

What We Have Learned about the Child's Ribs from Osteology Studies

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ICEOS

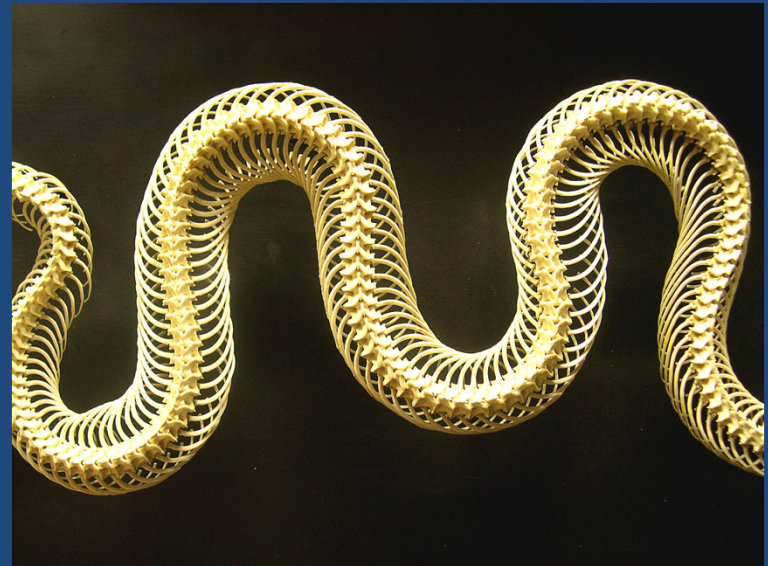
8TH INTERNATIONAL CONGRESS
ON EARLY ONSET SCOLIOSIS
AND GROWING SPINE

November 20–21, 2014

The Sheraton Hotel, Warsaw Poland

Disclosures

- K2M Research Support
- POSNA BOD
- Project Perfect World BOD
- Miracle Feet Medical
Advisory Board



Mel Smith in Dec 2001



Introduction

The shape of the thorax and individual ribs has been described in adults.¹ To our knowledge, however, the shape, size and growth of the ribs and vertebral bodies has **not been described for different aged children.**

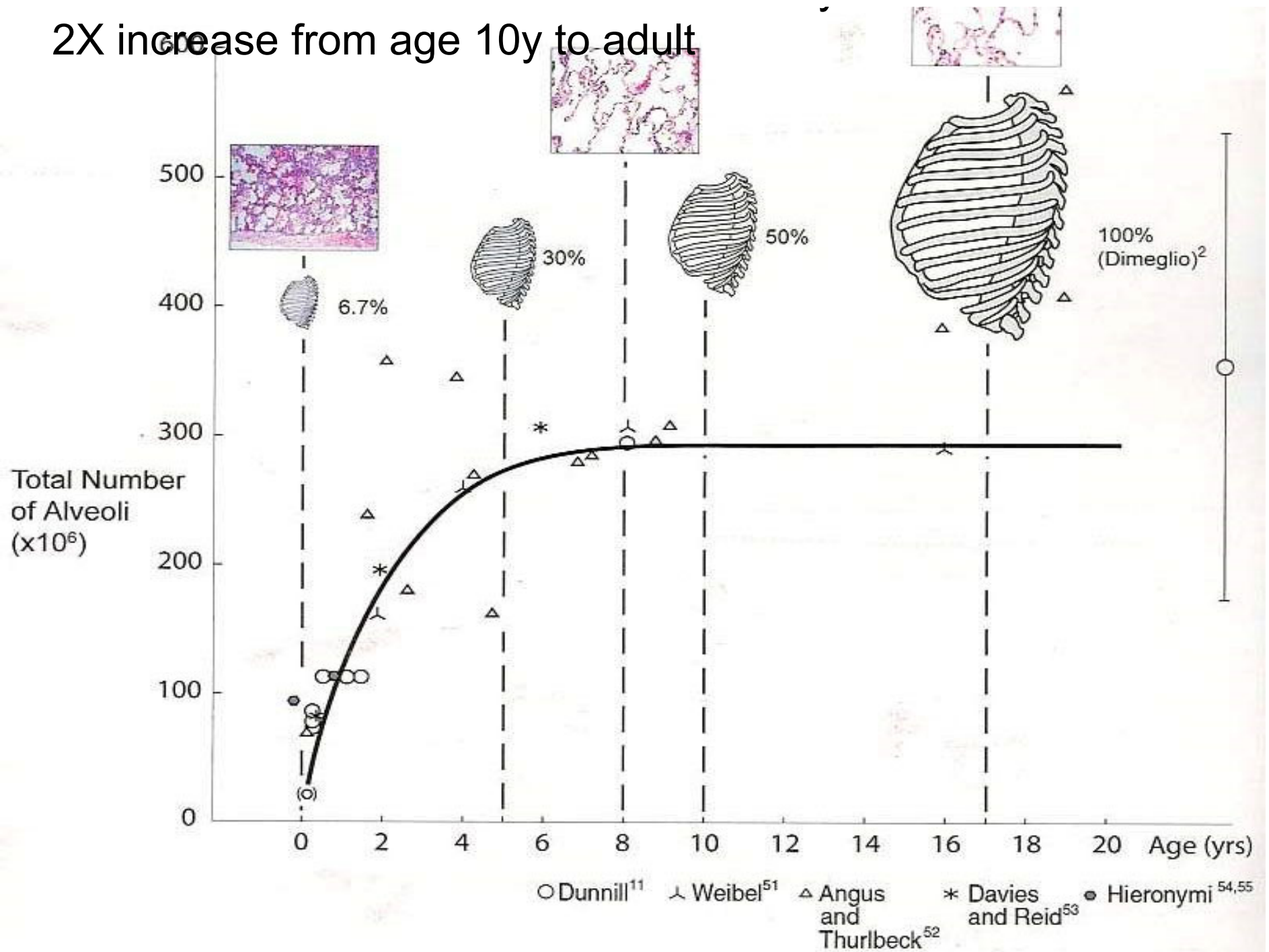
Rib and Thorax Growth

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

Paul Harrington
Library, KUMC.
Courtesy Mark Asher

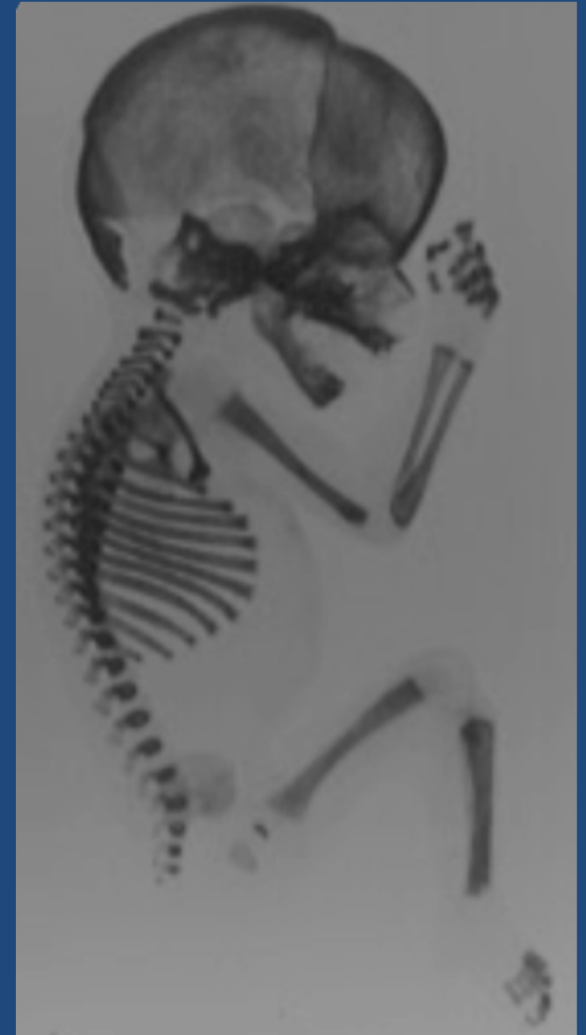


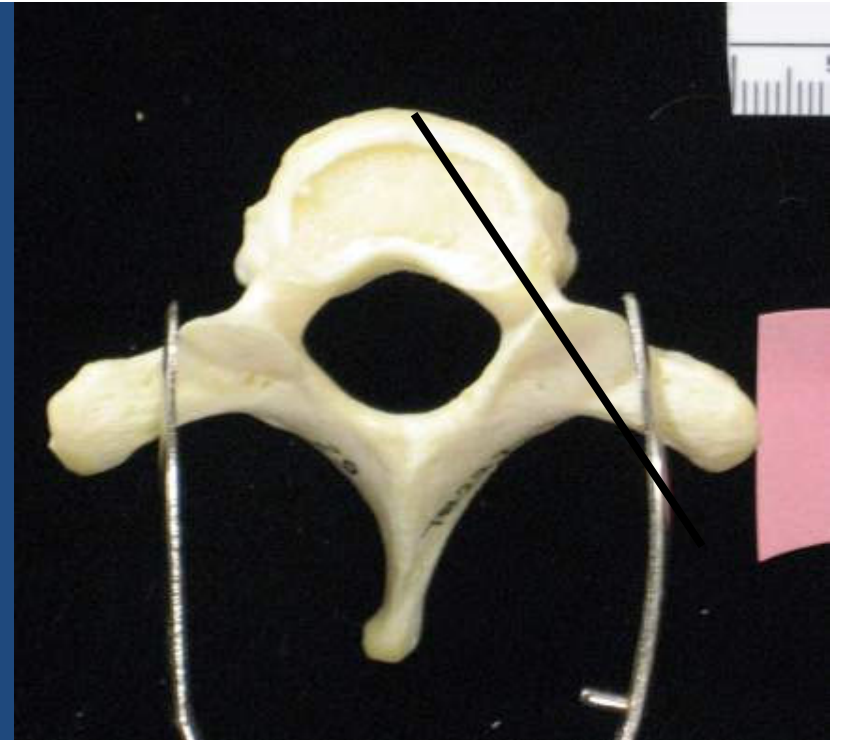
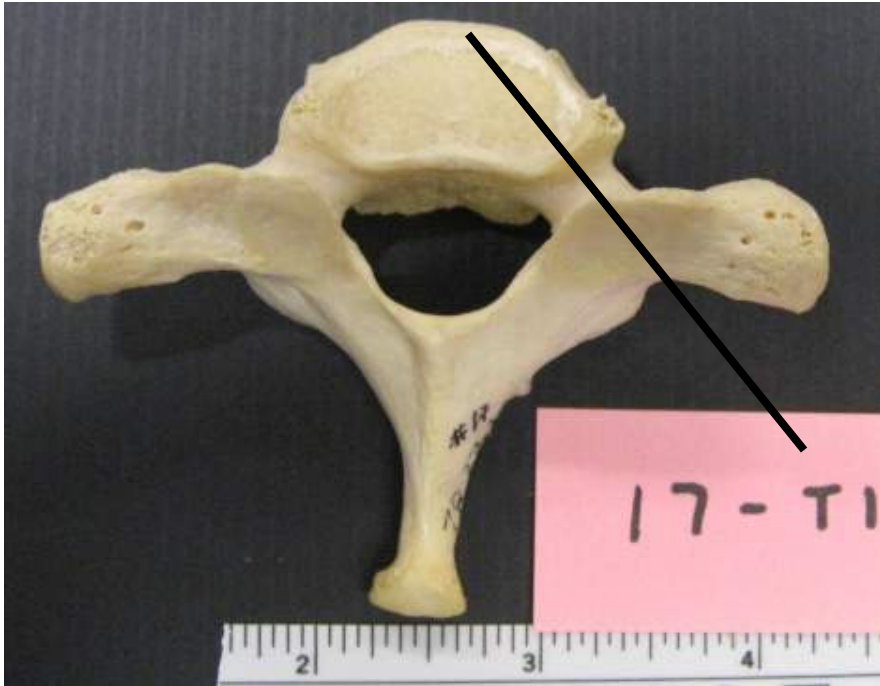
2X increase from age 10y to adult



My Questions

- How does the chest increase 15x in size?
- Even after age 10 years chest volume doubles
- Where is this volume increase occurring?
- 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





4 different
T1 vertebra
All 30 degrees

Maxwell museum
Osteology collection
University of New Mexico

CT Spine Thoracic/Lumbar w/o Contrast

1/16/1994
15 YEAR
M

11/5/2009 3:42:56 PM
CT09011637

LOC: -113
THK: 3
FFS

T4 level



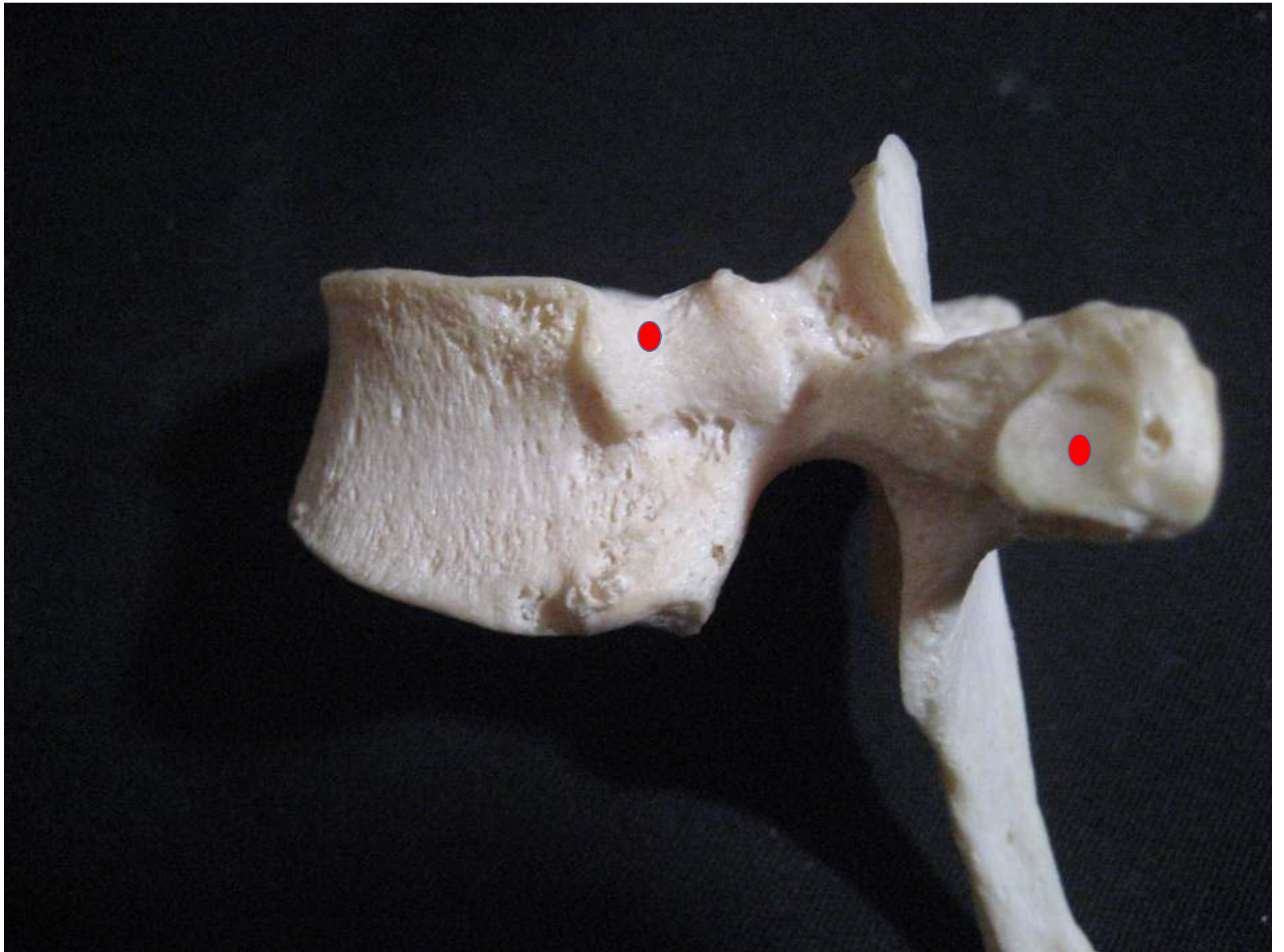
RD: 176.56
Tilt: 0
mA: 300
KVp: 120
Acq no: 4

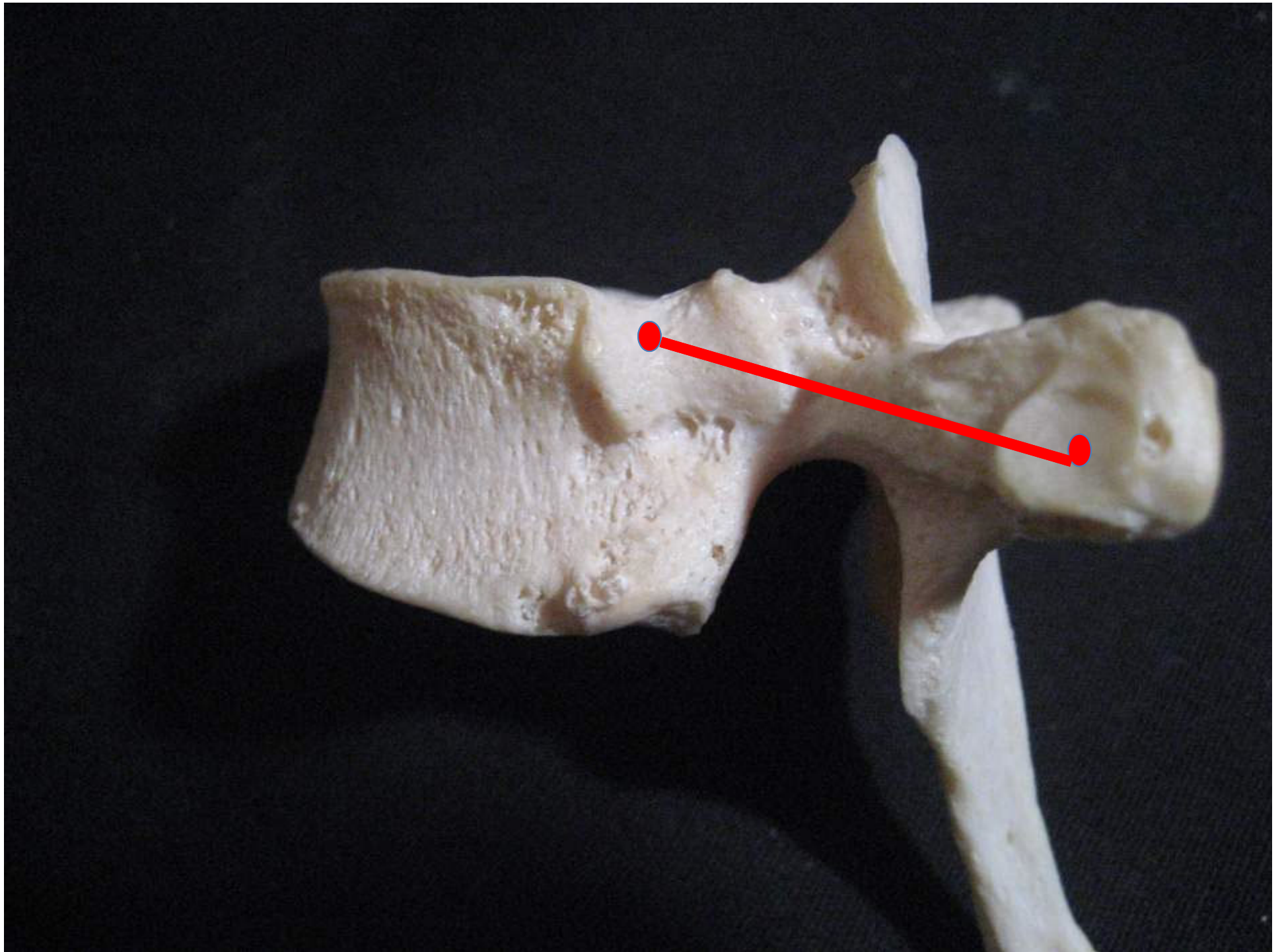
Page: 8 of 33

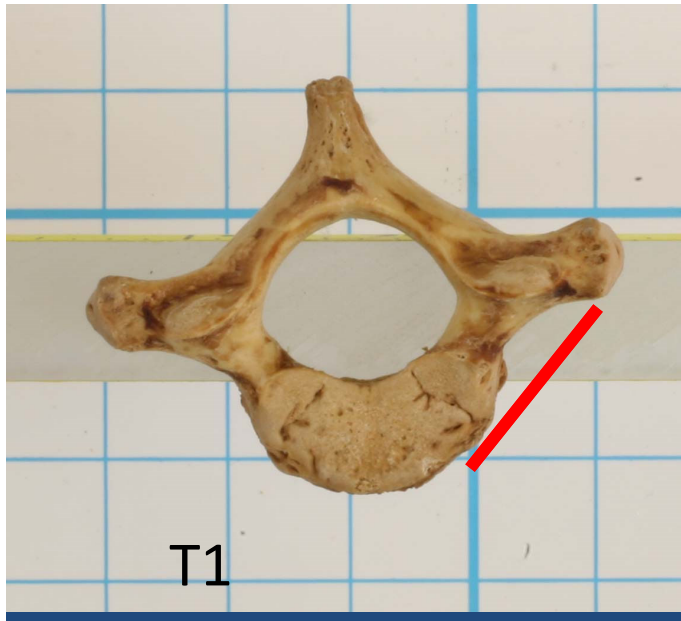
Z: 1
C: 400
W: 2000
DFOV: 17.6x17.6cm
Compressed 8:1
IM: 37 SE: 3

A

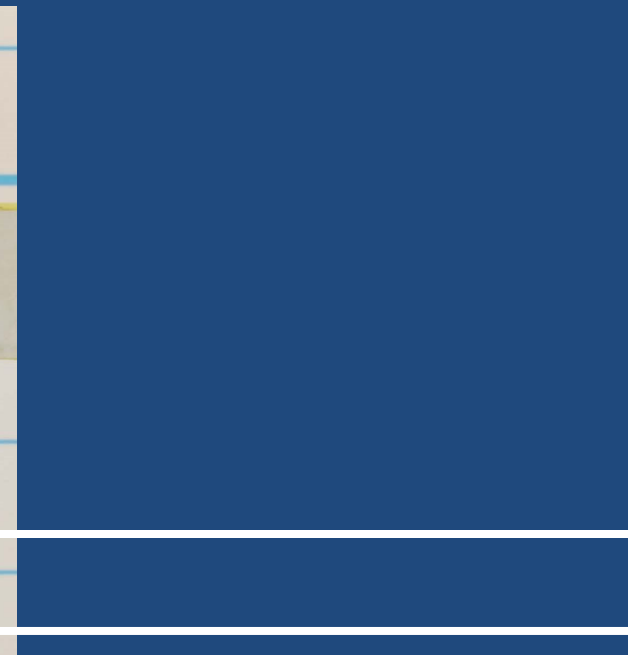
cm







What does this mean?



Rib elevation INCREASES simultaneously the transverse diameter of the lower thorax and the anteroposterior diameter of the upper thorax.

In the midthoracic 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.

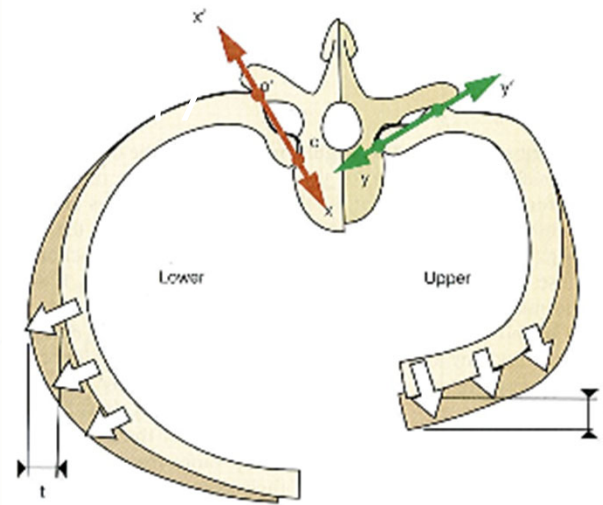


Figure 15

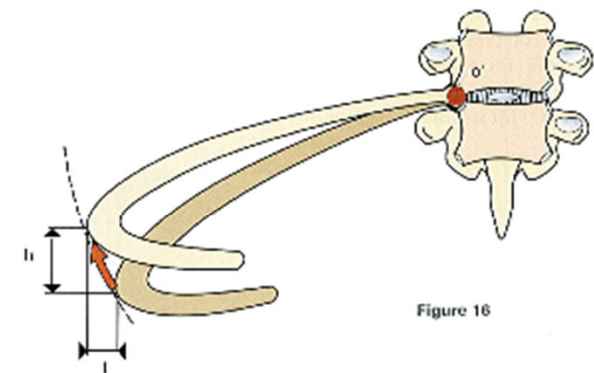


Figure 16

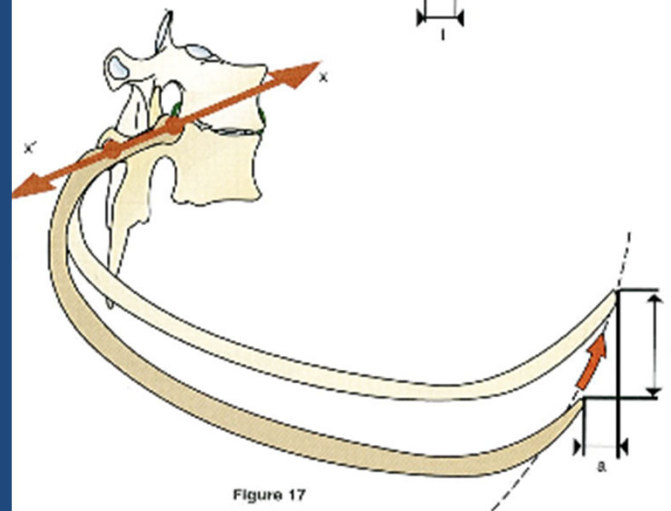


Figure 17

Pediatric Rib Anatomy Changes with Growth

AN ANATOMIC CT study

Joshua D. Stewart, BA₁
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₂.Department of Radiology

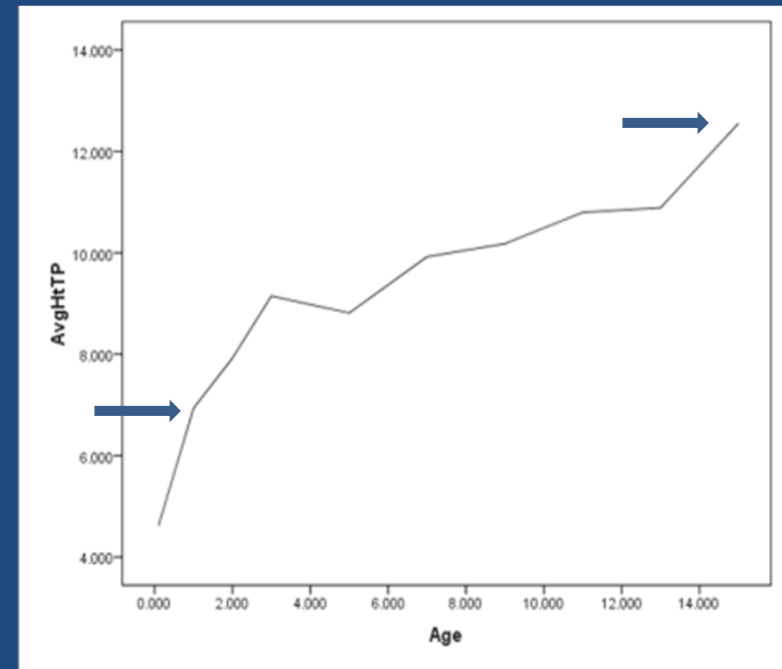
Children's Mercy Hospital
Kansas City, Missouri USA



Early CT Studies: Average Rib Heights

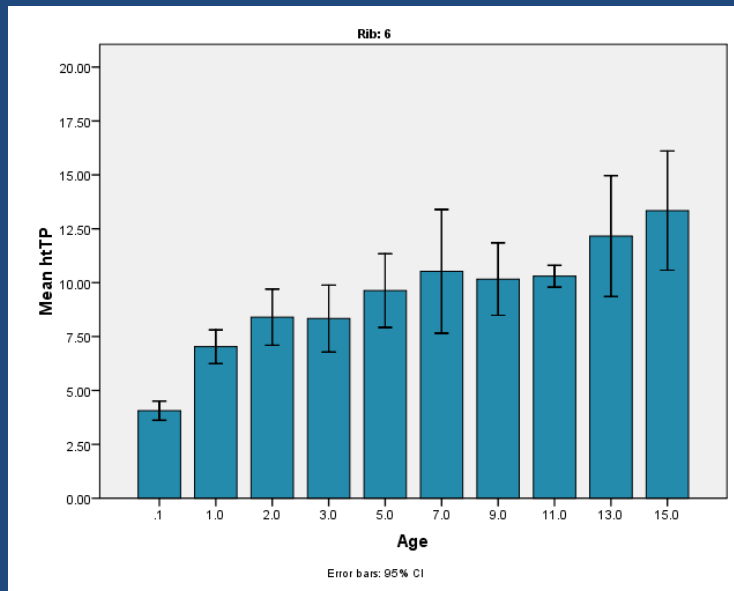
N=66 Normals, all ages

- By 1 year, the average rib height (6.9mm) is over 1/2 the average adult rib height (12.6mm). The average rib height reaches nearly $\frac{3}{4}$ the average adult rib height by age 3 years, and continues growth to reach adult rib height by approximately age 15 years.



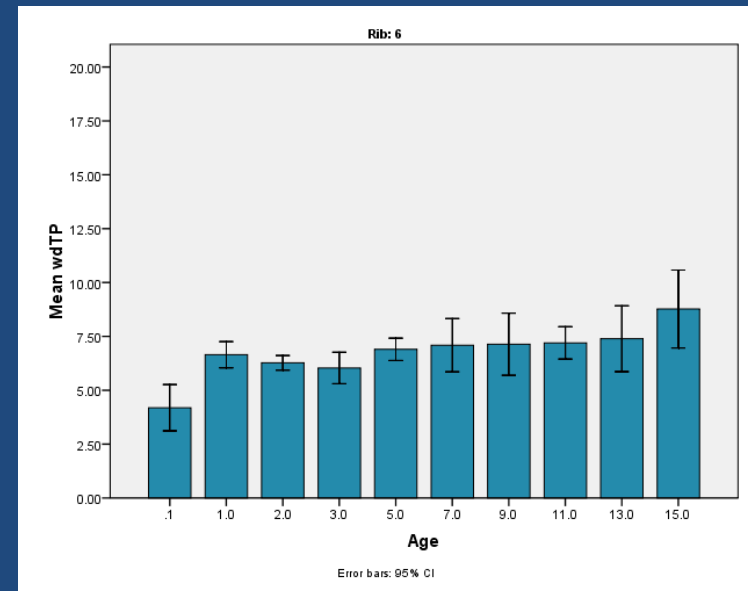
AVERAGE RIB HEIGHT GROWTH WITH AGE

Early CT Studies: Rib 6



Rib Height
(lateral to transverse process)

Rib Height Increases with Age
By 1 year it is $\frac{1}{2}$ adult height.
CT study 66 patients, aged infancy to adult



Rib Width
(lateral to transverse process)



Beginnings

- Scout trip July 2009
- First full trip September 2009
- Several follow-up trips



Purpose

- The purpose of the osteology study was to collect data on representative skeletons aged 1-18 years and study growth pattern of vertebra and ribs.

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



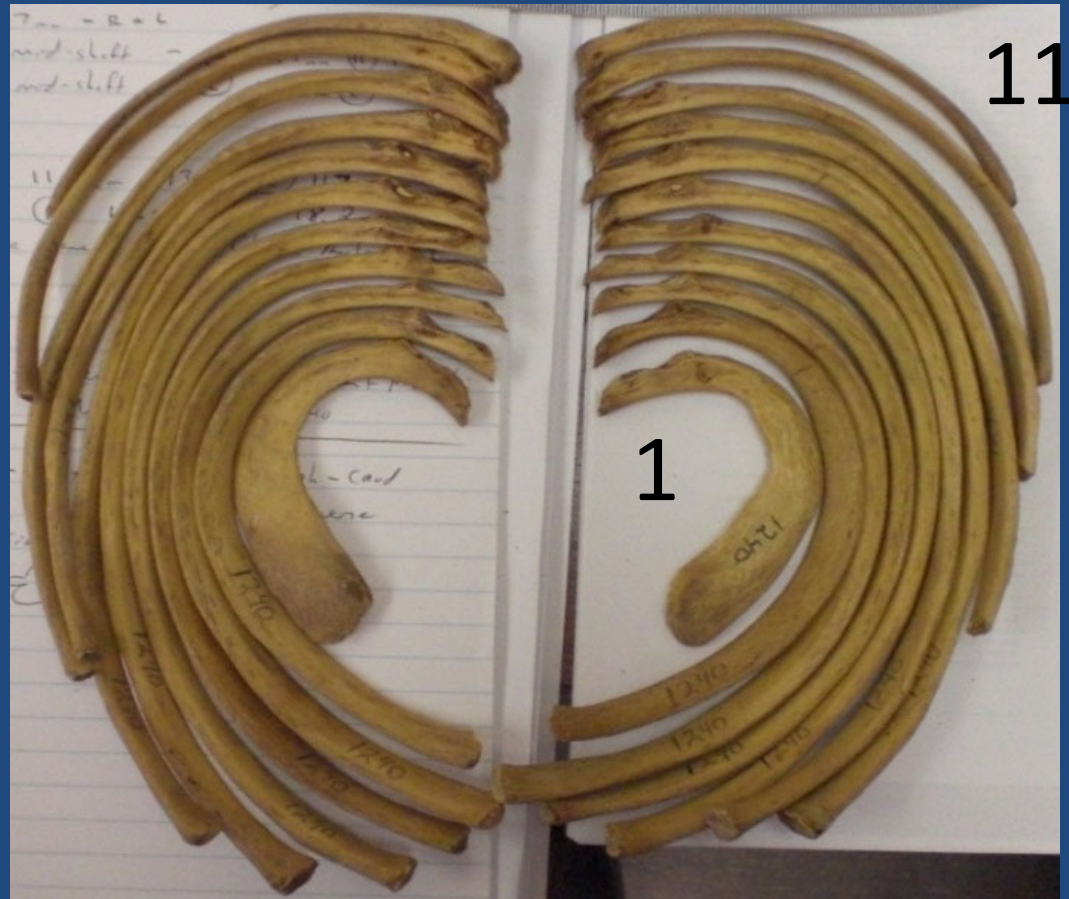
The Collection

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

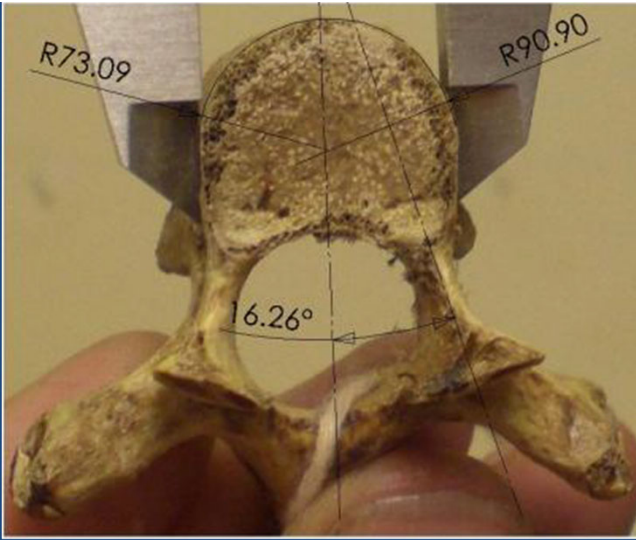


Specimen Demographics

- **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**
- **Our Study**
 - 32 Aged 1-18 YO (no 2 or 9 YO)
 - 19 Females, 13 Males
 - 29 Black, 3 Caucasian
 - Height and Weight



- **Basic rib shape arranged by location in the thorax.** The inner most rib, rib 1 shows the greatest curvature, while R11 is the straightest. For this specimen there was no R12.



Started with Calipers

3 Measurement Methods

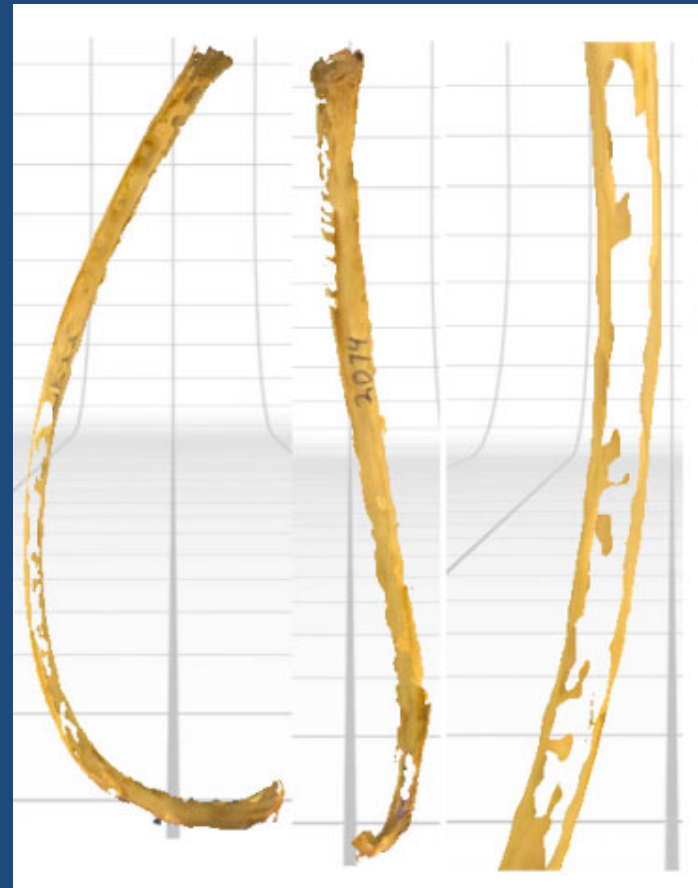
Caliper

- Good for Linear Measurements
- All initial data taken by this method
- Limited

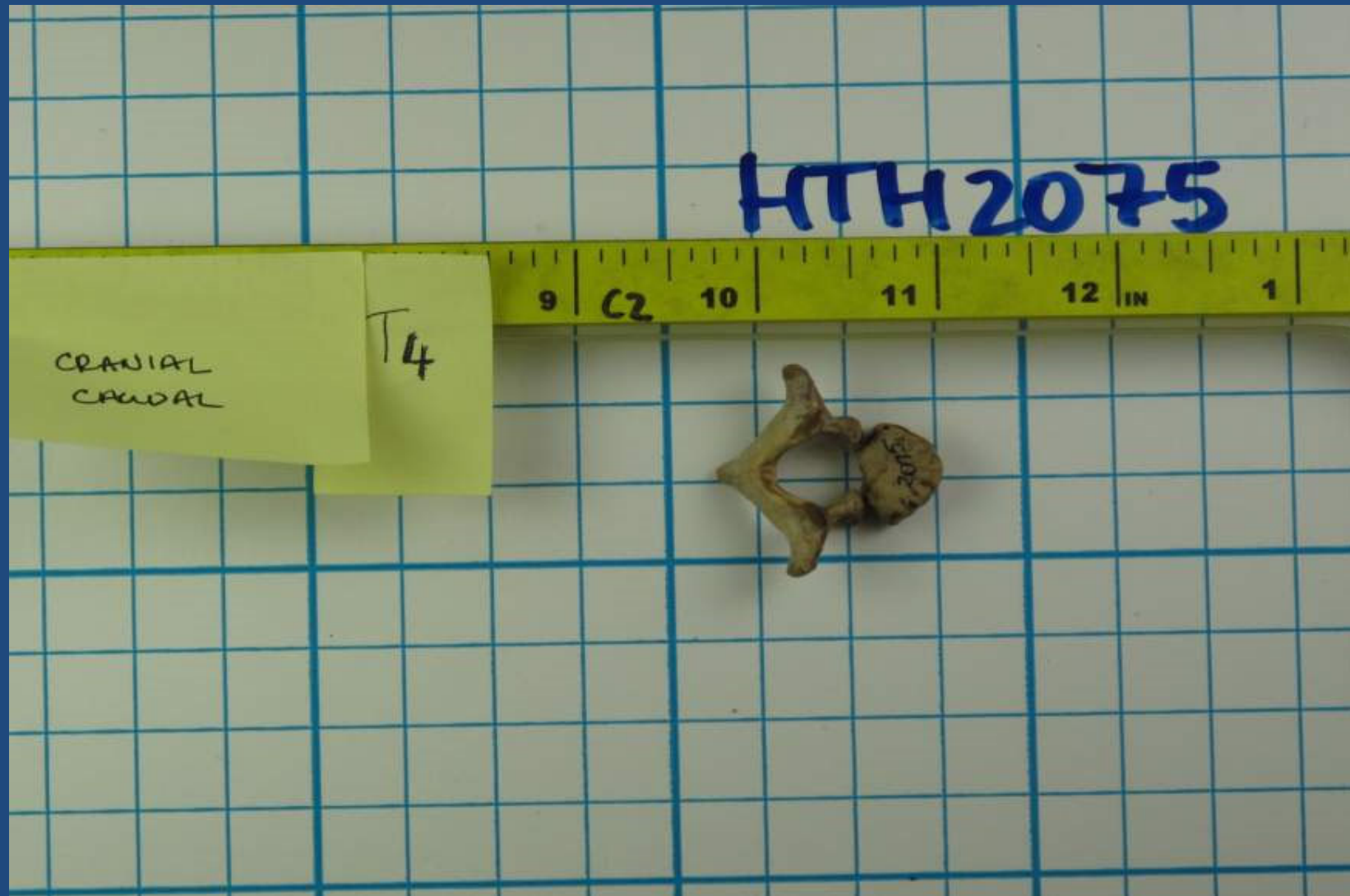


Laser Scans

- No good



We tried photography. Bad Setup



Hamann - Todd

2011

Six Spine Surgeons and 6 engineers

32 most complete specimens

4 Camera Stations HD cameras – 18 M pixel

6226 photographs in 6 Orthogonal planes

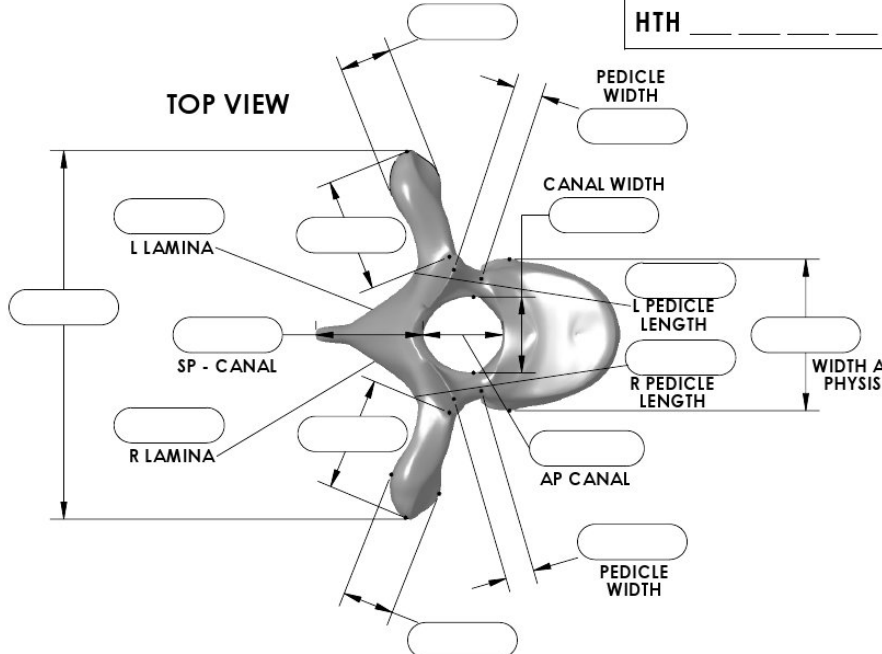
All Ribs, VBs, Sacrum, Femurs

>**32,000** quantitative measurements

Scandium IA Software

81 columns & 1600 rows

Thoracic and Lumbar Data Points



TOP VIEW

HTH _____

PEDICLE WIDTH _____

CANAL WIDTH _____

L PEDICLE LENGTH _____

R PEDICLE LENGTH _____

WIDTH AT PHYSIS _____

AP CANAL _____

PEDICLE WIDTH _____

L LAMINA _____

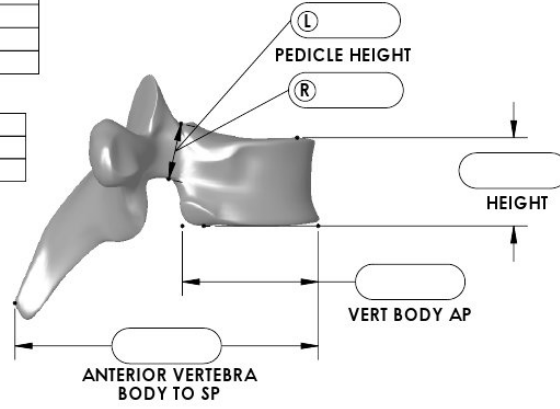
SP - CANAL _____

R LAMINA _____

FOR VERTEBRA #1 RECORD:		
	(R)	(L)
FERMUR LENGTH		
ILIAC COLUMN LENGTH		
ILIAC COLUMN WIDTH		
HUMERAL LENGTH		

FACET:		
RIGHT	HT	W
LEFT	HT	W

VERTEBRA _____



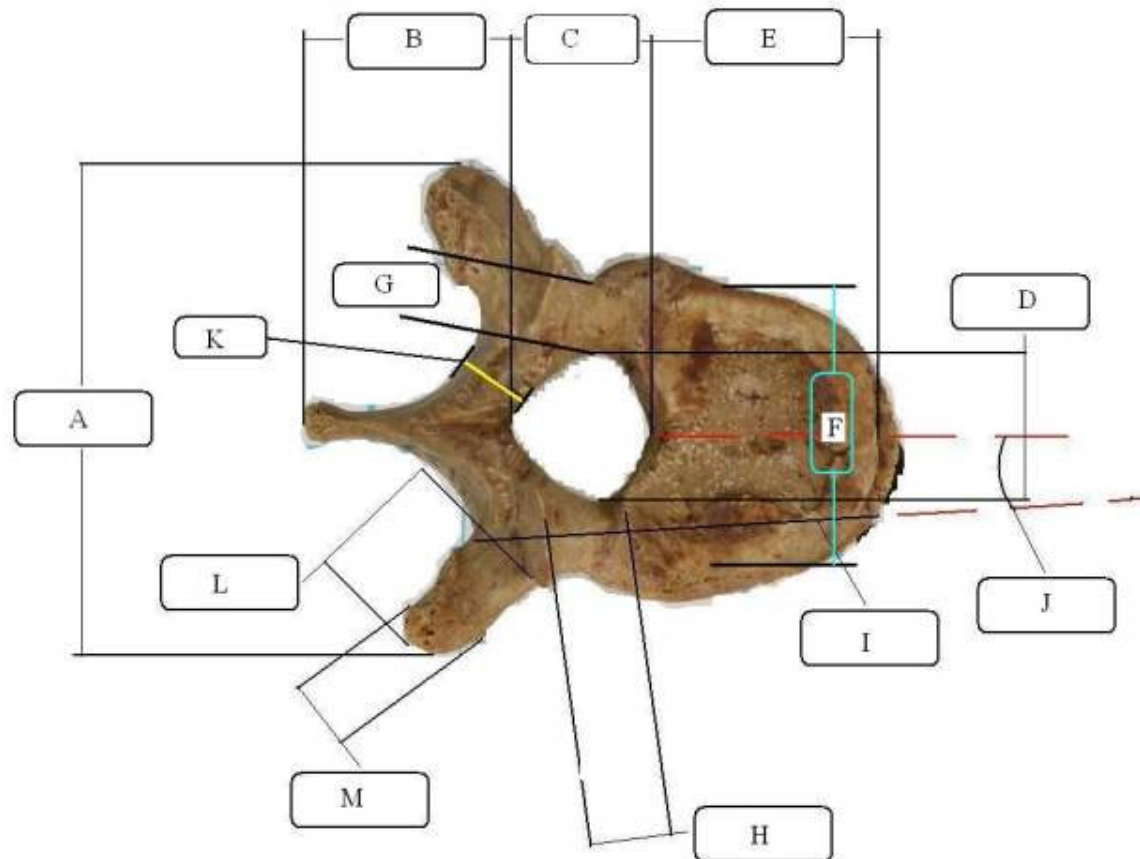
PEDICLE HEIGHT (L) _____

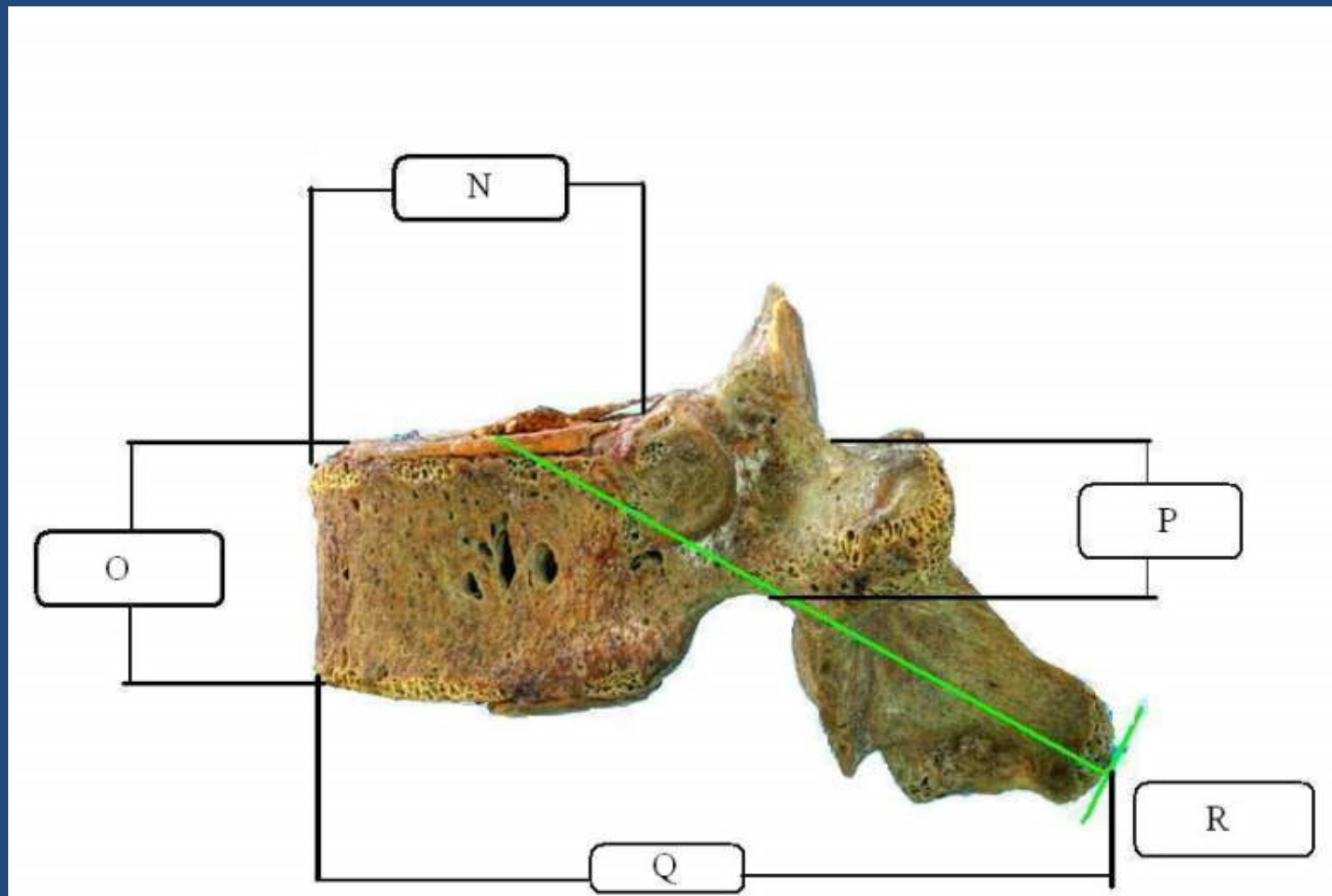
PEDICLE HEIGHT (R) _____

HEIGHT _____

VERT BODY AP _____

ANTERIOR VERTEBRA BODY TO SP _____





Photographs

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

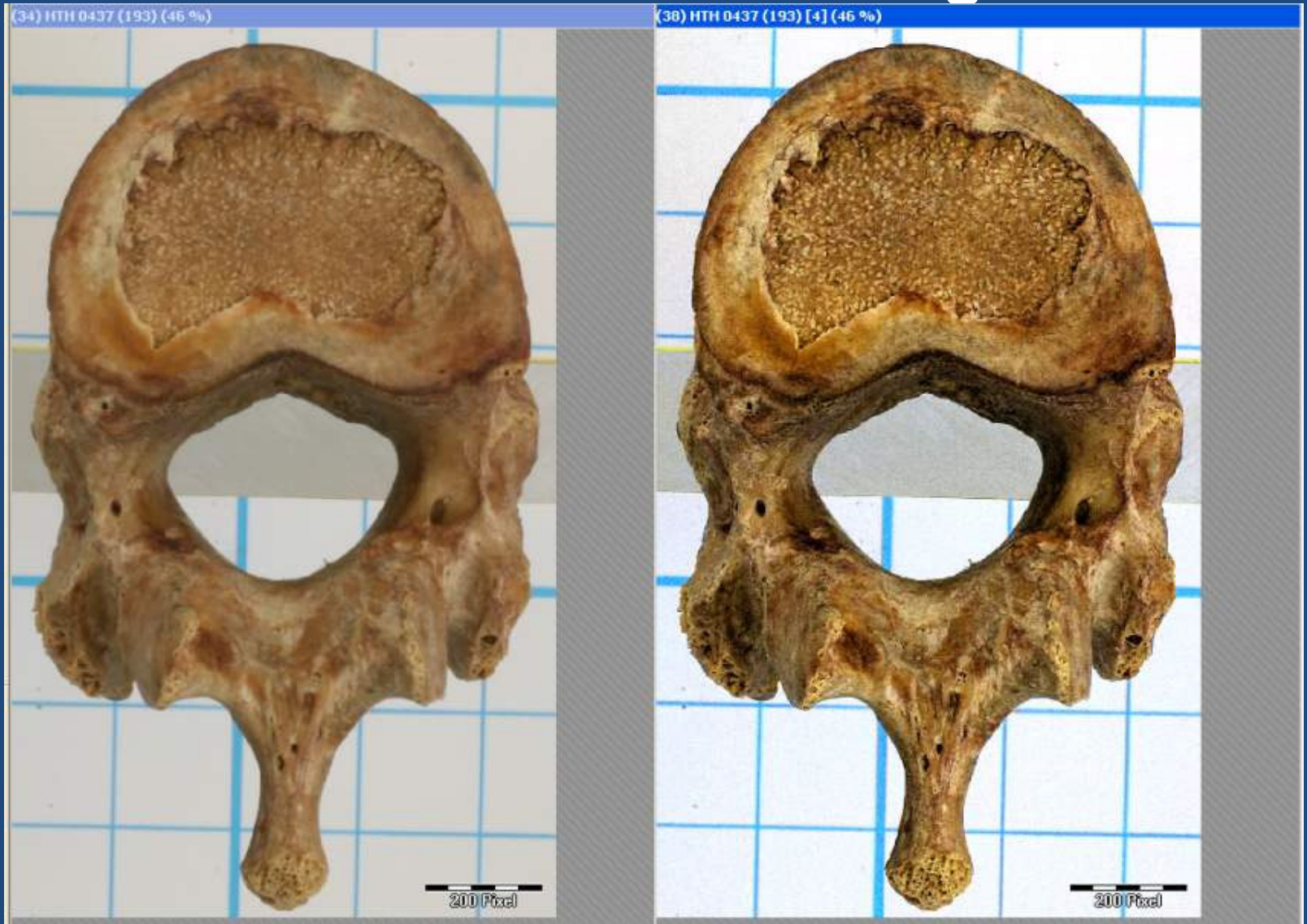


Image Analysis

- Took Hi-Res photos of bones
- Photo enhancement
- Linear data
- Fix transcription errors
- Non-Linear measurements



Enhancement of Good Images



Photographs

Image Enhancement

High Resolution

Magnification

Surface Areas

Projected Volumes

Various Angles

Arc Lengths



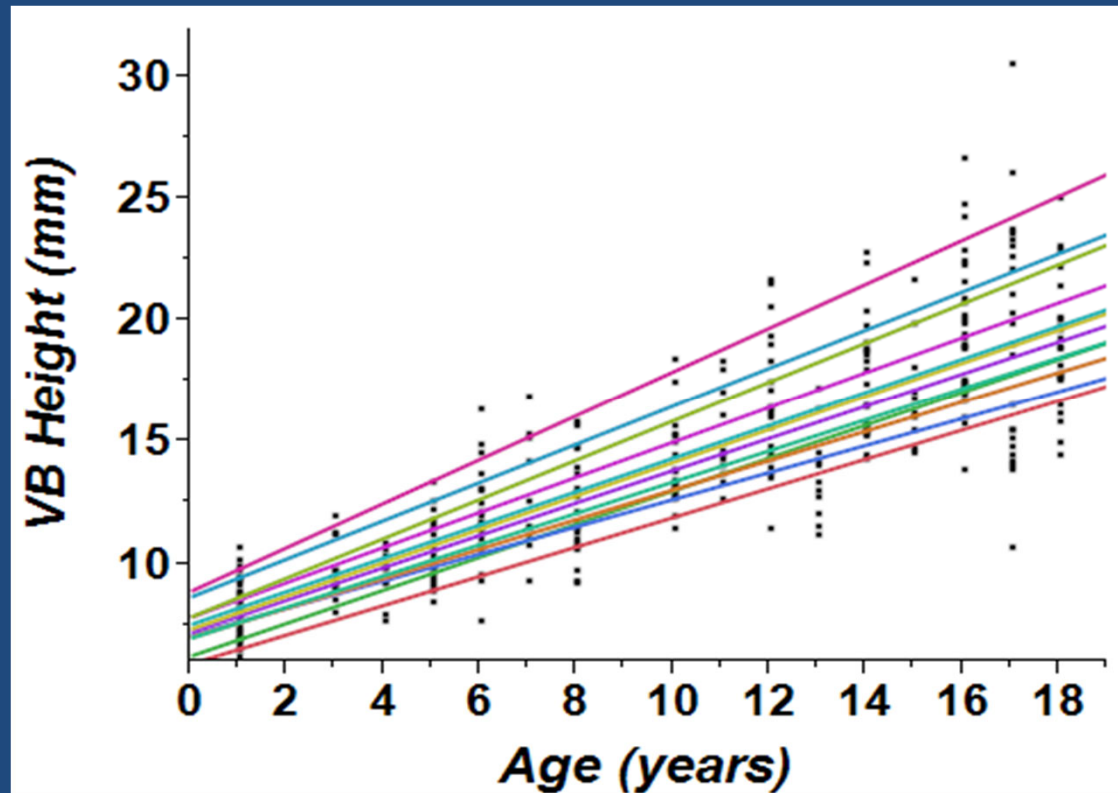
**All the non-linear information you
can't get with calipers**

Data Analysis

- **The Data Points were Analyzed by:**
 - **Specific Bone and Morphological Features across all ages**
- **More than 2,000 Cross Correlations were Studied**
- **Linear Regressions and t-Tests were Performed using SAS version 9.1.3 and JMP 11.0**

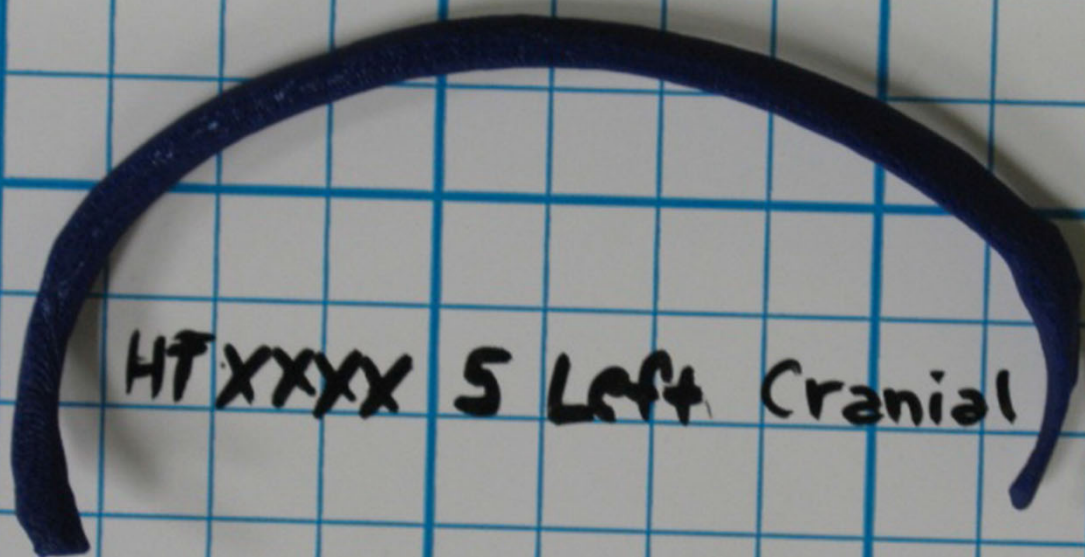
VB Height

Growth of 0.55-0.90 mm/year depending on
Vertebral level

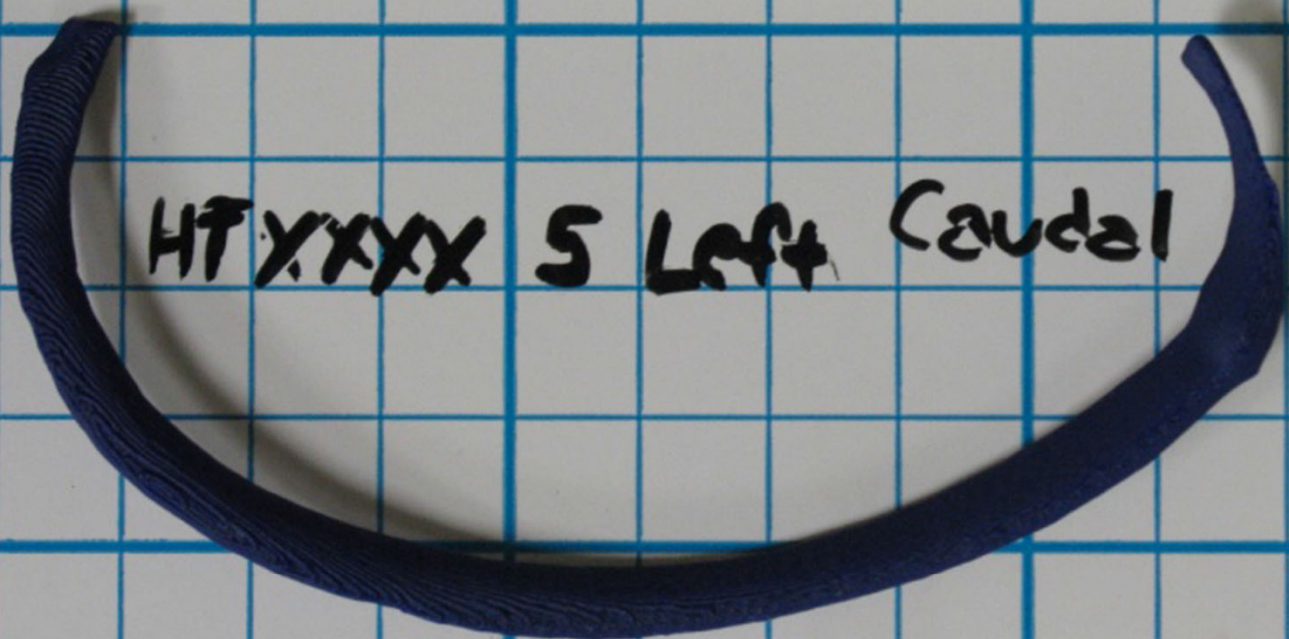


Better Setup

Photo #	Orientation
1	Cranial - taken from the cranial direction
2	Caudal - taken from the caudal direction
3	Medial - taken from a medial orientation
4	Lateral - taken from a lateral orientation
5	Anterior - taken from the anterior
6	Posterior - taken from the posterior

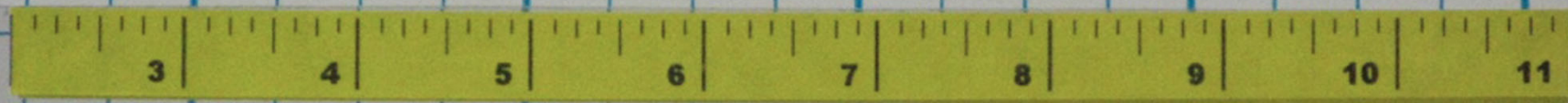


HT XXXX 5 Left Cranial



HT XXXX 5 Left Caudal

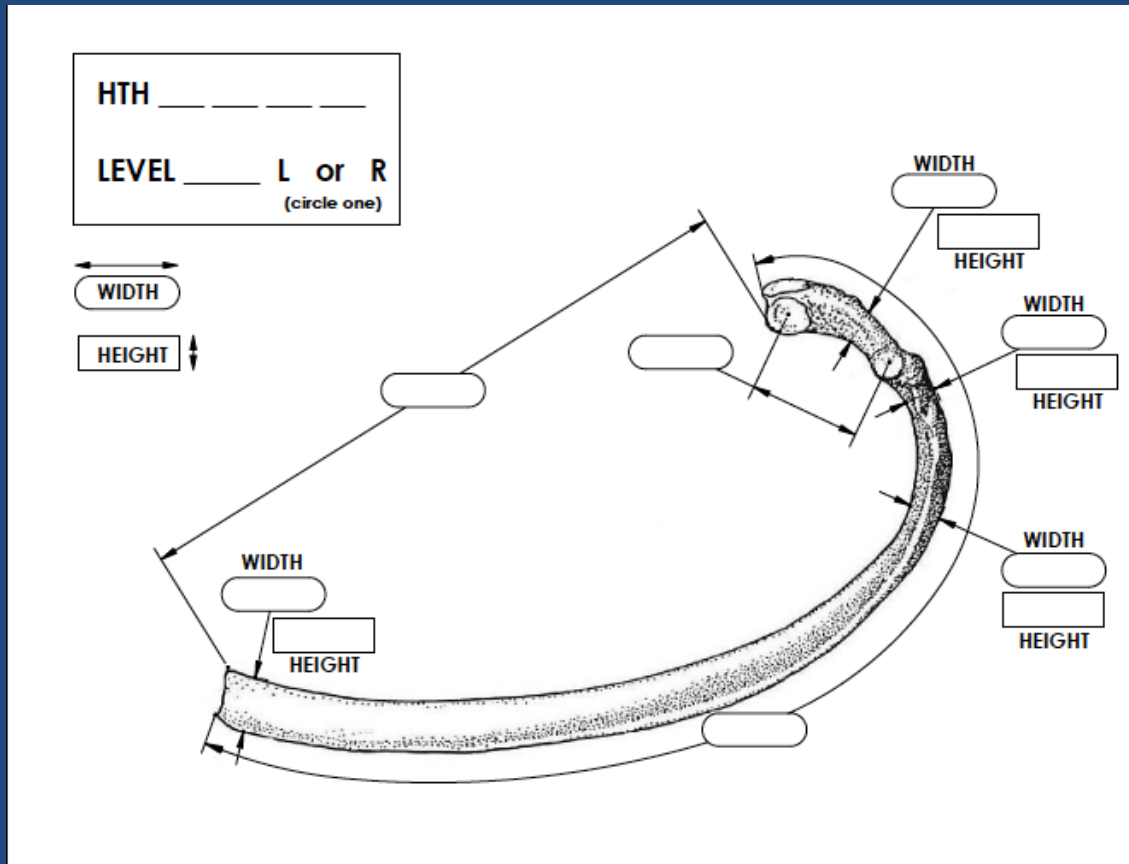
A photograph of a curved, dark blue object, possibly a medical device or a piece of equipment, resting on a blue grid background. A yellow ruler is placed above the object for scale, showing measurements from 5 to 11. The object has the handwritten text "HT XXXX 5 Left Caudal" written on it in black marker.



HTXXX 5 Left Anterior



Ribs



Rib #

Rib Side

Outer Costal Length (mm)

Base Diameter (mm)

Overall Length (mm)

Width @ 100% (mm)

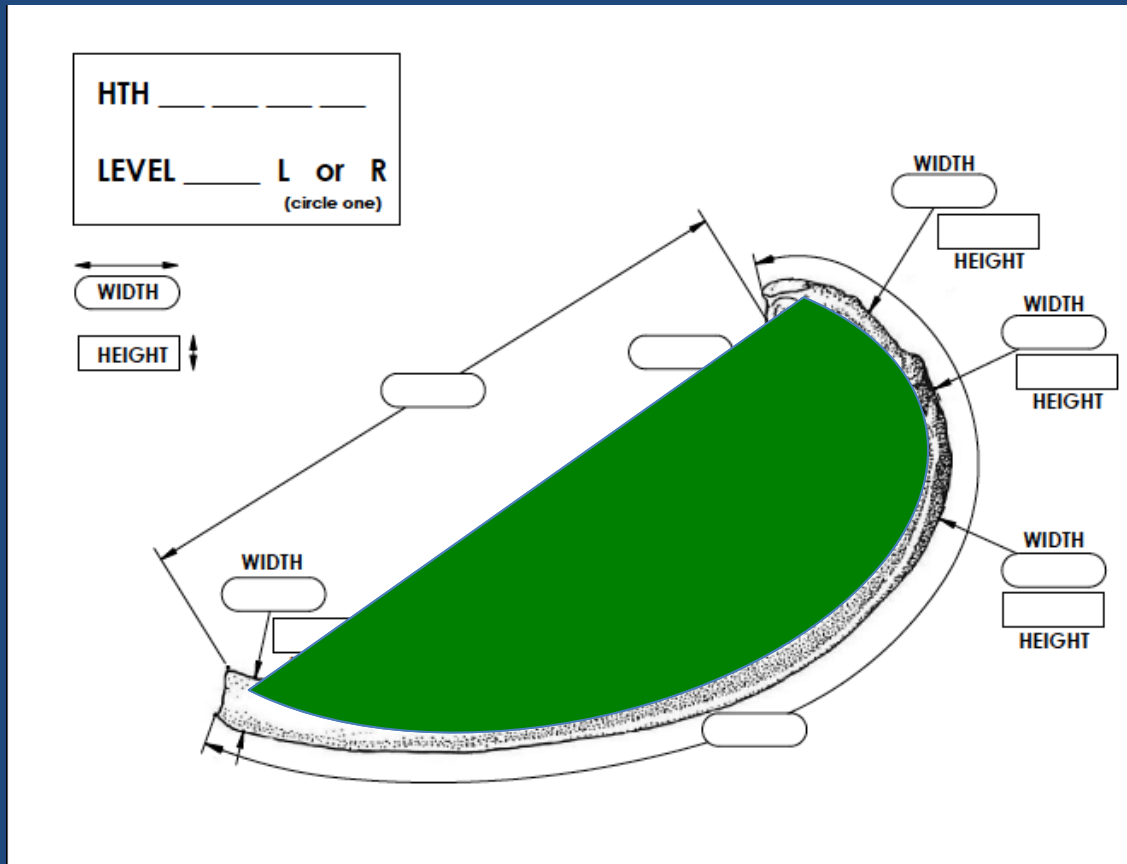
Width at 50% (mm)

Width Just off Articular (mm)

Width at Midpoint of Articular (mm)

Distance b/w Articular Facets (mm)

Ribs



Rib #

Rib Side

Outer Costal Length (mm)

Base Diameter (mm)

Overall Length (mm)

Width @ 100% (mm)

Width at 50% (mm)

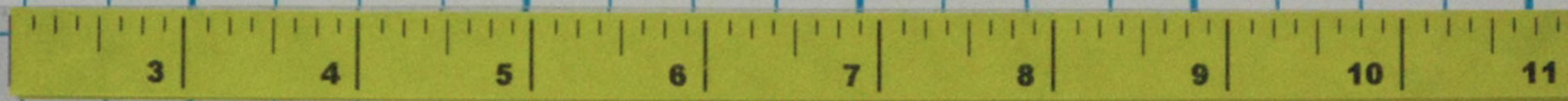
Width Just off Articular (mm)

Width at Midpoint of Articular (mm)

Distance b/w Articular Facets (mm)



CLBD=Projected Area



HTXXX 5 Left Posterior



Some Results

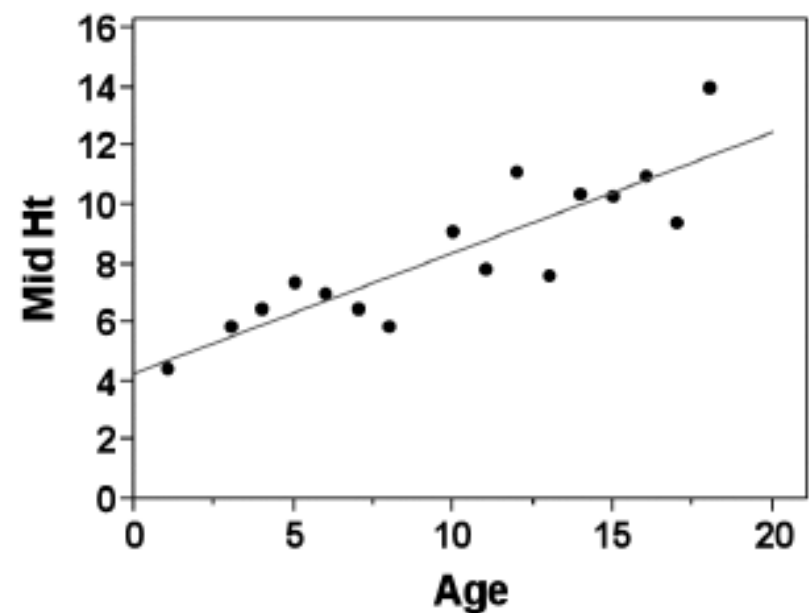
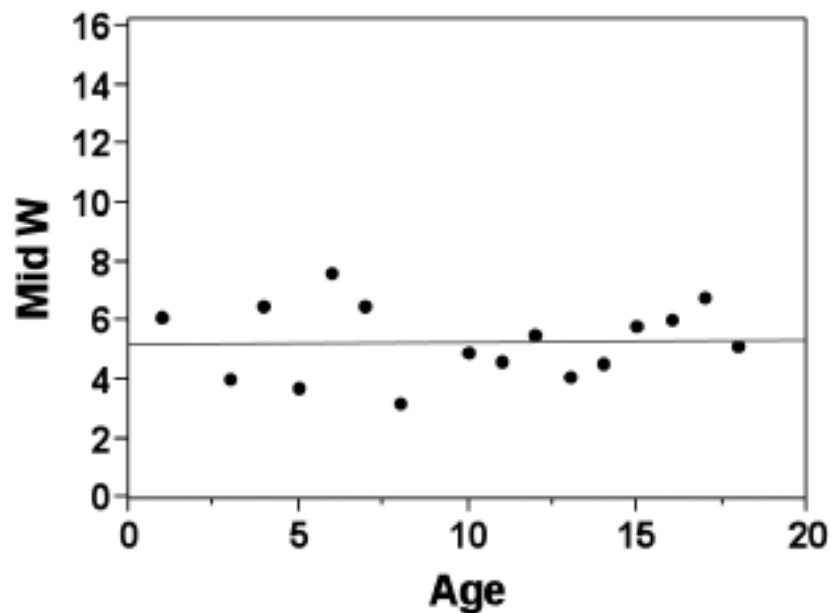
Some Results

Rib is thick just off the tip of the transverse process



Confirmation of CT Data. Rib height is 1/2 of adult rib height by age one year. Width is similar to adult by one year. Compared to femur, preferential early Development of the thorax.

Figure 1. Right T7 Rib. Mid-Rib Width (Mid W mm) data is on the left and Mid-Rib Height (Mid Ht mm) is on the right. The width shows no increase with age ($r^2 = 0.001$) while the height of the ribs increase with age ($r^2 = 0.754$).



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

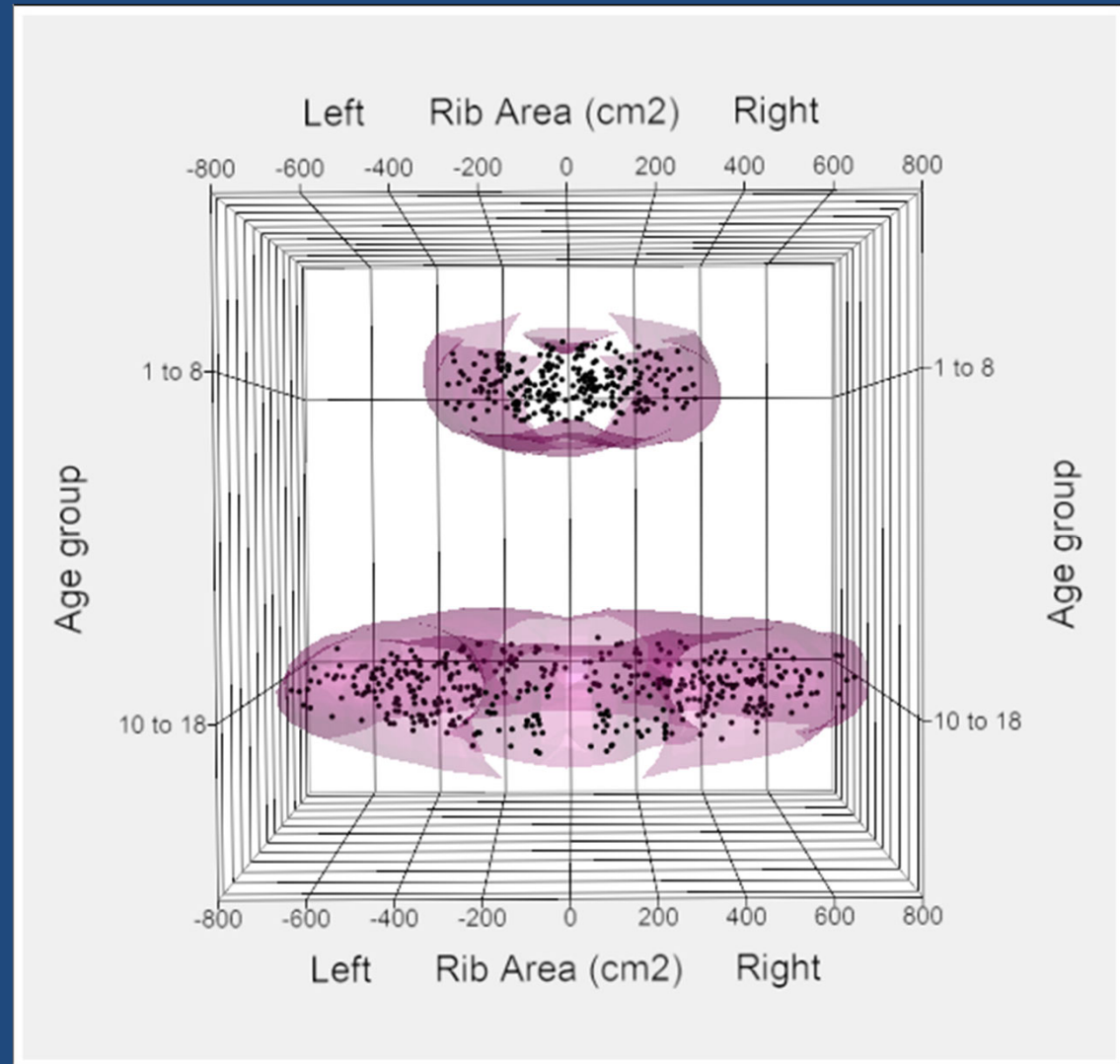
Clustering of 2 Age Groups



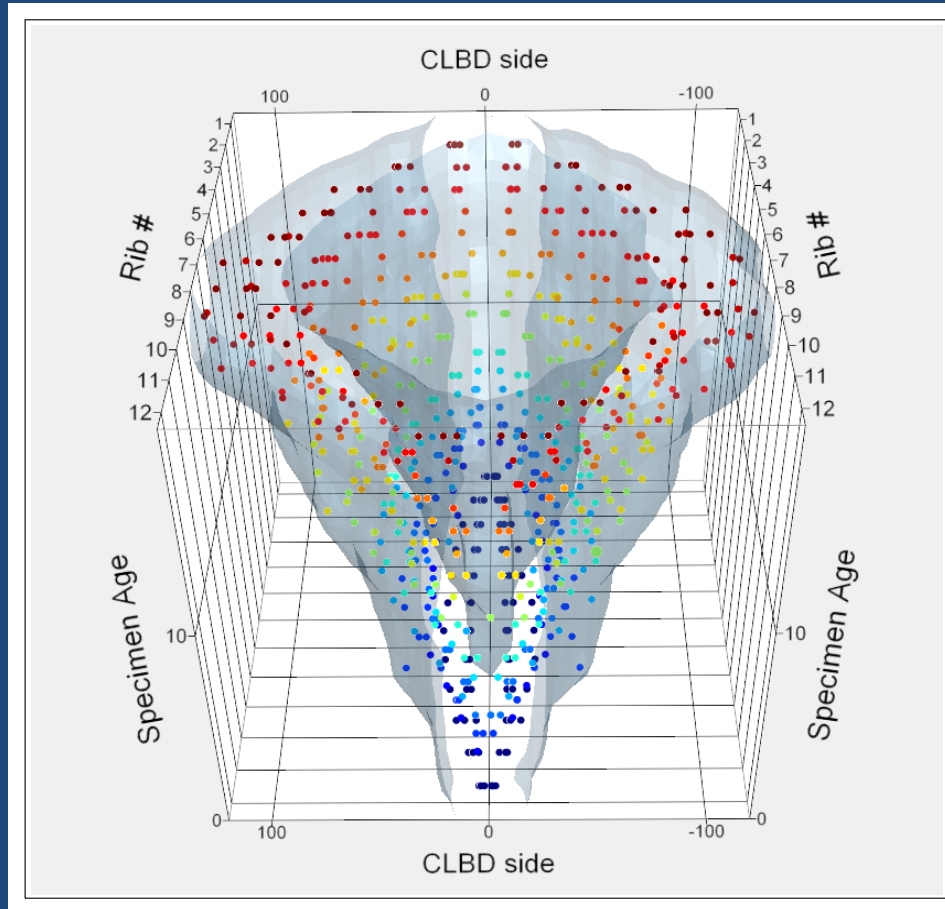
1-8 YO

10-18 YO

**Bigger Spread
with maturity**

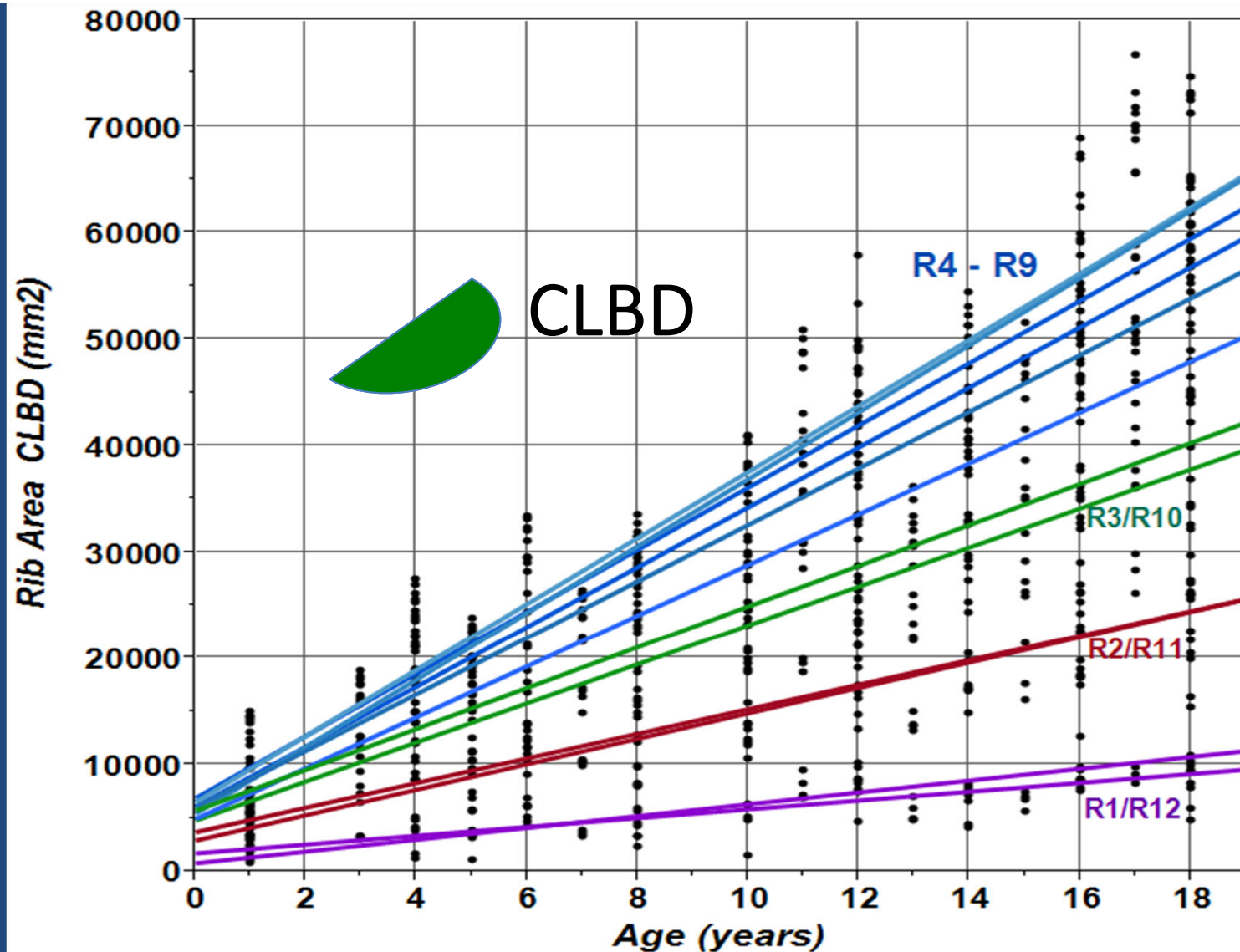


Proportional Rib Expansion



3D Scatterplot Depicting Specimen Age by Rib Number by Projected Area of Each Rib

- Proportional expansion of the rib cage through adolescence
- Coupled symmetry between superior and inferior paired ribs

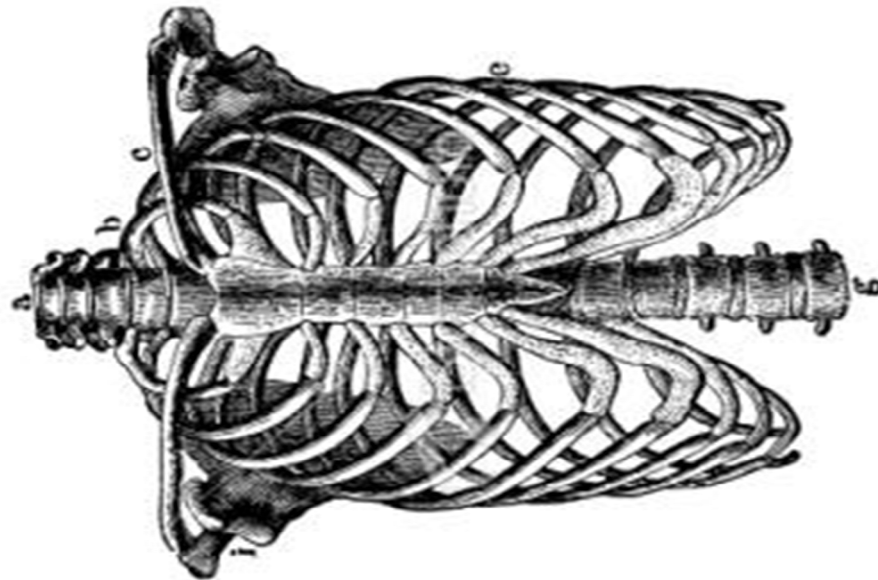
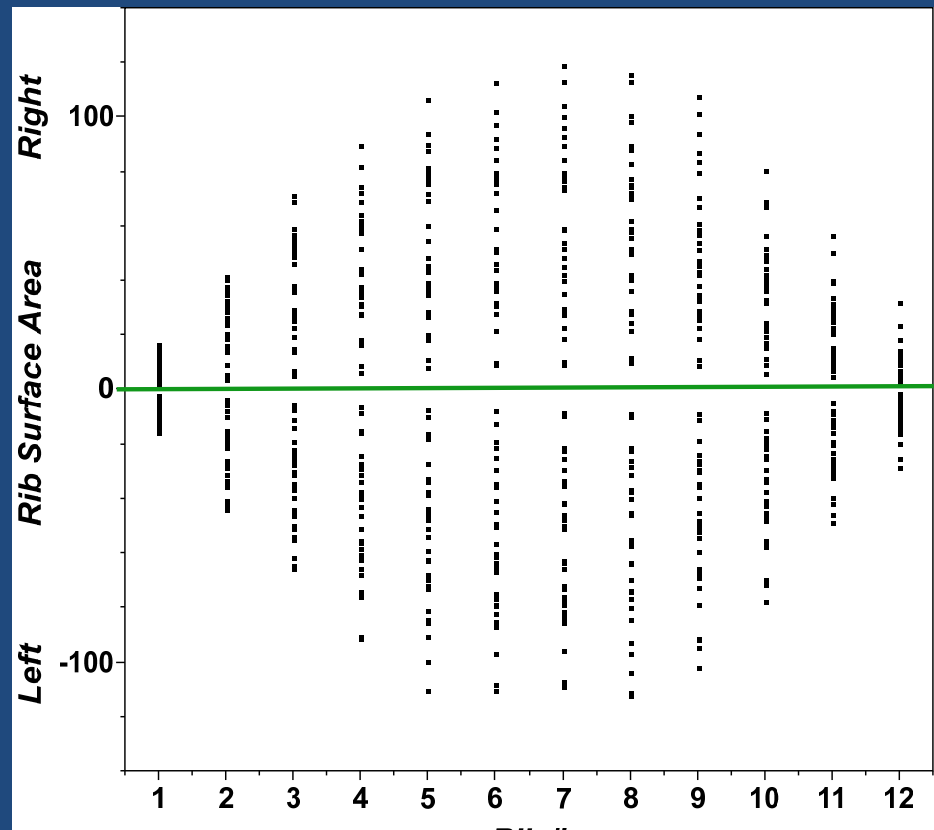


The Projected area of the ribs by age. The regression line for each rib is shown. Ribs 1 and 12 (purple) increased in projected area the least amount. Ribs 2 and 11 (red) were nearly superimposed and increased in area faster than ribs 1 and 12. Ribs in the middle thorax (blue) increased the fastest.

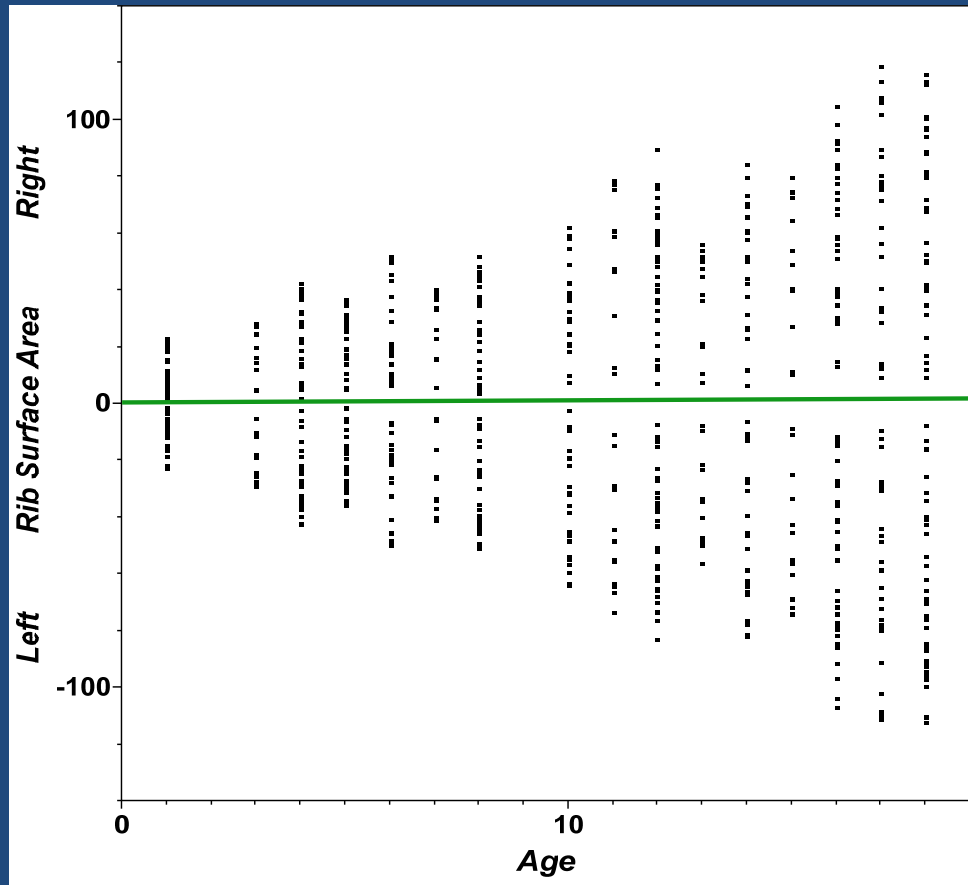
Rib Symmetry Proximal/Distal

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.



Rib Symmetry Right-Left



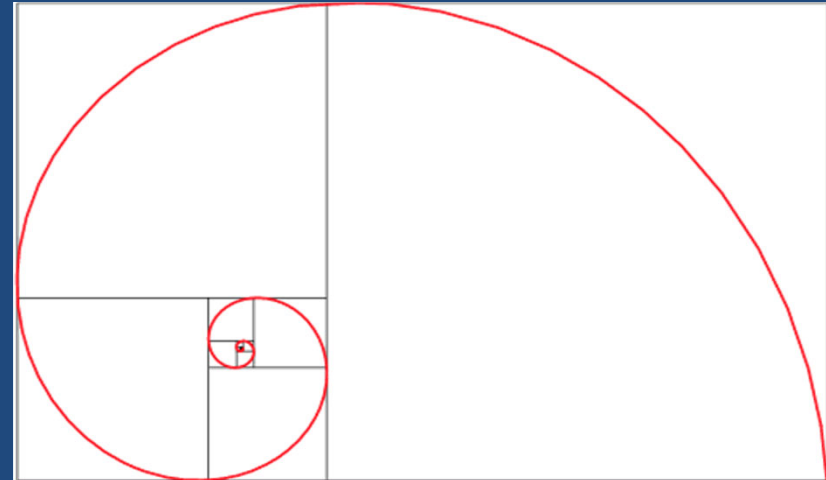
The symmetrical growth is demonstrated by looking at the projected area of each rib, each patient, at each age.

L/R symmetry on either side of the green line.



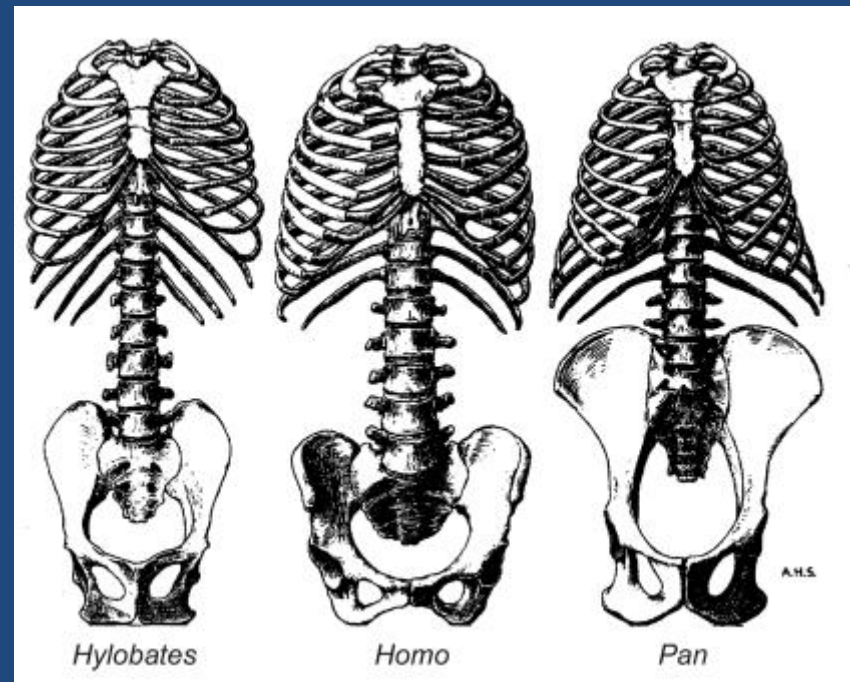
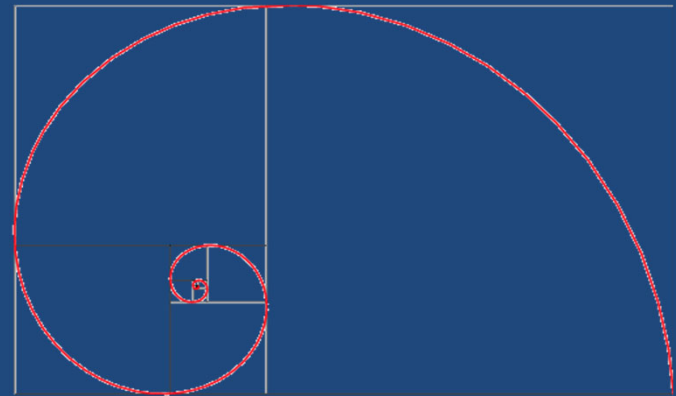
Ribs Follow Golden Spiral

- 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



Summary: Coupled Symmetry and Proportional Expansion of Ribs through Adolescence

- Thorax follows symmetric coupling **r/1 and proximal/distal**.
- Constant rib linear growth rates throughout childhood with the middle ribs growing the **fastest, about 2.6 times that of rib #1**.
- The projected area of ribs likewise had constant growth rates- middle ribs- greatest rates of growth, about **7.5x that of rib #1**.
- The faster growth the middle ribs and golden spiral growth pattern of all ribs results in the barrel chest of an older human.



Scoliosis Case

All 17, 18 YO (n=10)

Normal T8

CL = 294 mm

BD = 219 mm

Area: $CL \times BD = 644 \text{ cm}^2$

Ratio of CL/BD: 1.34

21 YO Female (n=1)

Scoliosis T8

CL = 370 mm

BD = 260 mm

Area: $CL \times BD = 962 \text{ cm}^2$

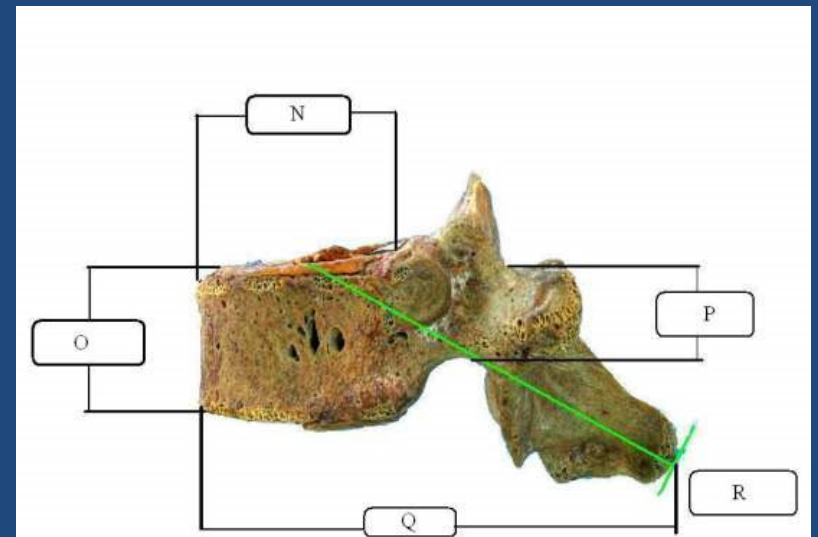
Ratio of CL/BD: 1.42

This rib is not so much deformed in shape
As it is malposition in the chest



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



Hamann-Todd

All of the 32 HT specimens were 'normal', no deformity

All died of natural causes
Influenza

All were somewhat malnourished

