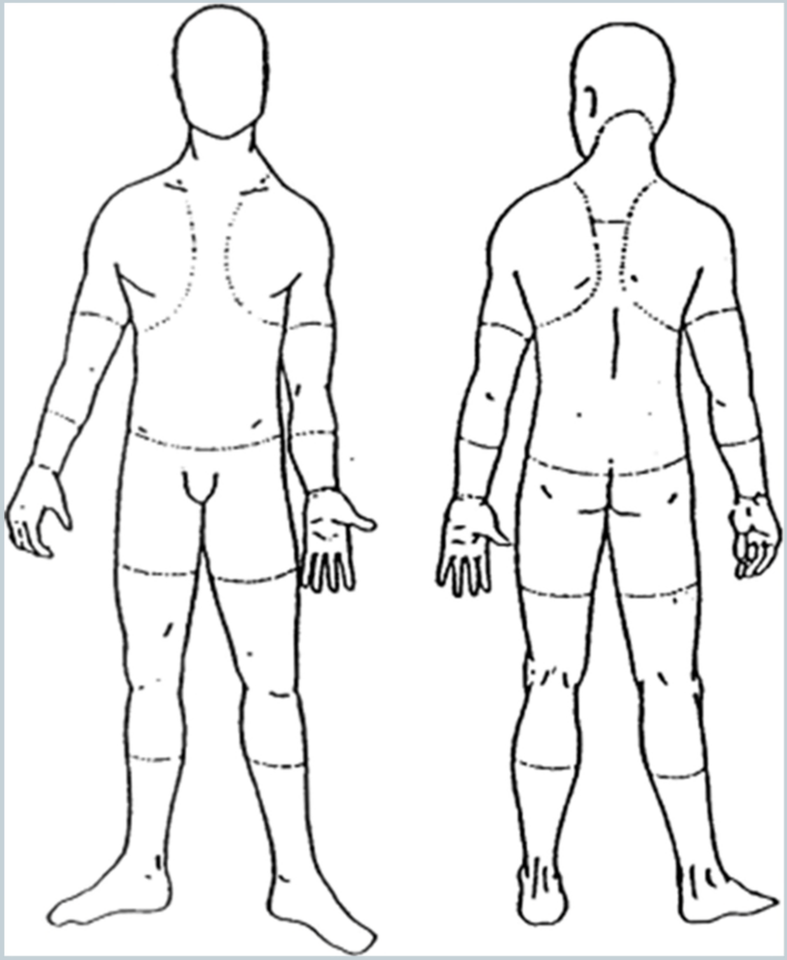
- Biomechanical Models (e.g. SSPP)
- NIOSH checklist
- Self reported regional discomfort

Figure 2.17



Body Diagrams





Summary

- Key characteristics for safe dynamic work:
  - Mechanical stability
  - Avoid fast movements
  - Damp high G forces
- Key characteristics of a good static posture
  - symmetry
  - an erect trunk
  - minimal static muscle activity
  - some kind of external support