

CHEST AND SPINE GROWTH. WHAT HAVE WE LEARNED FROM BONES?

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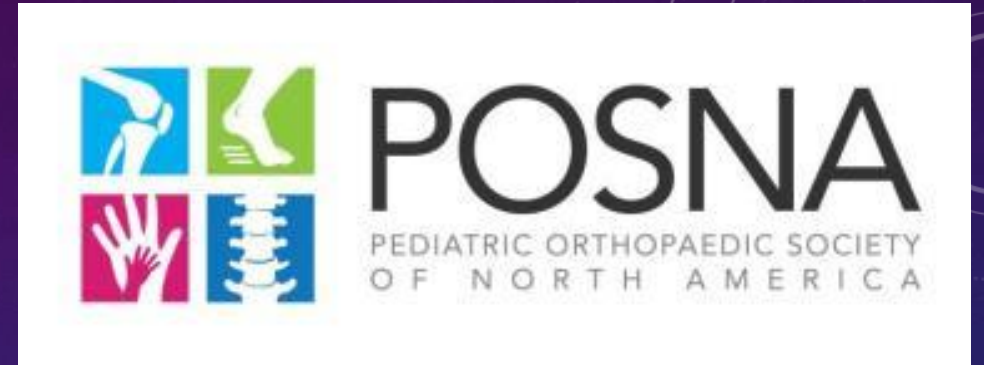
11th International
Congress on Early
Onset Scoliosis (ICEOS)

November 16 & 17, 2017

Hotel Del Coronado • San Diego, CA, USA

DISCLOSURES

- POSNA President and BOD member
- AAP Immediate Past Chair and Section on Orthopaedics Executive Committee
- K2M Consultant
- Medtronic Consultant
- Project Perfect World Board of Directors.
- Miracle Feet Medical Advisory Board.



TO UNDERSTAND DEFORMITY WE NEED TO UNDERSTAND NORMAL ANATOMY AND GROWTH

- Scoliosis is a 3D spinal deformity
- Each vertebra and disc have 3D deformity
- Obvious plane of deformity is coronal, but **axial** and **sagittal** are just as important
- But are the ribs deformed?



RIB AND THORAX GROWTH

- “Thorax is the 4th dimension of the spine”
 - Alain Dimeglio

Paul Harrington
Library, KUMC.
Courtesy Mark Asher



OBVIOUS REASONS TO KNOW SPINE ANATOMY



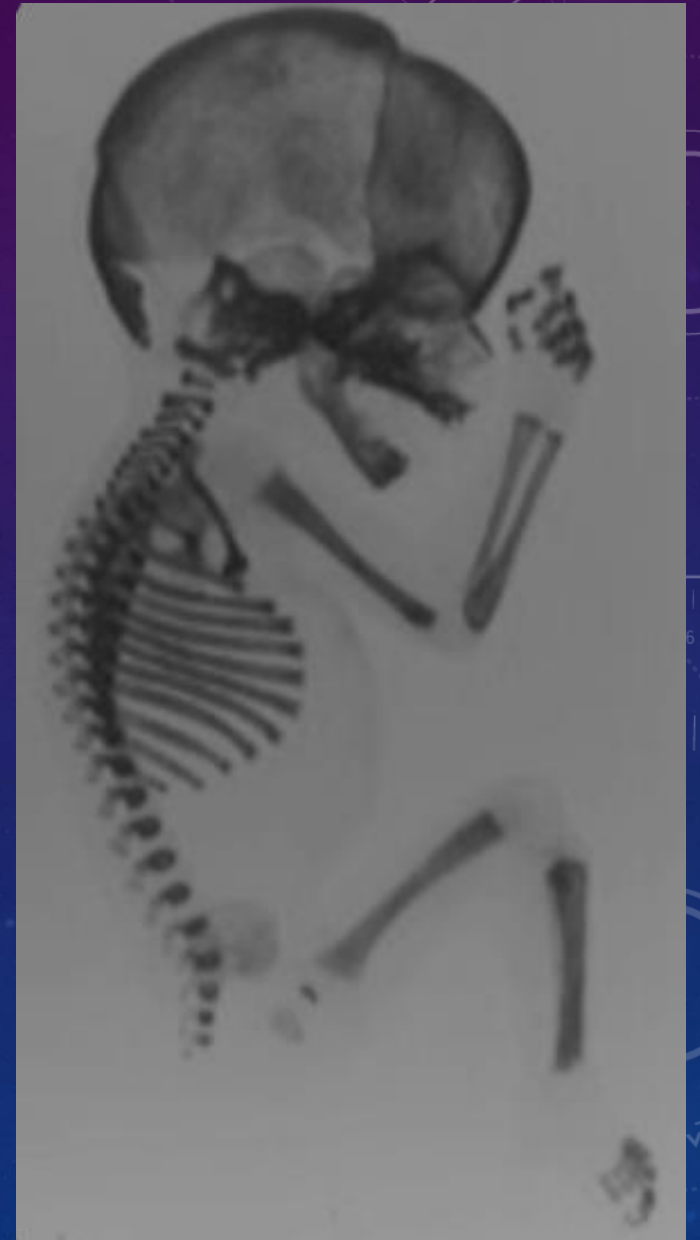
- To know where to put the screws safely



GROWTH GIVES DEEPER UNDERSTANDING

- At birth (3.5 kg)
 - 30% ossified
 - Trunk is longer than the lower limbs
 - Thoracic volume is 6% of adult
 - Needs to grow: T1-S1 25 cm, T1-T12 16 cm, L1-L5 9 cm
- At 5 years (20 Kg)
 - 65% ossification
 - **95% of spinal canal dimensions are adult size**
 - T1S1 segment gain from birth is 10 cm. Sitting height is 65% adult.
 - Thoracic volume is only 30% adult
- After age 5 years
 - Growth velocity decreases and lower limbs grow more than trunk
 - T1-S1 segment grows 1.1 cm/year.
- At 10 years (30 Kg)
 - **Thoracic volume and weight are 50% of adult size.**
 - Alain Dimeglio MD.

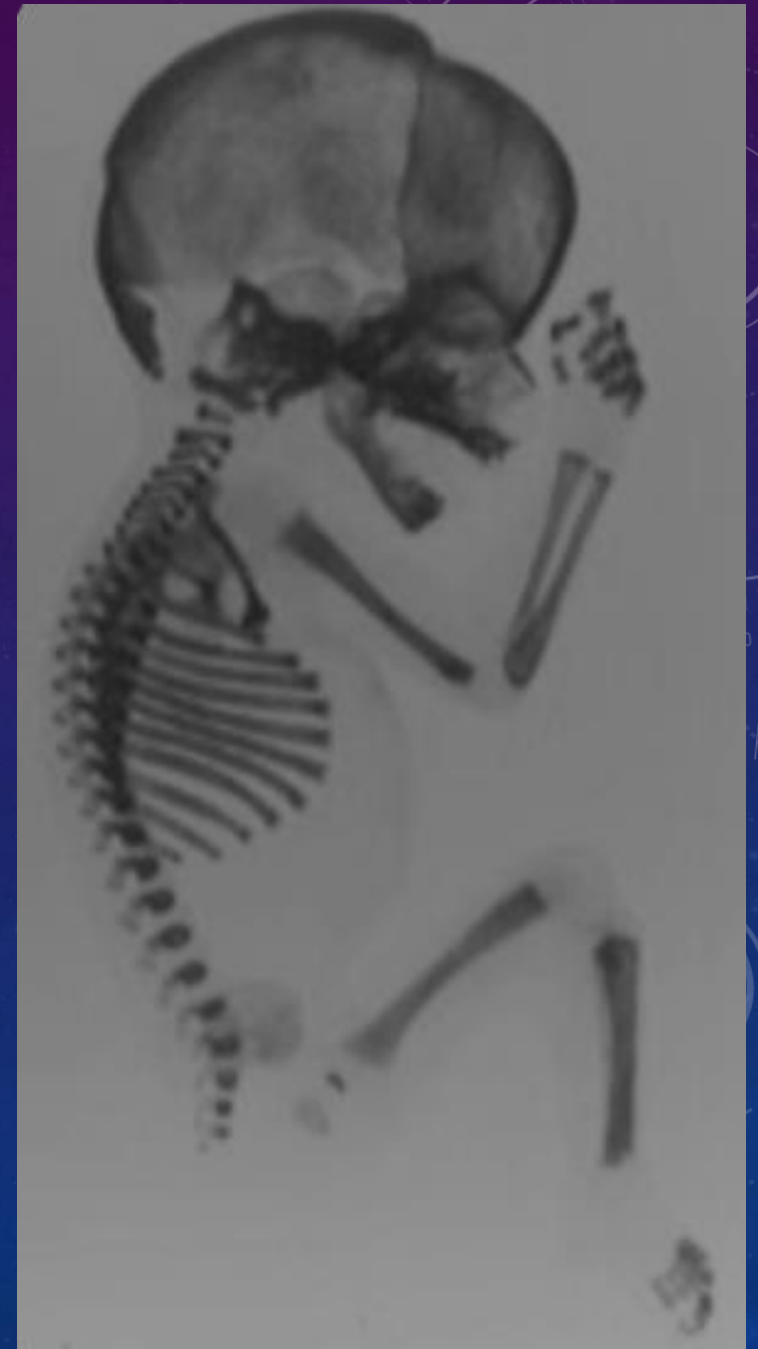
Femur triples in length, spine more than doubles in length



Ossification starts 3 mo in utero

MY QUESTIONS

- How does the chest increase 15x in size from birth to adult?
- Even after age 10 years how does chest volume double?
- What is the mechanism for volume increase?
 - Spine growth in height?
 - Rib growth in height, in length?
 - Soft parts- space between ribs, costal cartilage
 - Rib position in space?
 - When is this all occurring?
- How does the spinal canal increase in size?



BEGINNINGS

- First full trip September 2009
- Several follow-up trips next several years



LOTS OF PEOPLE INVOLVED

- Behrooz Akbarnia MD
- Laurel Blakemore MD
- Glen Ginsberg MD
- Shyam Kishan
- Neil Mardis MD
- Joe Perra MD
- Julie Reigrut MS
- Richard Schwend MD
- John Schmidt PhD
- Joshua Stewart MS2
- Chris Straight MA
- Kevin Strauss MA
- Caroline Weirich BA



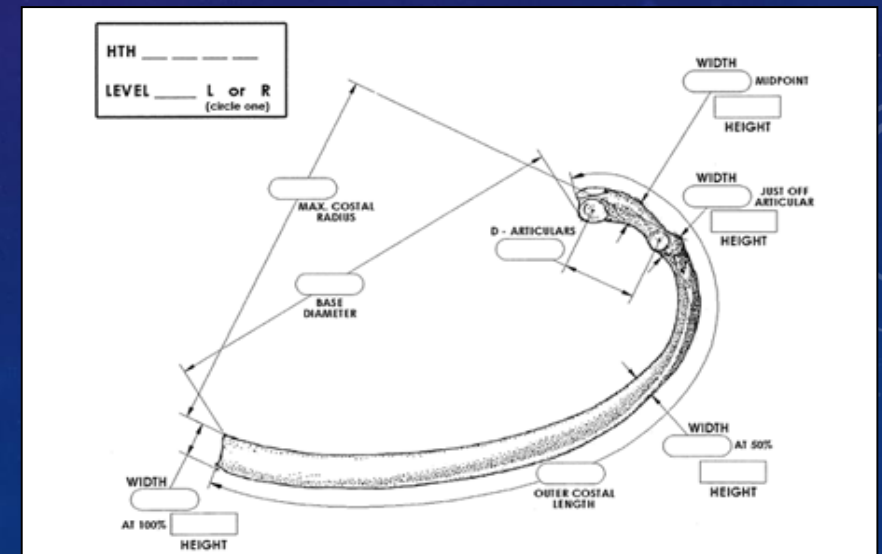
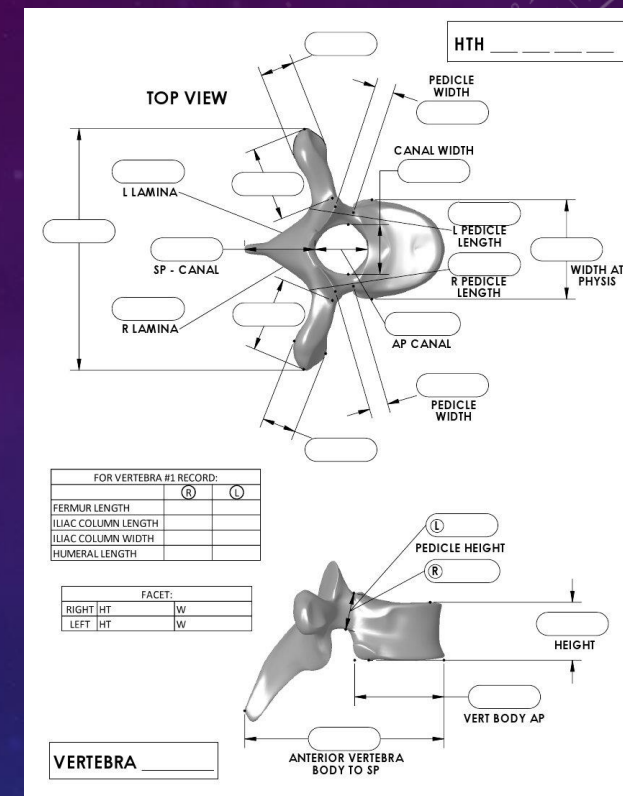
THE COLLECTION

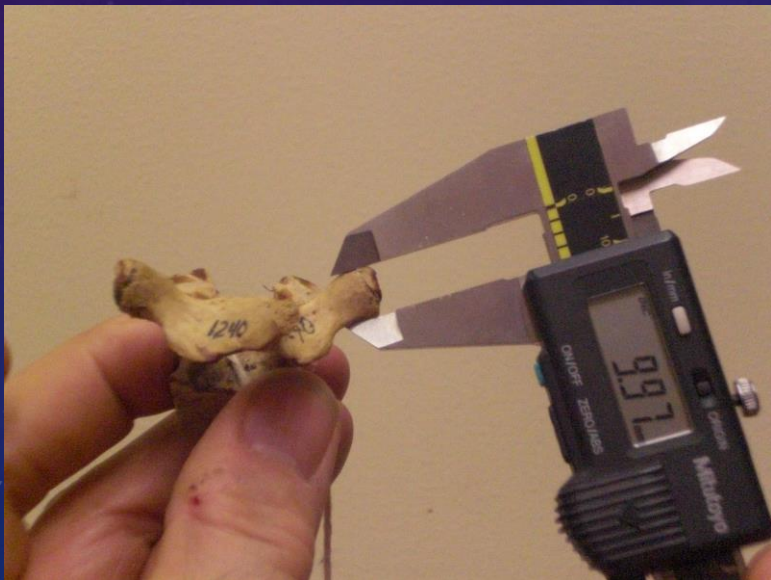
- Clean dry, preserved by removing all grease
- Large room accommodate 12 people
- Research lab, open to all with appropriate proposal.



SPECIMEN DEMOGRAPHICS

- Hamann-Todd (H-T) Collection, Cleveland Museum of Natural History (Cleveland, OH)
 - Contains 63 pediatric skeletal specimens
 - Largest of its kind in the world
 - Consists of 3,100 human and more than 900 non-human primates skeletons
- This Study
 - 32 Aged 1-18 YO (no 2 or 9 YO)
 - 19 Females, 13 Males
 - 29 Black, 3 Caucasian
 - Height and Weight





SCANDIUM

- Image analysis software
- Does not care from where the camera where the picture comes from
- You have to have a set dimension in the image

The rest is automatic

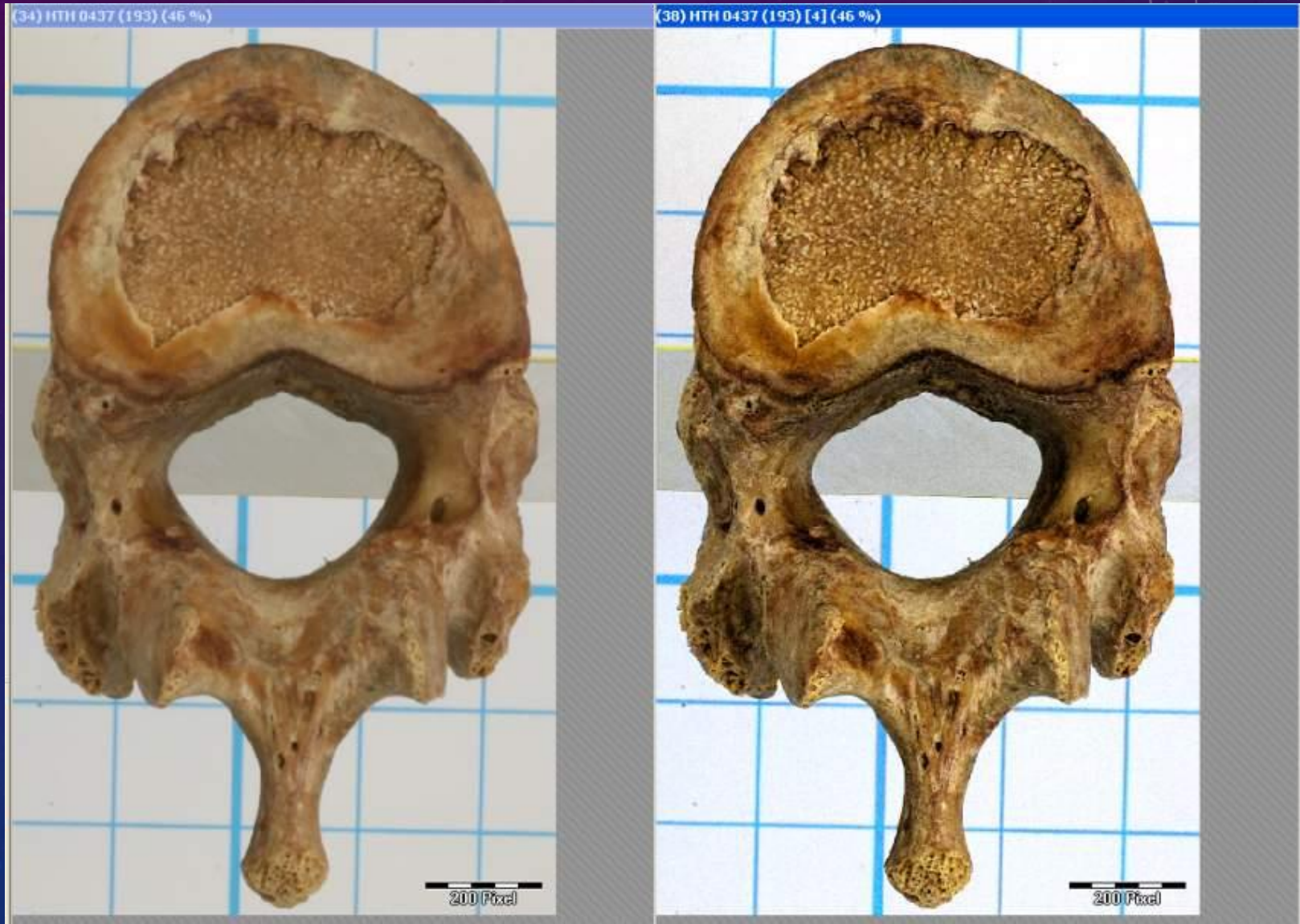


PHOTOGRAPHS

- High-Resolution photographs
- Image enhancement
- Increase image magnification



PHOTO ENHANCEMENT



1. NEUROCENTRAL SYNCHONDROSIS

- The neurocentral synchondrosis (NCS) is the cartilaginous growth plate of the pedicle and the vertebral body
- The timing of closure of the NCS is controversial
 - Most agree that the NCS are open until 4 years of age
 - Closure in the ensuing years remains unclear
- The mid- to lower thoracic spine seems to be the last to close
 - This is where the curves in juvenile and adolescent scoliosis occur
 - Interference with the NCS growth at this stage may be responsible for asymmetrical spinal growth



METHODS

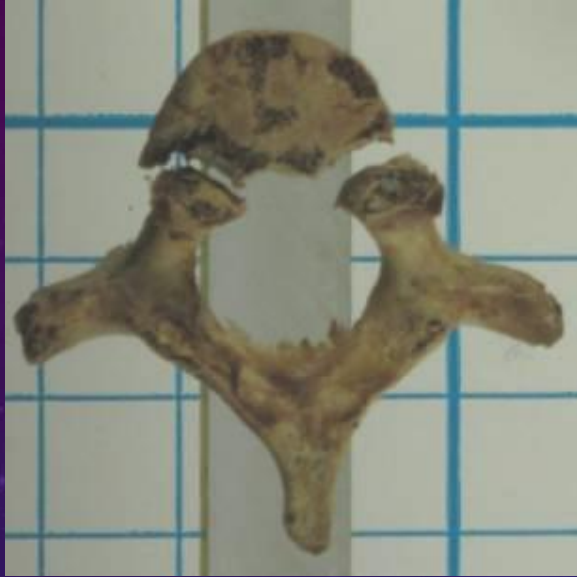
- Examined scalar measurements of cadaveric vertebrae from the Hamann-Todd Collection for neurocentral synchondrosis (NCS) during their developmental stages
- 13 specimens were examined
- Age of the children at time of death ranged from 1 to 16 Years
- Five vertebrae (T1, T3, T7, T10 and L3) from each were chosen for study

METHODS

- Each vertebra was inspected for NCS maturity
- Lengths of the NCS were measured and the percentage of open growth plate was compared to the entire length of the NCS
- A six point scale of percent of NCS closure^{1,2} was used
 - Stage 0 – No Closure
 - Stage 1 – Less than 25% Closure
 - Stage 2 – 25-49% Closure
 - Stage 3 – 50-74% Closure
 - Stage 4 – 75-99% Closure
 - Stage 5 – 100% Closure
- Findings were compared to recent data on NCS maturation in modern children with normal spines



1 YEAR OLD BLACK MALE (2075)



T1: Stage 0



T4:
Stage 0



T7:
Stage 0



T10:
Stage 0



L3:
Stage 0

4 YEAR OLD BLACK FEMALE (2141)

T1:
Stage 0



T4:
Stage 0



T7:
Stage 0



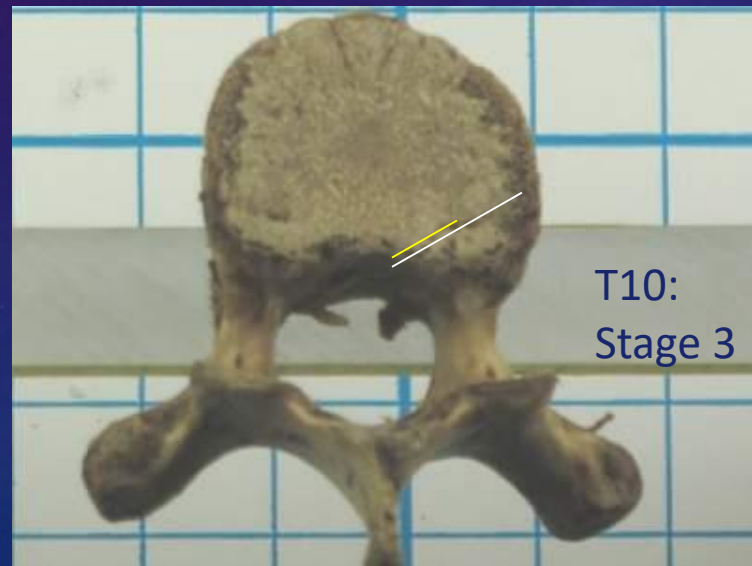
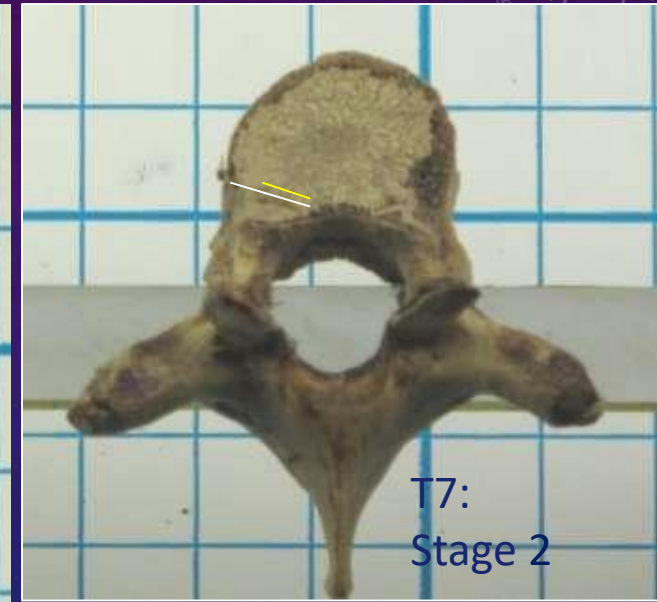
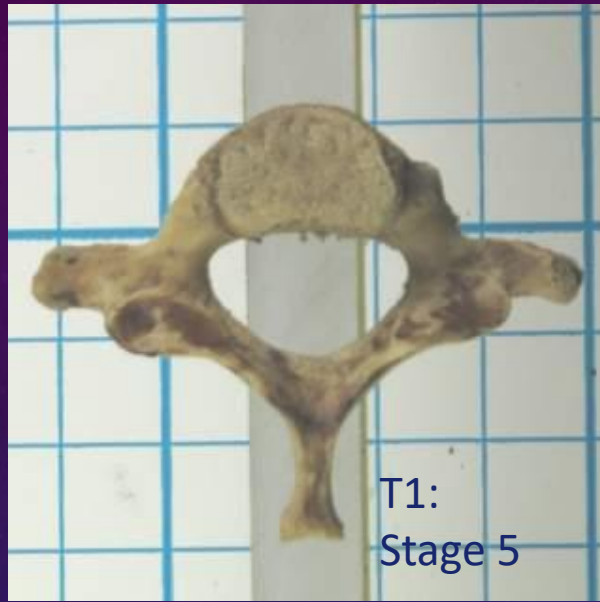
T10:
Stage 0



L3:
Stage 3



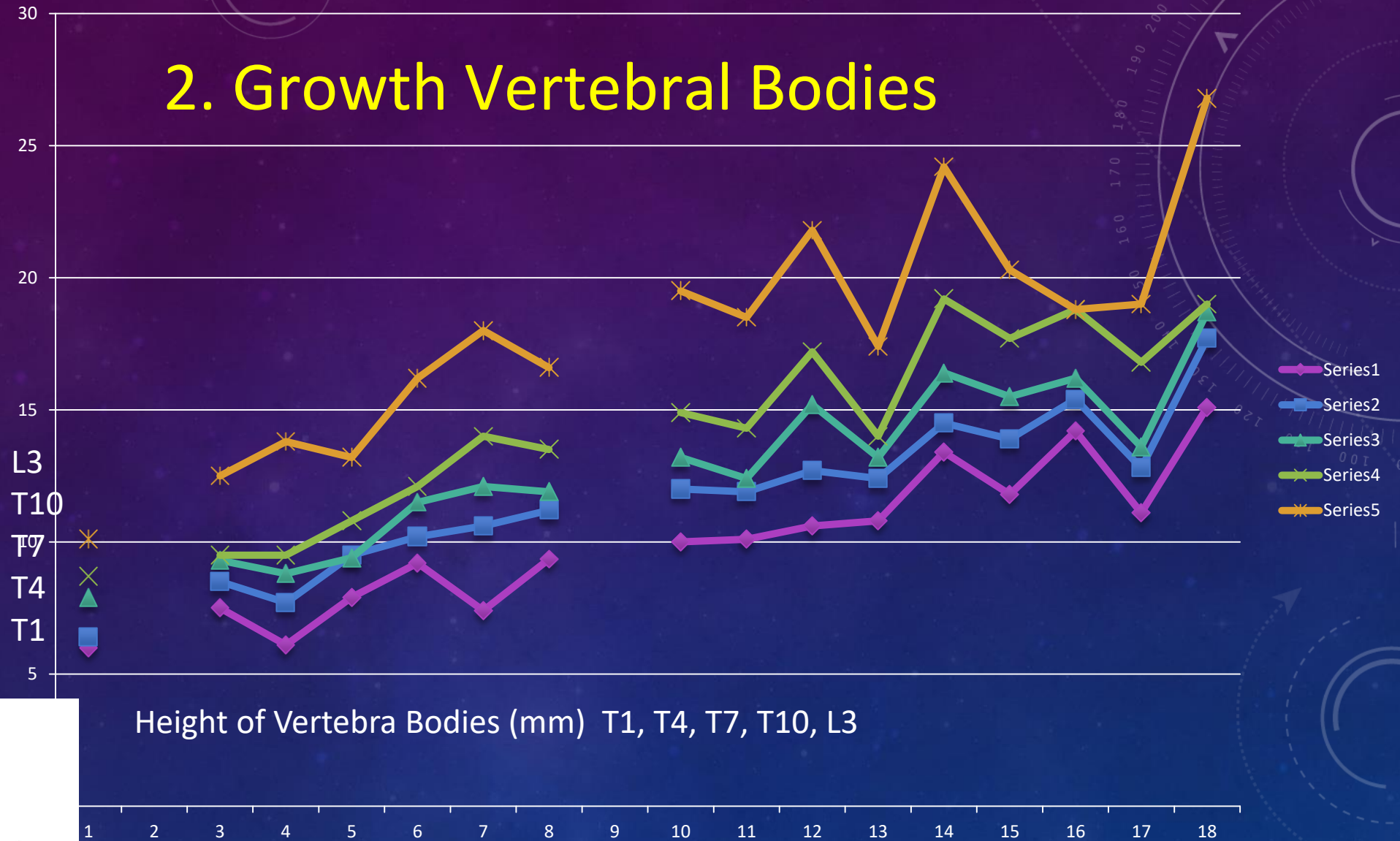
12 YEAR OLD CAUCASIAN FEMALE (1240)



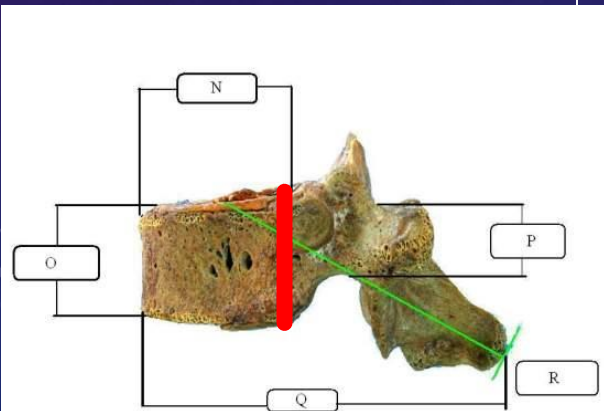
NEUROCENTRAL SYNCHONDROSIS

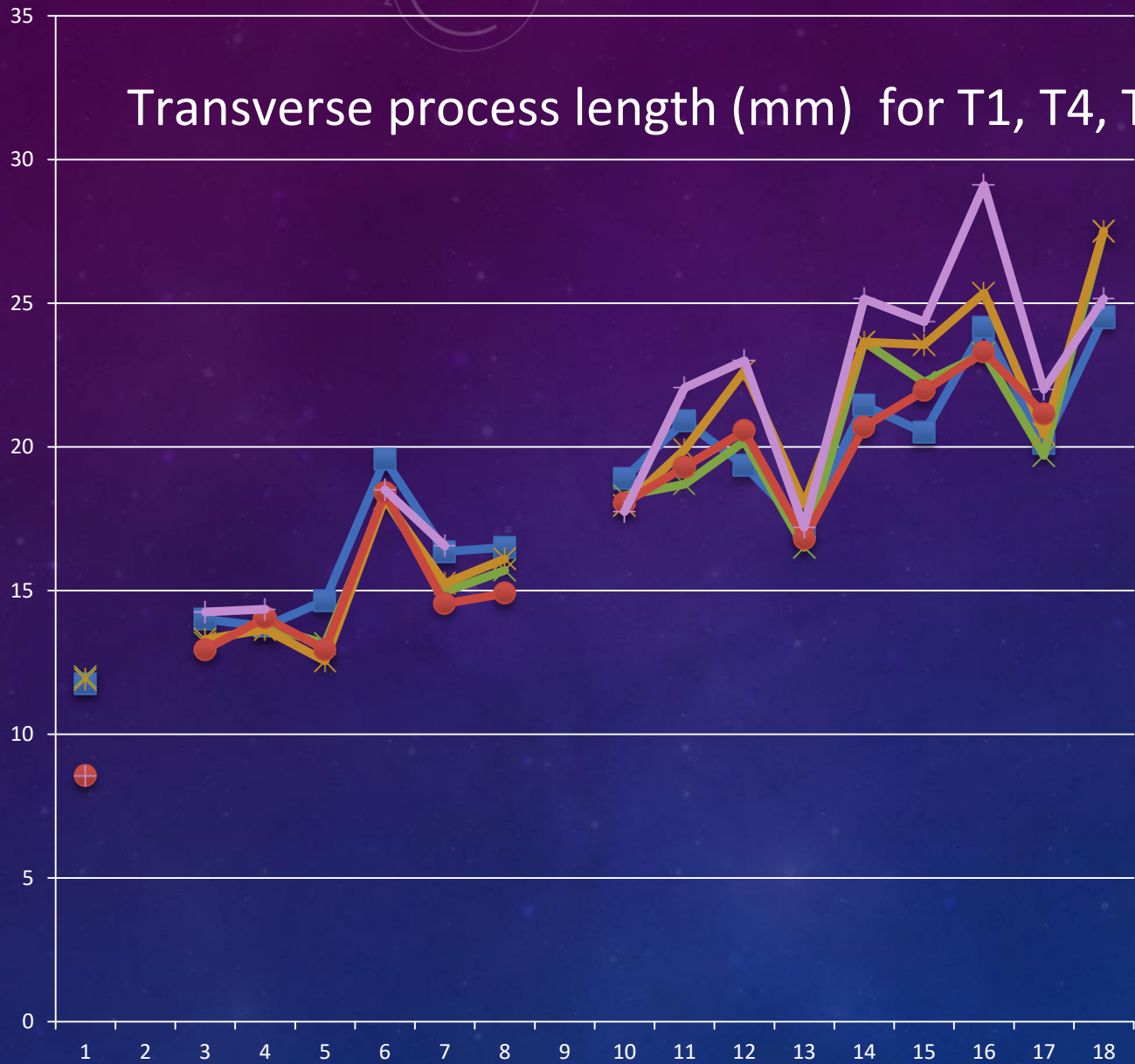
- The Results are in general agreement with recent MRI investigations into the characteristics of the NCS^{1, 2}
 - There was no closure of the NCS in any vertebra less than 3 chronological years
 - The lumbar vertebrae were starting to close the NCS in the 4-8 year age group, closely followed by the upper thoracic vertebrae
 - In the 8-12 year age group, the middle thoracic vertebrae (T4, T7, T10), the NCS were still only 50-74% closed
 - **Results support the theory that vertebral growth can be disturbed in the middle thoracic spine at the age of maximal growth rate, which is where most adolescent idiopathic scoliosis is seen.**^{3,4}

2. Growth Vertebral Bodies



Age (Years). Each body doubles in height



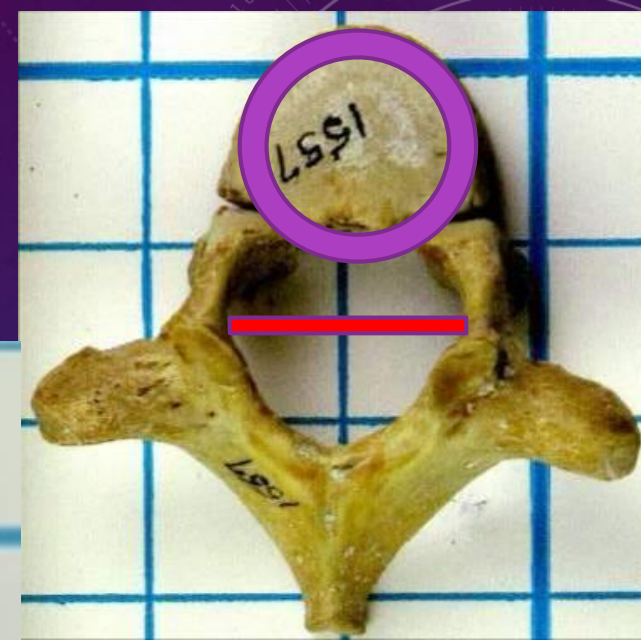
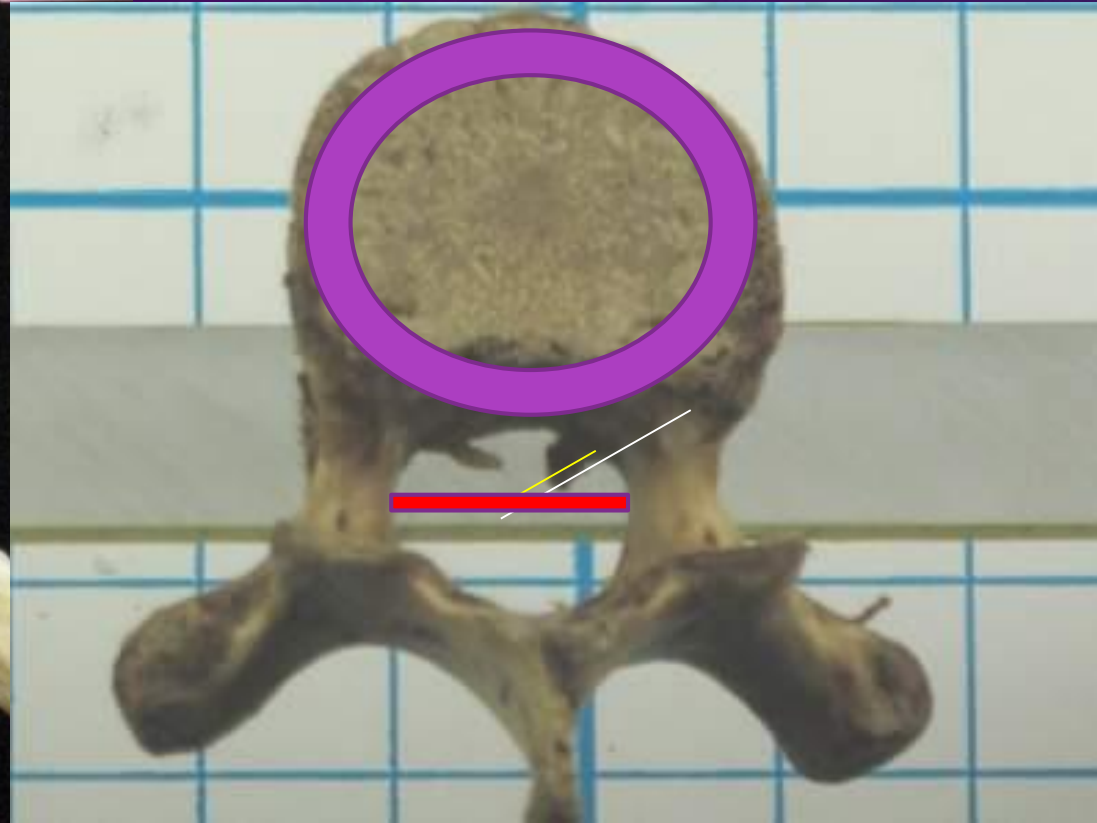
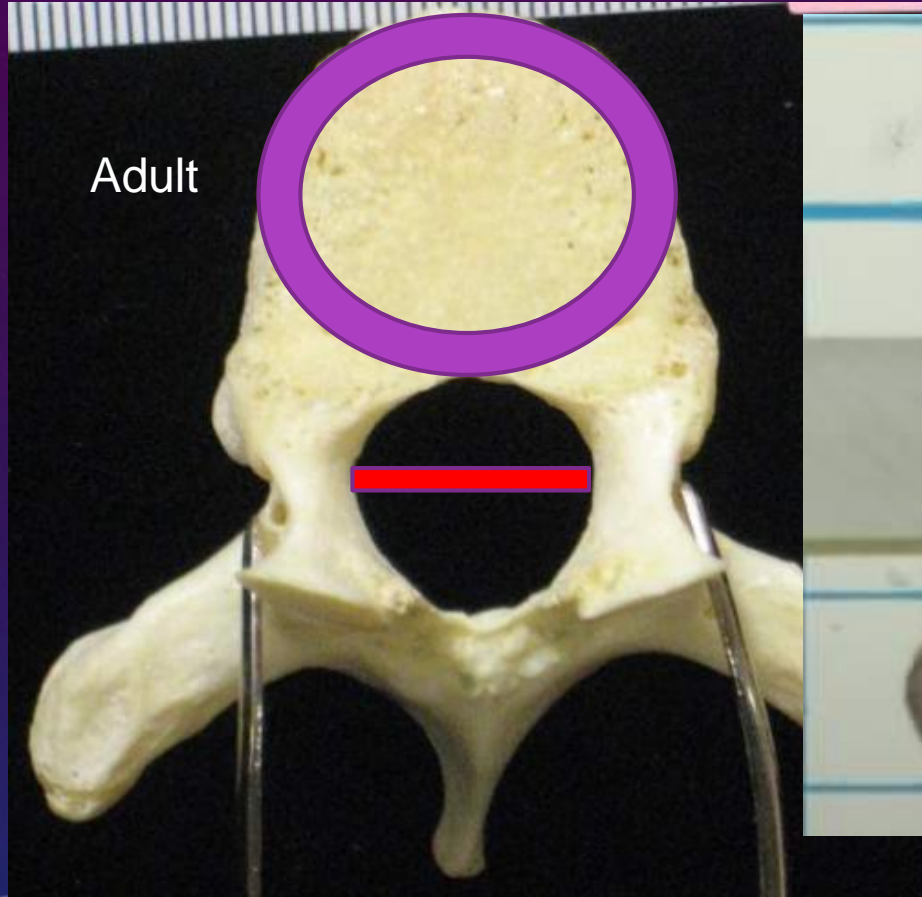


Transverse process length (mm) for T1, T4, T7, T10, L3

Age years. TPL doubles in length

3. SPINAL CANAL GROWTH

12 yo

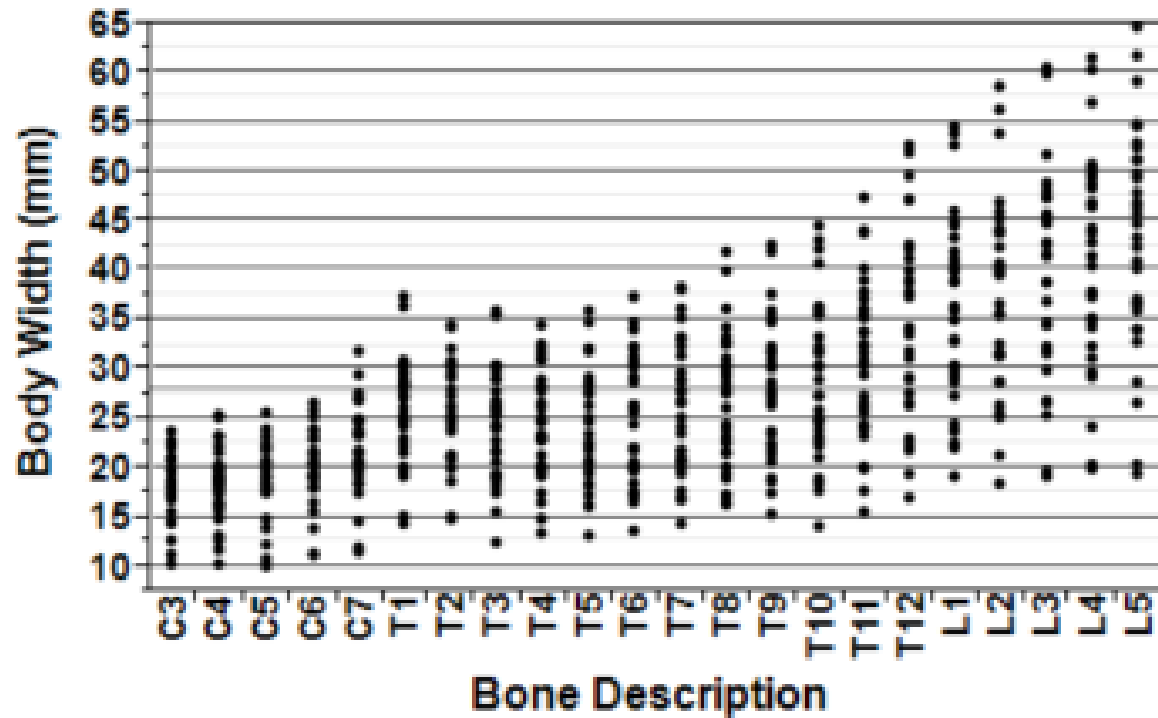


5 yo Child

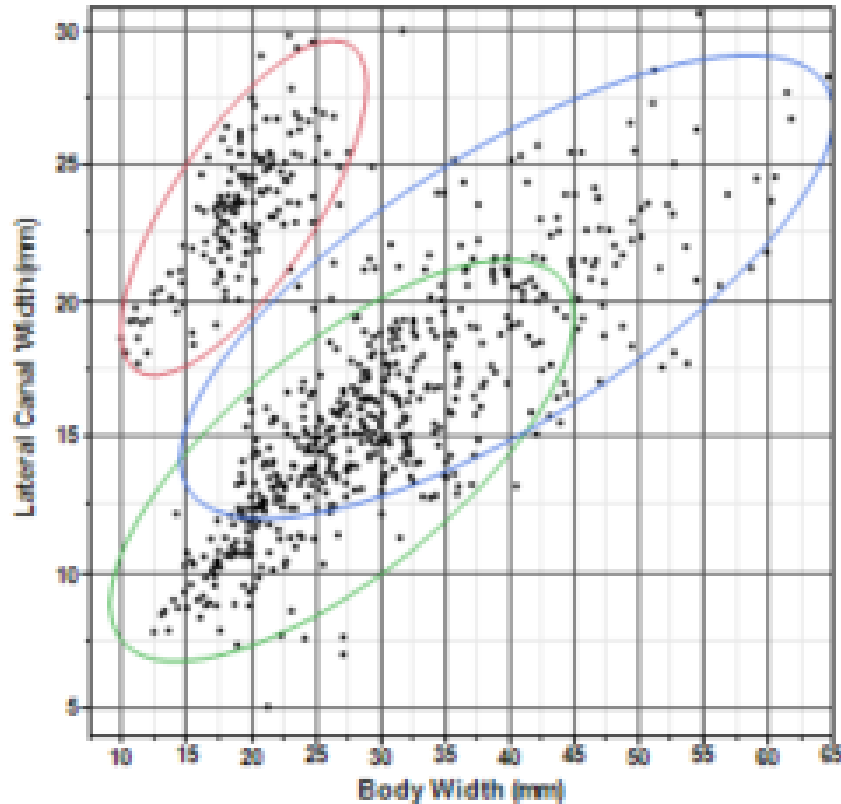
T12. Notice in the 5 year old child that the canal is almost as large as an adult, posterior elements are similar in size, but vertebral body is much smaller.

THORACIC BODY WIDTH

- Width of the bodies are similar in the upper thoracic spine but increase in width in lower



LATERAL CANAL WIDTH



Lateral canal width depends on the region of the spine.
Greatest proportional canal width is in the cervical spine

- Bivariate Normal Ellipse $P=0.950$ Region == "Cervical"
- Bivariate Normal Ellipse $P=0.950$ Region == "Thoracic"
- Bivariate Normal Ellipse $P=0.950$ Region == "Lumbar"

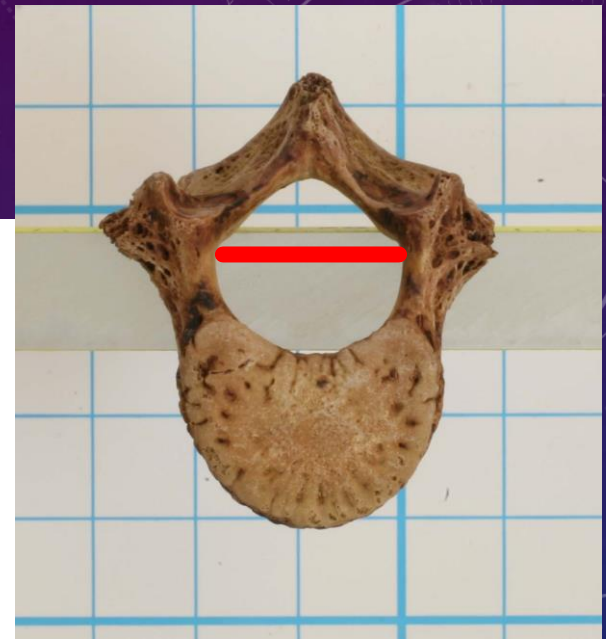


Figure 4. Lateral Canal Width (mm) by Vertebral Body Width (mm). Cervical canal data falls out of line with that of the thoracic and lumbar regions.

CANAL AREA

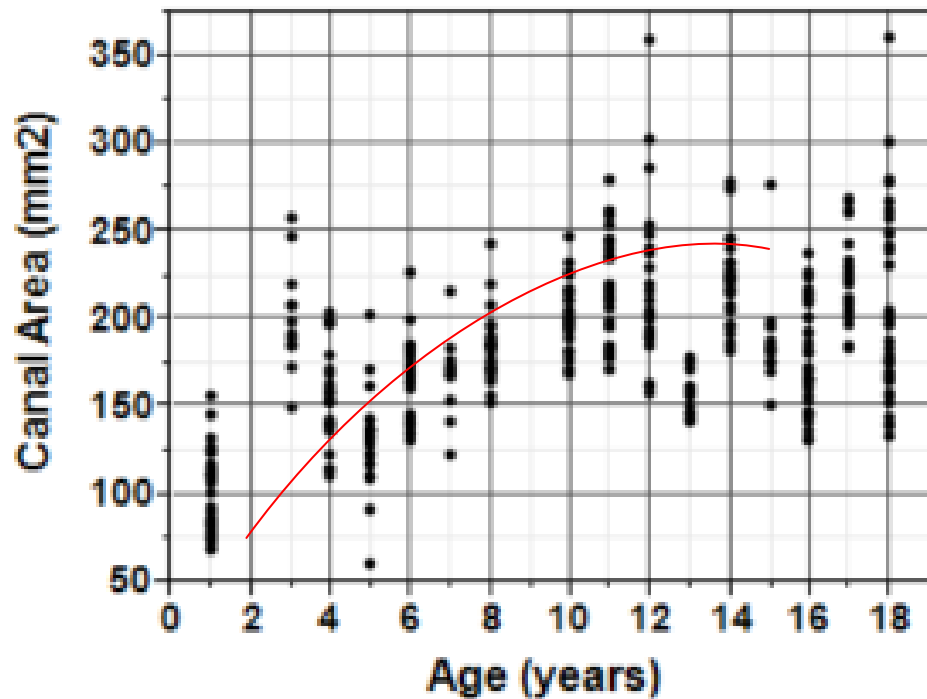
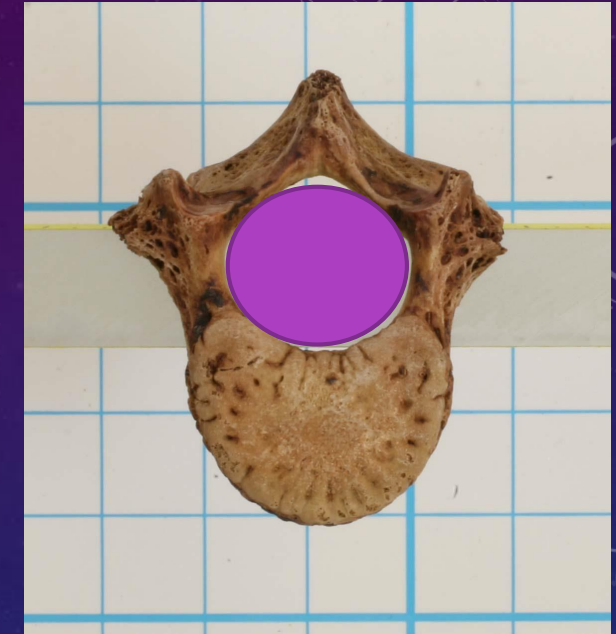
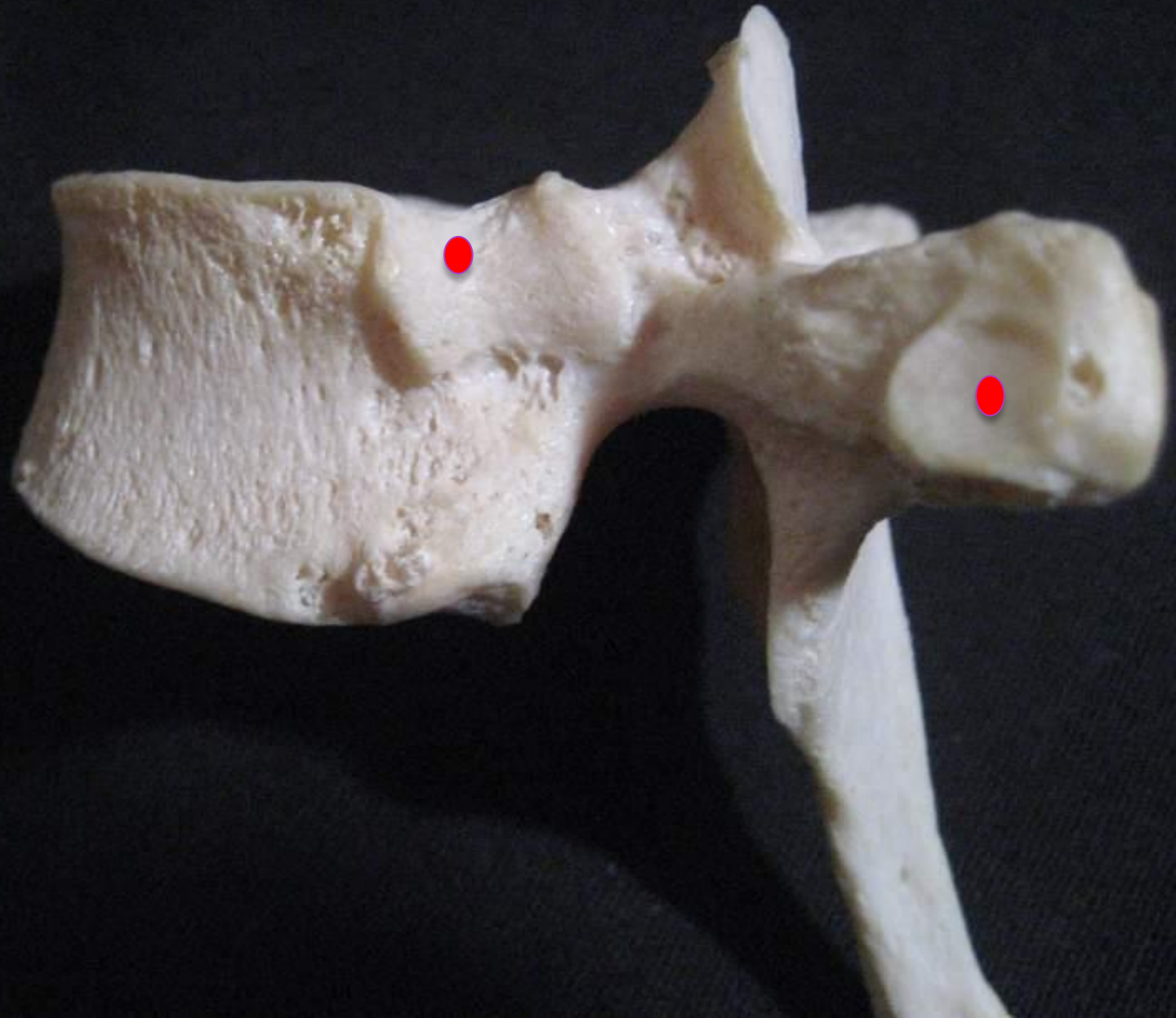


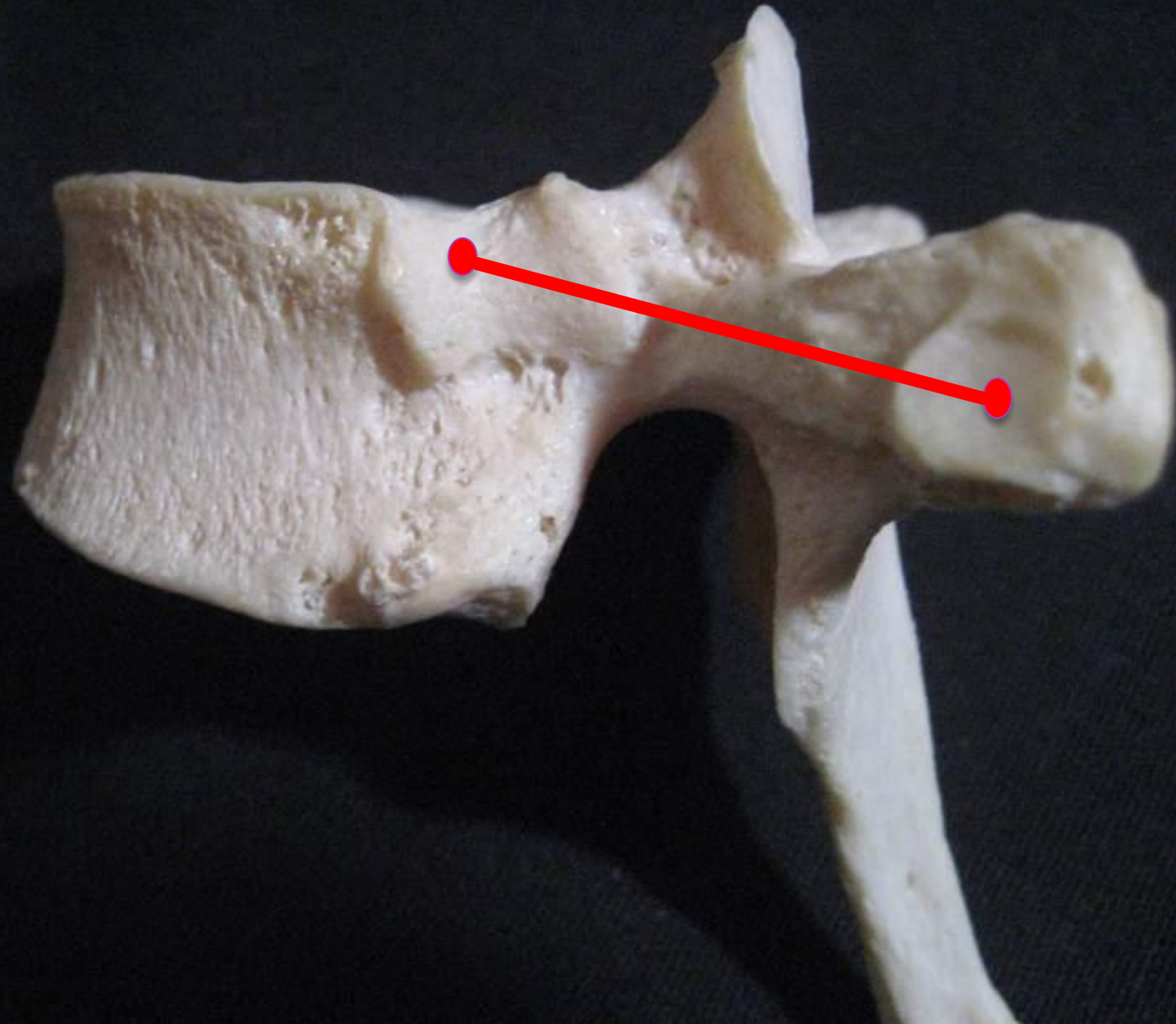
Figure 6. Thoracic Spine – Canal Area (mm²) by Age (years)

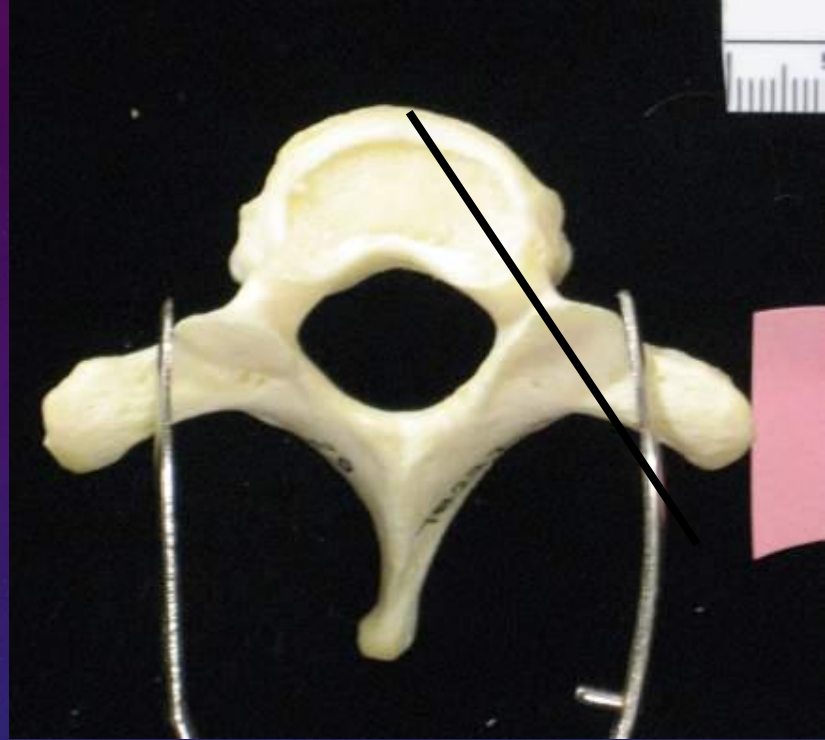
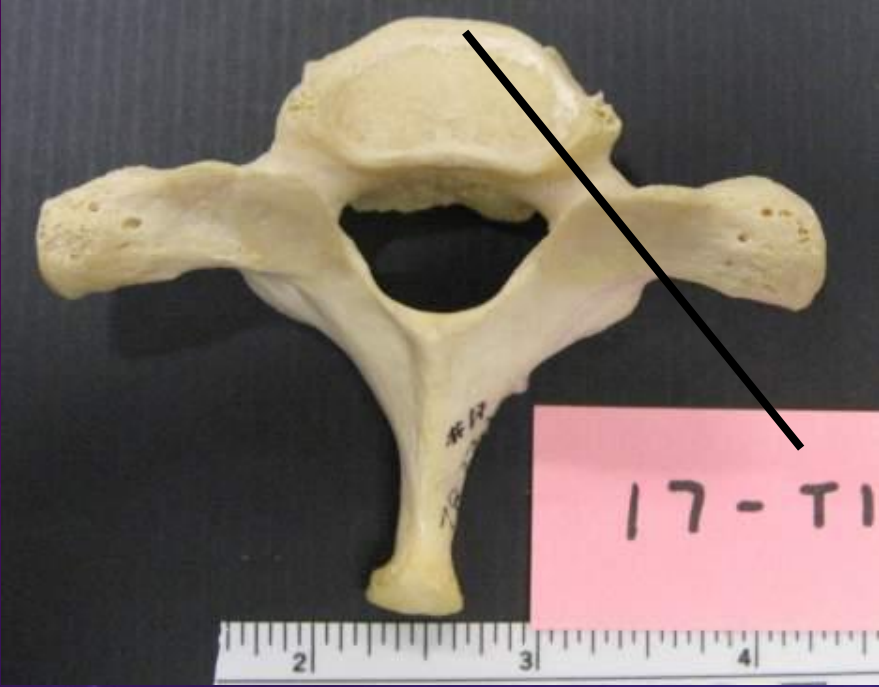


- Canal area continues to increase up to about age 10 years.
- Due to increase in M-L canal width.
- AP diameter of canal stops increasing about age 4-5 years.



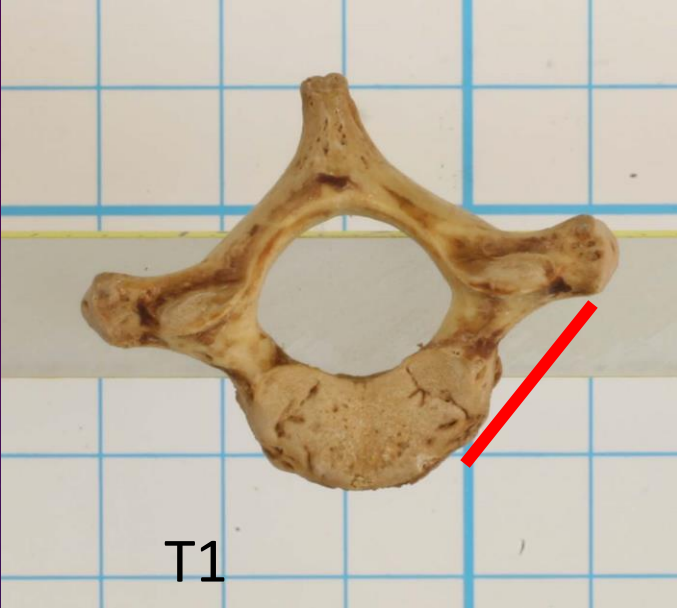
4. What about the ribs?





4 different
T1 vertebra
All 30 degree
Pedicle angles

Maxwell Museum
Osteology collection
University of New Mexico



T1



T4



T7

What does this mean?



T10



L3

The ribs determine both size, shape and motion of the thorax

Rib elevation INCREASES simultaneously the transverse diameter of the lower thorax and the antero-posterior diameter of the upper thorax.

In the mid-thoracic region, the Joints of the costal heads have an axis Running obliquely at roughly 45 deg to The sagittal plane so that both the Transverse and the anterior-posterior Diameters are increased.

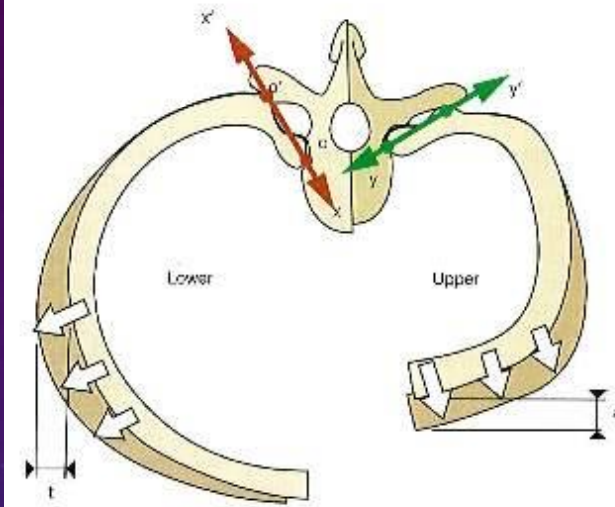


Figure 15

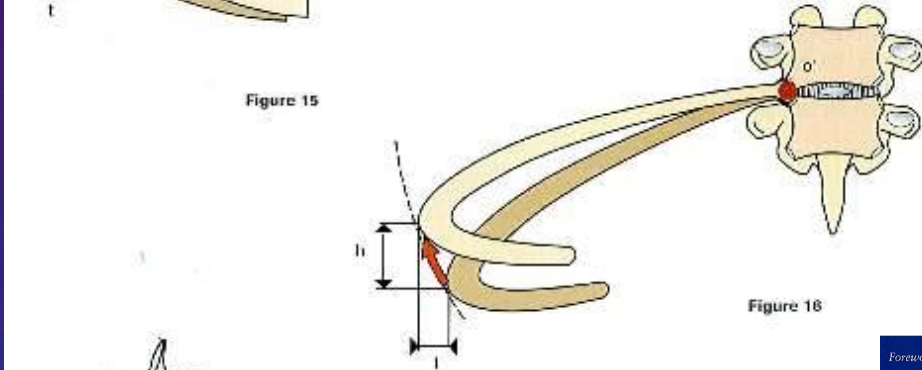


Figure 16

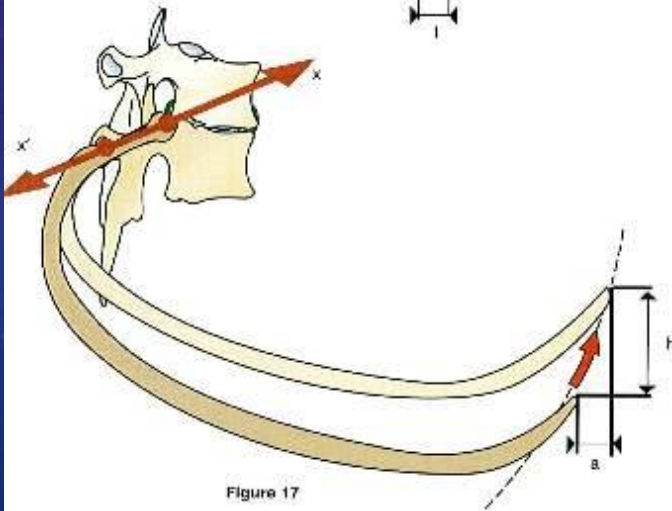
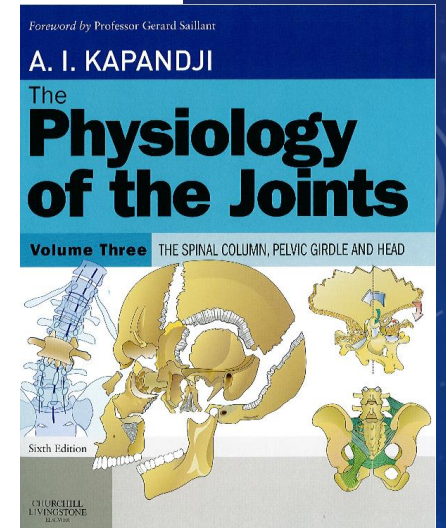
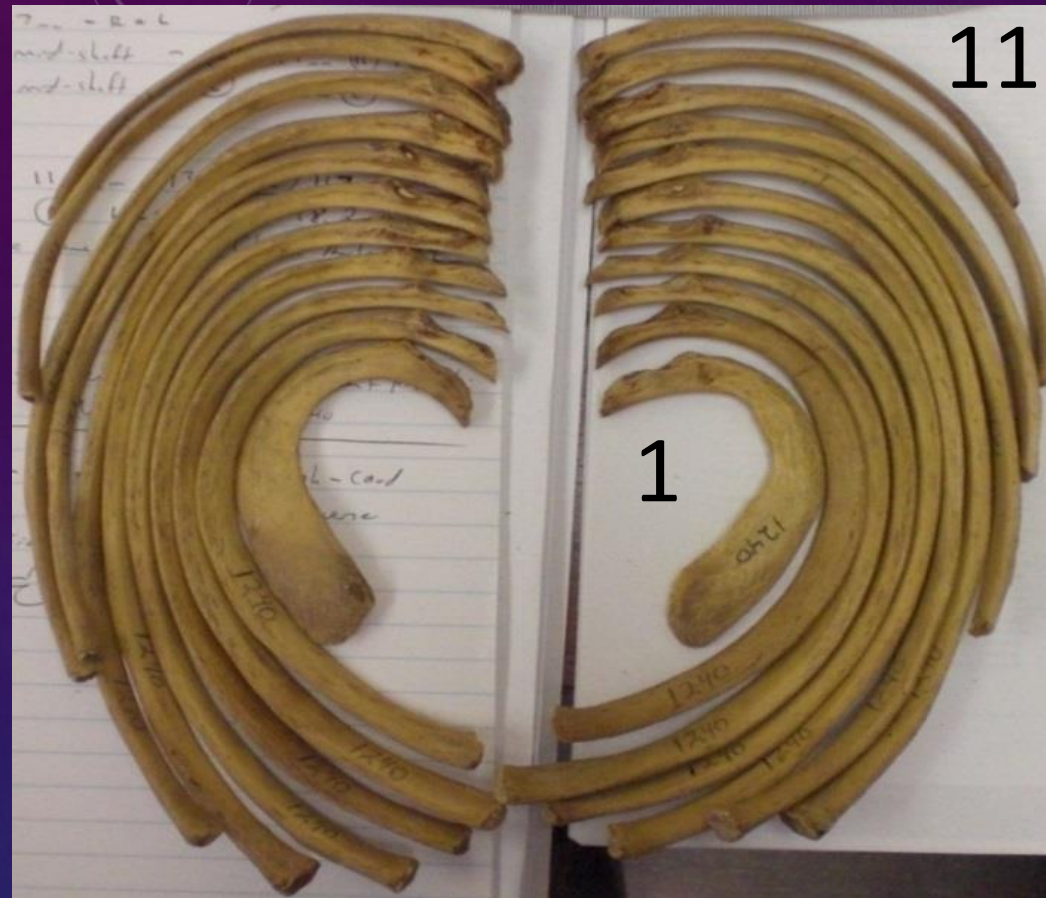


Figure 17





- **Basic rib shape arranged by location in the thorax.** The inner most rib, rib 1 shows the greatest curvature, while R11 is the straightest.

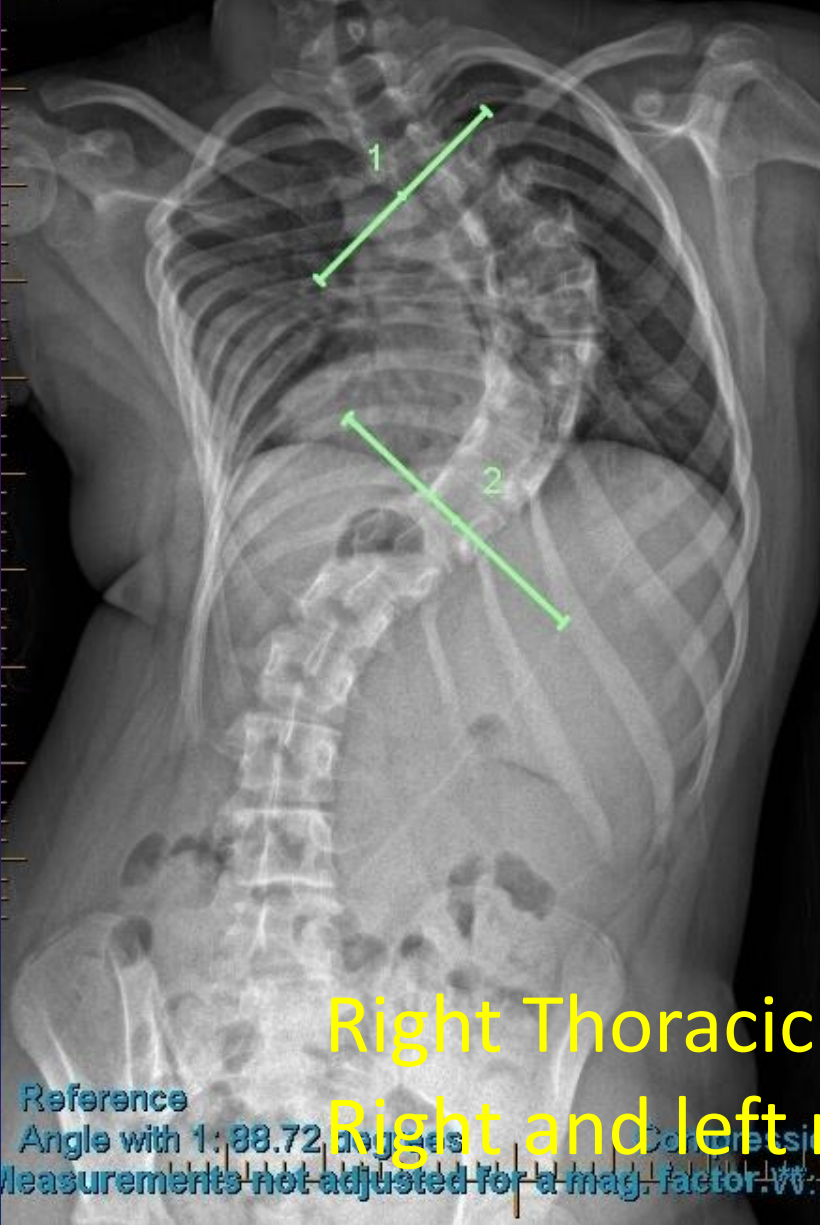
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#XR16002960CMH

DX #1452704899 - 1

1/1

PA



Reference
 Angle with 1: 88.72 degrees
 Measurements not adjusted for a mag. factor. WT: 6

SCOLIOSIS AP LAT UPRIGHT Chil

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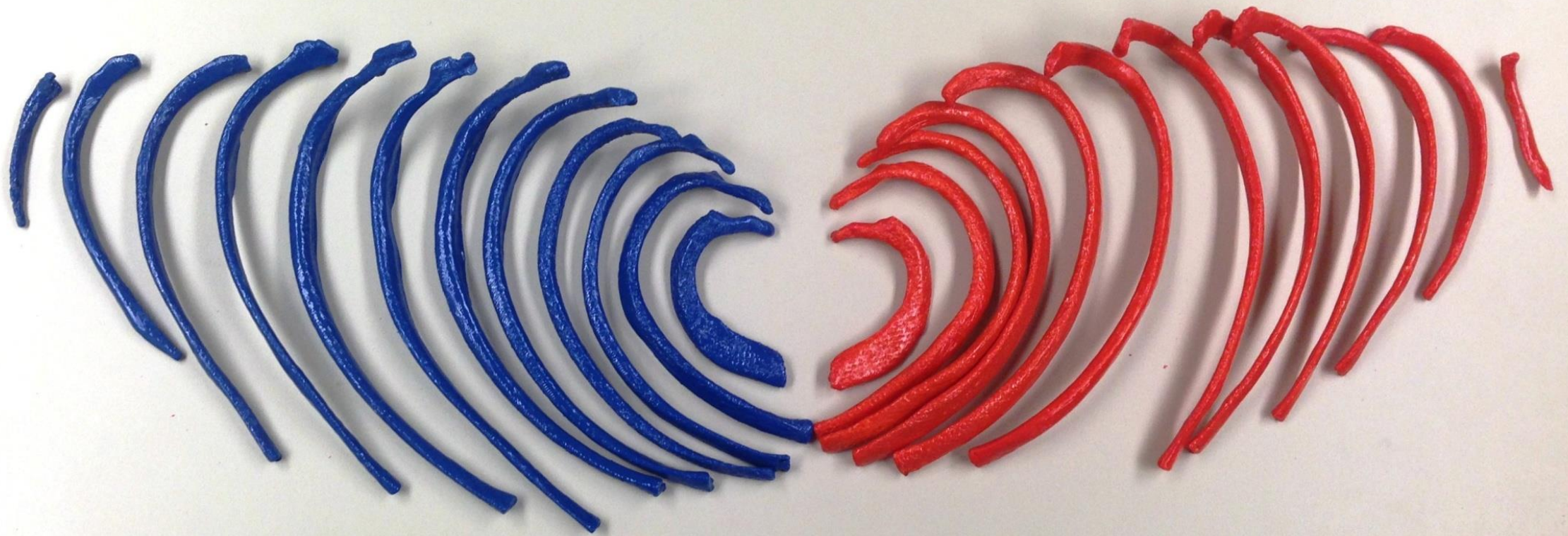
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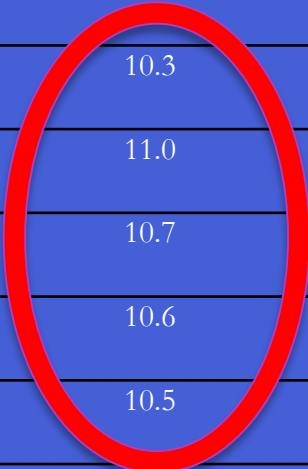
Right Thoracic Scoliosis.

Right and left ribs look very different



3D printing: Right and left ribs look very similar!
Suggests malposition of the ribs, not deformity

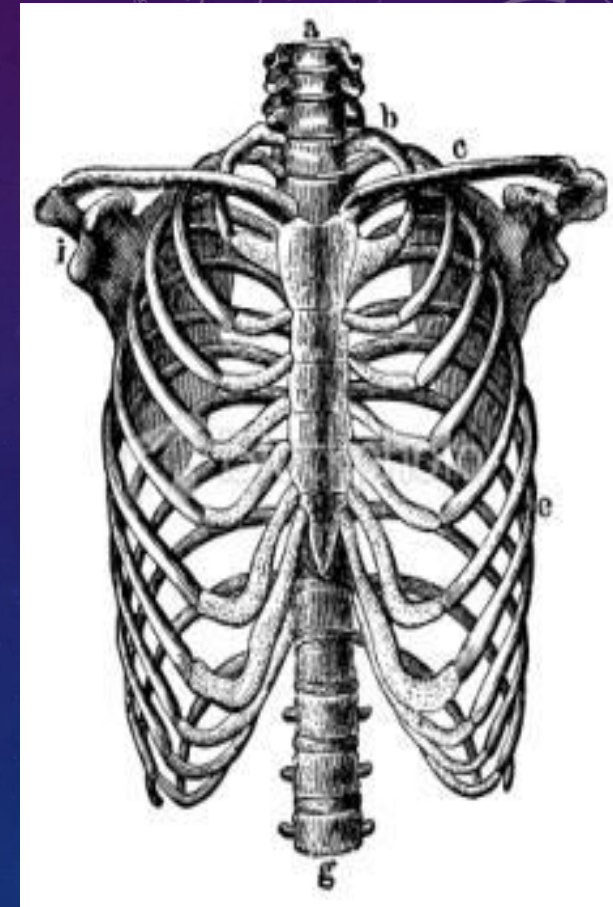
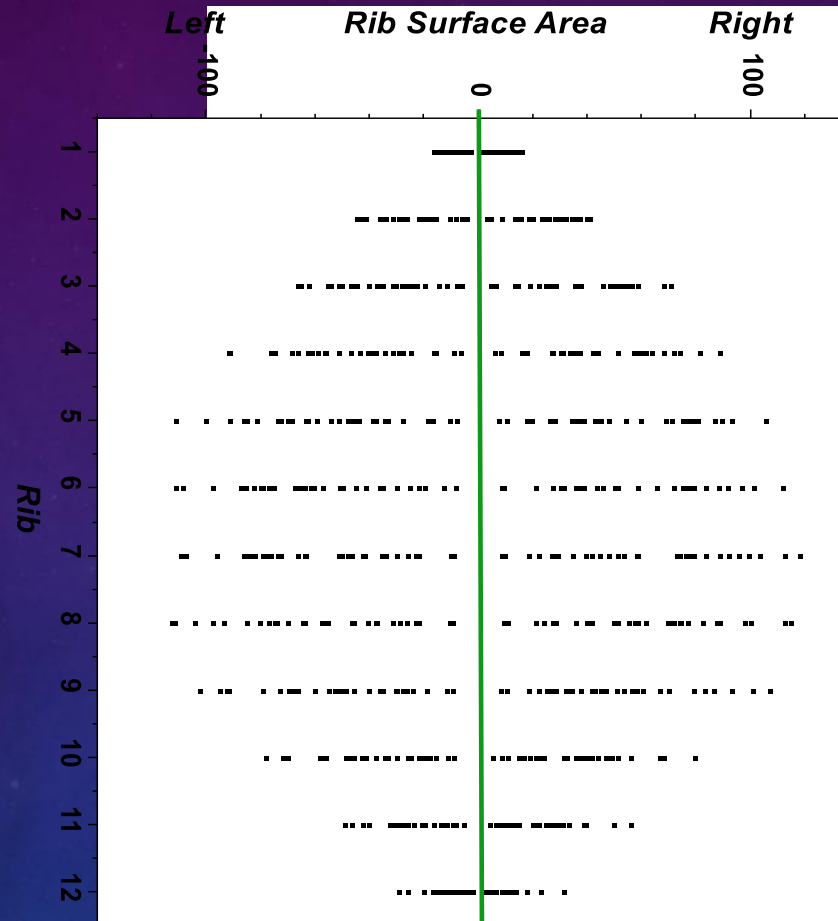
Rib No	b Start Length (mm)	m Growth Rate (mm/yr)	r ² Correlation Coefficient	n Sample Size
Ribs in the Middle Grow in <u>Length</u> the Fastest 10 mm/year, Compared to Ends 4 mm/year				
1	56.7	4.1	0.761	60
2	86.9	7.5	0.823	61
3	99.5	9.4	0.869	62
4	105.0	10.3	0.823	62
5	112.0	11.0	0.864	62
6	114.2	10.7	0.854	60
7	113.9	10.6	0.821	60
8	109.6	10.5	0.885	59
9	106.4	9.4	0.842	60
10	94.5	8.1	0.823	59
11	69.9	6.1	0.760	59
12	39.0	4.0	0.575	50



RIB SYMMETRY PROXIMAL/DISTAL

Symmetry of the thorax
(barrel chested nature of
humans) .

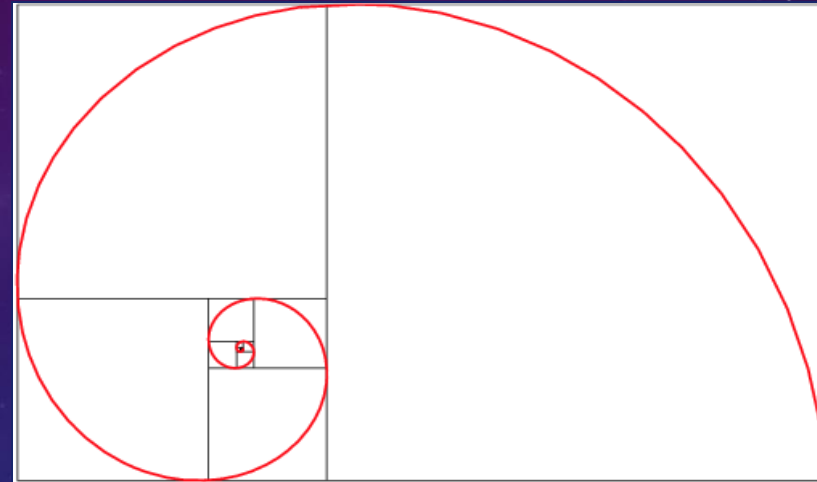
Projected area of the ribs
plotted by rib number.
Younger patients (age 1)
are close to the green line
while the 18 yo are the
farthest away.



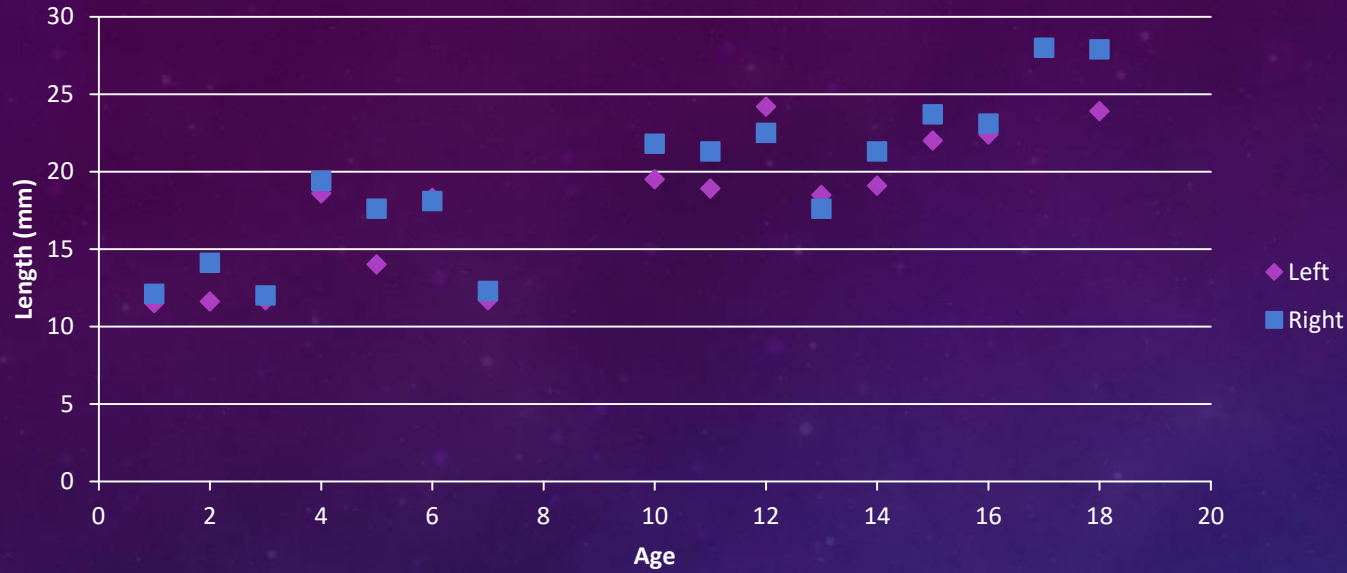


RIBS FOLLOW GOLDEN SPIRAL

- Ratio of 1.618 to 1.0
- Found throughout nature
- Ribs follow it (<10% error)
- Chest volume doubles age 10 y to adult
- Rib grows en length on sternal end
- Explains marked adolescent increase in volume.

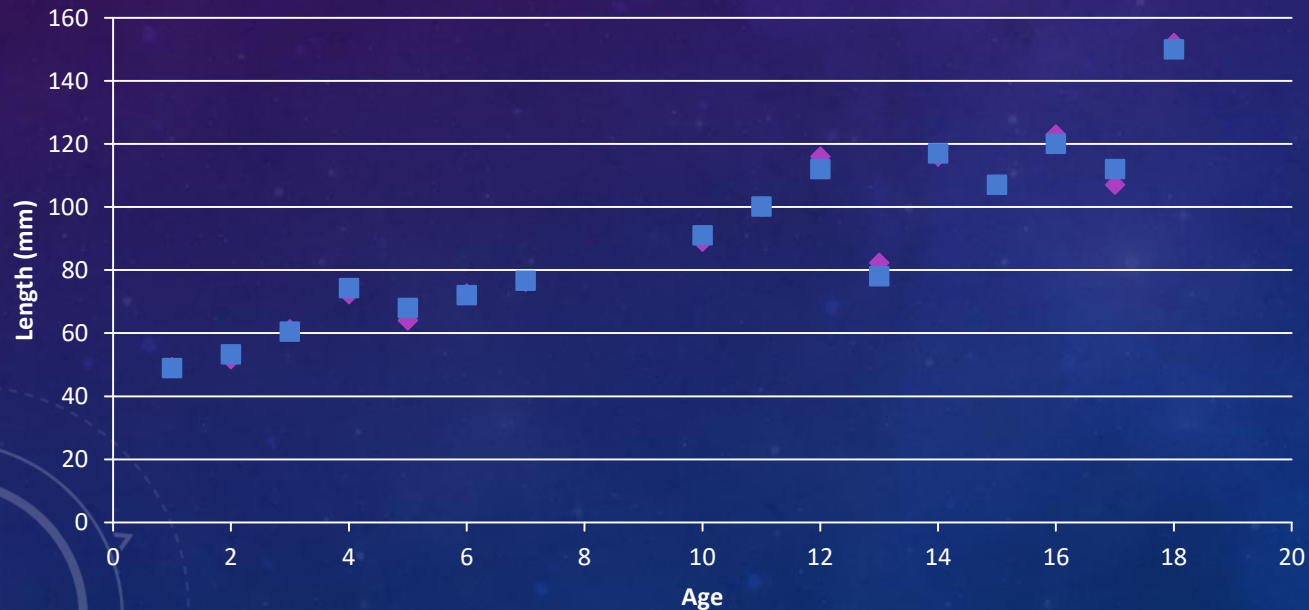


Iliac Column Width



Iliac columns showed a linear increase in length and width with age.

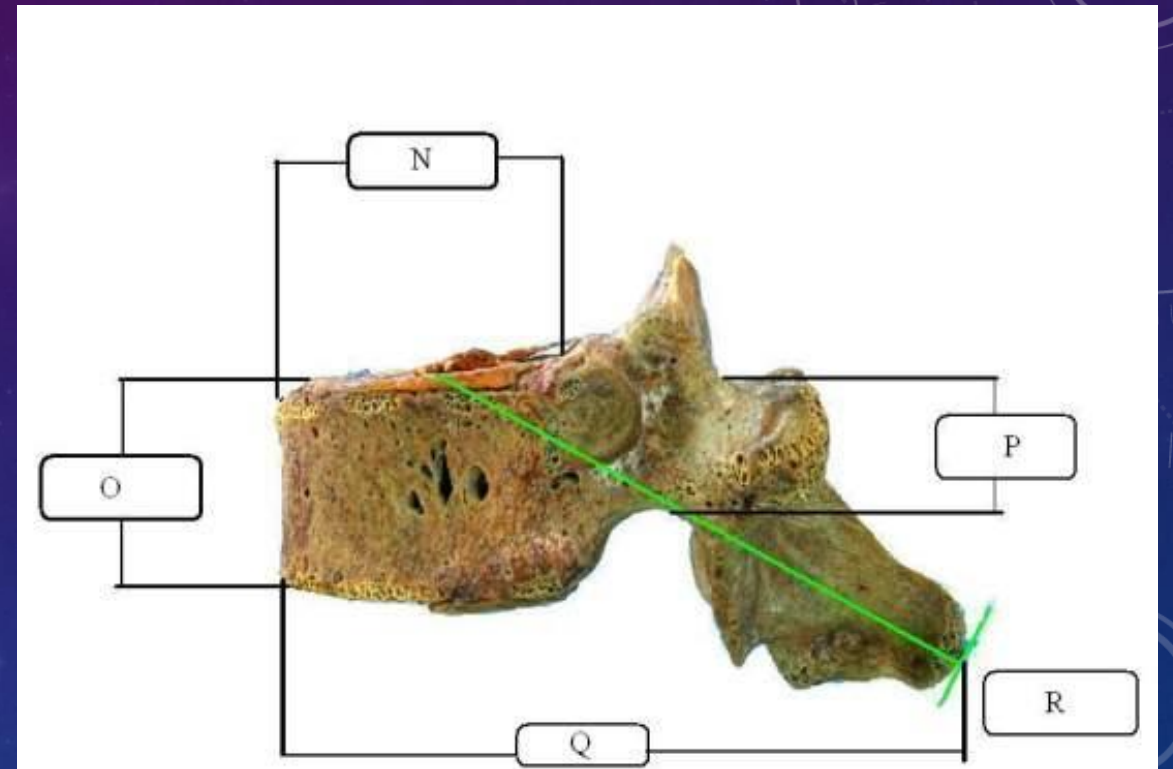
Iliac Column Length



Like the femur, triples in length.

MANY MANY LIMITATIONS

- Only 32 pediatric specimens
- Historical collection only
- No soft parts, especially anterior structures
- Nomenclature: 6 different definitions by 12 different authors



THANK YOU FOR
YOUR ATTENTION



14th Annual International Pediatric Orthopaedic Symposium

Presented by POSNA and AAOS

November 28 – December 2, 2017 • Orlando, Florida

Donald S. Bae, MD, Course Director

Michael G. Vitale, MD, MPH, Director Emeritus



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3. Zhang H, Sucato DJ . Unilateral Pedicle Screw Epiphyseodesis of the Neurocentral Synchondrosis. Production of Idiopathic-like Scoliosis in an Immature Animal Model. J Bone Joint Surg Am. 2008 Nov; 90(11): 2460-9
4. Sanders JO, Browne RH, Cooney TE et al. Correlates of the Peak Height Velocity in Girls with Idiopathic Scoliosis. SPINE 2006; 31: 2289-95.