BIOMECHANICS OF LOW BACK PAIN: A COMPUTATIONAL PERSPECTIVE

Babak Bazrgari, PhD
Associate Professor
F. Joseph Halcomb III, MD Department of Biomedical Engineering

Overview

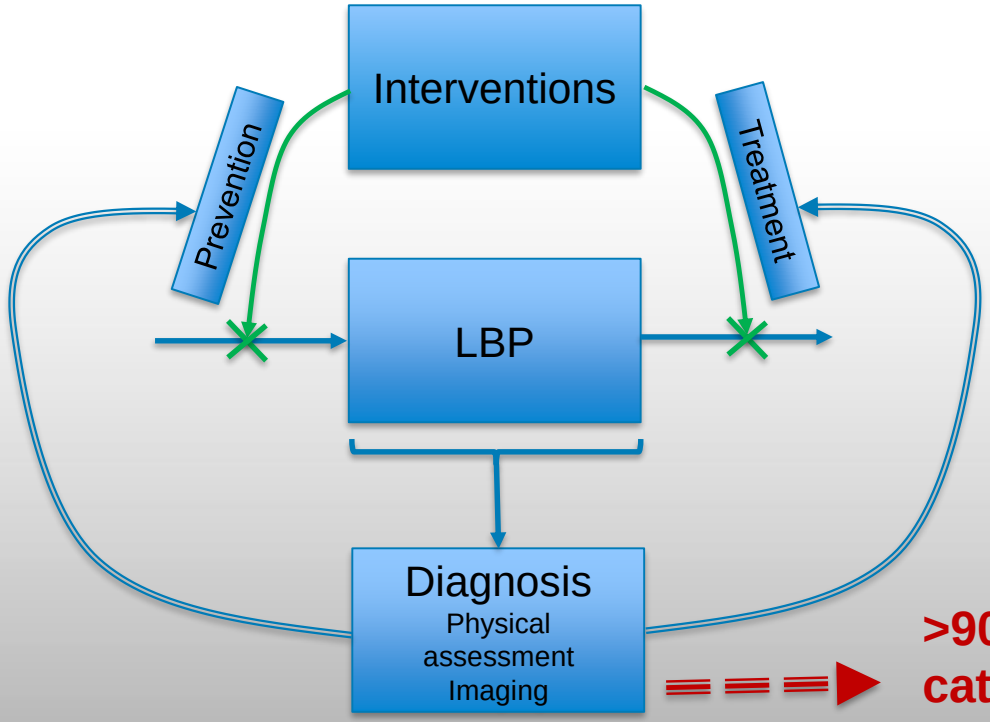
- Low back pain (LBP)
- Research focus
- Computational approaches
  - Spinal loads
  - Cumulative effects of abnormal spinal loads

Low Back Pain (LBP)

LBP Significance

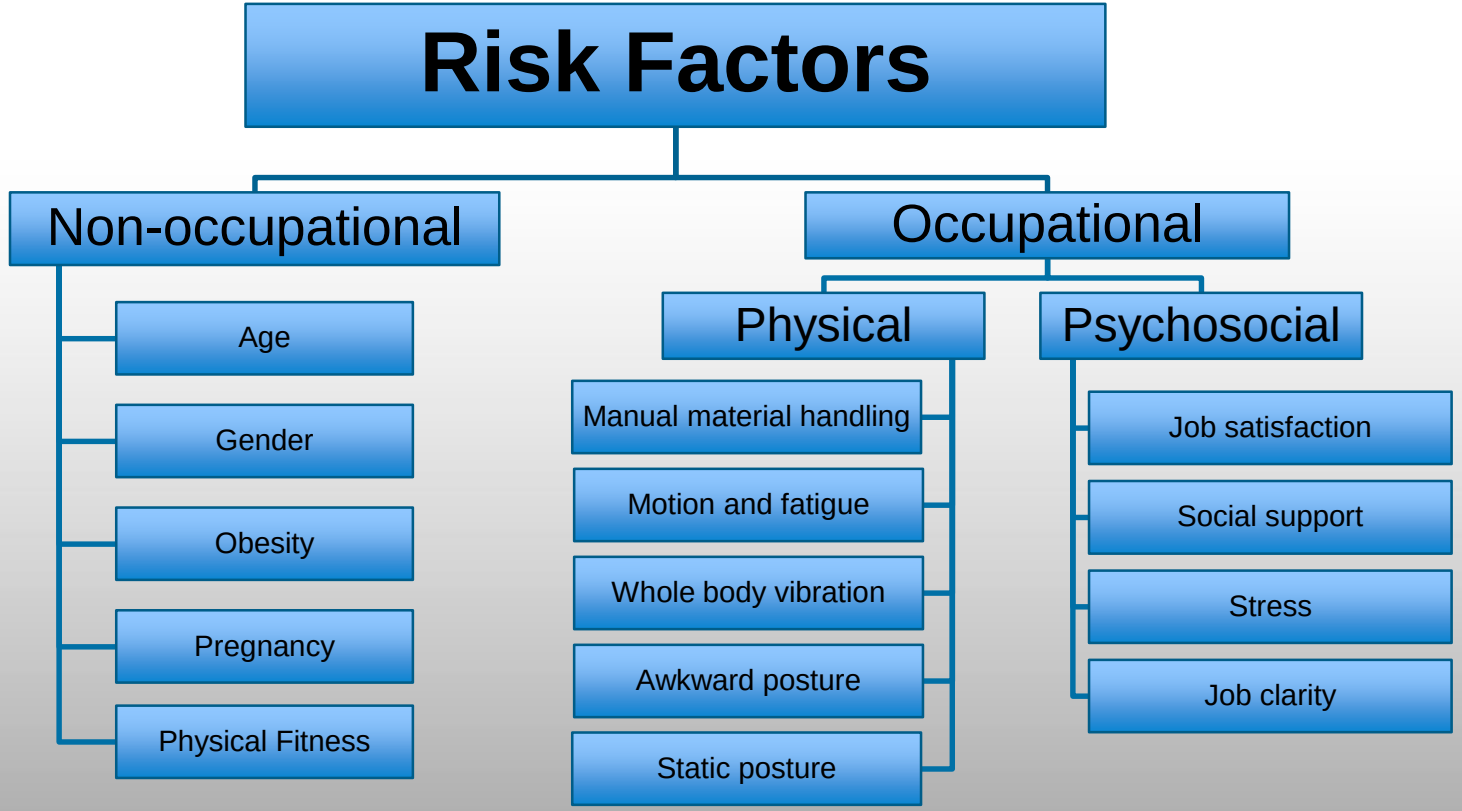
- **Prevalence**
  - ~ 20% of world population have LBP at any given time
  - Up to 80% of US population will experience LBP during their life time
  - Annual prevalence in old versus young individuals: 38% vs. 12%
  - Annual prevalence in person with and without lower limb amputation: 52-71% vs. 6-31%
- **Impact**
  - Chronic LBP is the leading cause of disability in the world
  - Chronic LBP force older workers to retire prematurely
  - Half of opioid users report LBP
  - Total cost associated with LBP has been reported to be >$100 billion per year

LBP Management

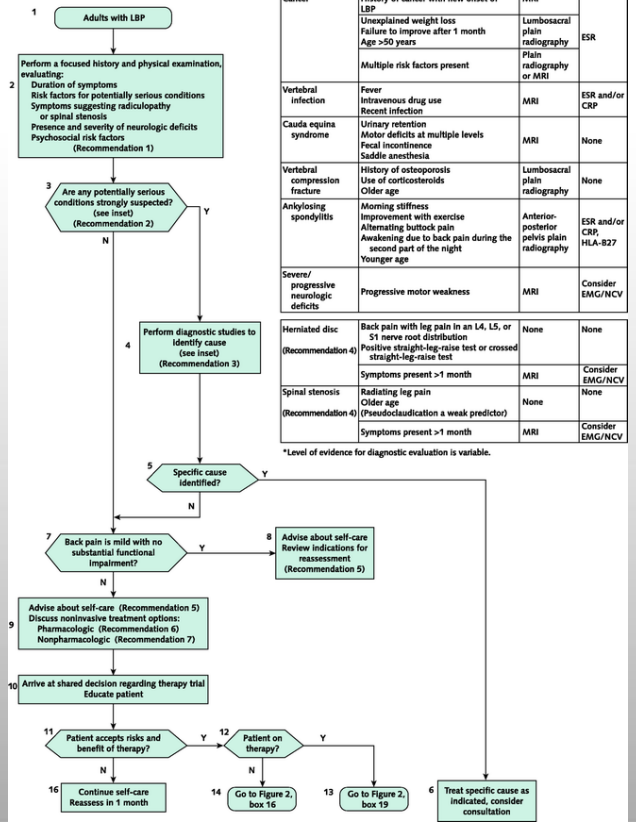


>90% LBP cases are categorized as non-specific LBP

Prevention: Risk Factor Management



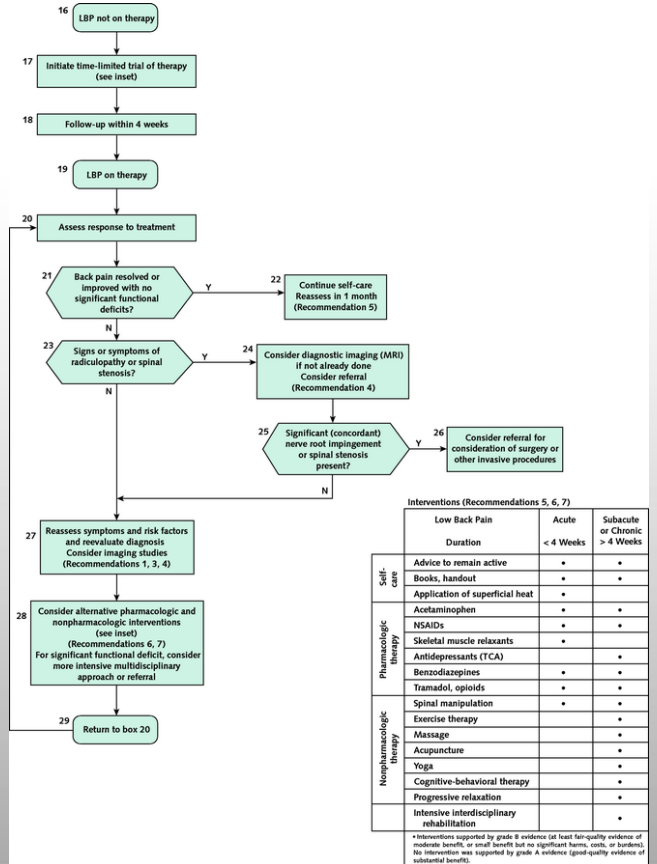
Treatment: Trial and Error Efforts



Diagnostic Work-up

Possible cause	Key features on history or physical examination	Imaging*	Additional studies*
Cancer	History of cancer with new onset of LBP	MRI	ESR
	Unexplained weight loss Failure to improve after 1 month Age >50 years	Lumbosacral plain radiography	
	Multiple risk factors present	Plain radiography or MRI	
Vertebral infection	Fever Intravenous drug use Recent infection	MRI	ESR and/or CRP
Cauda equina syndrome	Urinary retention Motor deficits at multiple levels Fecal incontinence Saddle anesthesia	MRI	None
Vertebral compression fracture	History of osteoporosis Use of corticosteroids Older age	Lumbosacral plain radiography	None
Ankylosing spondylitis	Morning stiffness Improvement with exercise Alternating buttock pain Awakening due to back pain during the second part of the night Younger age	Anterior-posterior pelvis plain radiography	ESR and/or CRP, HLA-B27
Severe/progressive neurologic deficits	Progressive motor weakness	MRI	Consider EMG/NCV
Herniated disc (Recommendation 4)	Back pain with leg pain in an L4, L5, or S1 nerve root distribution Positive straight-leg-raise test or crossed straight-leg-raise test	None	None
	Symptoms present >1 month	MRI	Consider EMG/NCV
Spinal stenosis (Recommendation 4)	Radiating leg pain Older age (Pseudoclaudication a weak predictor)	None	None
	Symptoms present >1 month	MRI	Consider EMG/NCV

*Level of evidence for diagnostic evaluation is variable.



Interventions (Recommendations 5, 6, 7)

	Low Back Pain Duration	Acute < 4 Weeks	Subacute or Chronic > 4 Weeks
Self-care	Advice to remain active	•	•
	Books, handout	•	•
	Application of superficial heat	•	
Pharmacologic therapy	Acetaminophen	•	•
	NSAIDs	•	•
	Skeletal muscle relaxants	•	
	Antidepressants (TCA)		•
	Benzodiazepines	•	•
	Tramadol, opioids	•	•
Nonpharmacologic therapy	Spinal manipulation	•	•
	Exercise therapy		•
	Massage		•
	Acupuncture		•
	Yoga		•
	Cognitive-behavioral therapy		•
	Progressive relaxation		•
	Intensive interdisciplinary rehabilitation		•

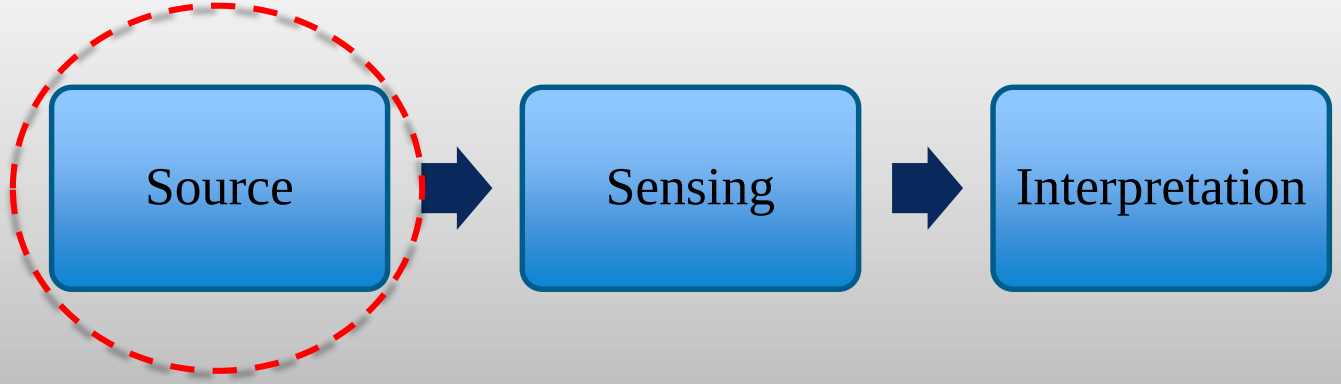
• Interventions supported by grade B evidence (at least fair-quality evidence of moderate benefit, or small benefit but no significant harms, costs, or burdens). No intervention was supported by grade A evidence (good-quality evidence of substantial benefit).

Chou et al (2007): Diagnosis and Treatment of Low Back Pain: A Joint Clinical Practice Guideline from the American College of Physicians and the American Pain Society

Research Focus

Research Need

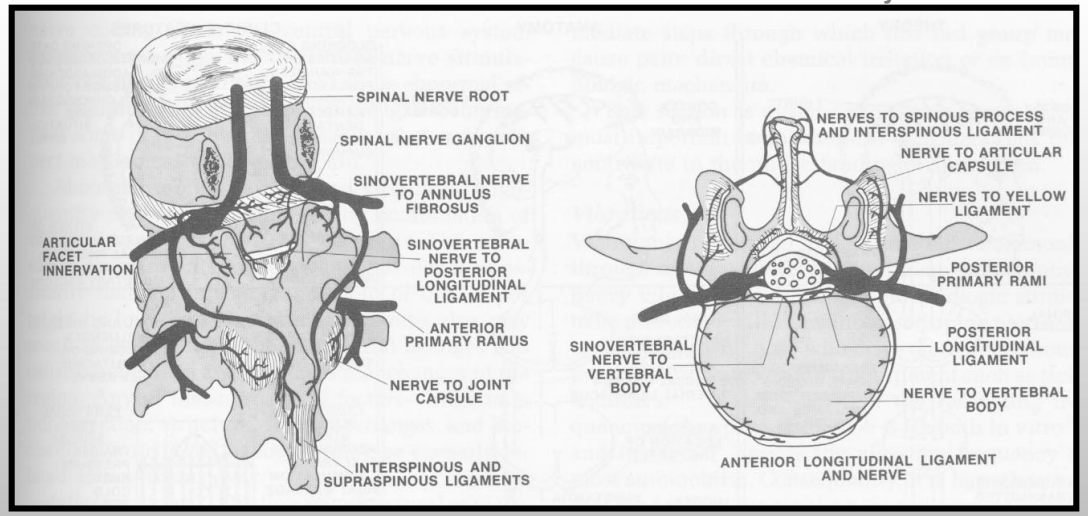
Determine the root cause(s) of LBP for a given patient



Research Focus

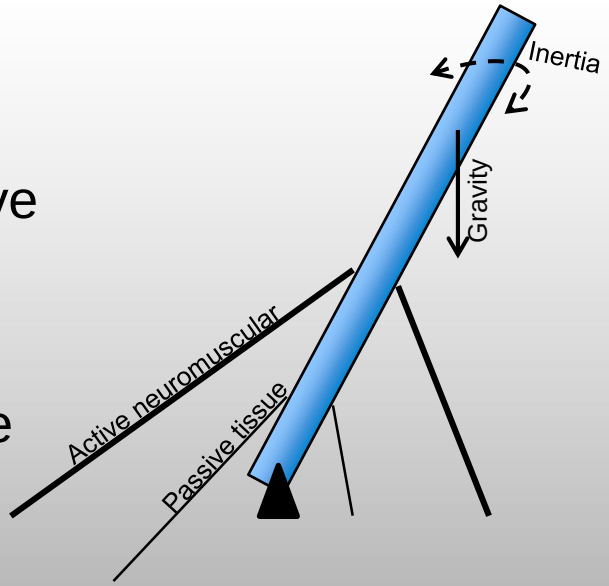
- Mechanical loading can cause LBP

White and Panjabi 1990

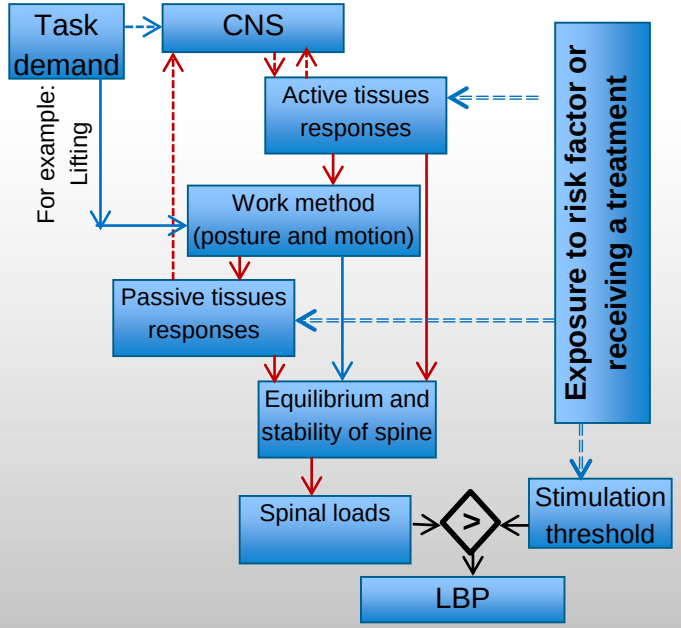


Spinal Loads

- Loads experienced in the spinal tissues are determined by the state of spine equilibrium and stability
- **Spine equilibrium:** A delicate balance between the physical demands of an activity and the active and passive responses of the spine tissues
- **Spine stability:** The capacity to regulate and sustain spine equilibrium within an optimal range that provides the spine both its rigidity and flexibility under diverse conditions



Research Design



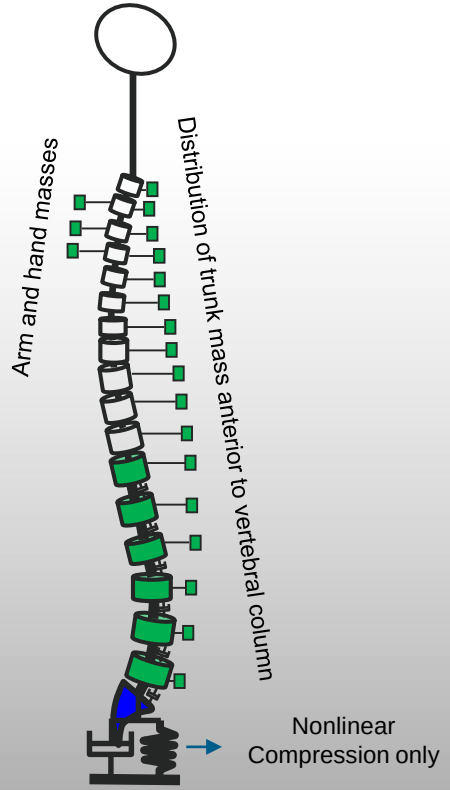
Evaluation of Spinal Loads

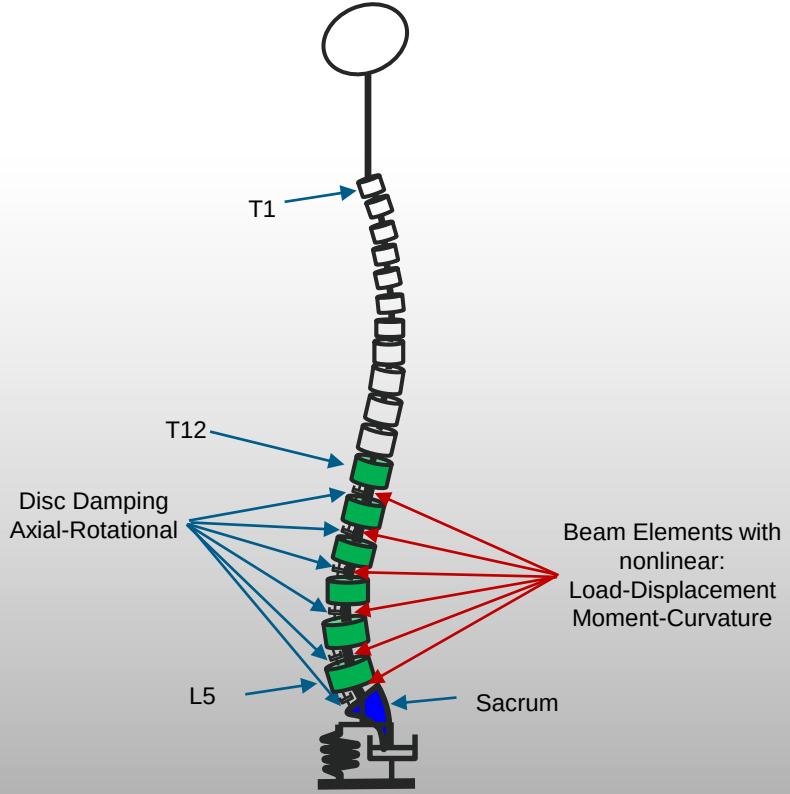
Spinal loads

Modeling Approaches

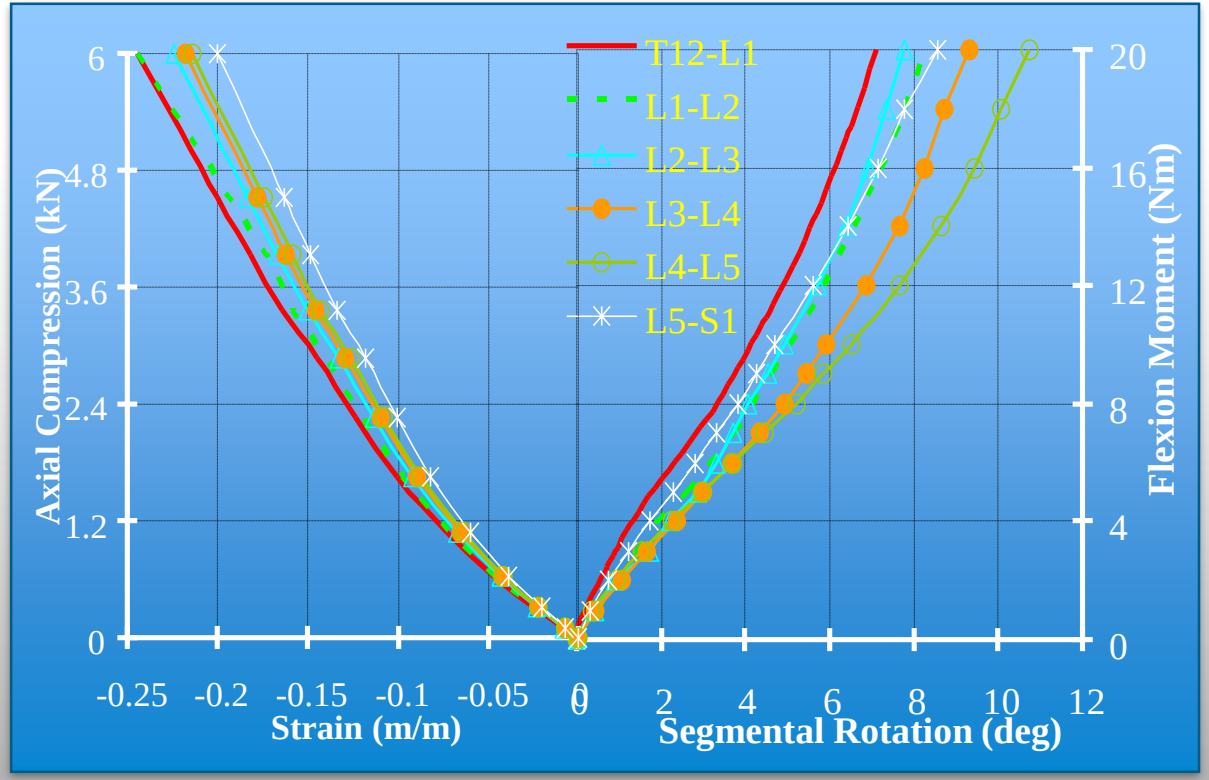
- **Modeling Approaches**
  - Rigid-body models
  - Rigid-body + muscle models (EMG-driven or Optimization-based)
  - Rigid-body + muscle + deformable-body models (finite element methods)
  - Equilibrium vs. stability-based models
- **Measures**
  - Mechanical demand of the task at lower back
  - Active and passive muscle forces
  - Passive mechanical response of ligamentous spine
  - Spinal loads (compression and shearing forces)

Finite Element (FE) Model

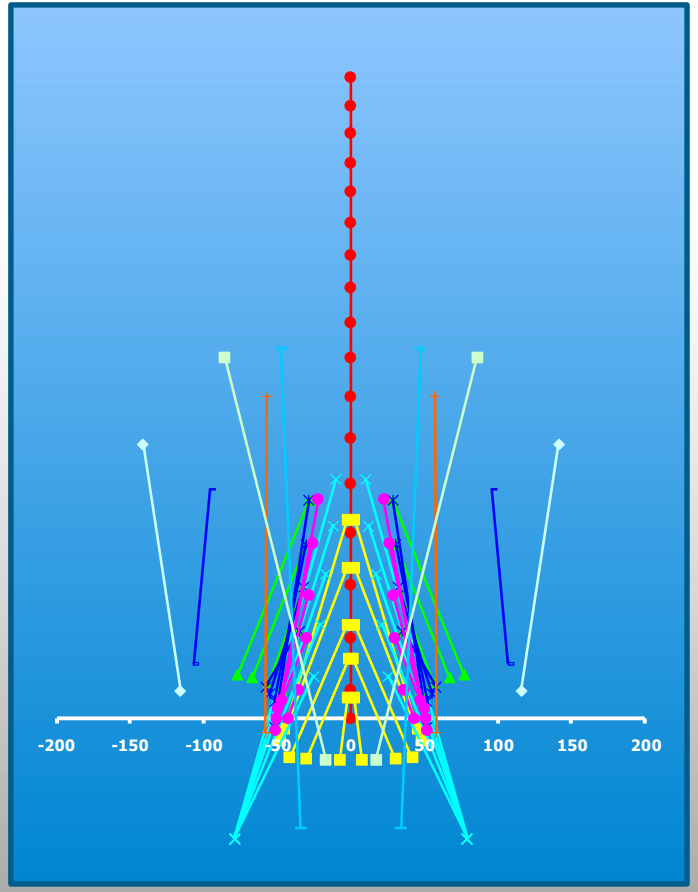


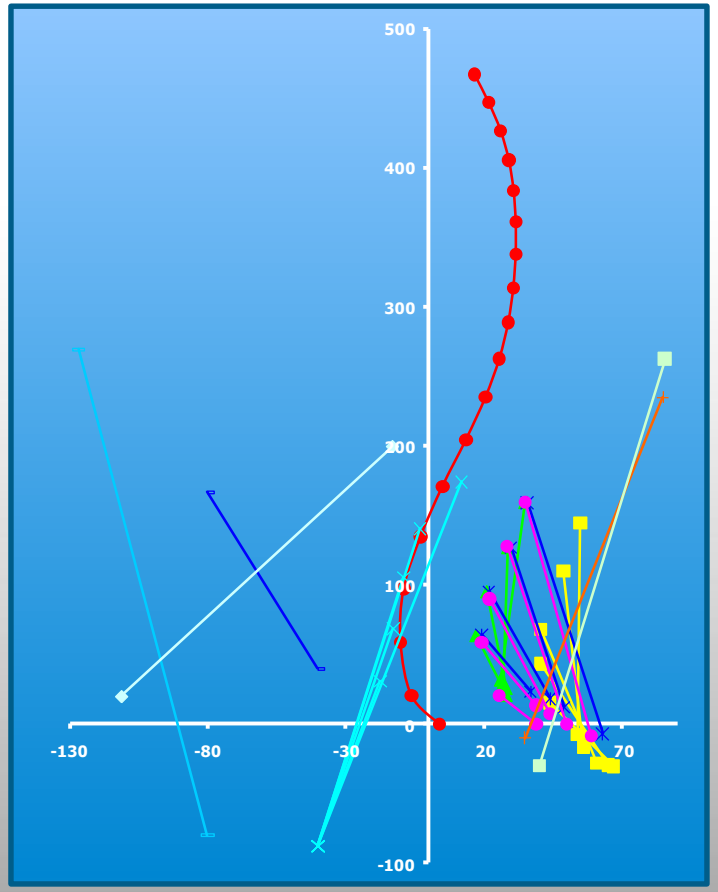


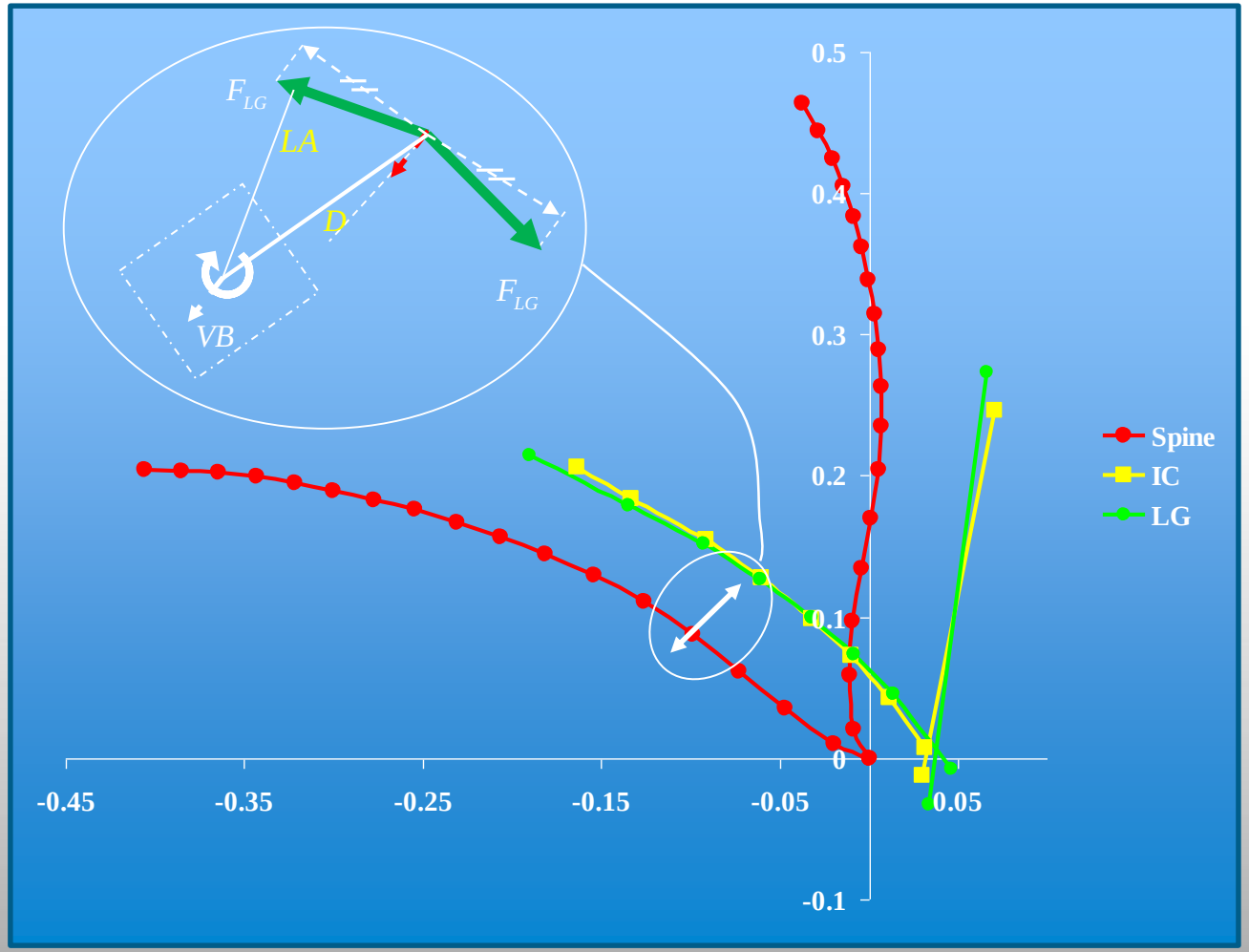
Passive Tissue Contribution



Active Tissue Contribution



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Spine
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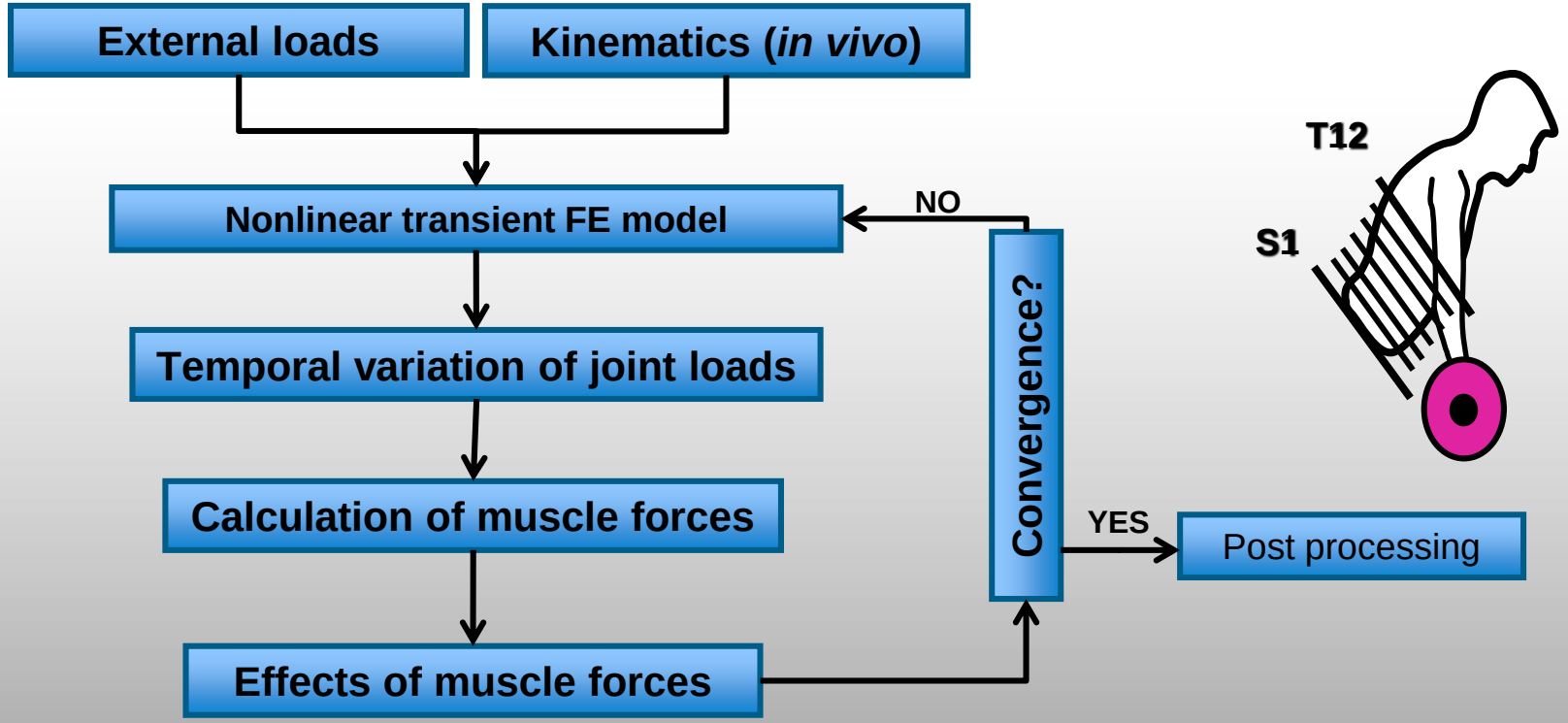
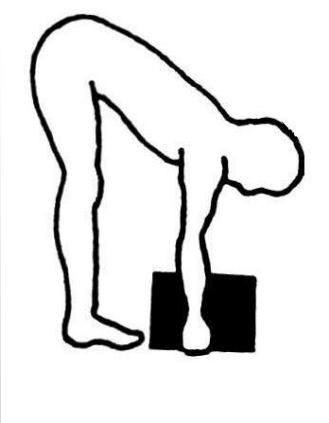
Kinematics-Driven Method



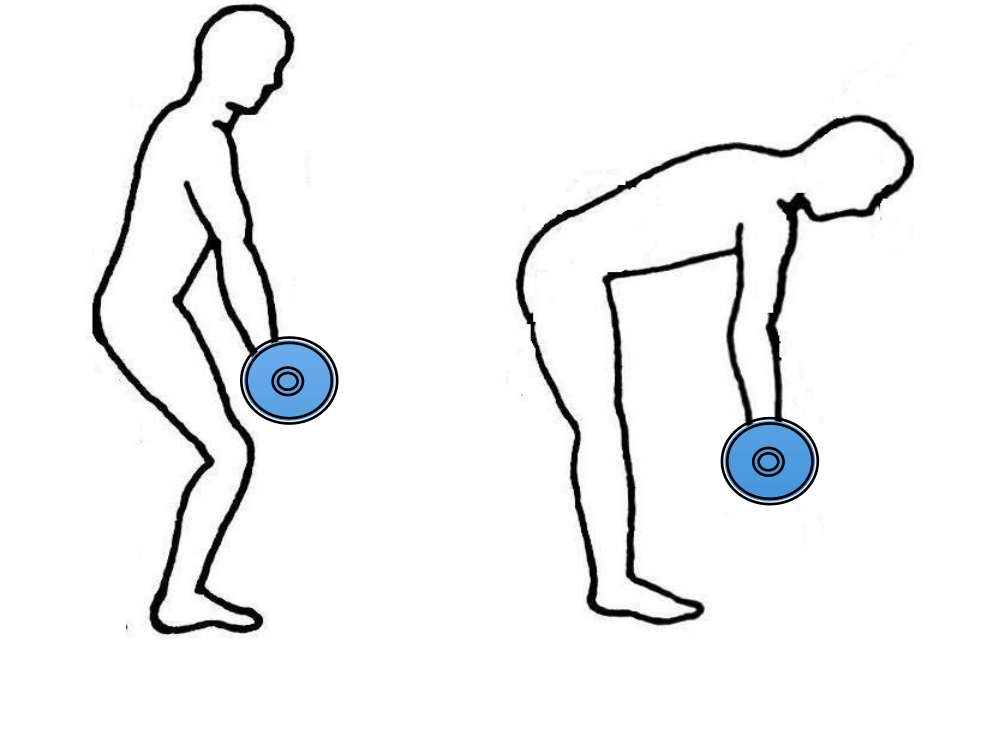
Squat vs. Stoop Lifting

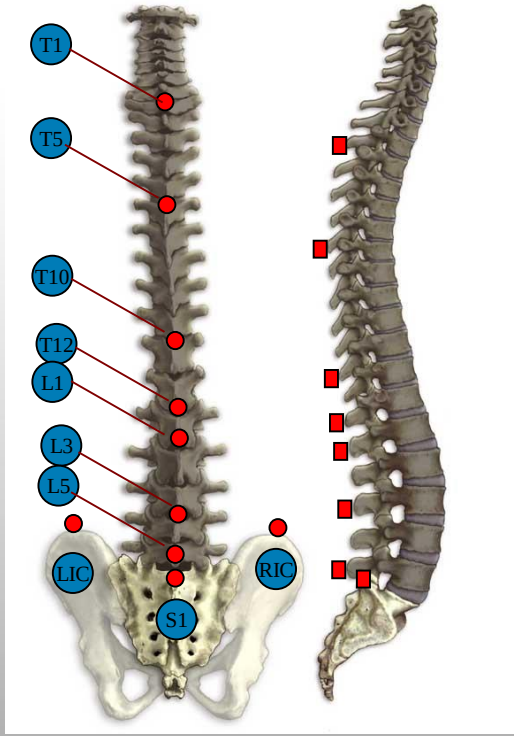


- Moment arm of load

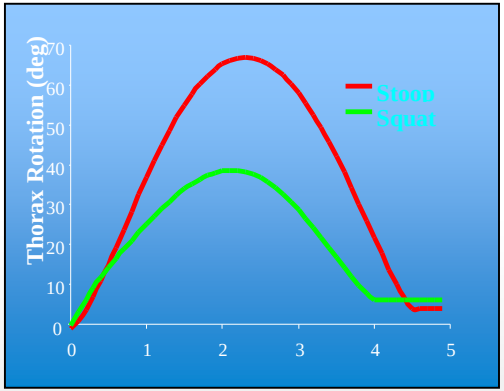
- Energy consumption
- Balance

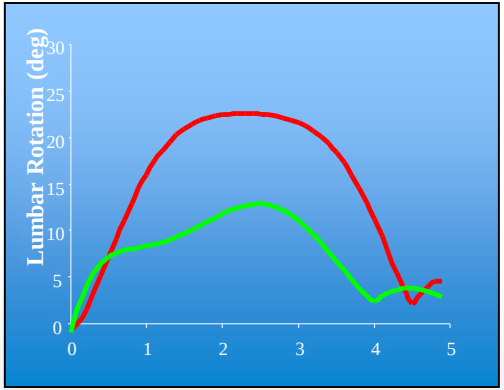
Experiments

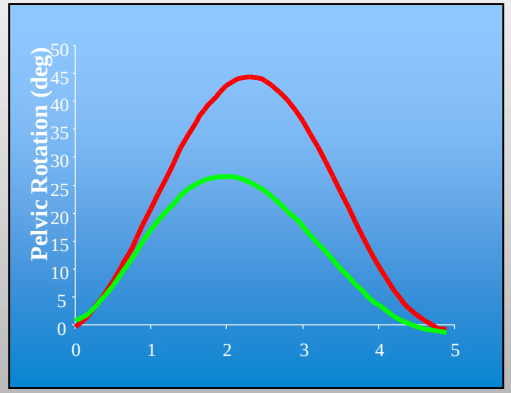




Trunk Kinematics







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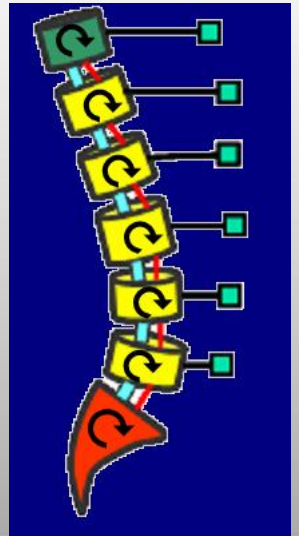
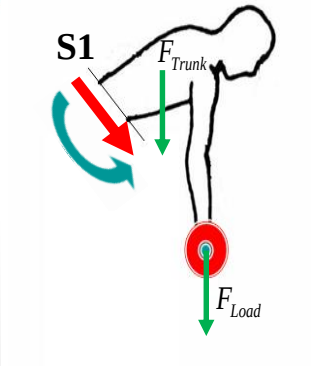
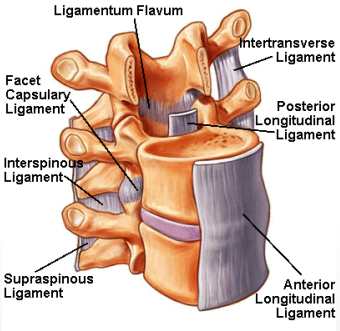
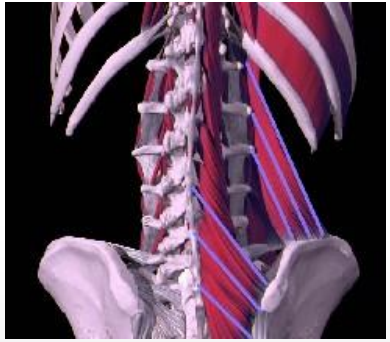
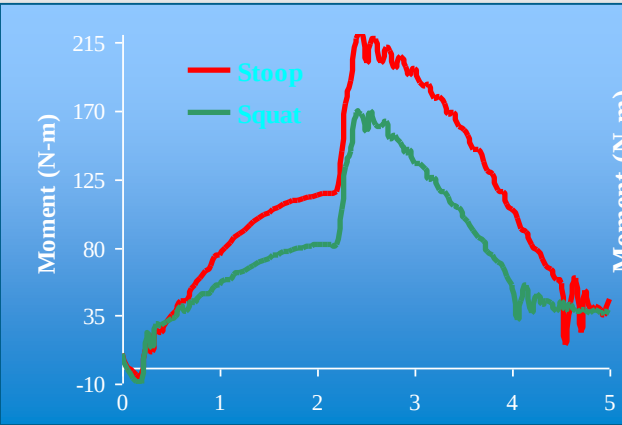


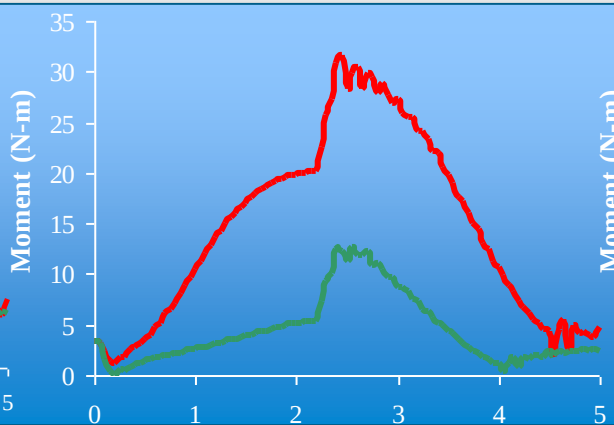


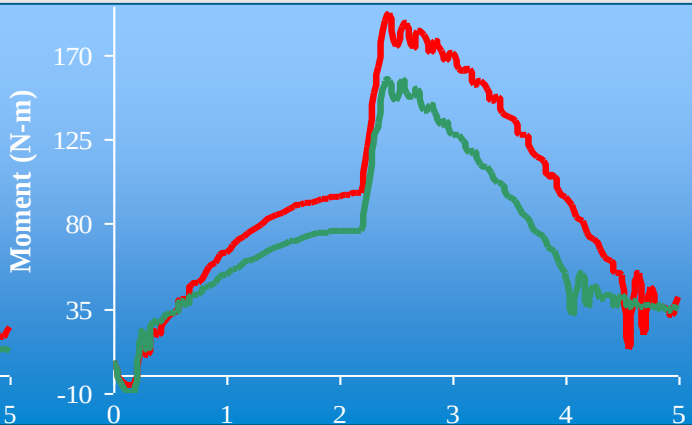




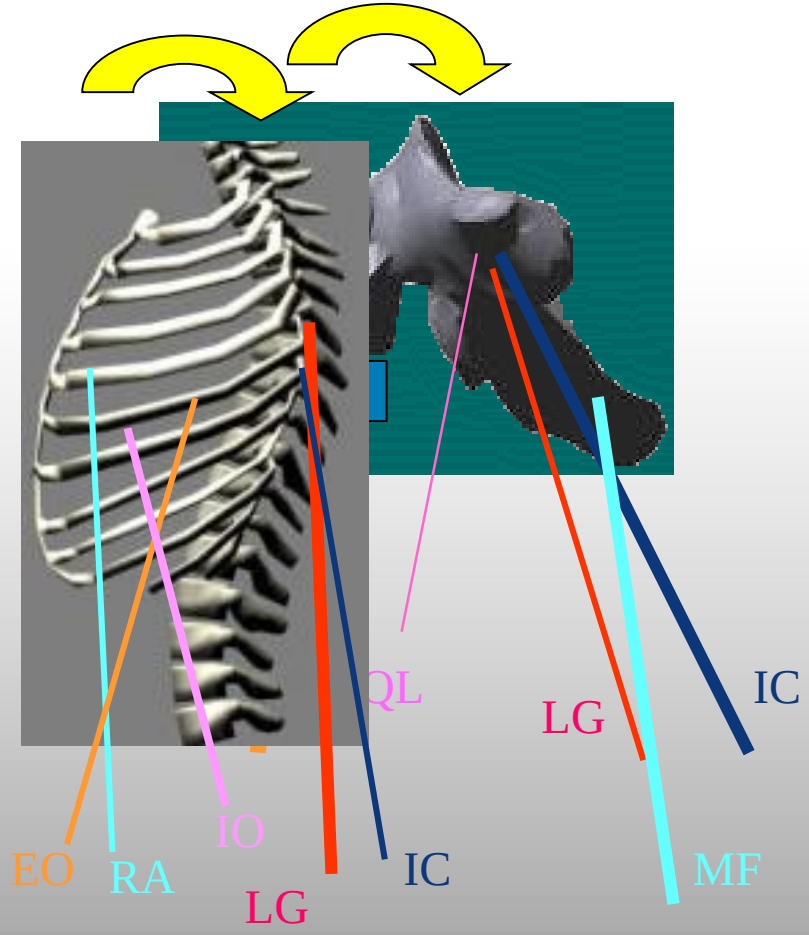
Net moment @ S1 = **Passive moment** + **Muscle moment**

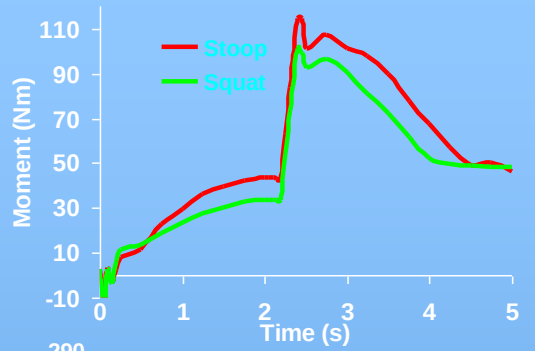


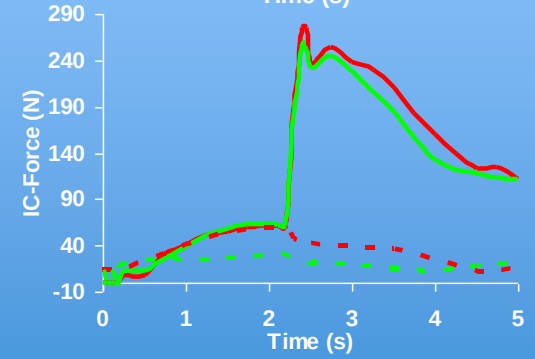


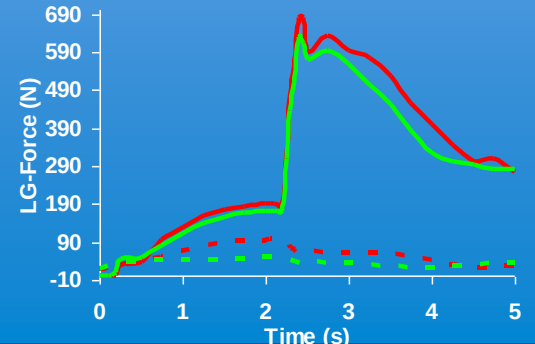


Muscle Forces



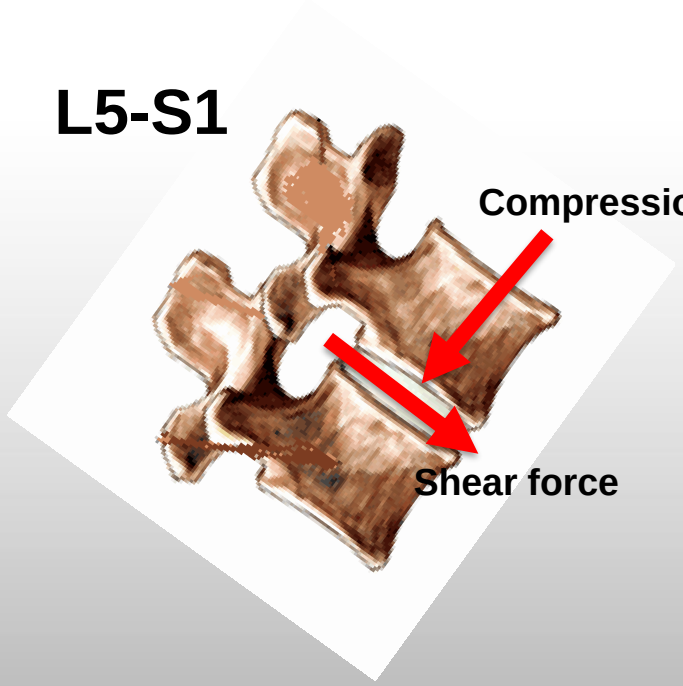


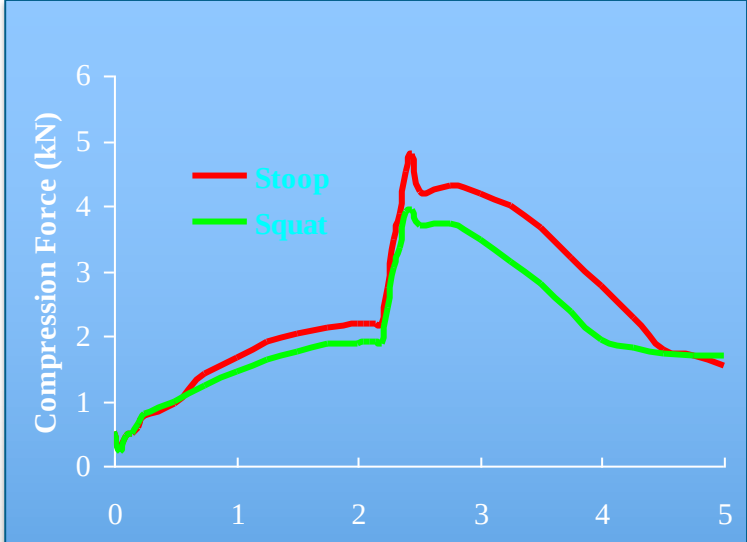


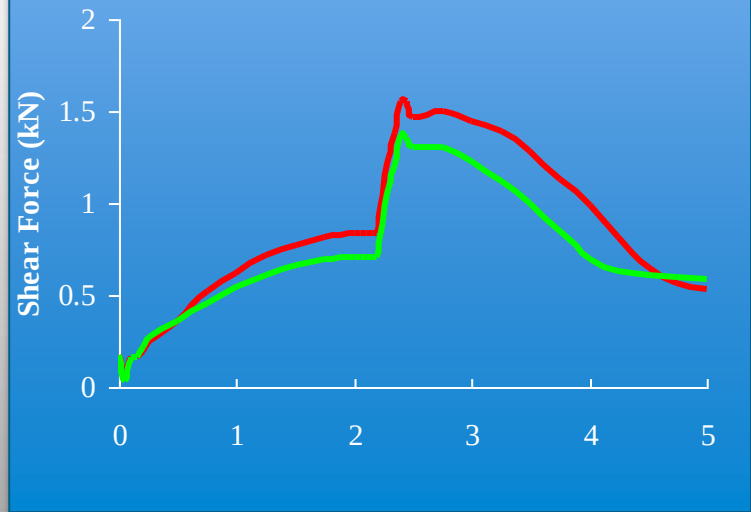


Spinal Loads

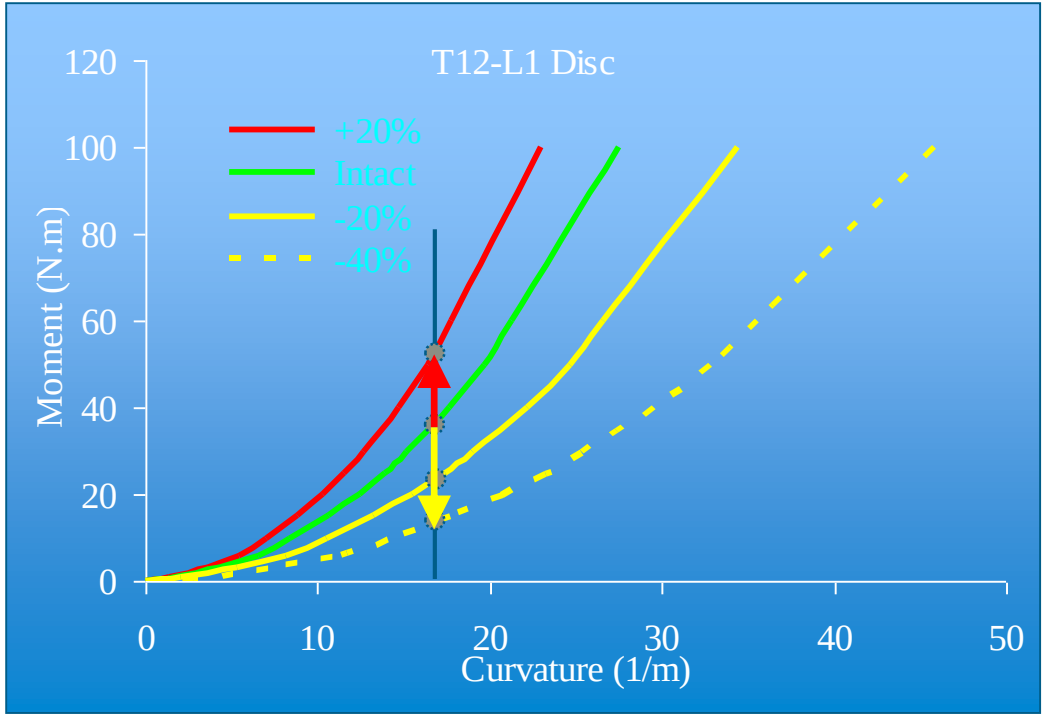
L5-S1



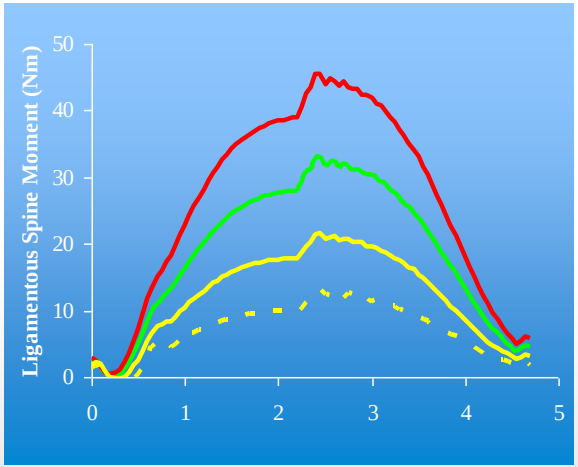


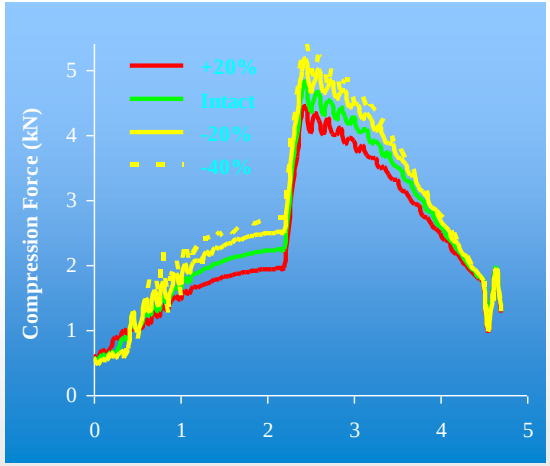


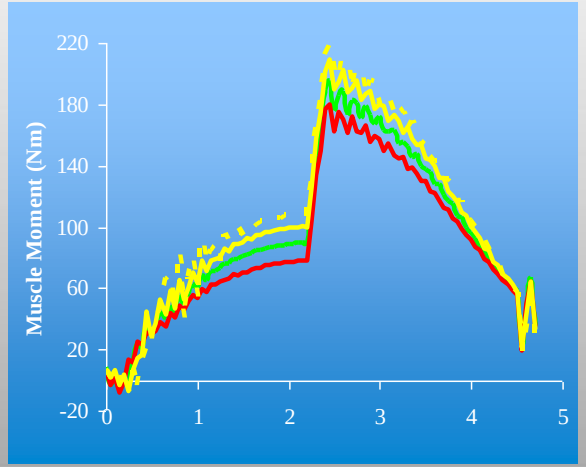
Alteration in Passive Properties

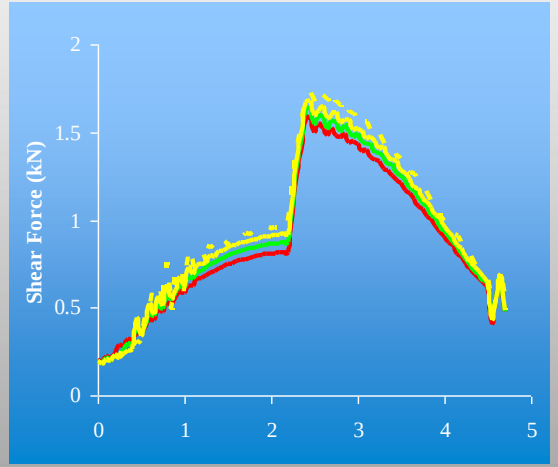


Alteration in Passive Properties





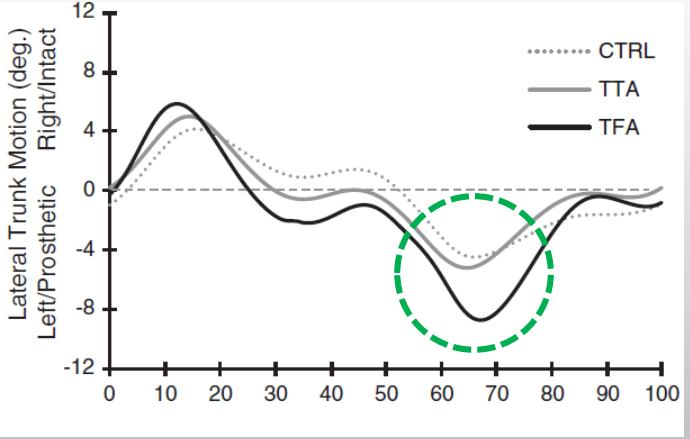


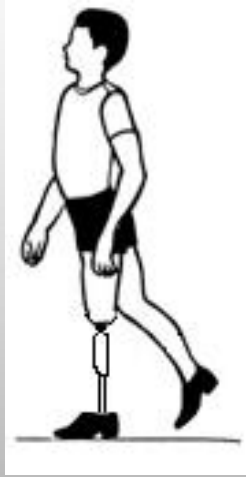


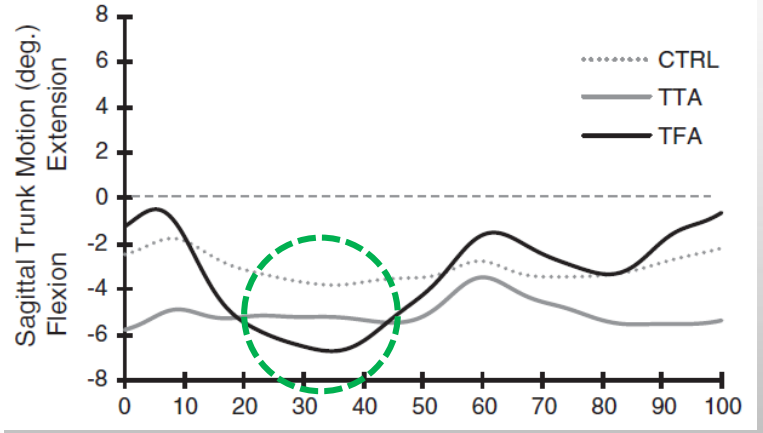
LBP and Lower Limb Amputation

Locomotion secondary to lower-extremity amputation

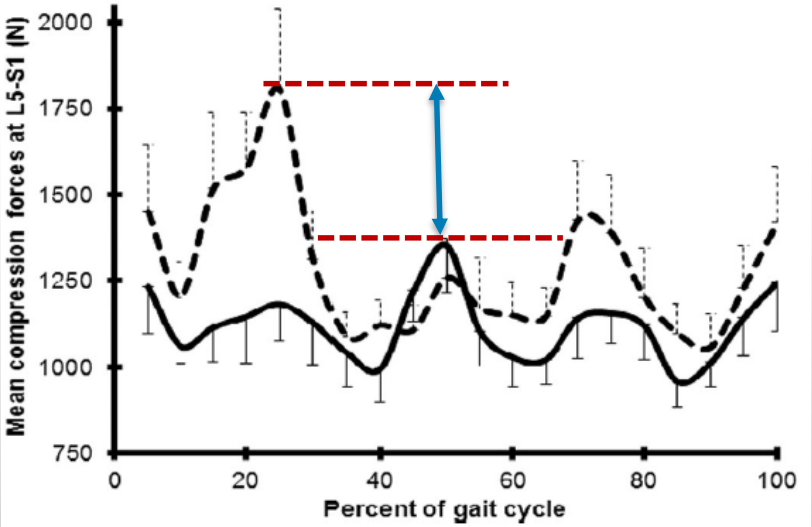
Increased and asymmetric trunk kinematics

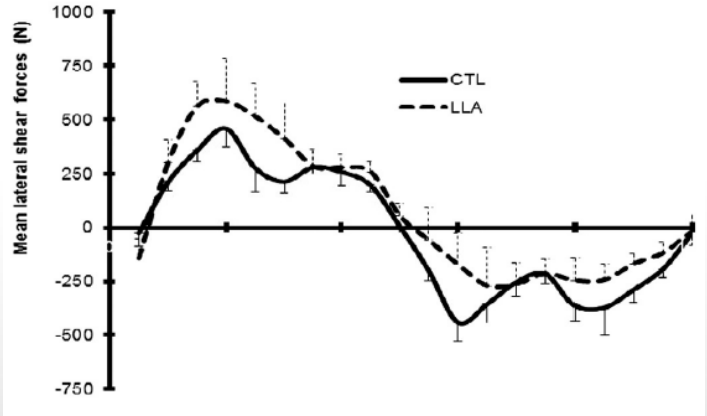


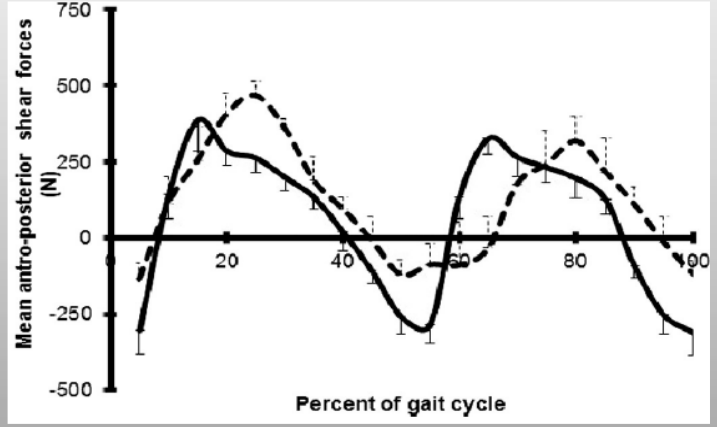




Spinal Loads During Walking

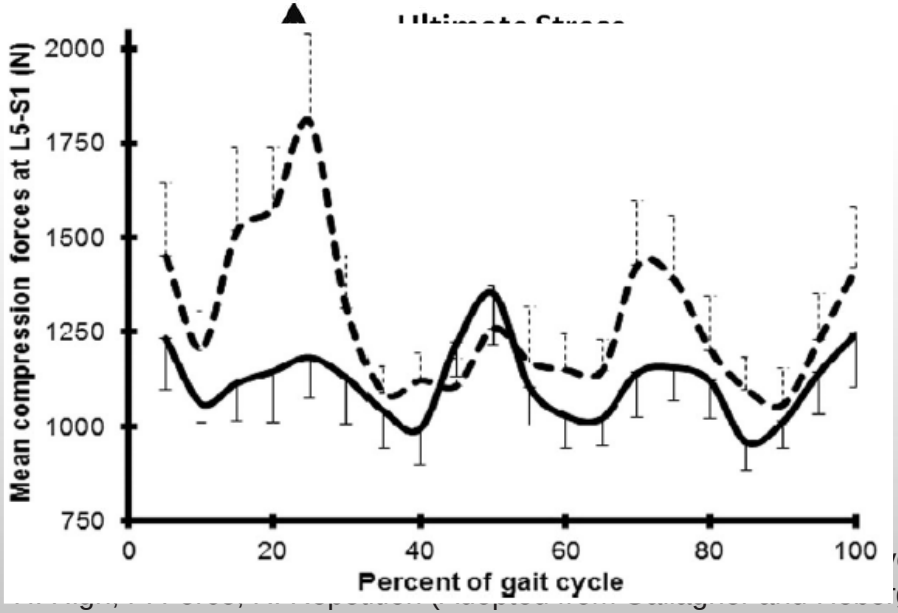






Cumulative effects of abnormal spinal loads

Fatigue Failure of Spinal Tissues



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Injury threshold of spine motion segment:
Compressive: 5-10 kN
Shear: 1-2 kN

Maximum spinal loads during walking:
Compressive: 1.2 vs 1.8 kN
Shear: 0.5 vs. 0.7 kN

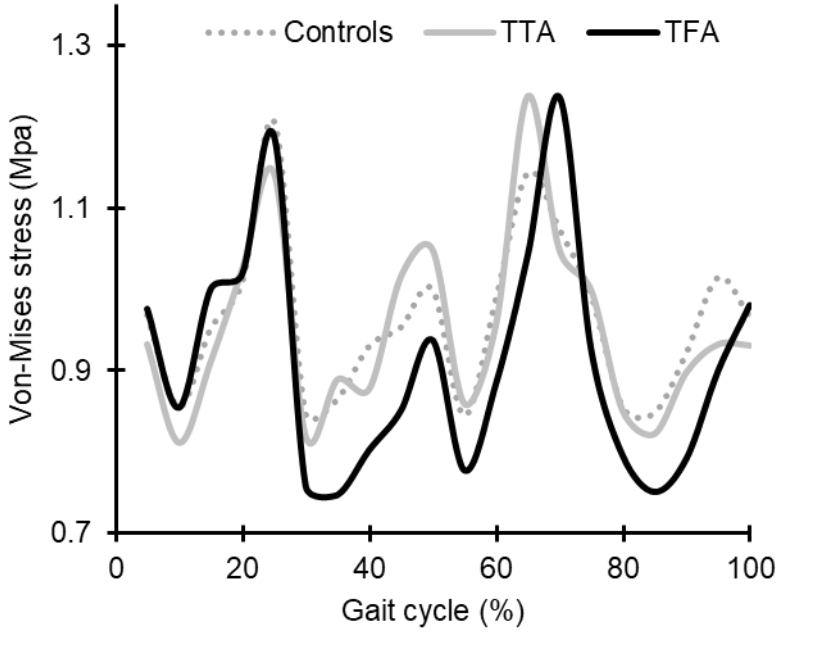
Fatigue Model (Motiwale et al 2018)

$$\sigma_{VM} = sign\left(\frac{F_{com}}{A_{disc}}\right)\sqrt{\left(\frac{F_{com}}{A_{disc}}\right)^2 + 3(\left(\frac{F_{AP}}{A_{disc}}\right)^2 + \left(\frac{F_{ML}}{A_{disc}}\right)^2)}$$

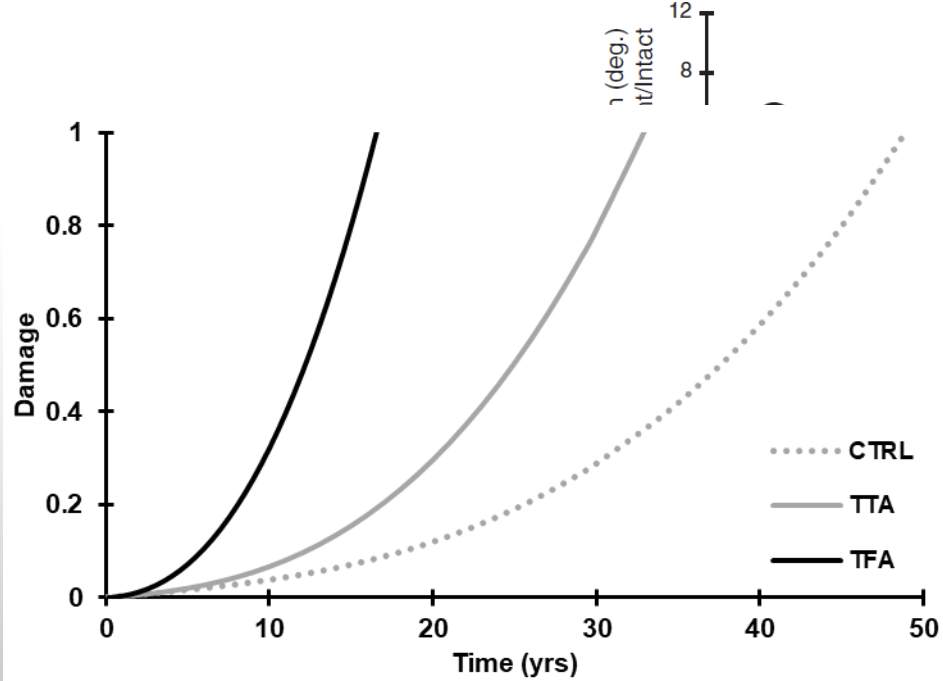
$$N_{fi} = \frac{1}{1-\alpha_i}\left[\frac{\sigma_{range}}{M_0(1-b\sigma_{mean})}\right]^{-\beta} \qquad \alpha_i = 1 - \langle a\frac{\sigma_{range}}{\sigma_u - \sigma_{max}}\rangle$$

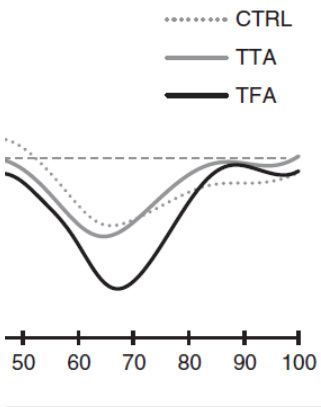
$$D_{mi} = \left(\frac{n_i^{eff}}{N_{fi}}\right)^{\frac{1}{1-\alpha_i}} \qquad n_i^{eff} = n_i + N_{fi}(D_{mi-1}^r)^{(1-\alpha_i)}$$

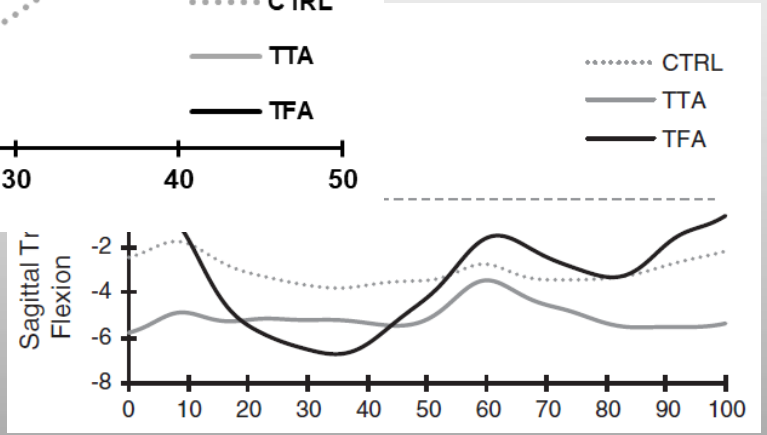
$$D_{mi}^r = D_{mi-1}^r + (D_{mi} - D_{mi-1}^r)(1-r)$$



Results


Damage
Time (yrs)
CTRL
TTA
TFA


CTRL
TTA
TFA


CTRL
TTA
TFA
Sagittal Tr
Flexion

Conclusions

- The inability to determine the cause of LBP for most cases poses a significant challenge for design of effective prevention and treatment interventions.
- Forces and deformations experienced in the lower back tissues can directly and indirectly stimulate pain sensitive nerve endings within the lower back
- Significant advances related to the assessment of lower back mechanical environment have been made
- An enhanced and more personalized evaluation of lower back mechanical environment can help design more effective preventive and/or rehabilitation strategies.

Questions