FINITE ELEMENT MODELING AND ANALYSIS OF THE HUMAN SPINE

Presenter:

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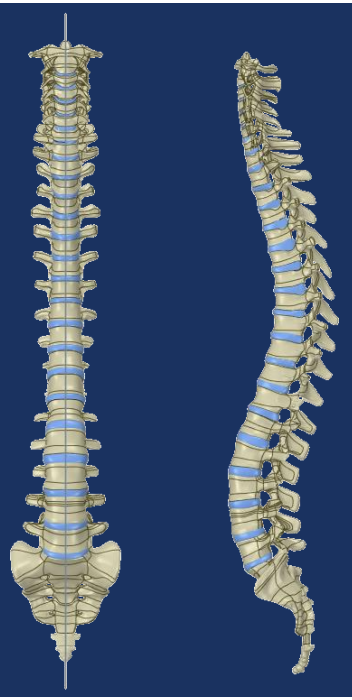
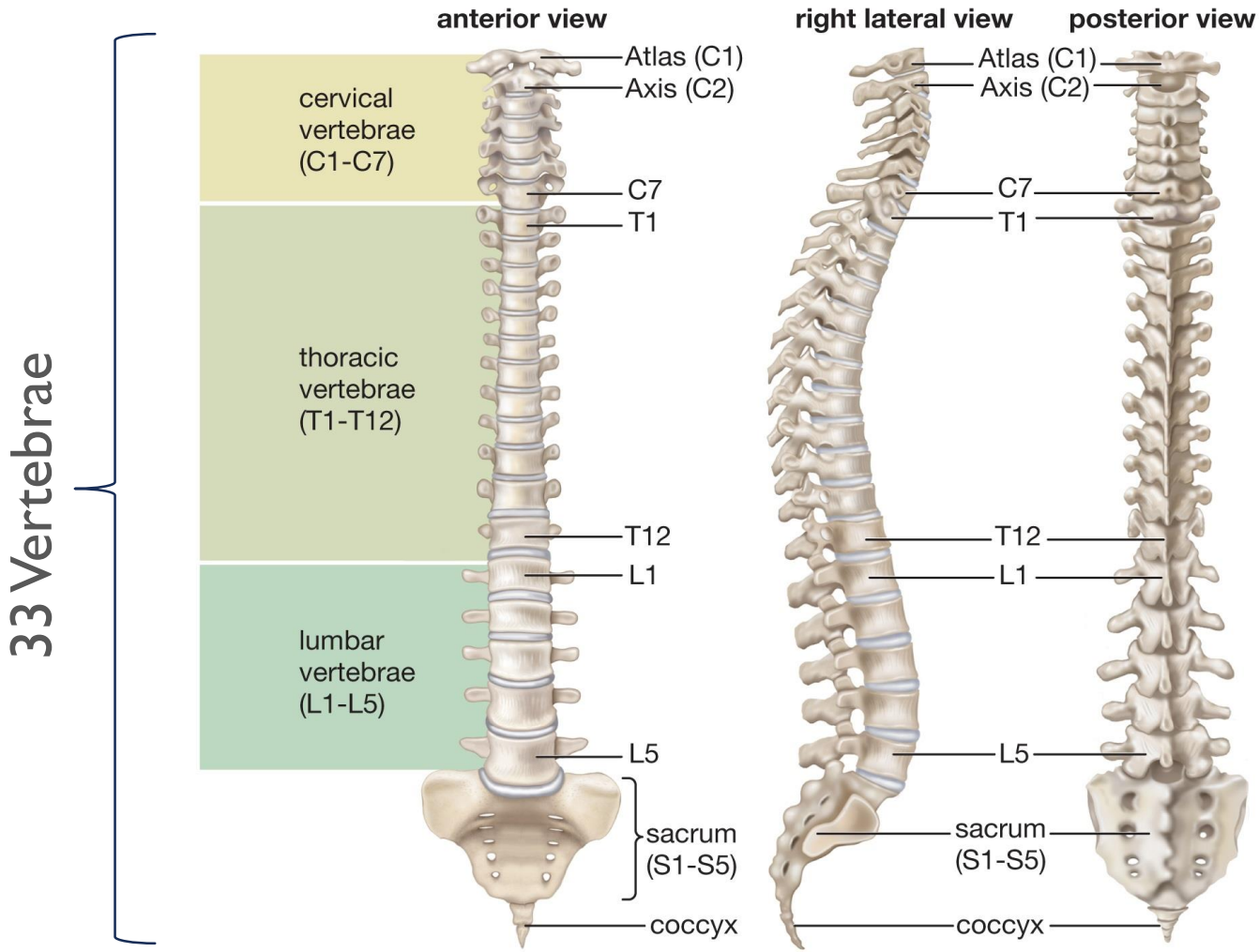
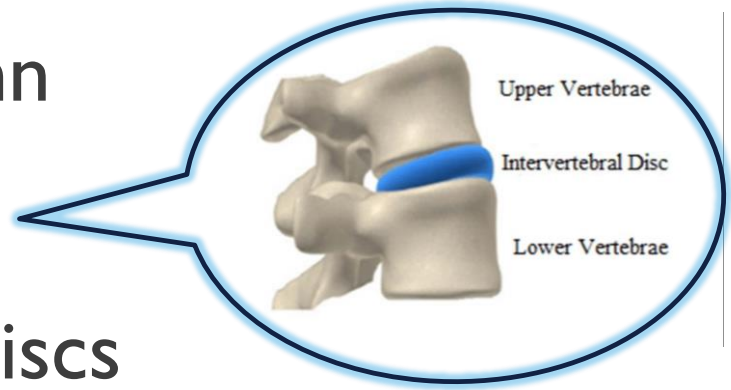


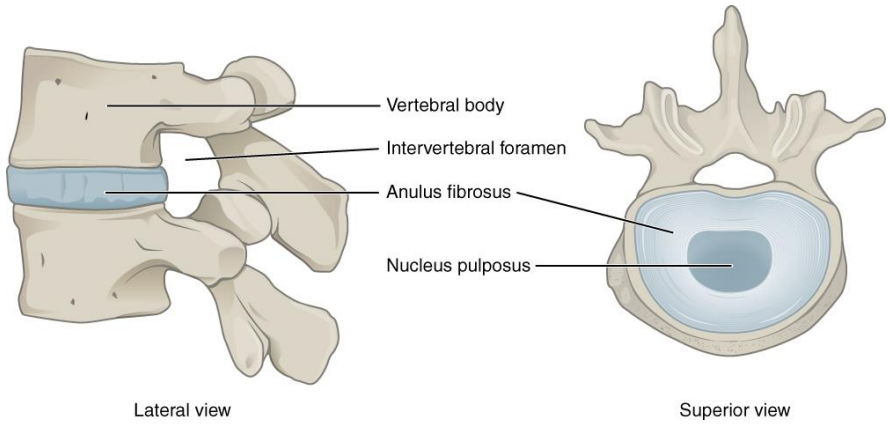
STRUCTURE OF THE SPINE



STRUCTURE OF THE SPINE

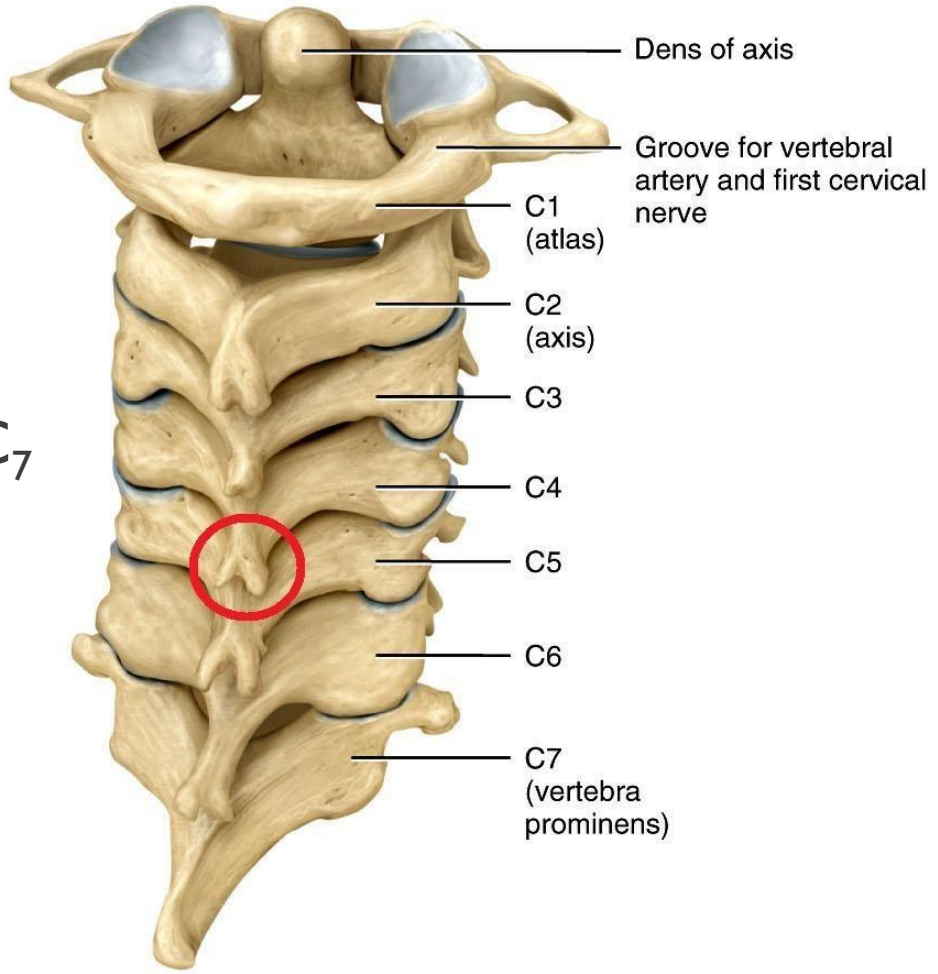
- Vertebral Column
- Motion Segment
- Intervertebral Discs
  - Annulus Fibrosus
  - Nucleus Pulposus



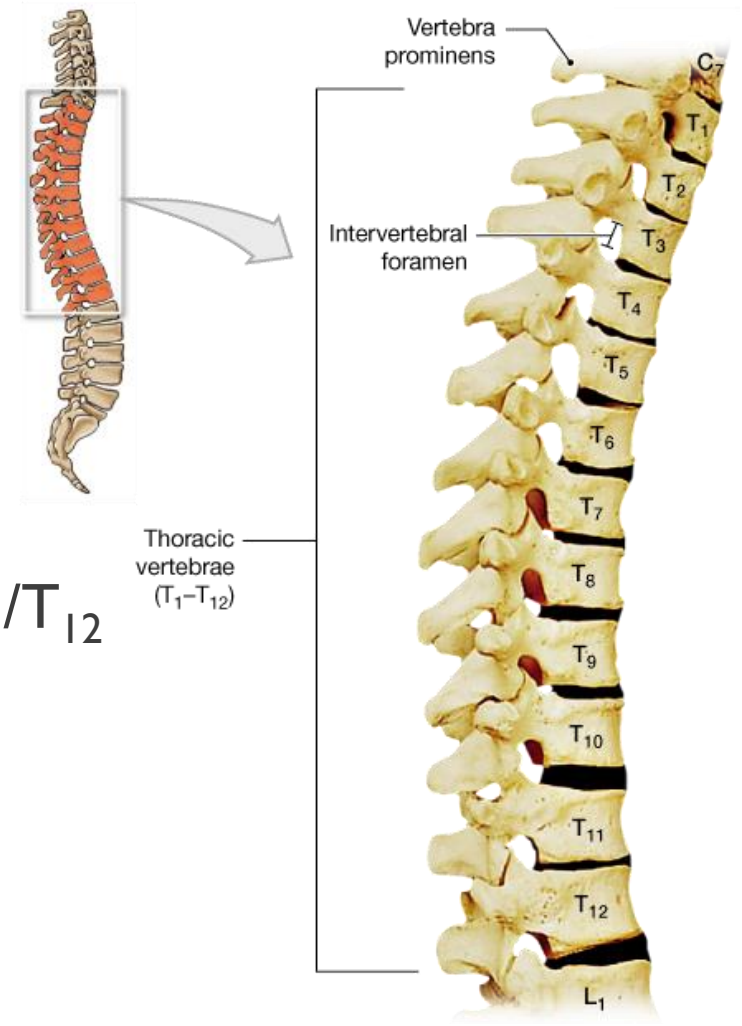


CERVICAL VERTEBRAE

- Typical C_3-C_4-C_5-C_6
- Atypical vertebral C_1/C_2 - C_7



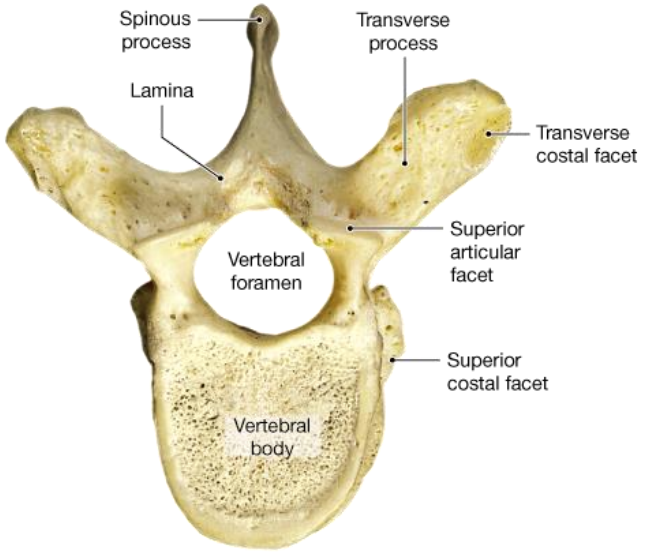
THORACIC VERTEBRAE



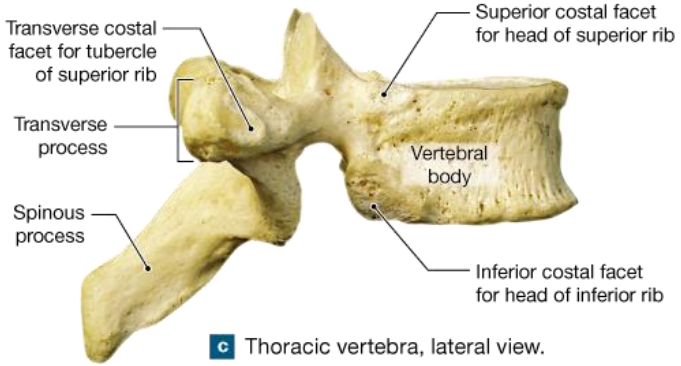
- Typical vertebrae T_2-T_9
- Atypical vertebrae T_1/T_{10}/T_{11}/T_{12}

THORACIC VERTEBRAE

- 1 spinous process
- 2 transverse process
- 2 superior facet
- 2 inferior facet



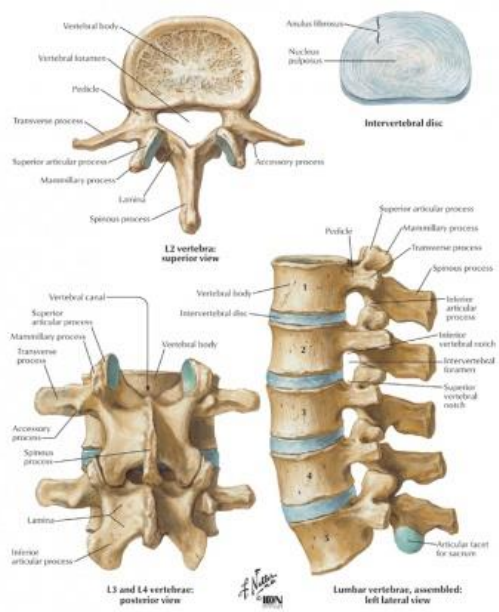
b Thoracic vertebra, superior view.

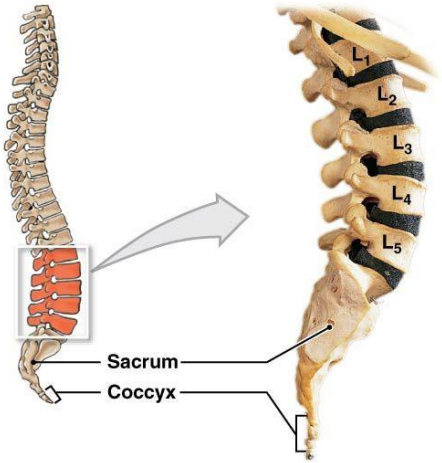


c Thoracic vertebra, lateral view.

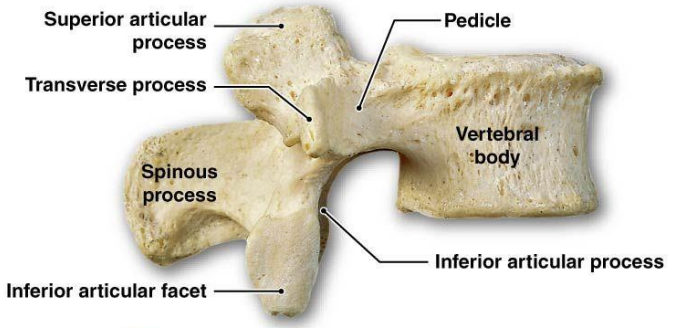
LUMBAR VERTEBRAE

- Typical vertebra: L1-L4
- Atypical vertebra: L5

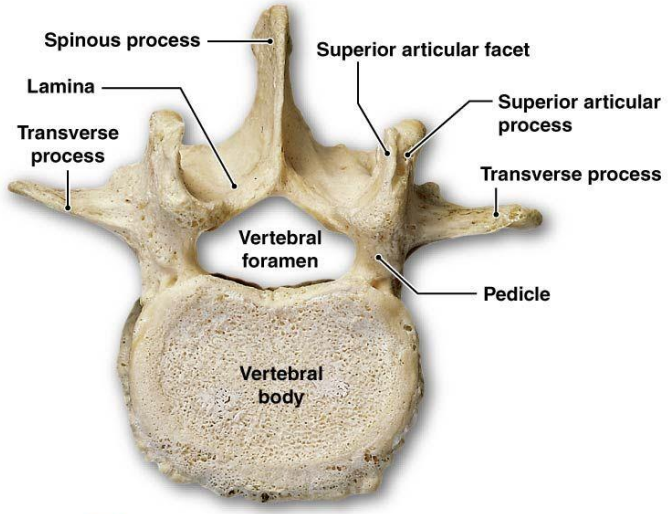




a A lateral view of the lumbar vertebrae, sacrum, and coccyx



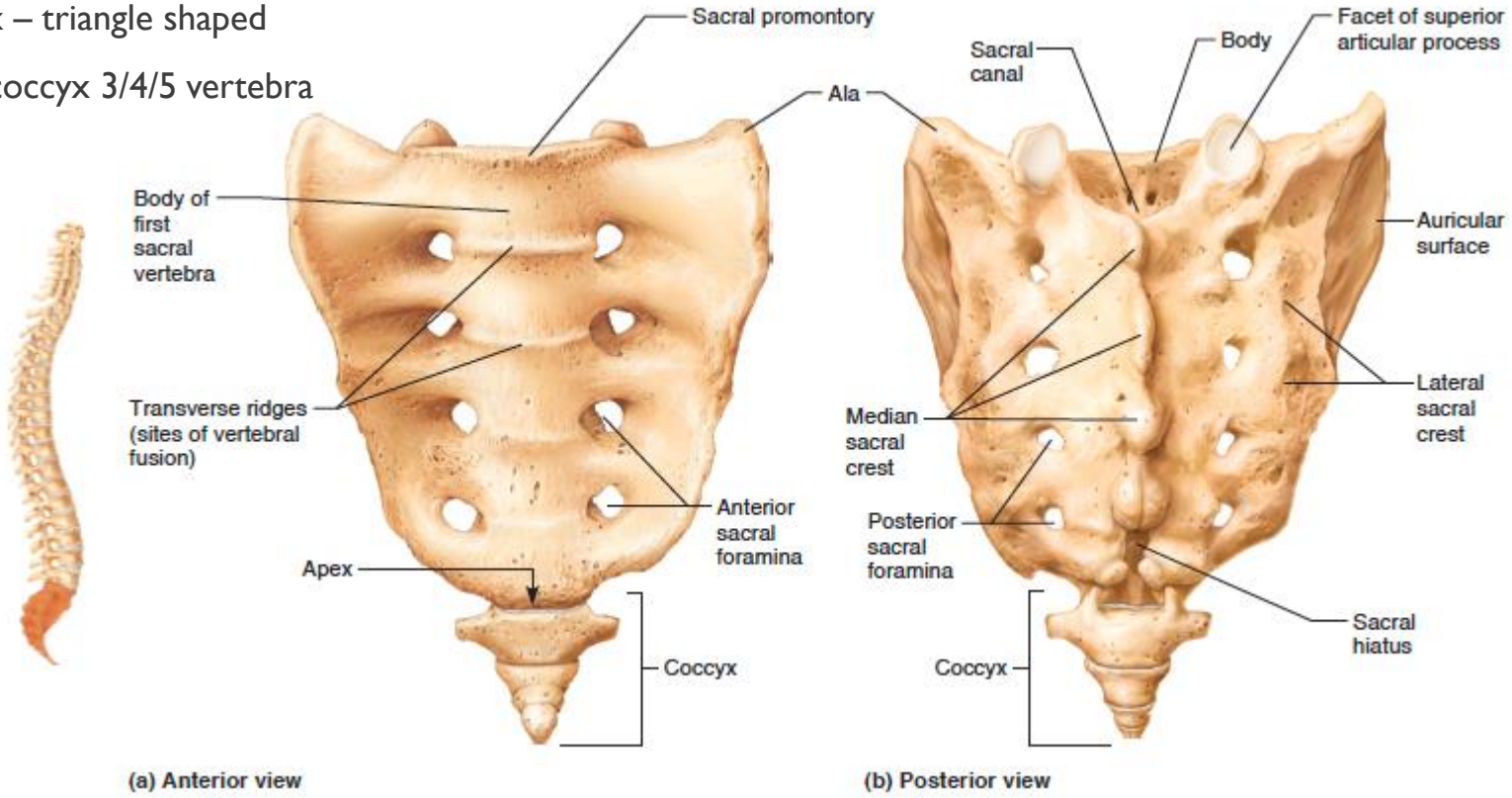
b A lateral view of a typical lumbar vertebra



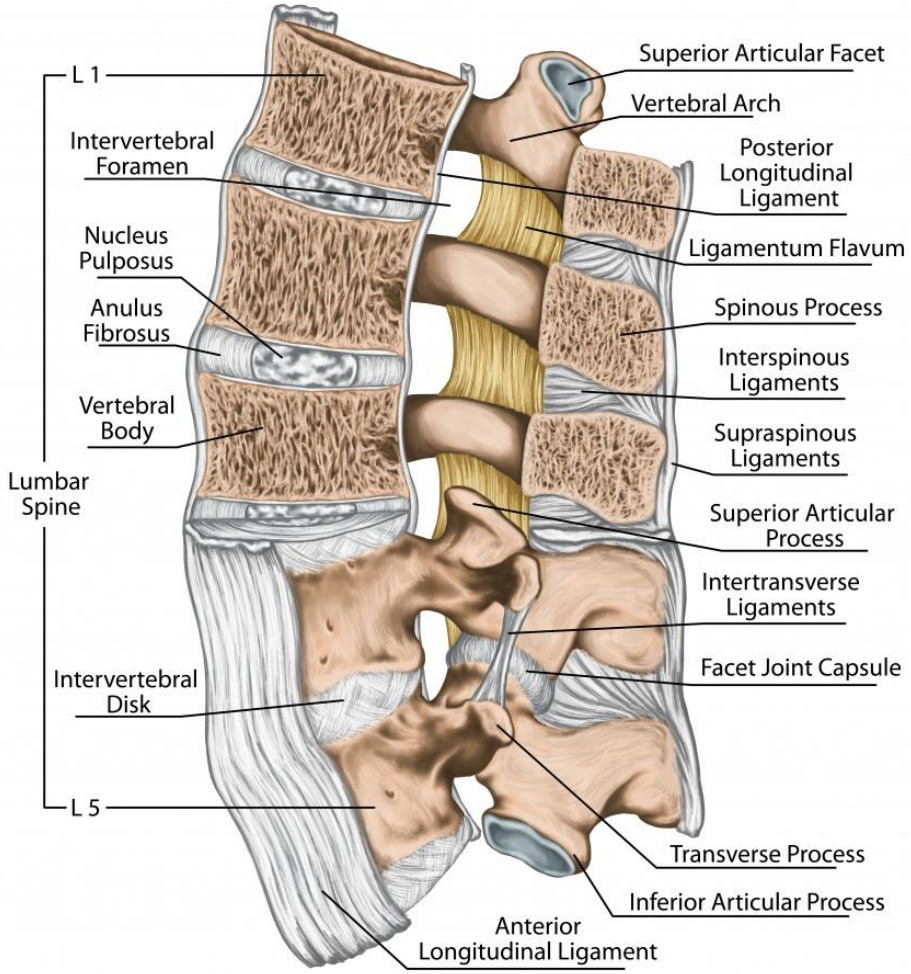
c A superior view of the same vertebra shown in part b

SACRUM AND COCCYX

- Sacrum – triangular shaped
- Fused – 5 vertebra
- Coccyx – triangle shaped
- Fused coccyx 3/4/5 vertebra



LIGAMENTS OF THE SPINE



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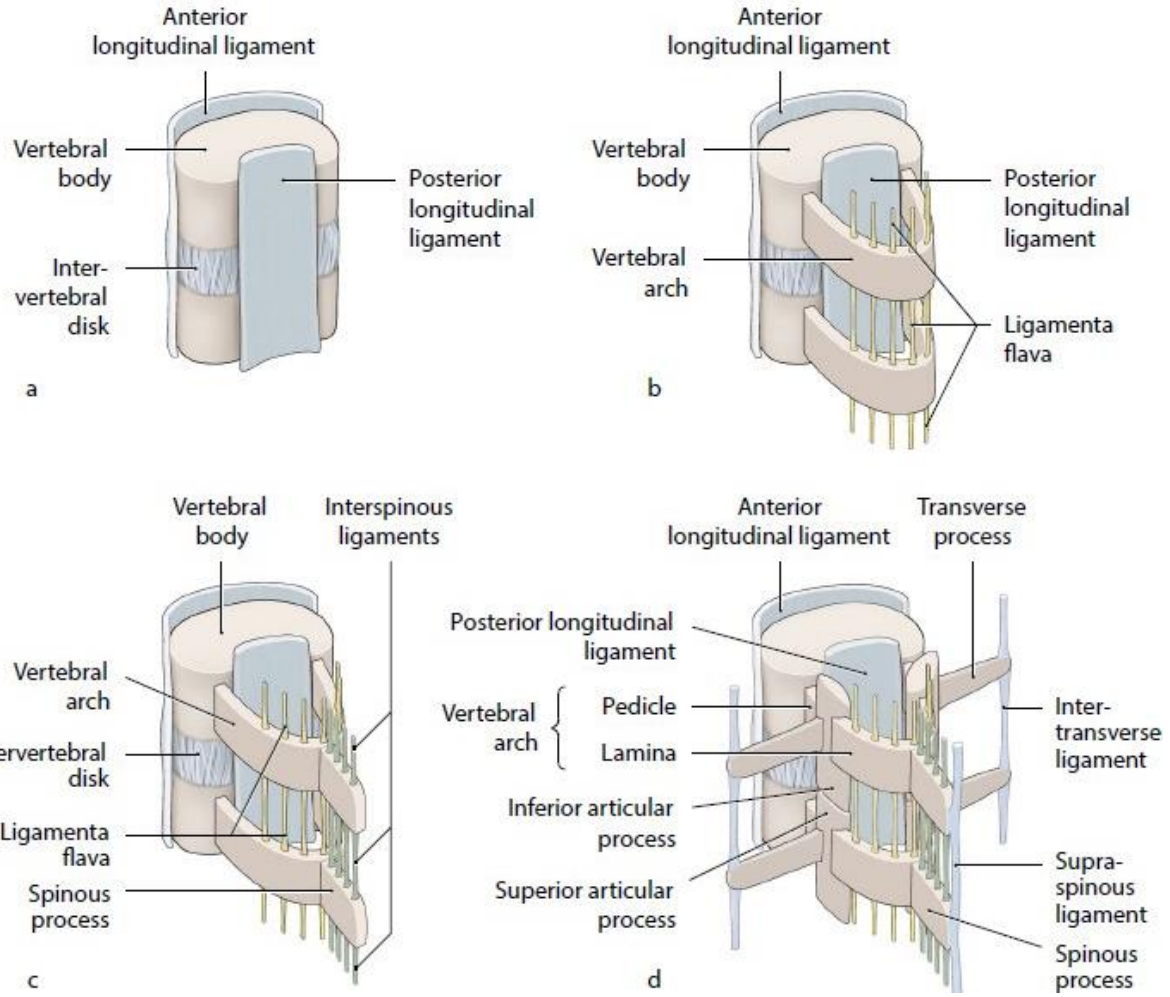

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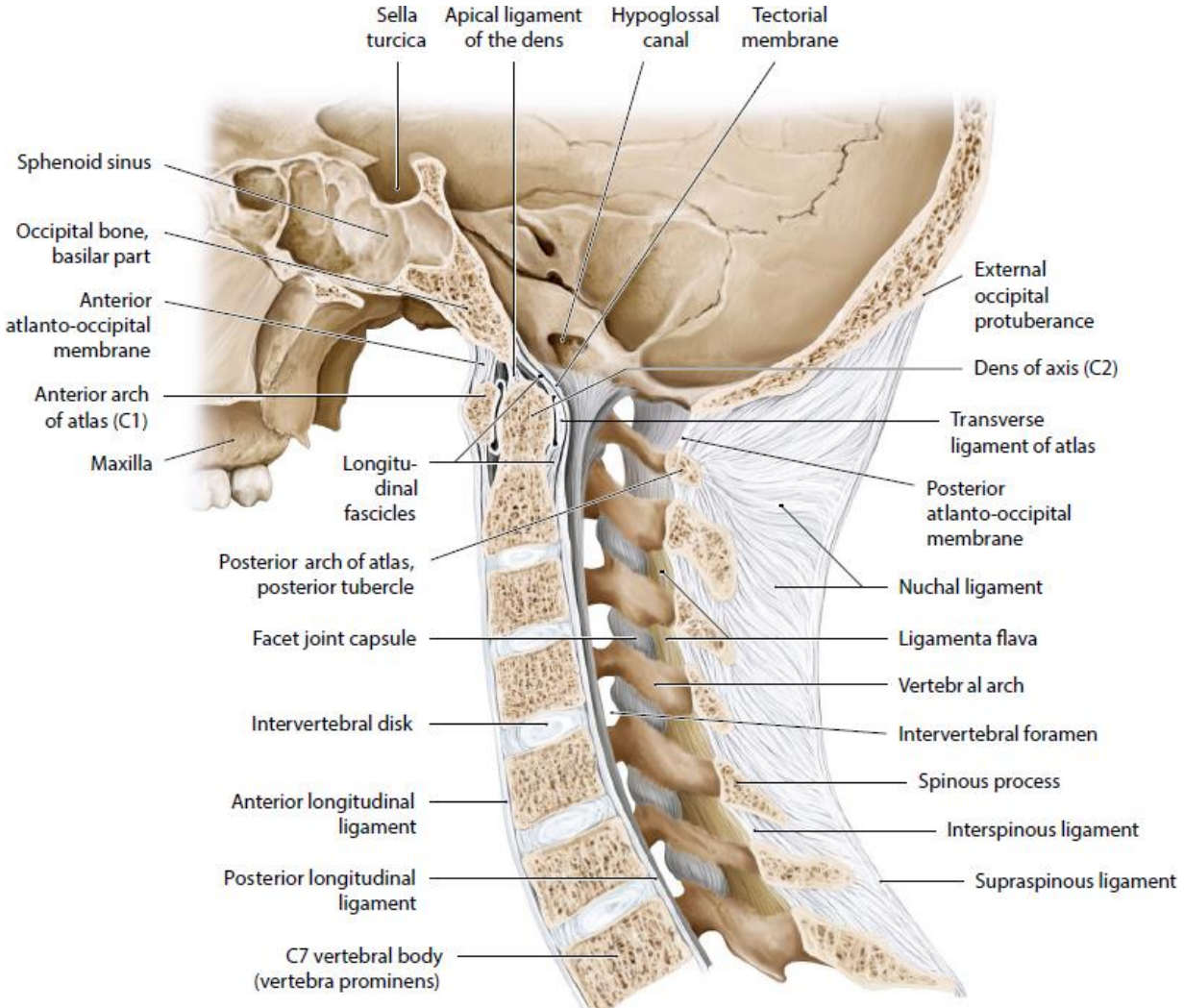
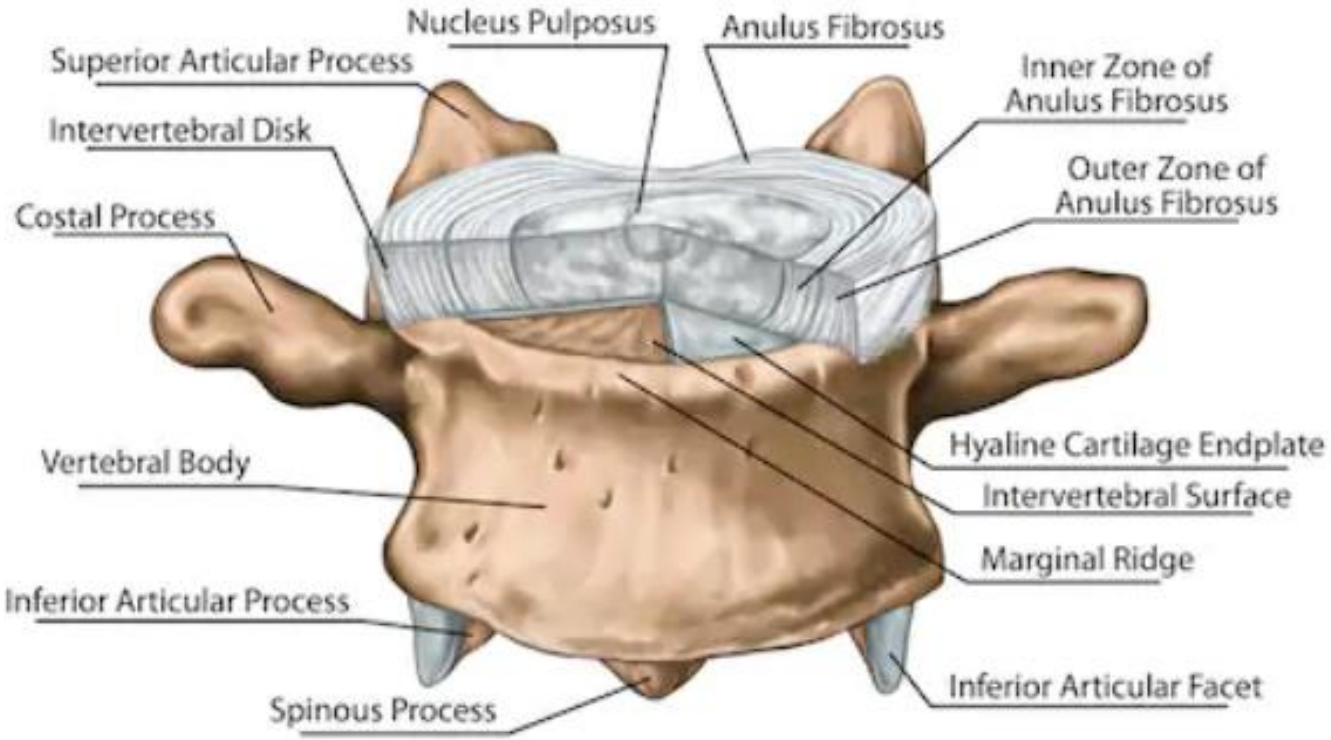


LIGAMENTS OF THE SPINE

- Give strength to spinal column
- Keep vertebrae in alignment
- Keep discs in position
- Can become damaged through over stretching
- Have a poor blood supply, and therefore a slow recovery from damage

INTERVERTEBRAL DISKS



INTERVERTEBRAL DISCS

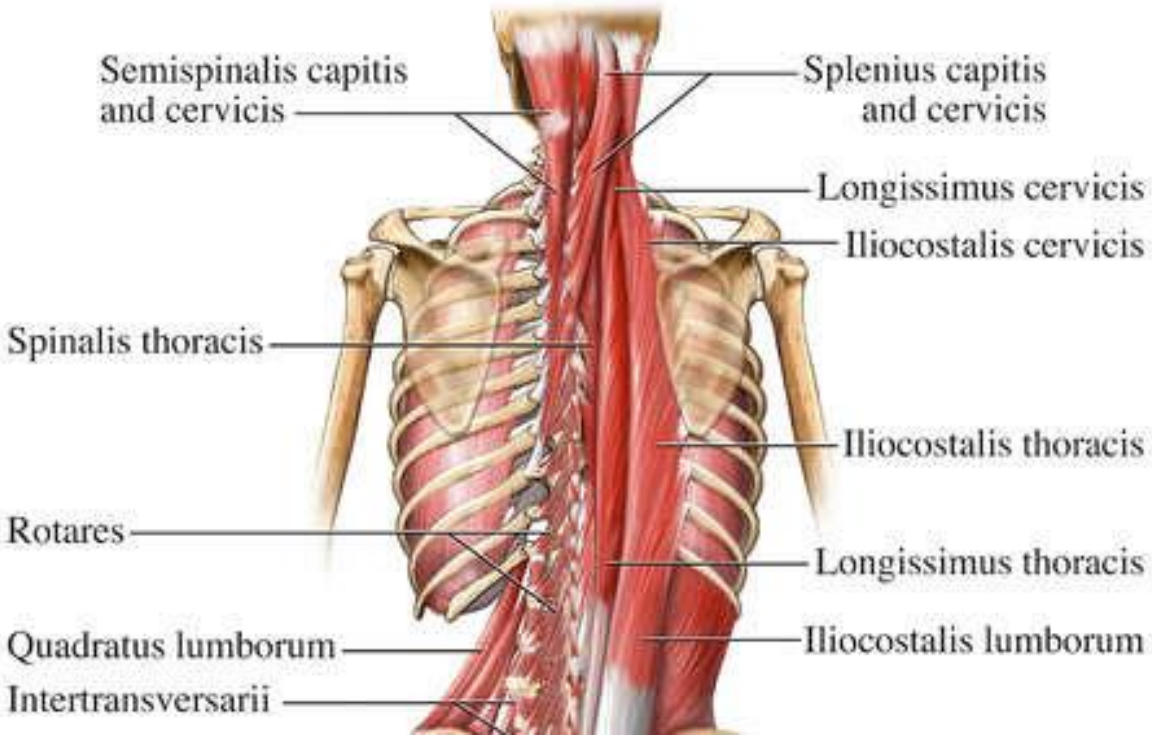
- Occur between each vertebra and are made up of an annulus and a nucleus.
- Act as separator and shock absorber.
- Pressure within discs can be kept low by maintaining natural curves of the spine and frequent postural changes.
- A healthy back needs all components of the spine to be in good working order

MUSCLES

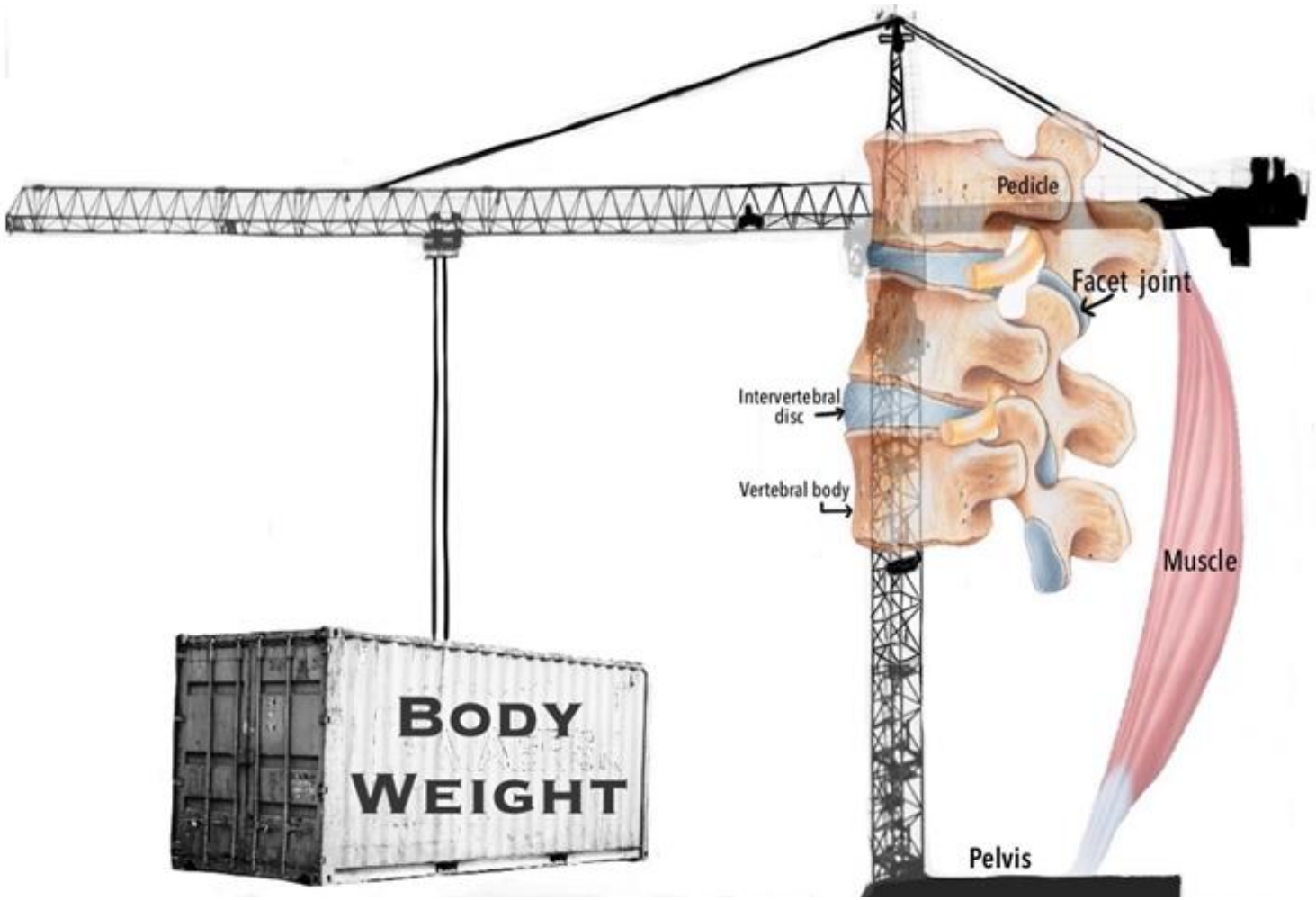
- Work in pairs to maintain postural control.
- Abdominal muscles are important in reducing the stress of lifting.
- Muscle strength and balance
- They are important in maintaining a healthy back.

LUMBAR MUSCLES

LUMBAR MUSCLES	FUNCTION
Psoas Major	Flexes thigh at hip joint & vertebral column
Intertransversarii Lateralis	Lateral flexion of vertebral column
Quadratus Lumborum	Lateral flexion of vertebral column
Interspinales	Extends vertebral column
Intertransversarii Mediales	Lateral flexion of vertebral column
Multifidus	Extends & rotates vertebral column
Longissimus Lumborum	Extends & rotates vertebral column
Iliocostalis Lumborum	Extension, lateral flexion of vertebral column, rib rotation



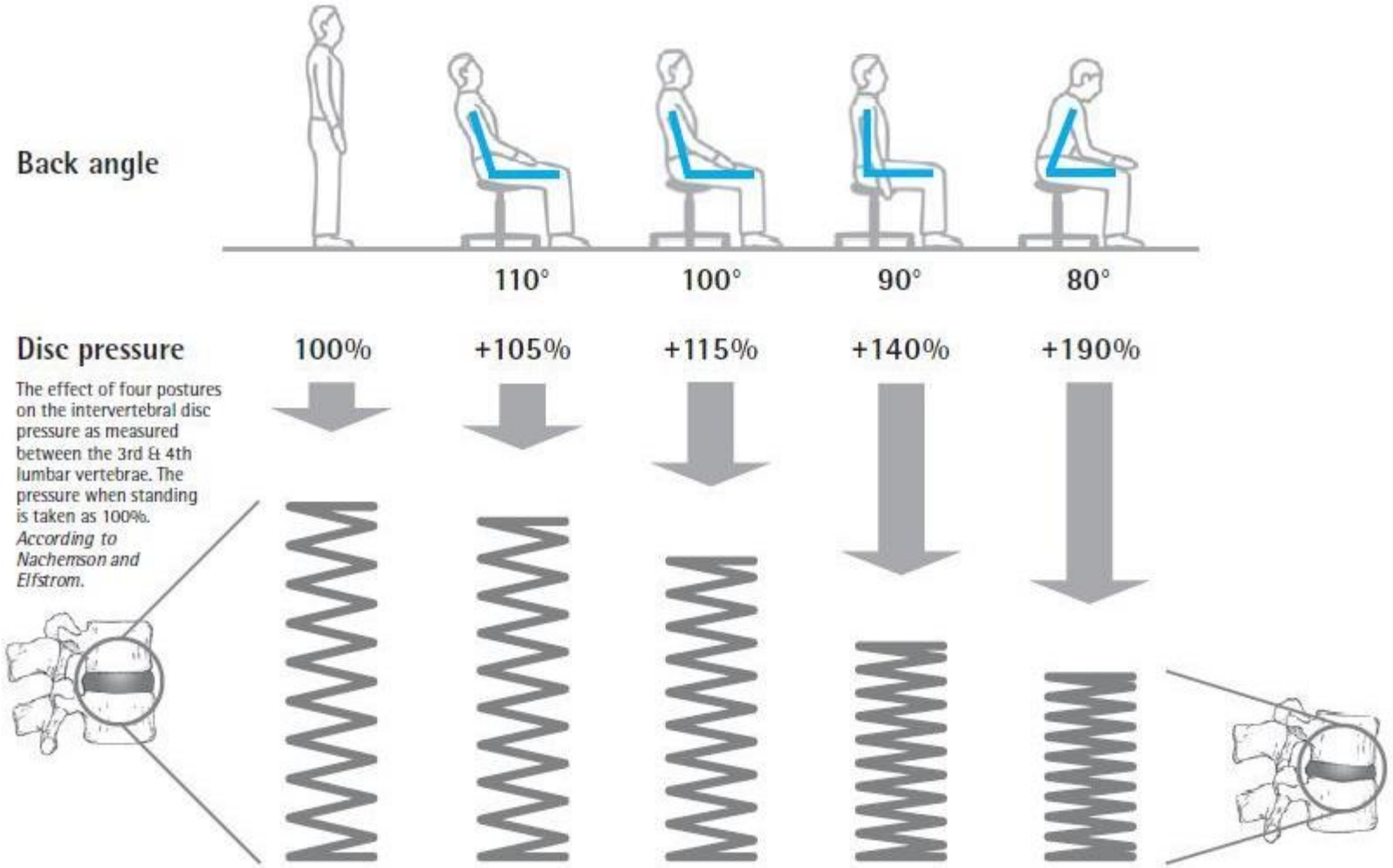
THE SPINE WORKS LIKE A CRANE



DISC PRESSURE RELATED TO POSTURE AND MUSCULATURE

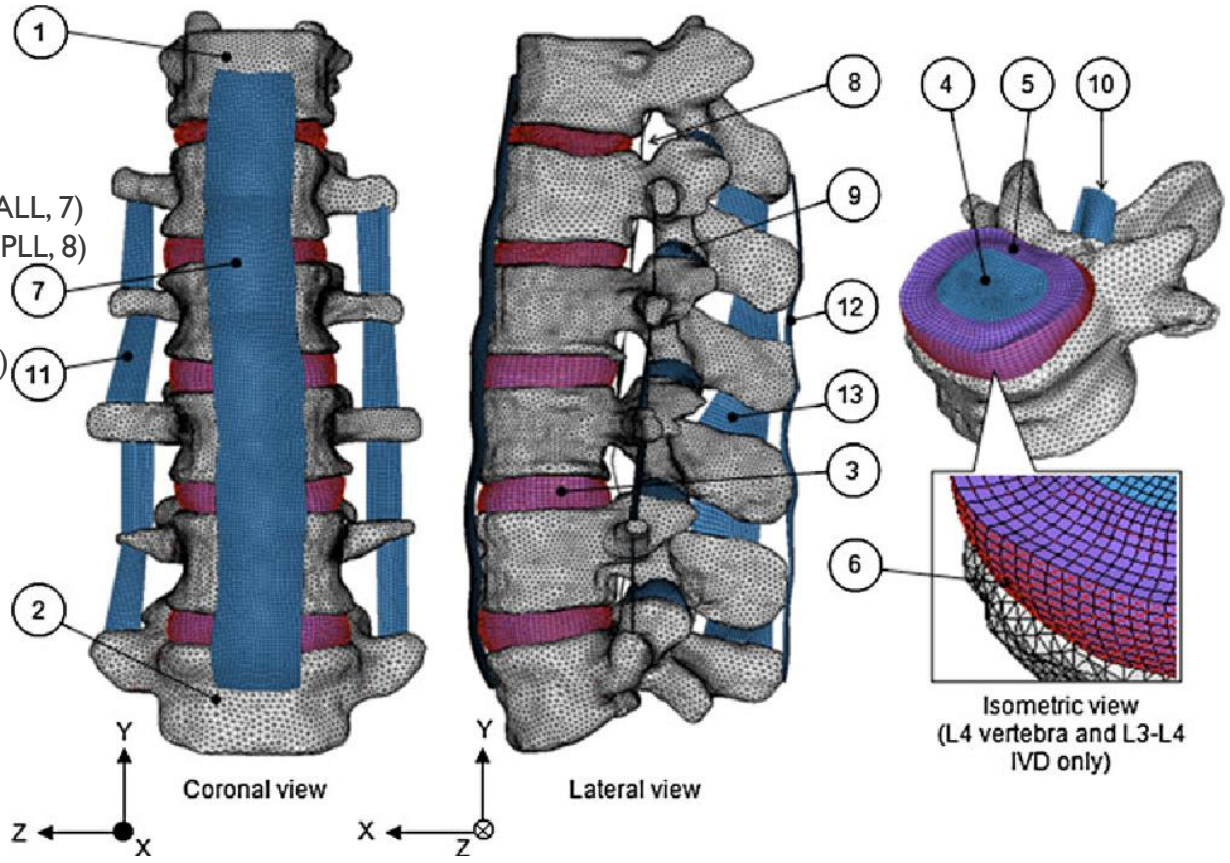
- The weight of your body acts as a compressive and shear forces that in younger people, the intervertebral discs bear most of this load.
- After the discs degenerate, more pressure is transferred to the facet joints in the back, causing arthritis in these synovial joints.
- Cervical Disc Pressure:
  - Correct alignment & muscular support = 5.6kg/cm2
  - Incorrect alignment without correct muscular support = 40kg/cm2

HOW POSTURE AFFECTS DISC PRESSURE



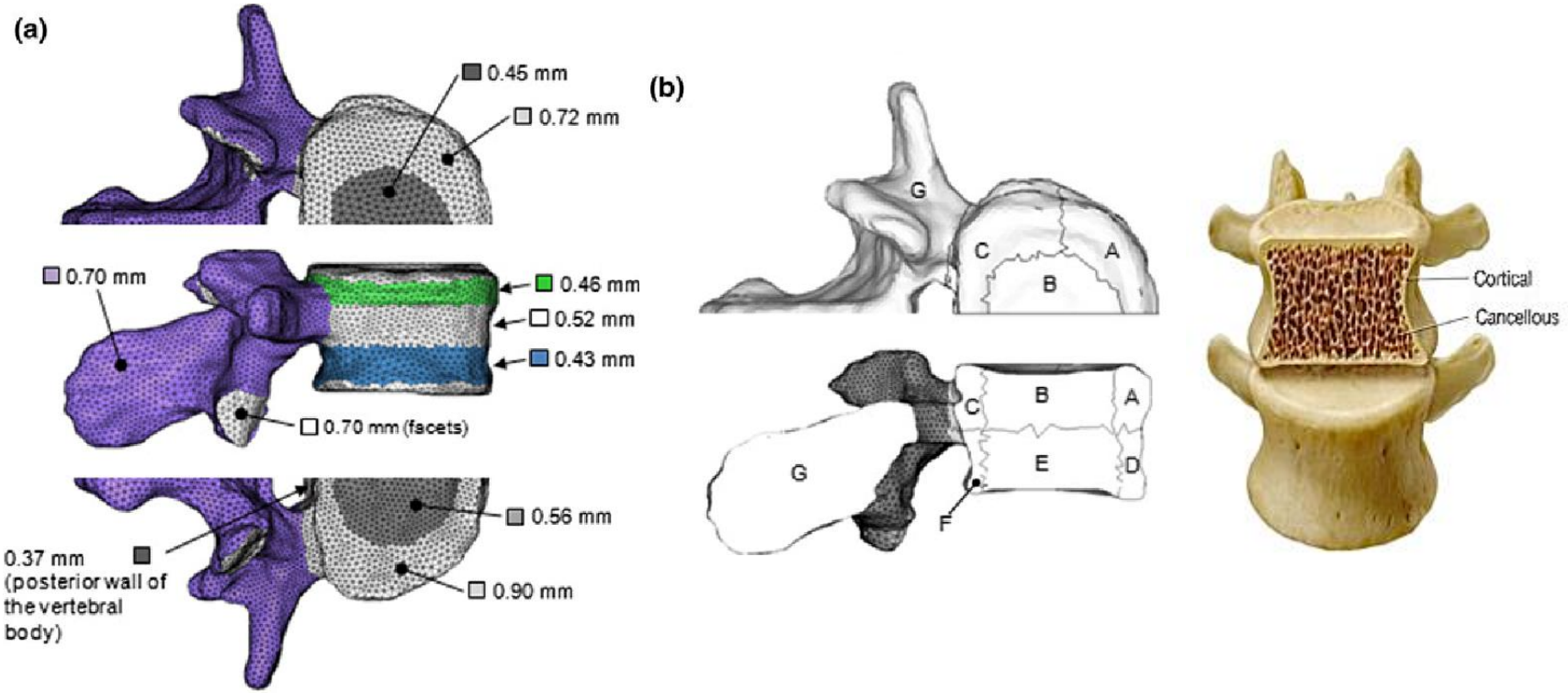
FINITE ELEMENT MODEL OF T12-L5 SEGMENT OF THE SPINE

- T12 (1) to L5 (2) vertebrae
- Intervertebral discs (3)
- Nucleus (4)
- Annulus (5)
- Collagen fibers (6)
- Anterior Longitudinal Ligament (ALL, 7)
- Posterior Longitudinal Ligament (PLL, 8)
- Capsular Ligament (CL, 9)
- Flavum Ligament (FL, 10)
- Intertransverse Ligament (ITL, 11)
- Supraspinous Ligament (SSL, 12)
- Interspinous Ligament(ISL, 13)



Wagnac, E., Arnoux, P. J., Garo, A., & Aubin, C. E. (2012). Finite element analysis of the influence of loading rate on a model of the full lumbar spine under dynamic loading conditions. *Medical & biological engineering & computing*, *50*(9), 903-915.

CORTICAL AND CANCELLOUS BONES



(a) Subdivision of the vertebrae into nine zones of different cortical bone thicknesses
(b) Subdivision of the cancellous bone into seven zones of different material properties

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MECHANICAL PROPERTIES OF BONY TISSUES

Material properties	Cancellous bone (per zone) and bony endplate center[a]							Cortical bone and bony endplate margin
	A	B	C	D	E	F	G	
Density ($\times 10^{-3}$ g/mm^3)	1.8	1.8	2.0	2.0	2.5	2.5	1.8	0.2
Modulus of elasticity, E (MPa)	93.7	93.7	93.7	93.7	93.7	93.7	93.7	4,014
Poisson's ratio, v	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.3
Yield stress, a (MPa)	1.95	1.95	1.95	1.95	1.95	1.95	1.95	105
Hardening modulus, b (MPa)	8.5	7.0	8.5	8.1	12.5	12.5	7.0	492.9
Hardening exponent, n	1	1	1	1	1	1	1	1
Failure plastic strain, ε_p	0.082	0.06	0.082	0.08	0.104	0.104	0.06	0.071
Maximum stress (MPa)	2.65	2.3	2.65	2.6	3.25	3.25	2.3	140
Strain rate coefficient, c	0.533	0.533	0.533	0.533	0.533	0.533	0.533	0.272
Reference strain rate, $\dot{\varepsilon}_0$	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008

[a] Material properties used for the bony endplate center are the same as zone B

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MECHANICAL PROPERTIES OF THE SOFT TISSUES

Intervertebral Discs

Material properties	Nucleus pulposus		Annulus matrix		Fibers
	Low dyn.	High dyn.	Low dyn.	High dyn.	
a.					
Density (E^{-6} kg/mm^3)	1	1	1.2	1.2	–
Poisson's ratio, ν	0.499	0.499	0.45	0.45	–
C_{10}	0.64	31.8	0.24	11.8	–
C_{01}	−0.16	−8.0	−0.06	−2.9	–
Load–disp. curve	–	–	–	–	Nonlinear

Spinal Ligaments

Material properties	Spinal ligaments						
	ALL	PLL	CL	LF	ISL	SSL	ITL
b.							
Density (E^{-6} kg/mm^3)	1	1	1	1	1	1	1
Modulus of elasticity E (MPa)	19.2	84.1	0.6	4.2	4.7	10.2	4.7
Poisson's ratio, ν	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Update coef., E_1 (MPa/ms)	469.4	1,432.1	3.6	199.7	98.3	476.5	98.3
Update coef., E_2 (MPa)	19.0	83.5	0.6	4.0	4.6	10.0	4.6
Failure strain, ε_1	0.68	0.38	1.75	1.01	1.10	0.94	1.10
Failure strain, ε_2	0.90	0.50	1.85	1.25	1.30	1.08	1.30
Scaling function, SF	Tabulated curves						

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MECHANICAL PROPERTIES OF THE THORACOLUMBAR-PELVIS COMPLEX

Component	Young's Modulus (MPa)	Poisson's Ratio	Density (kg/mm²)	Cross-Section Area (mm²)
Cortical bone	14,000	0.30	1.83E-06	
Cancellous bone	100	0.2	0.17E-06	
Posterior elements	3,500	0.25	1.83E-06	
Endplate	10,000	0.25	1.06E-06	
Pelvis	5,000	0.2	1.83E-06	
Annulus	Mooney–Rivlin c = 0.18, c = 0.045		1.0E-06	
Nucleus pulpous	Mooney–Rivlin c1 = 0.12, c2 = 0.03		1.2E-06	
Collagenous fiber	Calibrated stress-strain curves			
Ligament				
ALL	Calibrated deflection-force curves		1.0E-06	63.7
PLL	Calibrated force-deflection curves		1.0E-06	20
FL			1.0E-06	40
ITL			1.0E-06	3.6
ISL			1.0E-06	40
SSL			1.0E-06	30
CL			1.0E-06	60

Note: ALL, anterior longitudinal ligament; PLL, posterior longitudinal ligament; FL, ligamentum flavum; ITL, intertransverse ligament; ISL, interspinous ligament; SSL, supraspinous ligament; CL, capsular ligament.

Zhang, M., & Fan, Y. (Eds.). (2019). *Computational biomechanics of the musculoskeletal system*. CRC Press.