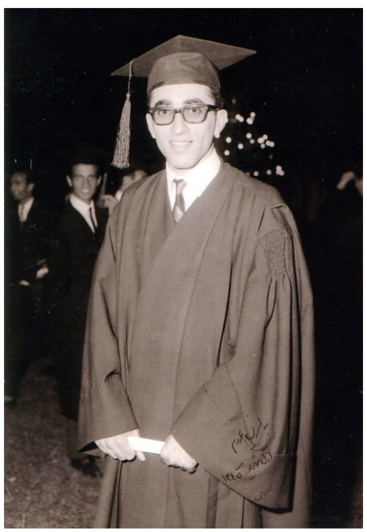
ICEOS 2015

David W. Polly, Jr., MD
President SRS 2015-2016

Where is the Excitement in SRS Today

- Ends of the spectrum of live
  - Aging spine with reconstruction and realignment
  - Early onset



EOS

- My personal experience
  - Taught growing rods in fellowship
  - Experience with EOS case in arthrogryposis
    - Had Rick McCarthy come to Walter Reed to do co-surgery
    - Significant efforts and follow-up
  - Shriners Twin Cities
    - Lots of learning opportunities

What Are Important Outcomes Goals

- Improved thoracic volume
- Improved lung function
- Improved spinal height
- ‘Normal life’

Bob Campbell

- Modern day 'Dogged Persistence'
- Rib synostosis
- Interaction with FDA
- Challenge of HDE approval

Development of Classification Systems

- Want to compare like to like
- Mike Vitale significant work

ICEOS Moves from Anecdote to Data

- That is when I felt that this meeting had arrived as a meaningful event
- Study groups co-operating by agreeing on same data fields

Challenges Today

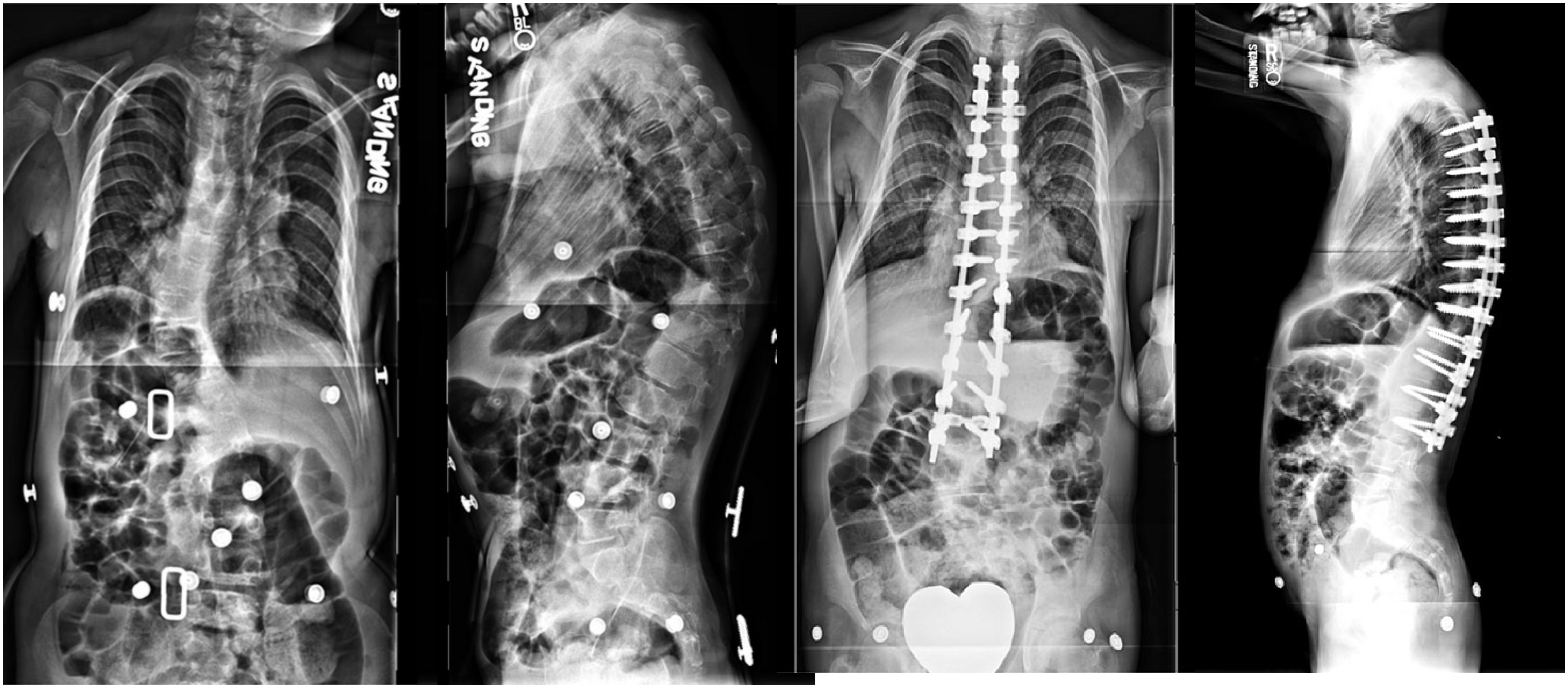
- Technically we are able to improve spinal alignment BUT
- We stiffen the chest wall
  - Greg Redding challenges us as an honest broker
- Are we making a difference????

Thoracic Volume Modeling

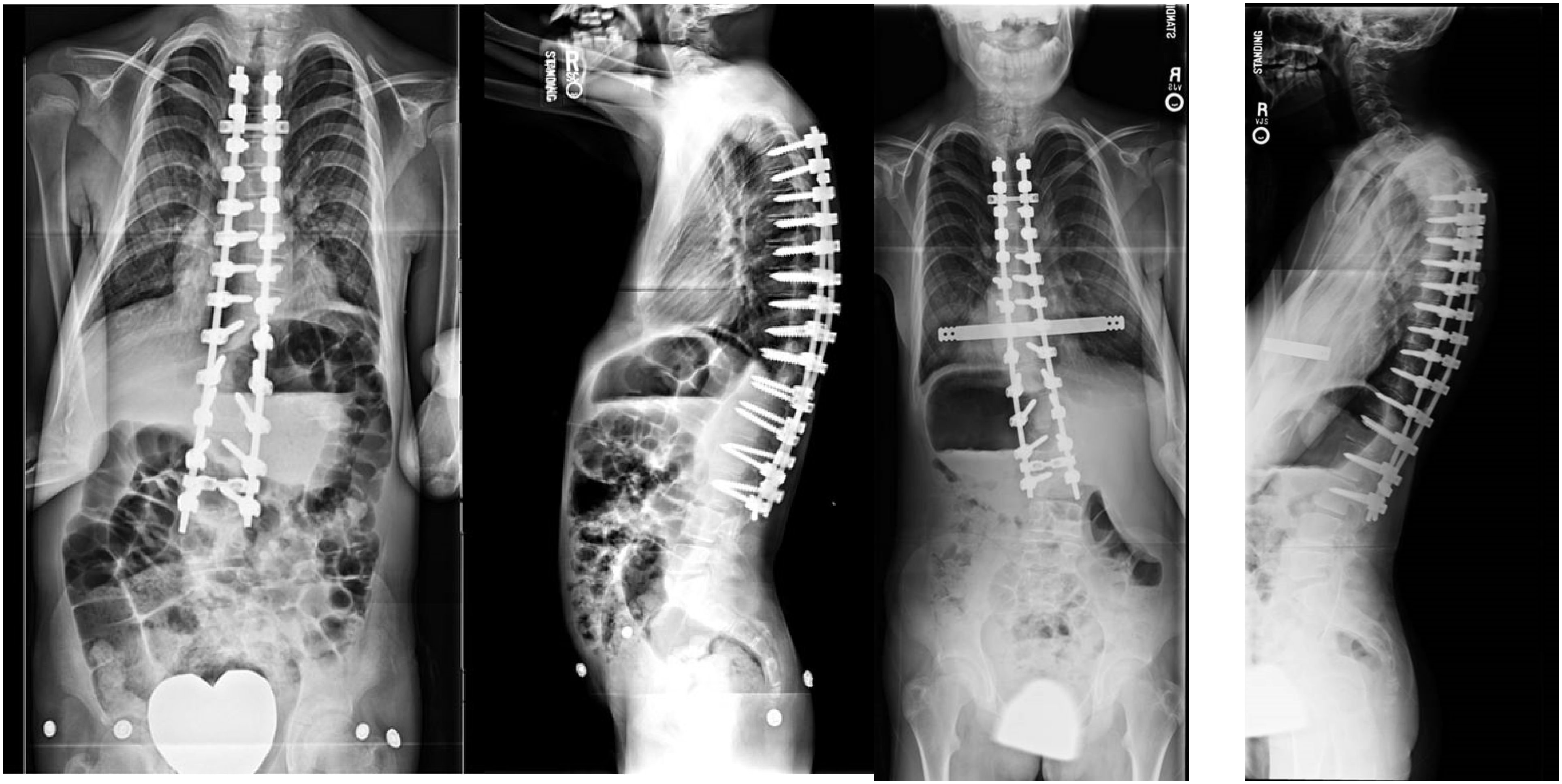
MANY many contributors

Special thanks to Charlie Ledonio, MD

Radiographs from case



After Pectus Reconstruction

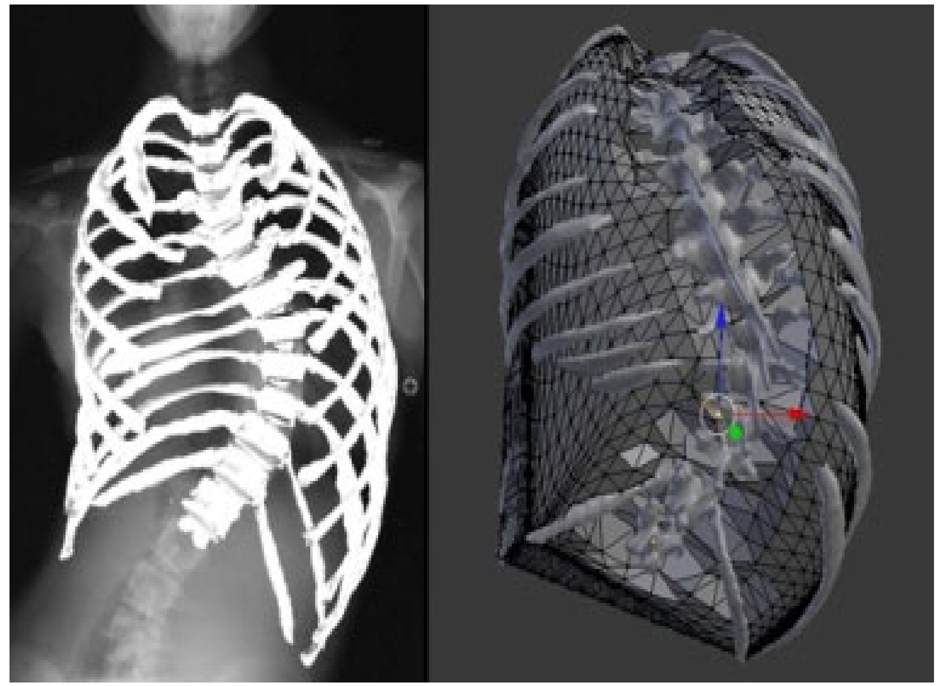


Initial Breakthrough

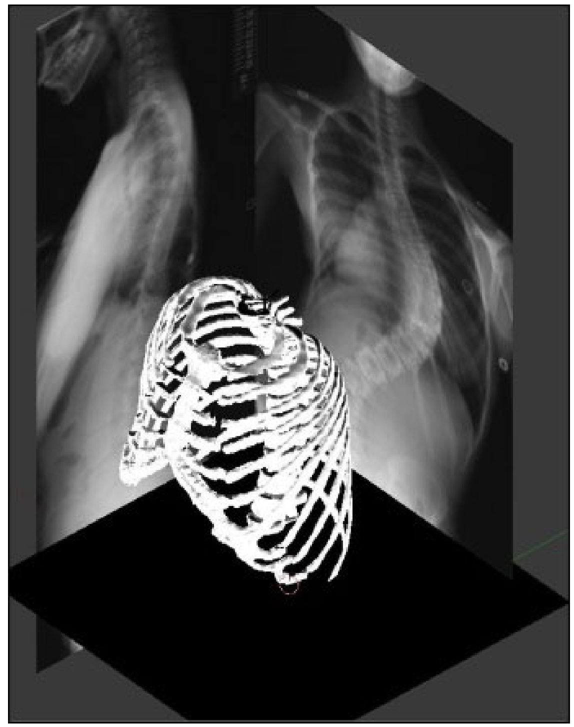
- David Nuckley showed us how to use a software program to morph a standard thoracic spine and chest to match patient specific x-rays
- Then using a different program we could calculate the volume within the distorted model
- This allowed before and after surgery comparison

Methods

- Scoliosis films (AP and Lateral) were utilized to deform an existing thorax model to produce a patient specific thorax model and then measure the mediastinal volume.
- Blender 2.63a™ software used to construct computational model of the spine and thorax and perform deformation

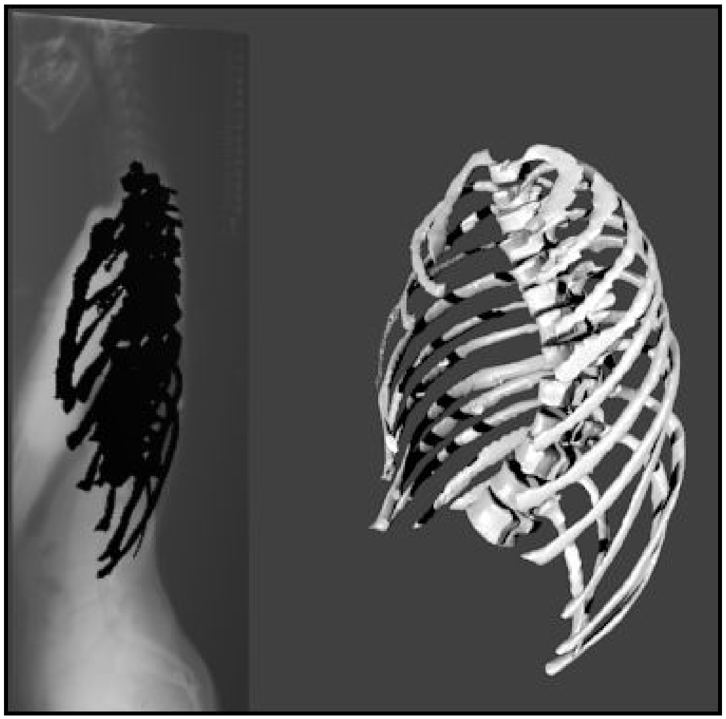


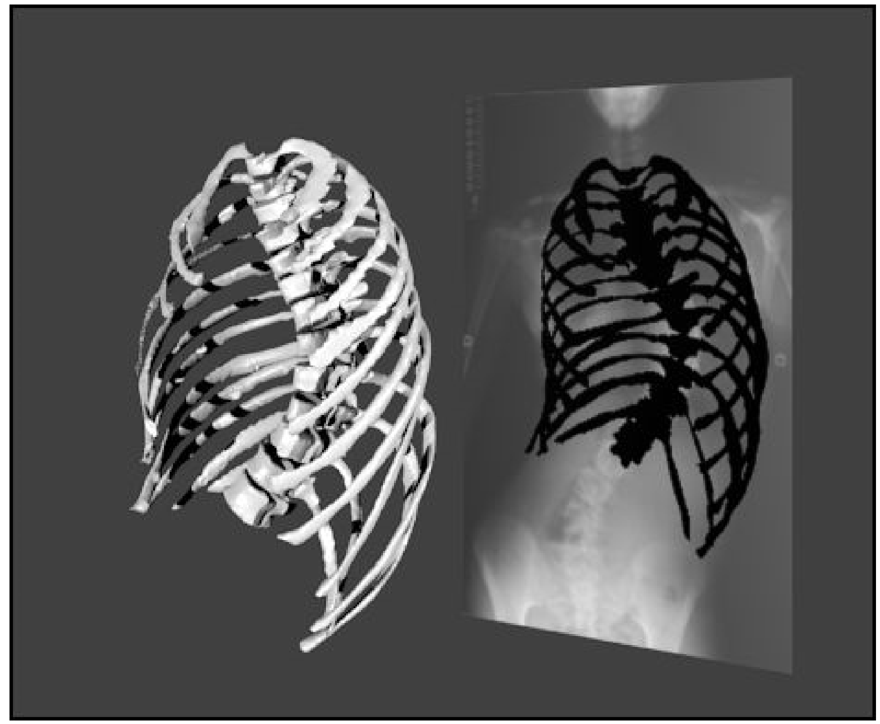
Thoracic Volume Modeling



The initial model is placed in a virtual x-ray where calibrated patient x-rays are placed orthogonal within the space. An x-ray projection of the 3D torso is overlayed on the x-rays and the bones are then deformed to match the x-rays.

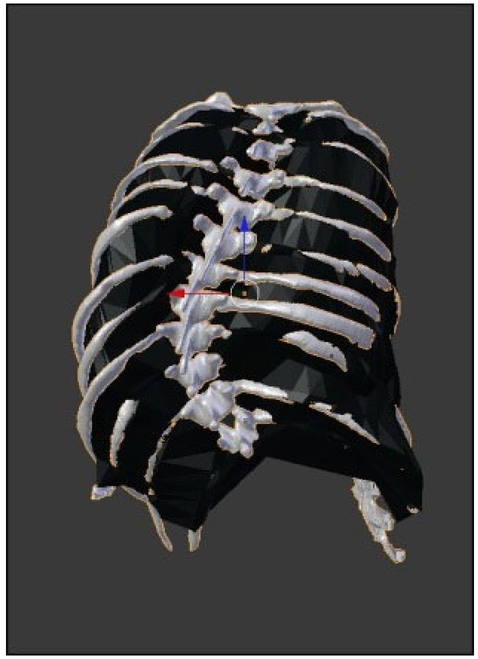
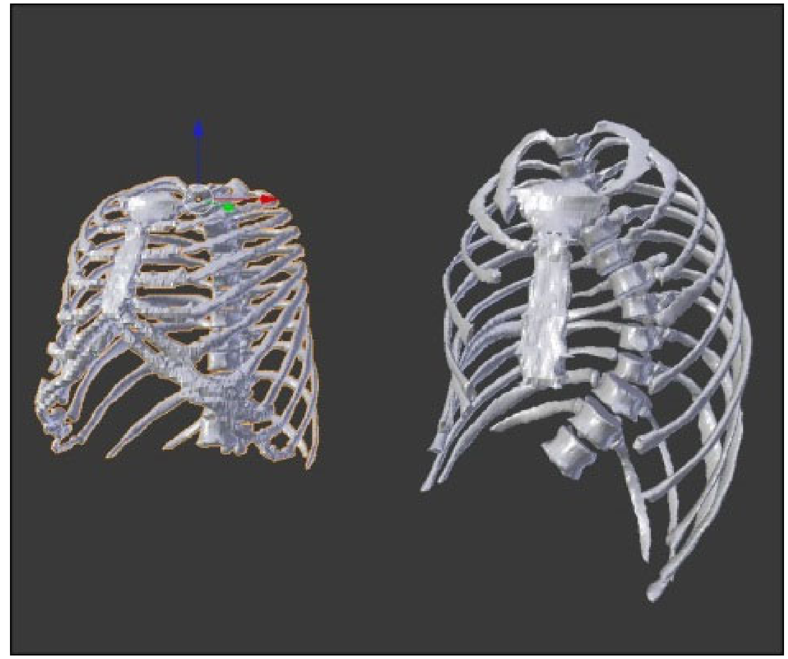
Thoracic Volume Modeling





The deformed spine and ribs are projected in the virtual x-ray to evaluate how well they match the patient films.

Thoracic Volume Modeling

After deforming the spine and ribs and altering their orientation, the thoracic volume was computed above the diaphragm.

Model Validation

- Model development with 4 healthy adult CTs of the thorax.
- Tested on 4 cases (2 pectus and 2 scoliosis)

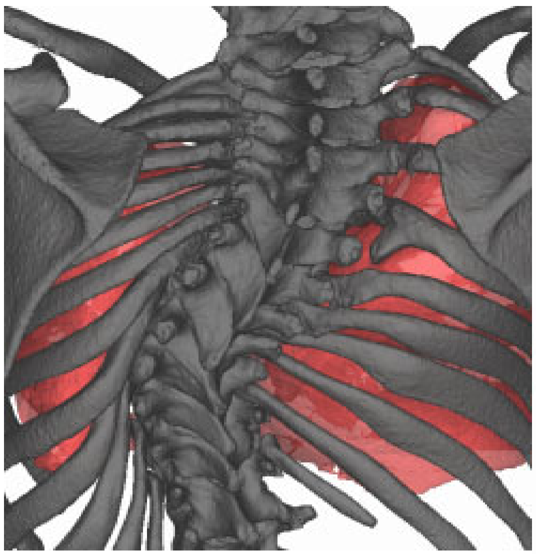


Figure A. Scoliosis

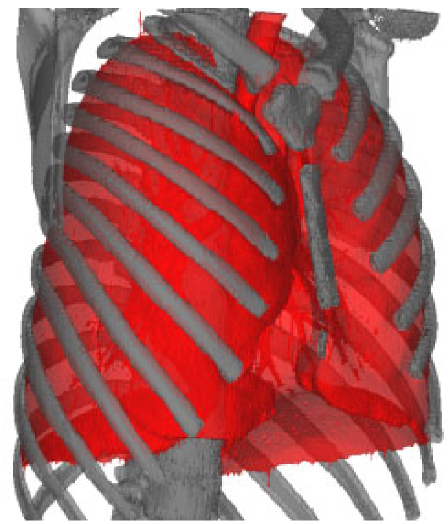
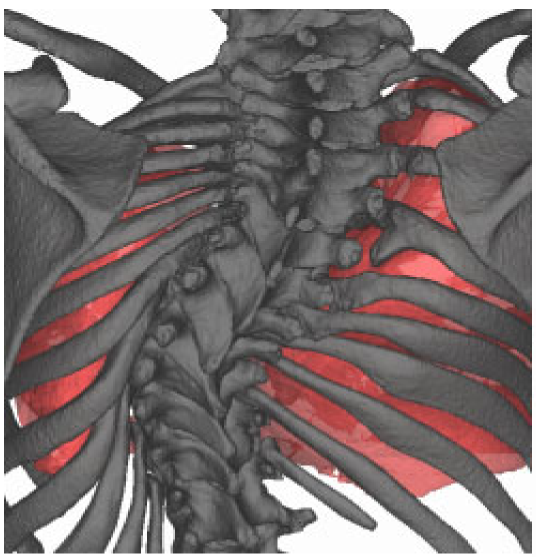
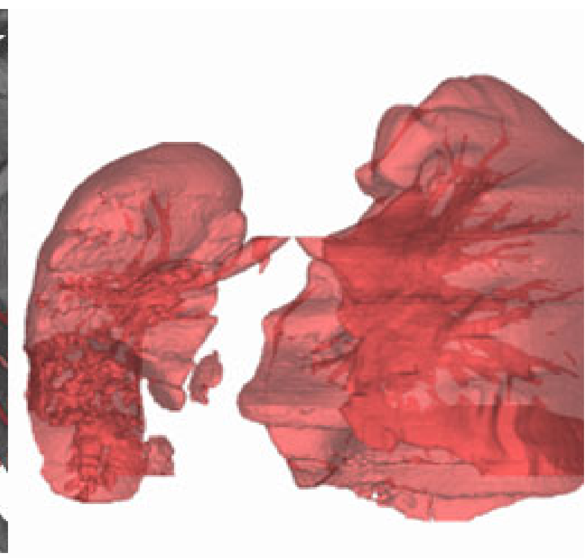


Figure B. Pectus Excavatum

Results

- Both scoliosis (Figure A.) and pectus excavatum (Figure B.) display thoracic volume decrease.
- The volumes measured for the scoliosis cases were 60.9 cm^3 different (4%) between CT and chest X-rays.
- The pectus patients had a much higher volume, but remained fidelic within 4%.





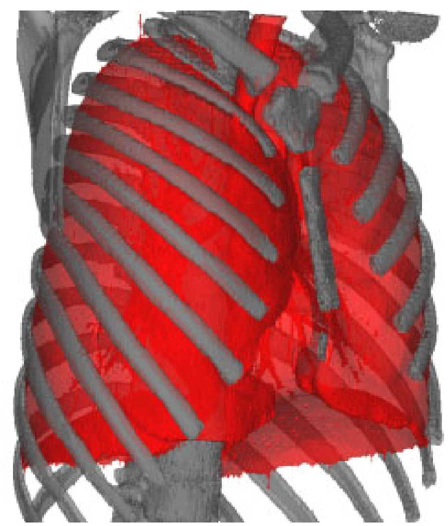
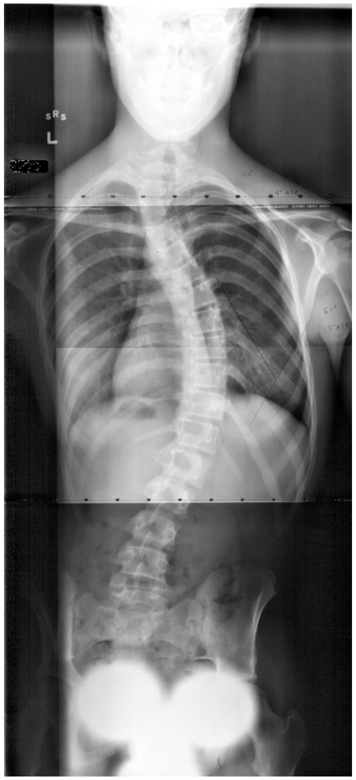


Figure A. Scoliosis

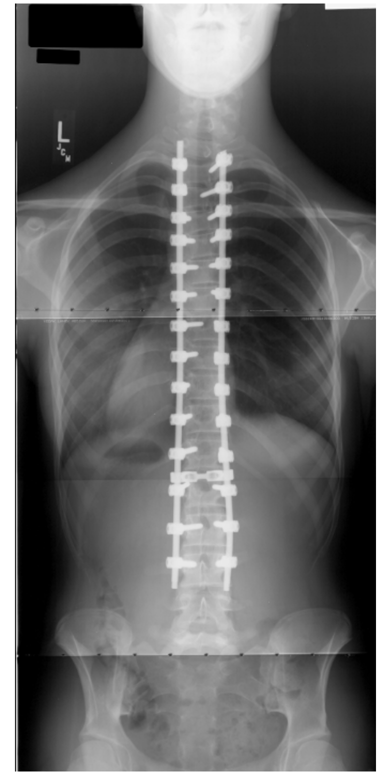
Figure B. Pectus Excavatum

Clinical Case Series

- We have been participants in a large multicenter study of adolescent idiopathic scoliosis (PPSS)
- A previous study looked at the pre-operative and post-operative lung function before and 2 years after surgery in these patients
- We took the same cohorts and modeled them before and after surgery



Thoracic Volume Predicts Pulmonary Function Recovery in Scoliosis Patients

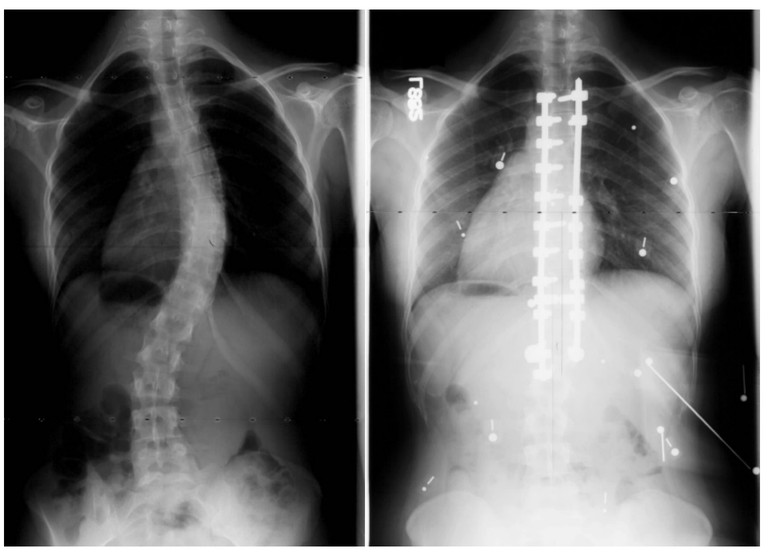


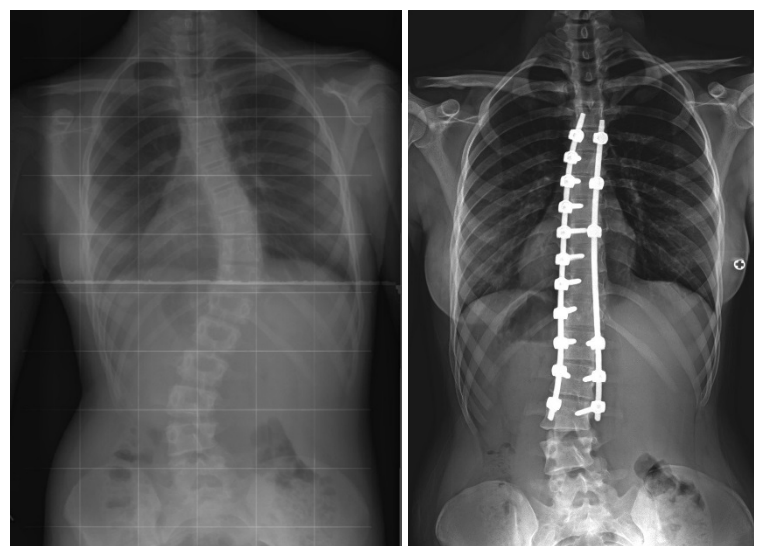
Charles Ledonio, MD[1], David Polly Jr. MD[1], Benjamin Rosenstein[2], Charles Johnston, MD[3], and David J Nuckley, PhD[2]

[1]Department of Orthopaedic Surgery and [2]Department of Physical Medicine and Rehabilitation; University of Minnesota, Minneapolis, MN.
[3]Texas Scottish Rite Hospital for Children, Dallas, TX.

Objective

The objective of this research was to define the relationship between pulmonary function and the thoracic volume for adolescents before and after AIS deformity correction.

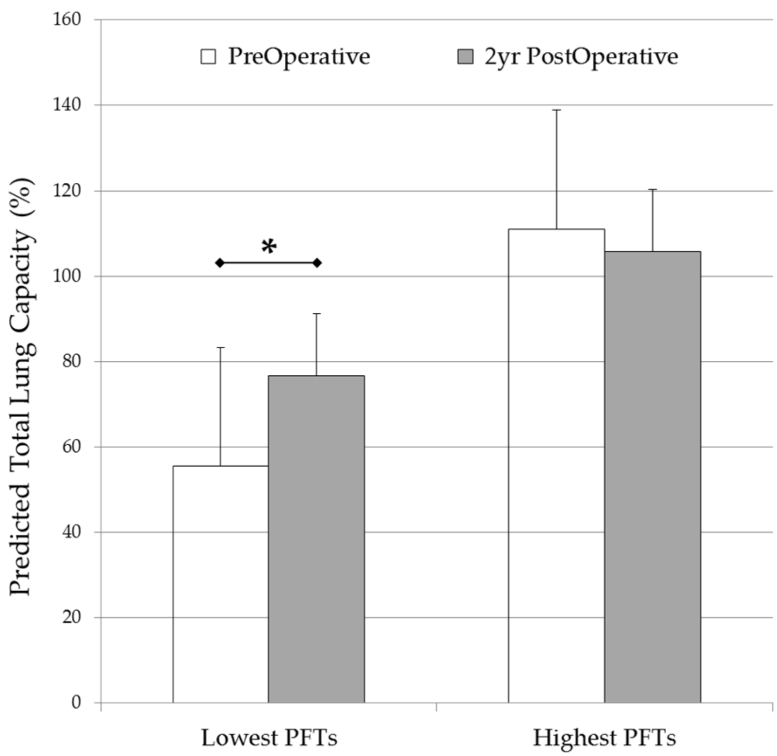




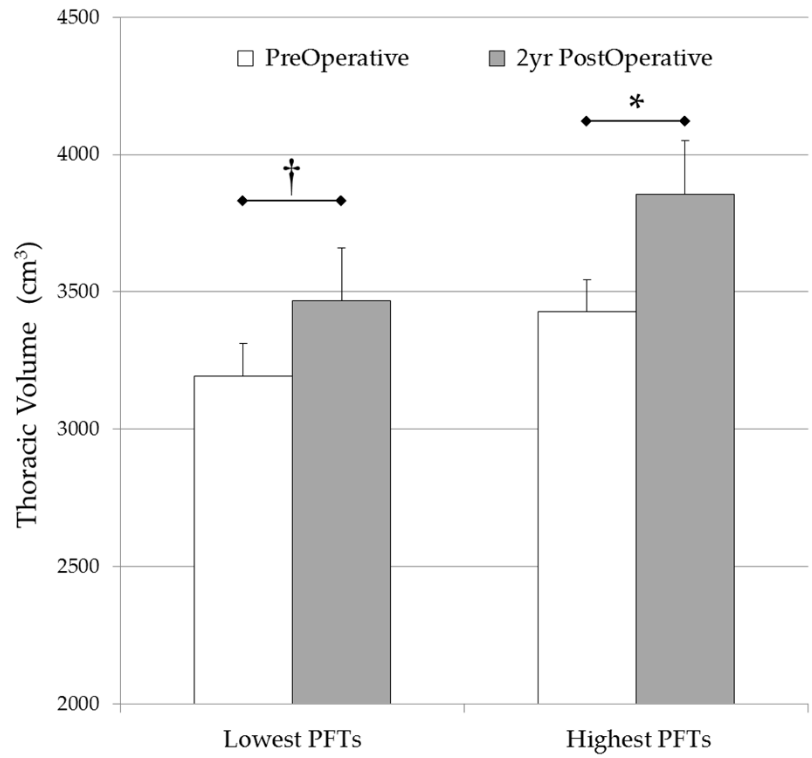
Methods

- Study Design. Retrospective case control correlational analysis of pulmonary function test (PFT) data and modeling reconstructions of thoracic volumes from plain x-rays.
- AIS patients from a multicenter database (PPSS) were sorted by presurgery PFT as a % predicted value.
- 10 patients with the highest and 10 with the lowest PFT values were analyzed.
- Thoracic volume was modeled and correlated with PFT values before and after surgery (2 year follow-up)

Results



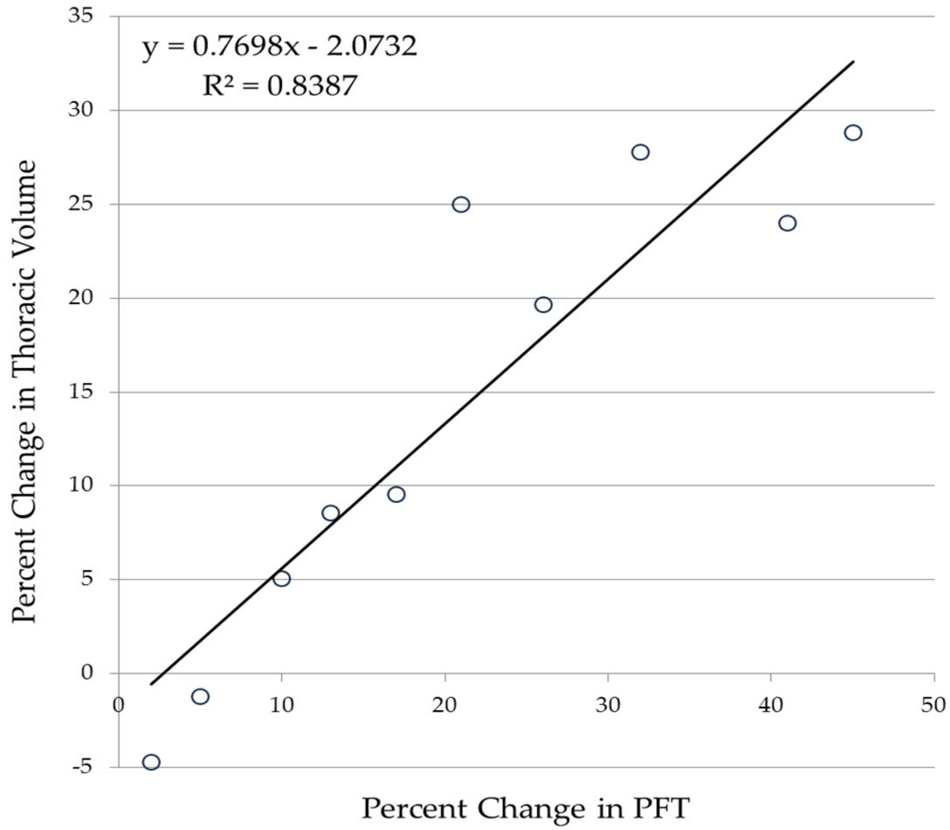
Pulmonary Function



Thoracic Volume

† $p=0.065$; * $p<0.001$

Correlation of PFTs with Volume



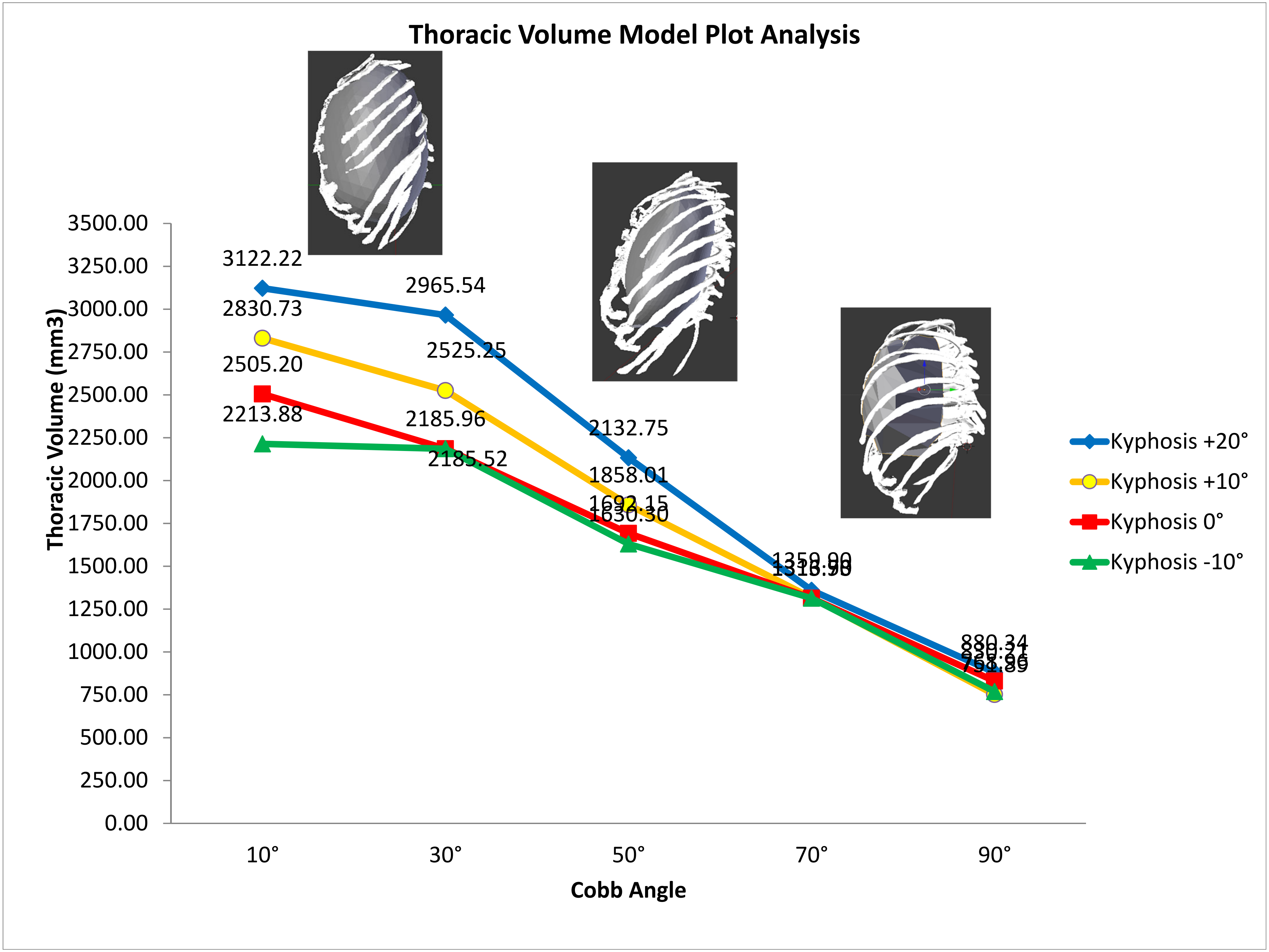
AIS Patients with the Pre-Surgical Lowest PFT Values

Conclusion

- Pre-operative thoracic volume was diminished in patients with the lowest PFT values (3194±1358 cm^3) compared with with the highest PFT values (3427±874 cm^3) although the groups were not height matched ($p=0.085$).
- The adolescents with the most severe pulmonary compromise prior to surgery exhibited a strong positive relationship between post-operative change in PFT and thoracic volume ($r^2 = 0.839$; $p<0.001$).
- The mean increase in thoracic volume (space available to the lungs) in this group was 373.1 cm^3 (11.7%) which corresponded to a 21.2% improvement in PFTs.
- AIS surgical intervention was found to increase thoracic volume which was strongly correlated with improved pulmonary function in severe cases.

Theoretical Volume Modeling

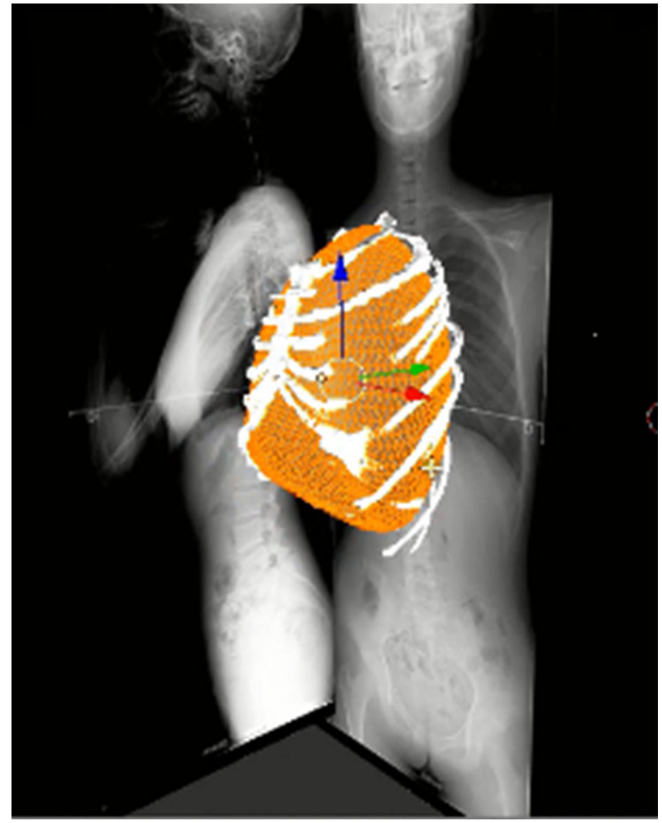
- We had the idea to progressively vary the amount(severity) of the deformity and look at the effect on thoracic volume


Thoracic Volume Model Plot Analysis
Thoracic Volume (mm3)
3500.00
3250.00
3000.00
2750.00
2500.00
2250.00
2000.00
1750.00
1500.00
1250.00
1000.00
750.00
500.00
250.00
0.00
3122.22
2830.73
2505.20
2213.88
2965.54
2525.25
2185.96
2185.52
2132.75
1858.01
1630.30
10°
30°
50°
70°
90°
Cobb Angle
Kyphosis +20°
Kyphosis +10°
Kyphosis 0°
Kyphosis -10°

Clinical Series of Increasing Severity

- From the previously mentioned study group data set, we identified progressively severe deformity (50,60,70,80, and 90 degree curves)
- These were then modeled pre- and post-operatively

Thoracic Volume Modeling in Adolescent Idiopathic Scoliosis: The Effect of Increasing Cobb Angle and Sagittal Contour on Pulmonary Function



Jennifer Wozniczka, MD[1], David Polly Jr. MD[1], Charles Ledonio, MD[1] , Benjamin Rosenstein[2], and David J Nuckley, PhD[2]
[1]Department of Orthopaedic Surgery and [2]Department of Physical Medicine and Rehabilitation; University of Minnesota, Minneapolis, MN.

Results: Cobb angle, sagittal contour and thoracic volume

MT Cobb	Sagittal profile T5-T12	Volume (mm3)
50	15	1861.989
60	19	1262.535
71	33	1538.234
80	34	1421.105

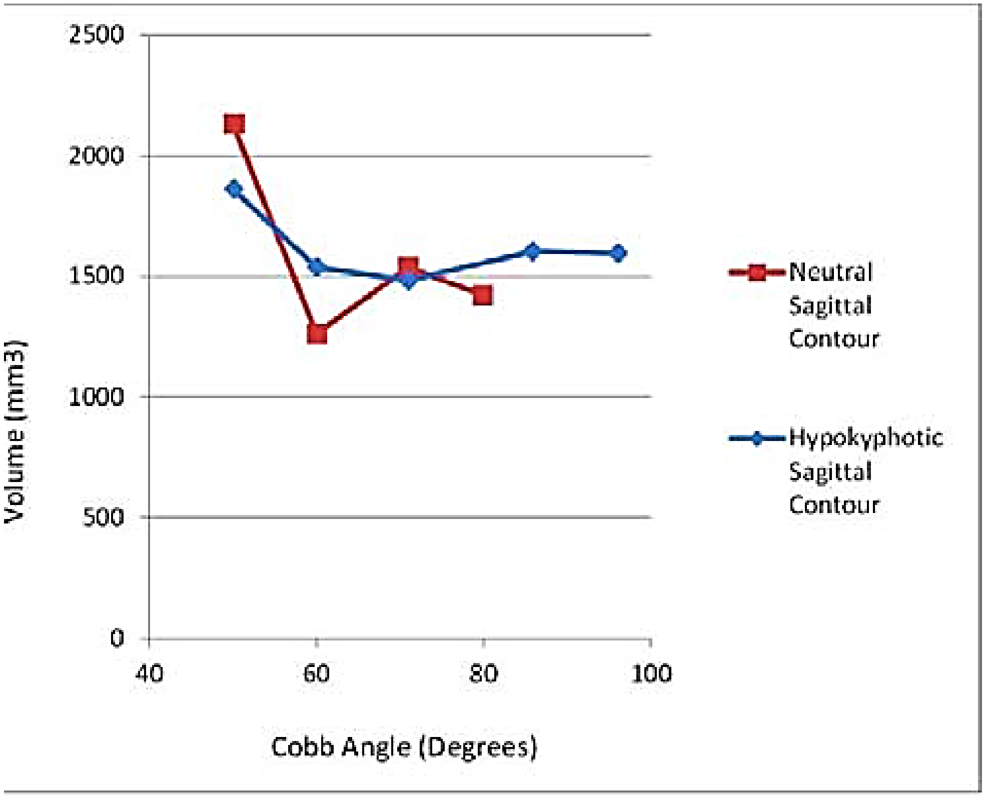
Neutral Sagittal Contour

MT Cobb	Sagittal profile T5-T12	Volume (mm3)
50	0	1858.01
60	2	1538.22
71	4	1482.96
86	8	1604.48
96	9	1595.71

Hypokyphotic Sagittal Contour

Results

- Moderate inverse correlation between Cobb angle and thoracic volume in samples with neutral sagittal contour (*r = -0.629)*
- Weak inverse correlation in the samples with hypokyphotic sagittal contour (*r = -0.458)*
- A weak inverse correlation was also noted between the sagittal angle and thoracic volume in the neutral and hypokyphotic groups (*r = -0.490, r = -0.436*)

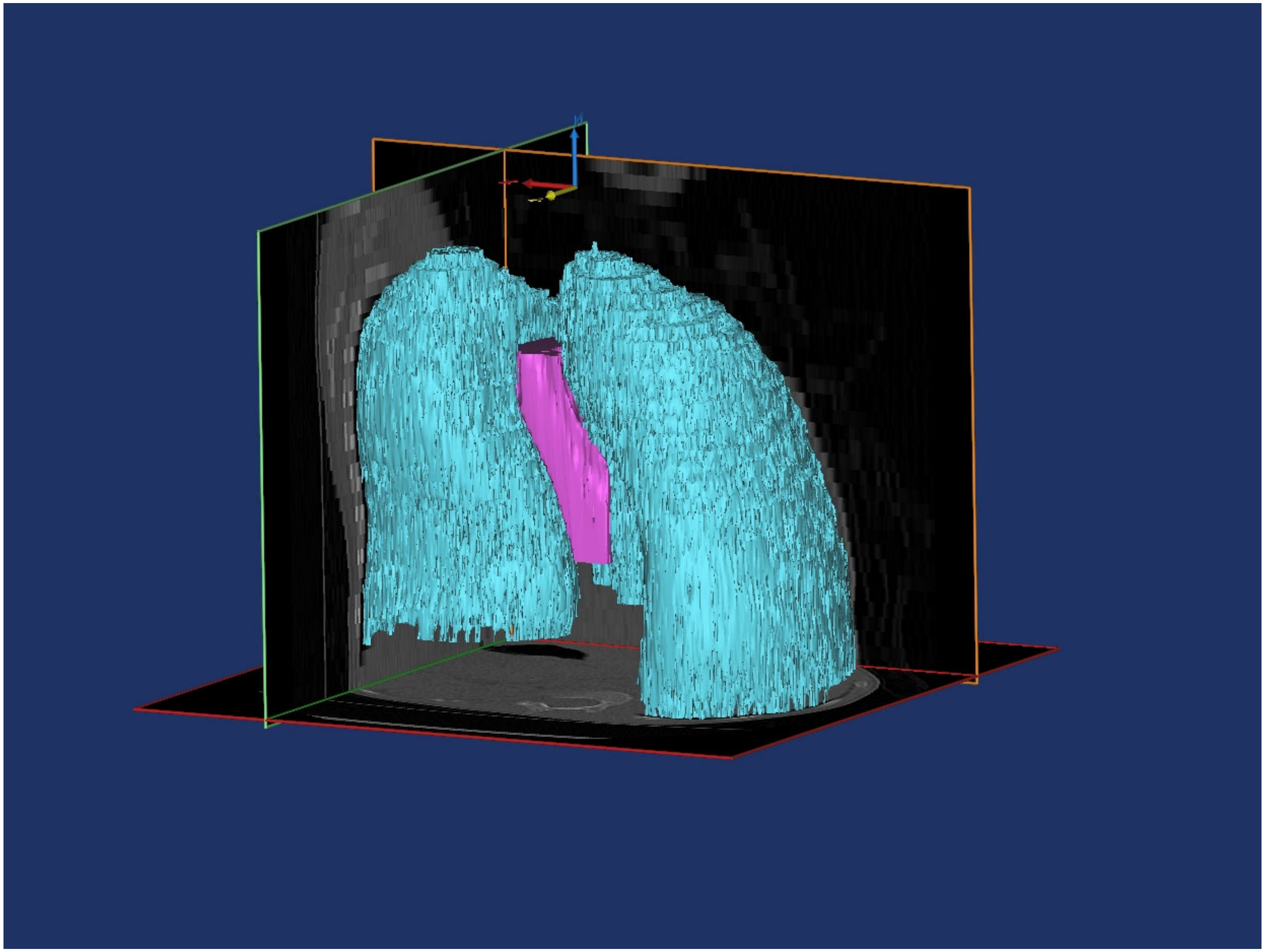


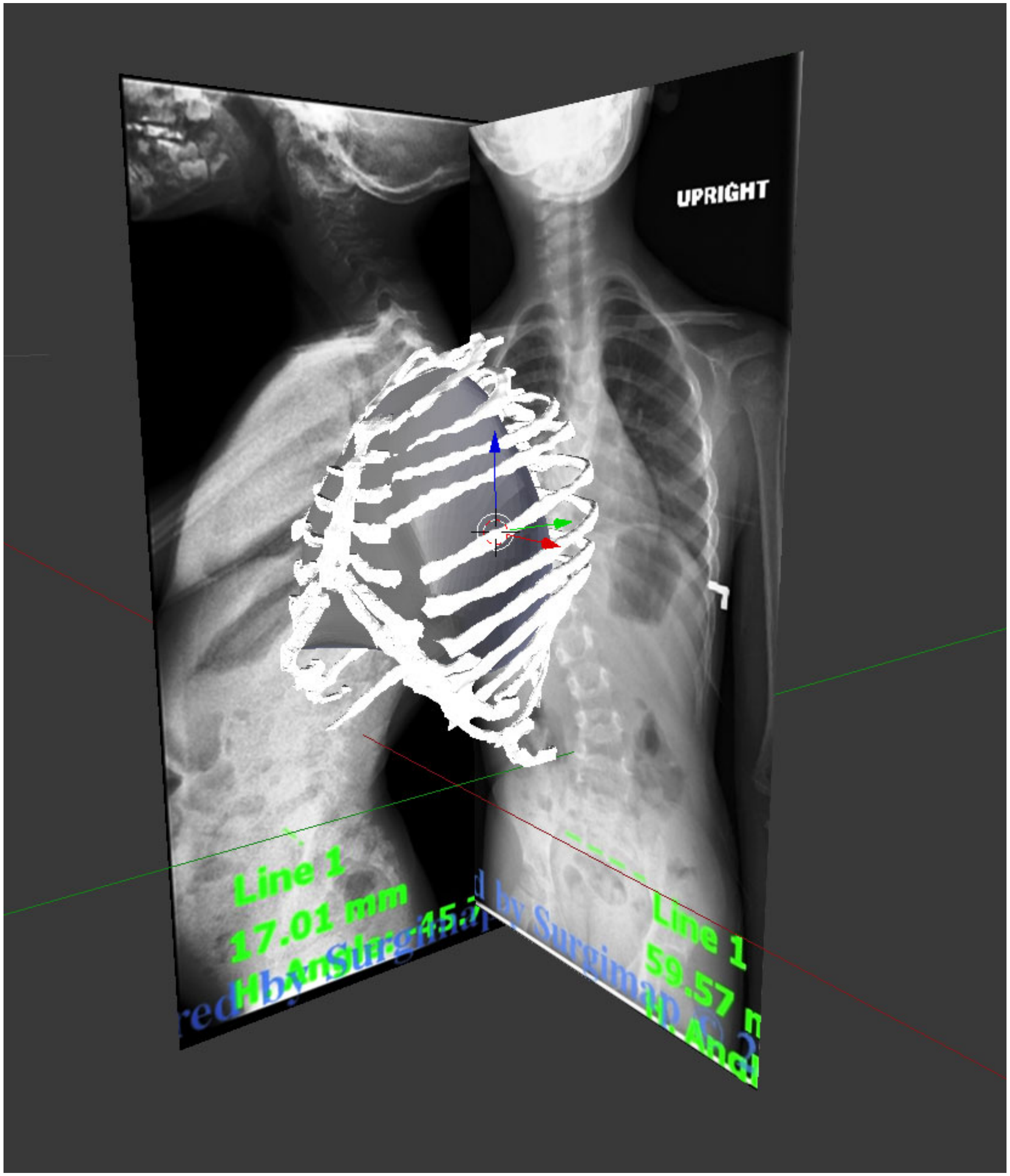
Conclusions

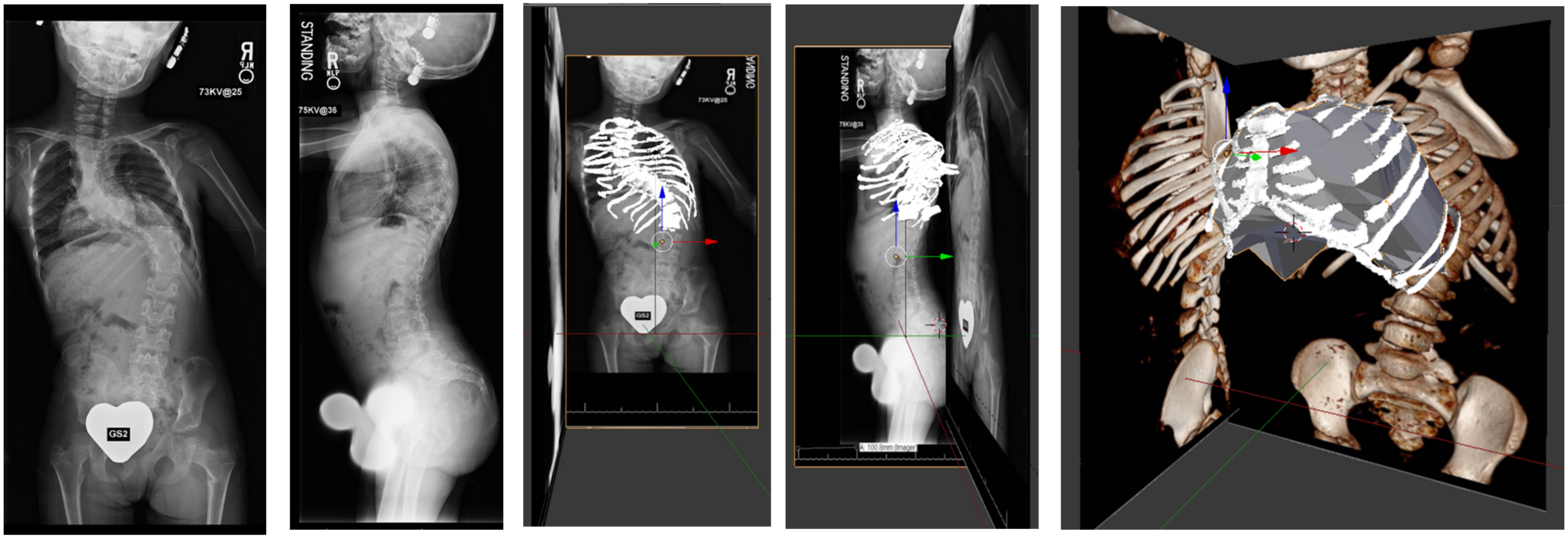
- Despite a small sample size, a weak to moderate inverse correlation between Cobb angle and thoracic volume was observed in samples with hypokyphotic and neutral sagittal contour respectively
- Additionally, a weak inverse correlation was also noted between the sagittal angle and thoracic volume in the neutral and hypokyphotic groups
- This provides pilot data suggesting the expected correlations

Additional Work

- The thoracic model was developed to mimic a standard adult
- Young children have different geometric chest configurations
- Kristin England has now done validation of accuracy in 3 cases of children with x-rays and CT scans



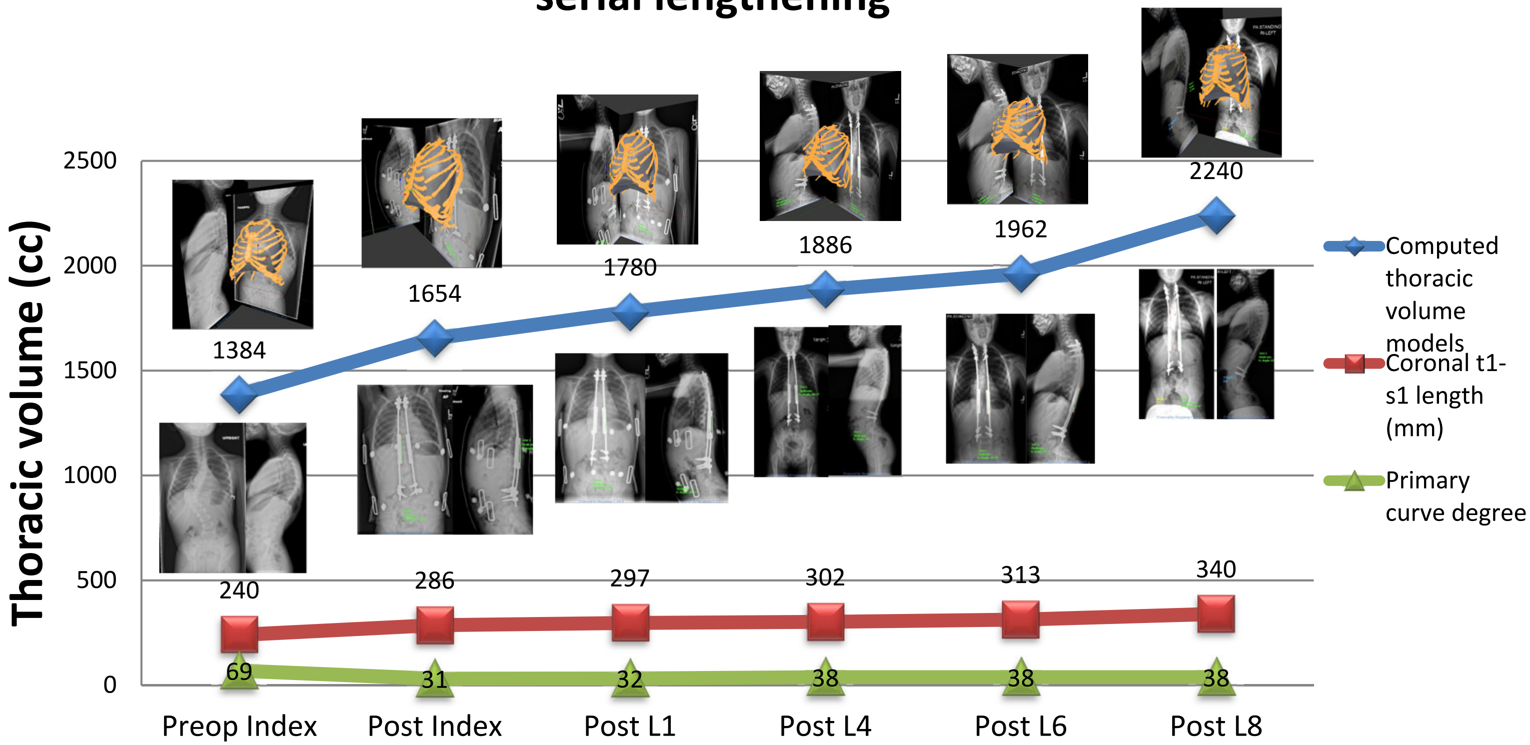

UPRIGHT
Line 1
17.01 mm
Line 1



Subject #	Age	Sex	Height (cm)	Weight (kg)	R lung vol-calc (cc)	L lung vol-calc (cc)	Mediastinum--calc (cc)	Calculated thoracic volume (cc)	Predicted thoracic volume (mm3)	Percent error (%)	Cobb Angle (º)	Thoracic Kyphosis (T2-T12) (º)
1	5y 7mo	F	89	12.2	314.8	244	206	764.8	751.9	1.6	74	60
2	4y 10mo	F	103	16.9	198.3	100	246	544	500	8.3	92	90
3	2y 10mo	M	84.1	9.9	247.1	115.6	179	542	530	2.2	76	61

Results: One male and two female patients with EOS and an average age of 4 years (range 2y 10mo- 5y 7mo). Demographic data and calculated volumes are summarized in Table 1. Subject 1 had 1.6% error, subject 2 8.3% error, and subject 3 2.2% error. This averaged to 4% error.

Computed thoracic volumes in an EOS patient with growing rod serial lengthening



	Preop Index	Post Index	Post L1	Post L4	Post L6	Post L8
Computed thoracic volume models	1384	1654	1780	1886	1962	2240
Primary curve degree	69	31	32	38	38	38
Coronal t1-s1 length (mm)	240	286	297	302	313	340
Coronal t1-t12 length	165.2	176.2	178	184	195	212
Maximum kyphosis (global kyphosis)	77	19	11	63	50	45
T2-T5 degree	21	10	23	11	41	20
T5-T12 degree	45	13	16	28	14	27

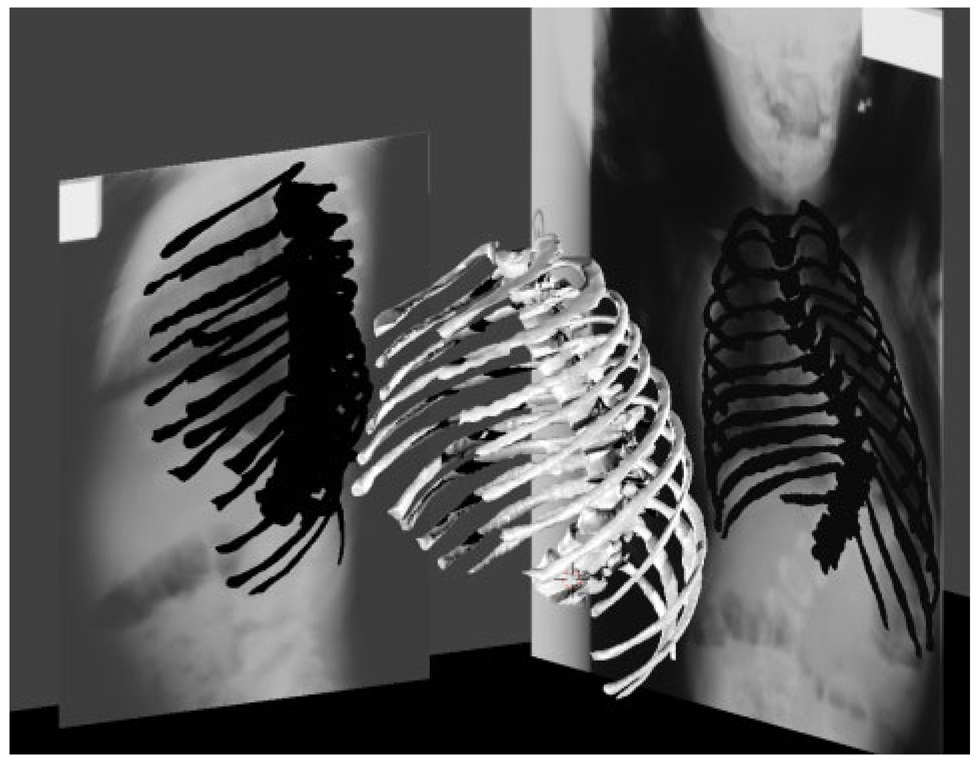
Thoracic Volume Modeling in Early Onset Scoliosis

David Matson, MS2[1]; Charles Ledonio, MD[2]; David Polly Jr., MD[2]; Kristin England, MD[2]; Jeff Pawelek, BS[4]; and Behrooz Akbarnia, MD[3,4]

[1]University of Minnesota Medical School; Minneapolis, MN. [2]Department of Orthopaedic Surgery, University of Minnesota Medical School; Minneapolis, MN. [3]Department of Orthopaedic Surgery, University of California, San Diego; San Diego, CA. [4]San Diego Center for Spinal Disorders; La Jolla, CA.

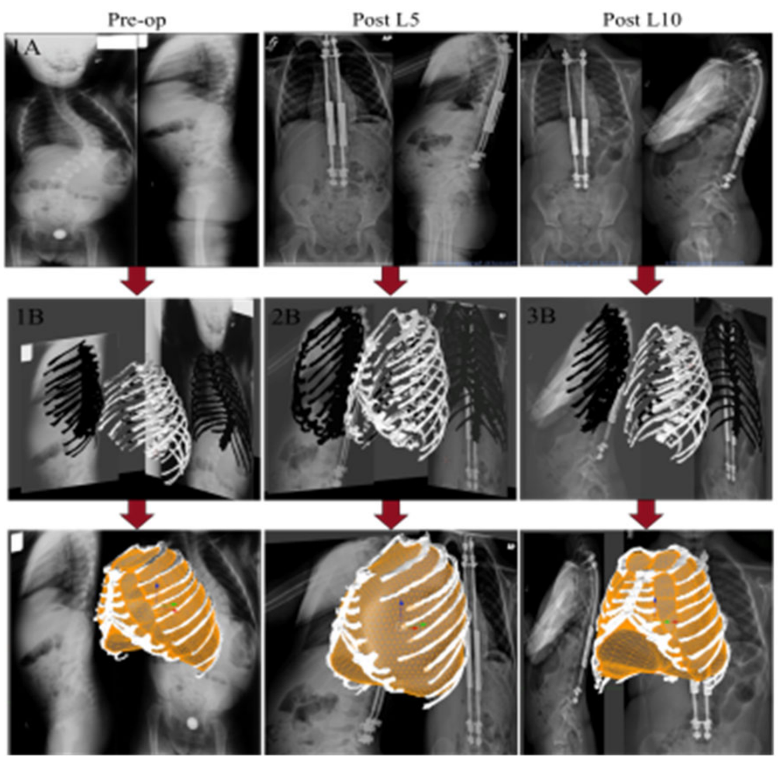
Purpose

- Objective: to assess thoracic volume change with growing rod interventions in patients with early onset scoliosis.



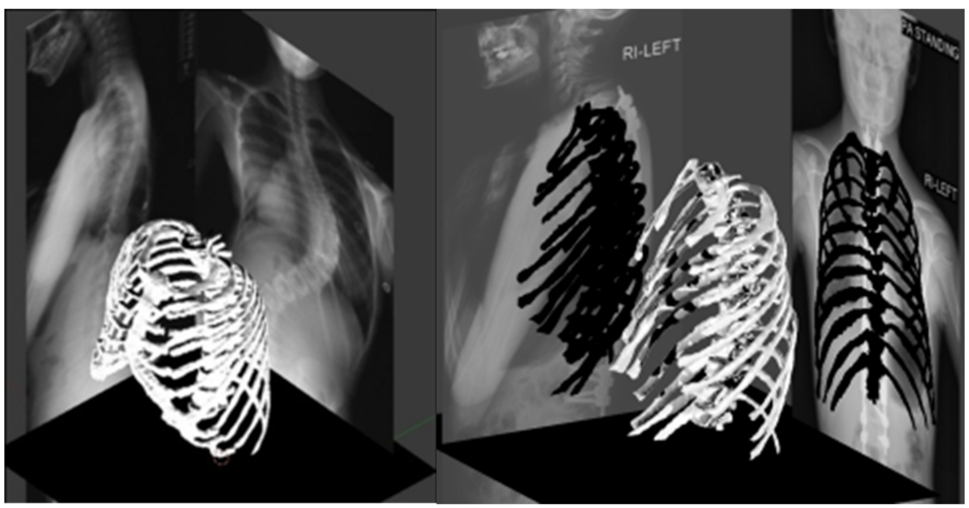
Methods

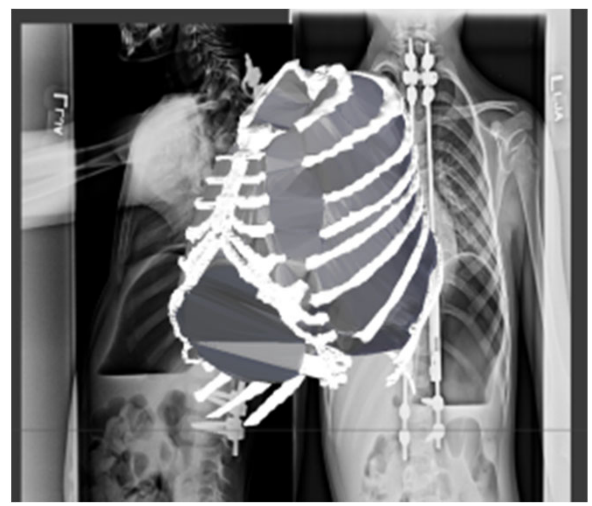
- Retrospective case study of children 10 years of age and younger with diagnosis of EOS
- Convenience sample of 6 patients with EOS from Growing Spine Study Group
- Coronal and sagittal radiographs used to model thoracic volume

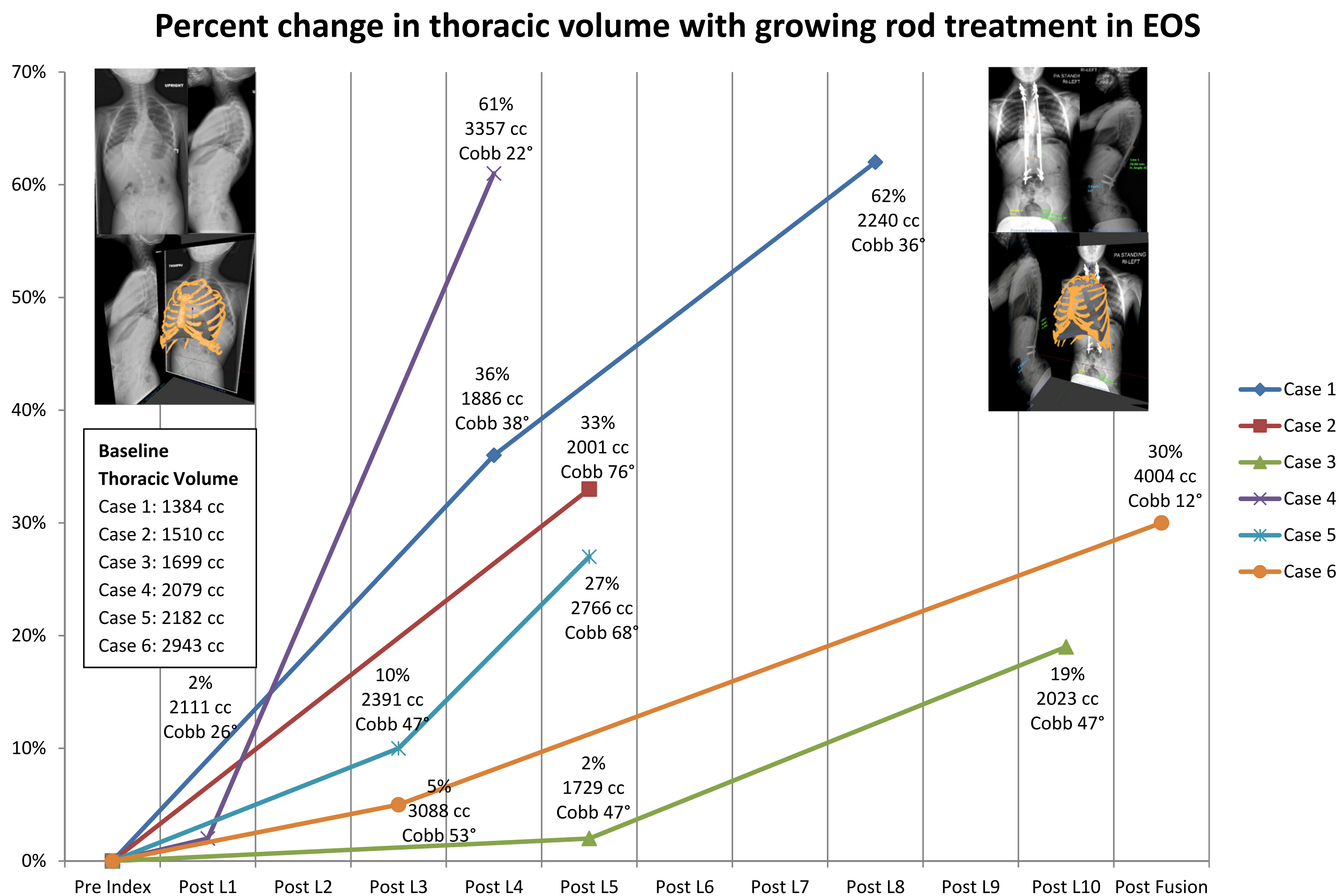


Methods

- Patients all underwent growing rod surgery with varying number of lengthening procedures for treatment of diagnosed early onset scoliosis
- Blender software (2.71, open access) to create 3D model from coronal and sagittal radiographs
  - ‘computationally deformed’ to match chest X-rays
- 3D models created with pre- and post-operative radiographs
  - Post-op taken from midpoint of treatment and final lengthening
  - Up to 3 models per patient
- Thoracic volume determined from models in Blender

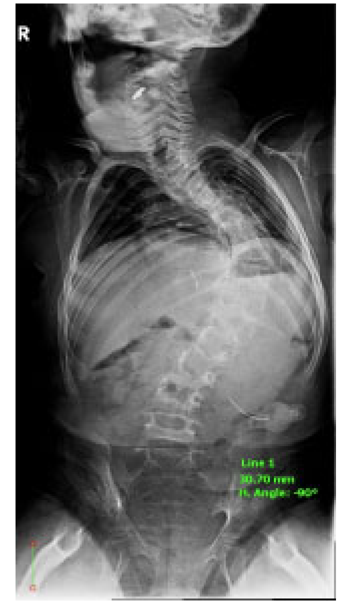





Percent change in thoracic volume with growing rod treatment in EOS
70%
60%
50%
40%
30%
20%
10%
0%
Pre Index
Post L1
Post L2
Post L3
Post L4
Post L5
Post L6
Post L7
Post L8
Post L9
Post L10
Post Fusion
Baseline Thoracic Volume
Case 1: 1384 cc
Case 2: 1510 cc
Case 3: 1699 cc
Case 4: 2079 cc
Case 5: 2182 cc
Case 6: 2943 cc
2% 2111 cc Cobb 26°
10% 2391 cc Cobb 47°
5% 3088 cc Cobb 53°
61% 3357 cc Cobb 22°
36% 1886 cc Cobb 38°
33% 2001 cc Cobb 76°
27% 2766 cc Cobb 68°
2% 1729 cc Cobb 47°
62% 2240 cc Cobb 36°
19% 2023 cc Cobb 47°
30% 4004 cc Cobb 12°
Case 1
Case 2
Case 3
Case 4
Case 5
Case 6

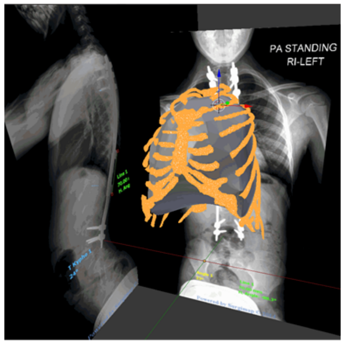
Correlational Findings: Thoracic Volume

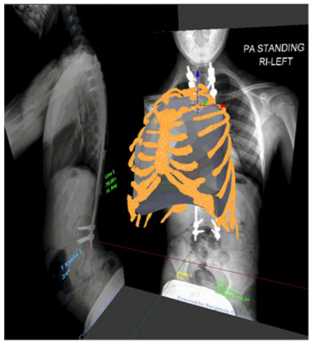
- Strong correlation with T1-T12 thoracic height (r = 0.85, 95% CI: 0.94, 0.62)
- Moderate inverse correlation with Cobb angle (r = -0.59, 95% CI: -0.84, -0.16)
- Moderate inverse correlation with kyphosis (r = -0.53, 95% CI: -0.81,-0.07)
- All correlations statistically significant ($p<0.05$)

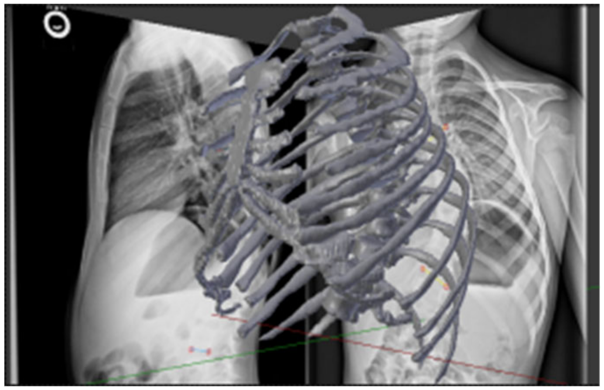


Conclusion

- Growing rod technique effectively increases thoracic volume with subsequent lengthenings
- Increased thoracic space for lung expansion during child growth
- Changes in thoracic volume correlate significantly with other markers such as thoracic height, Cobb angle, and kyphosis



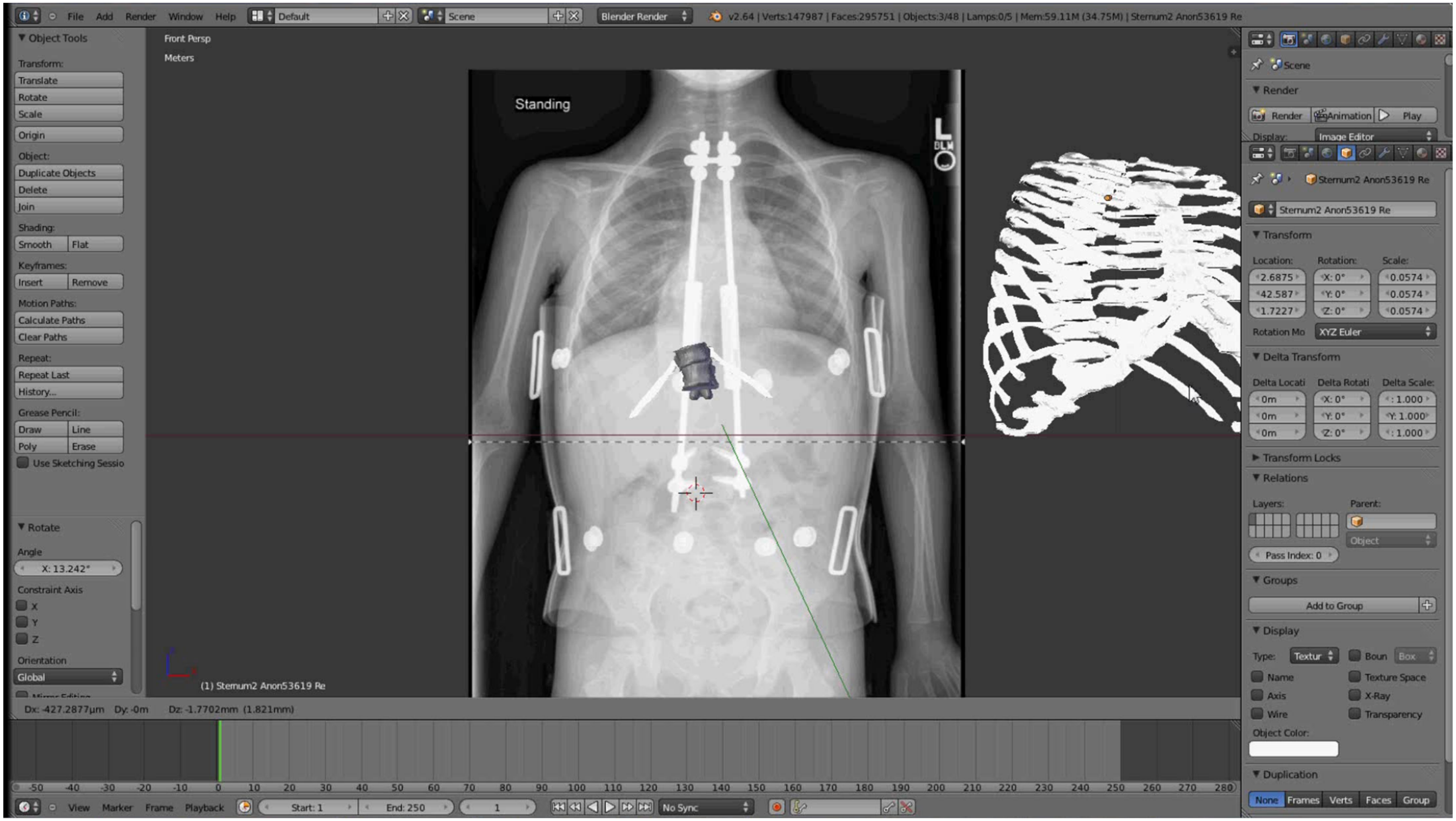


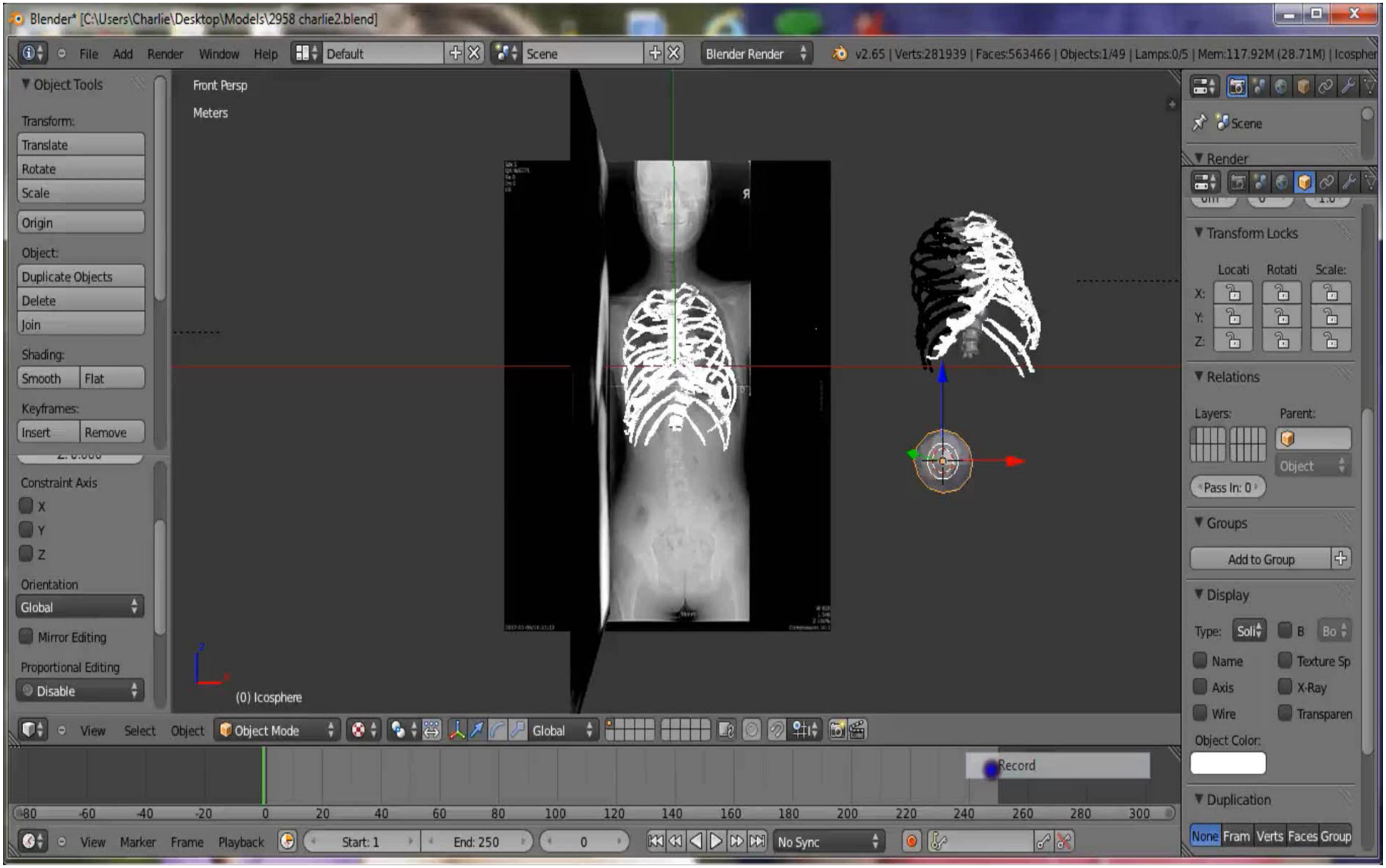


3D Rendering of the Thoracic Cage from Plain 2D Radiographs of Scoliosis in Children

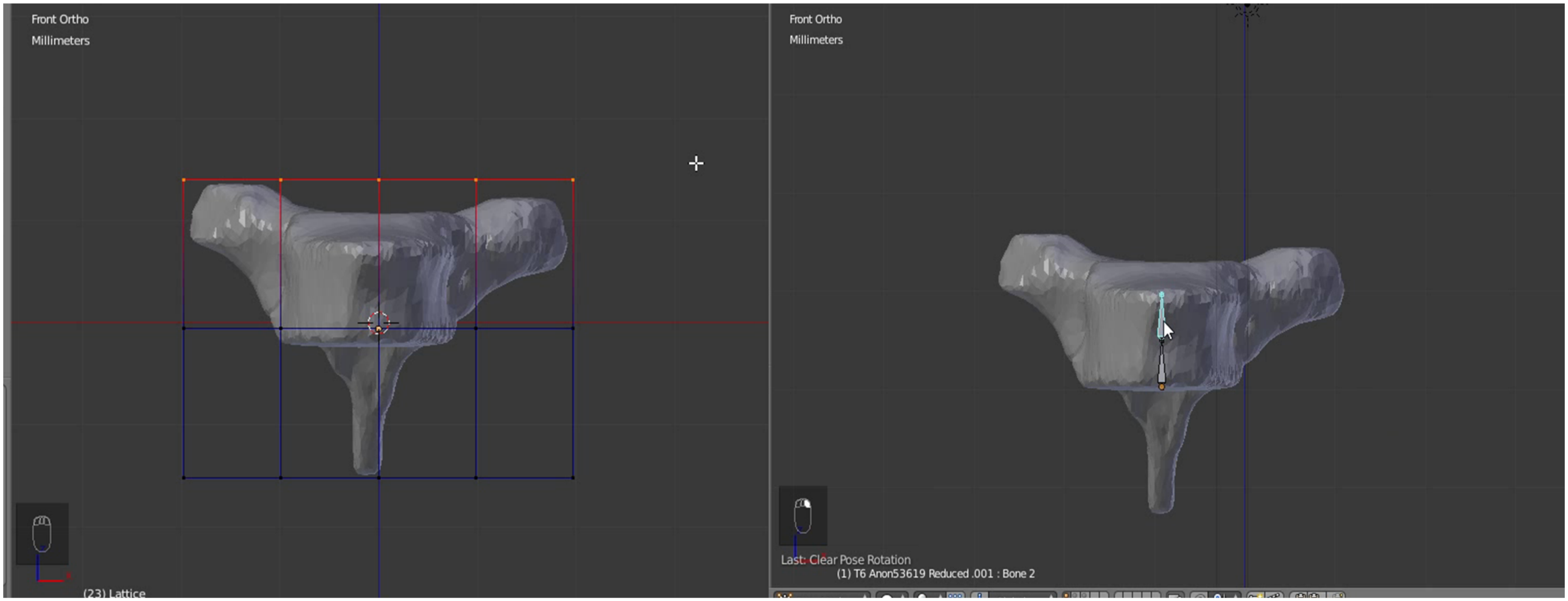
Charles T. Ledonio, MD
Po-Chih Lee, PhD student
Evan F. Bollig, PhD
Scott Haiden
Arthur Erdman, PhD
David W. Polly, Jr., MD
Nancy Rowe

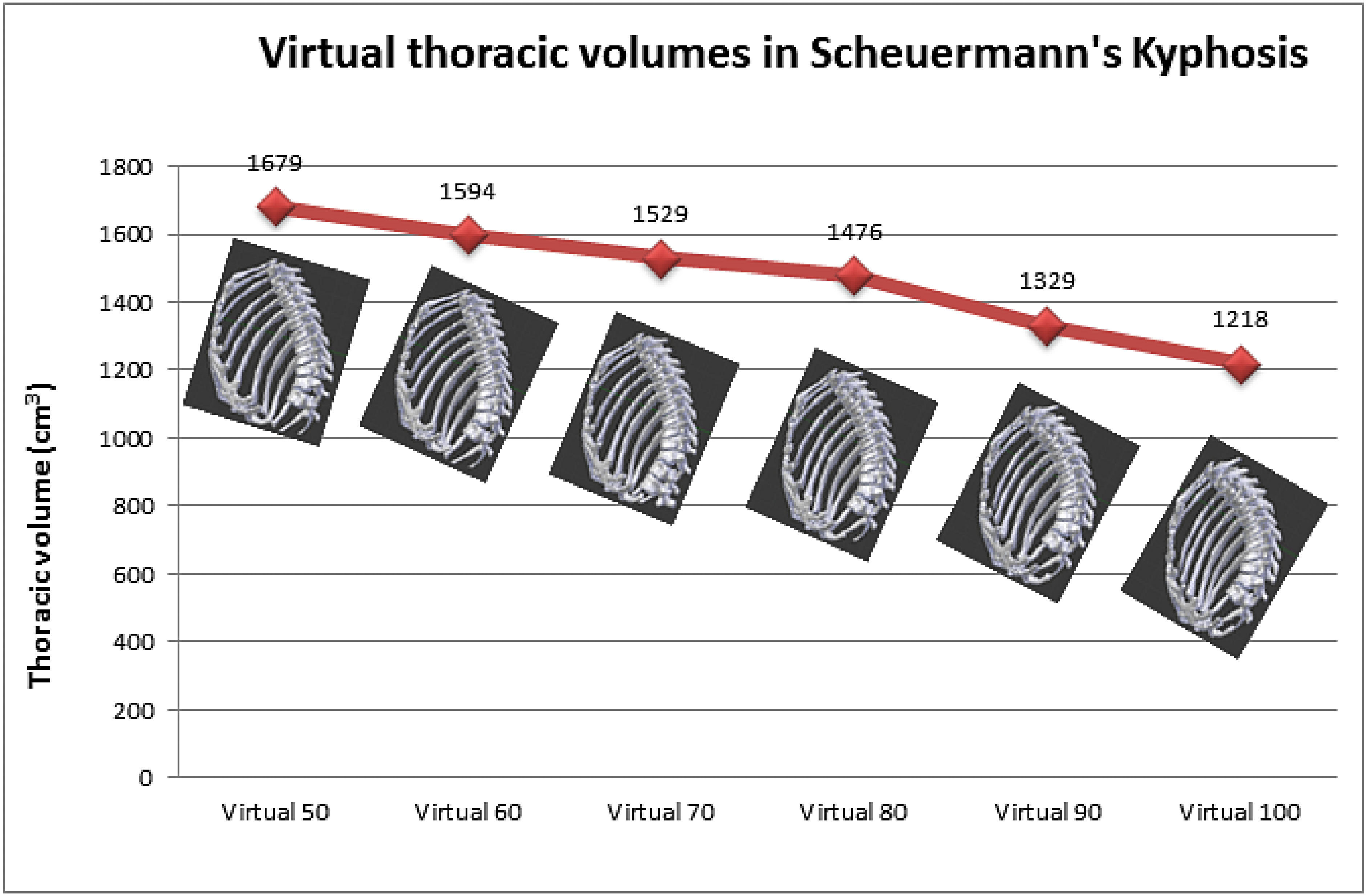
Methods (6-8 hours)



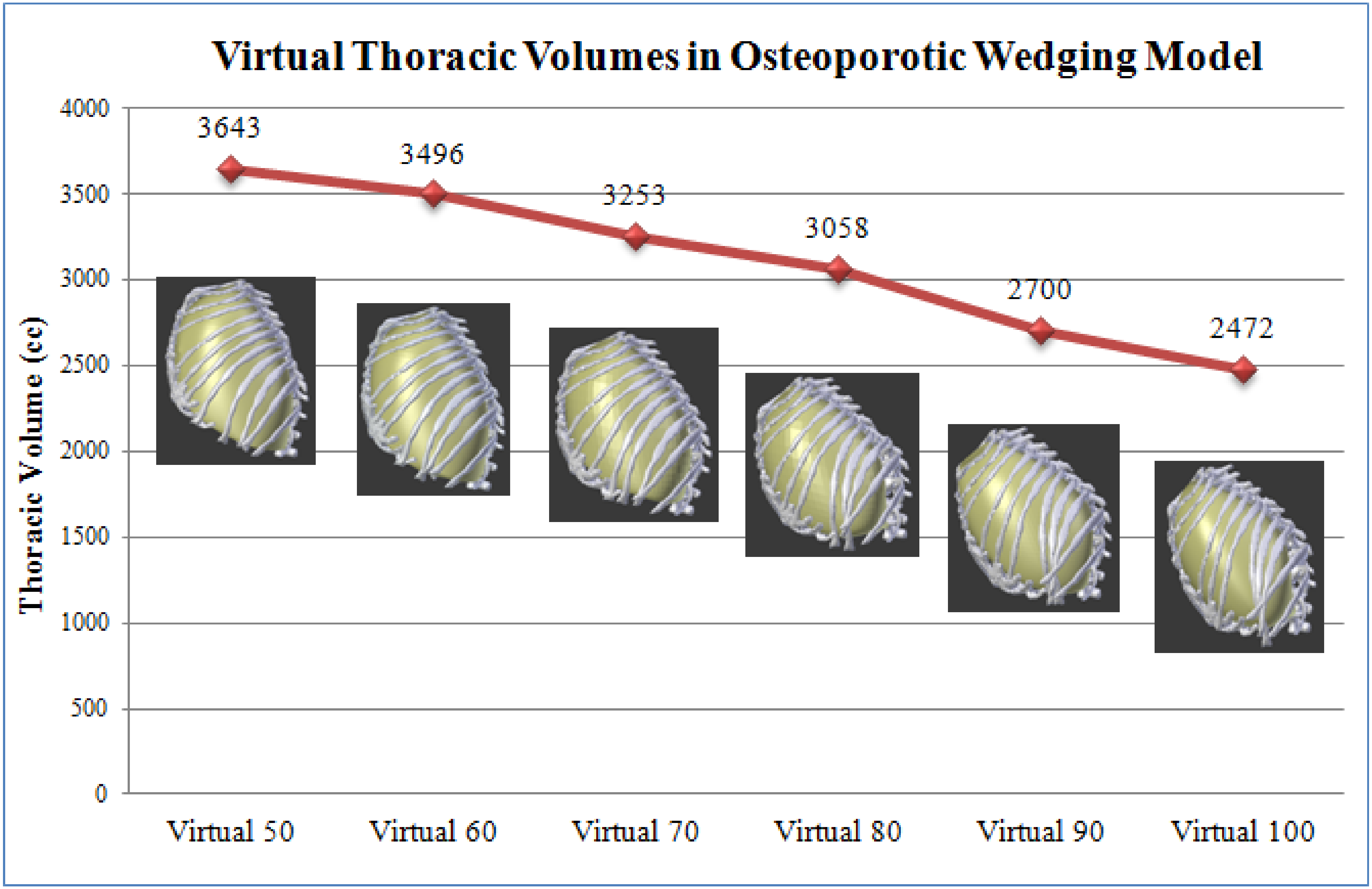

Blender* [C:\Users\Charlie\Desktop\Models\2958 charlie2.blend]
File
Add
Render
Window
Help
Default
Scene
Blender Render
v2.65 | Verts:281939 | Faces:563466 | Objects:1/49 | Lamps:0/5 | Mem:117.92M (28.71M) | Icospher
Object Tools
Transform:
Translate
Rotate
Scale
Origin
Object:
Duplicate Objects
Delete
Join
Shading:
Smooth
Flat
Keyframes:
Insert
Remove
Constraint Axis
X
Y
Z
Orientation
Global
Mirror Editing
Proportional Editing
Disable
Front Persp
Meters
(0) Icosphere
Scene
Render
Transform Locks
Locati
Rotati
Scale:
X:
Y:
Z:
Relations
Layers:
Parent:
Object
Pass In: 0
Groups
Add to Group
Display
Type:
Soli
B
Bo
Name
Texture Sp
Axis
X-Ray
Wire
Transparen
Object Color:
Duplication
None
Fram
Verts
Faces
Group
View
Select
Object
Object Mode
Global
Record
-80
-60
-40
-20
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
View
Marker
Frame
Playback
Start: 1
End: 250
0
No Sync

Wedging Deformity in Vertebral Body

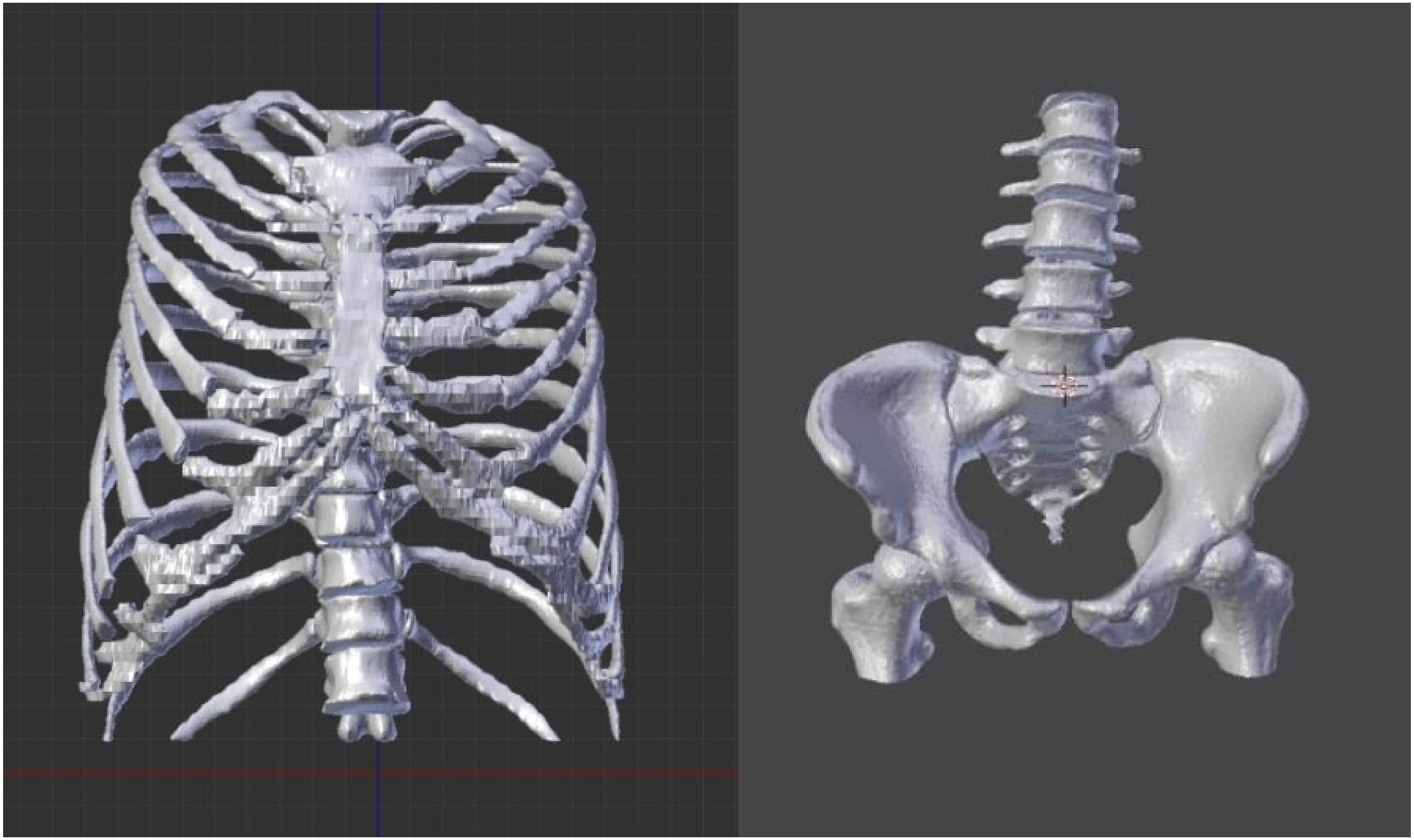


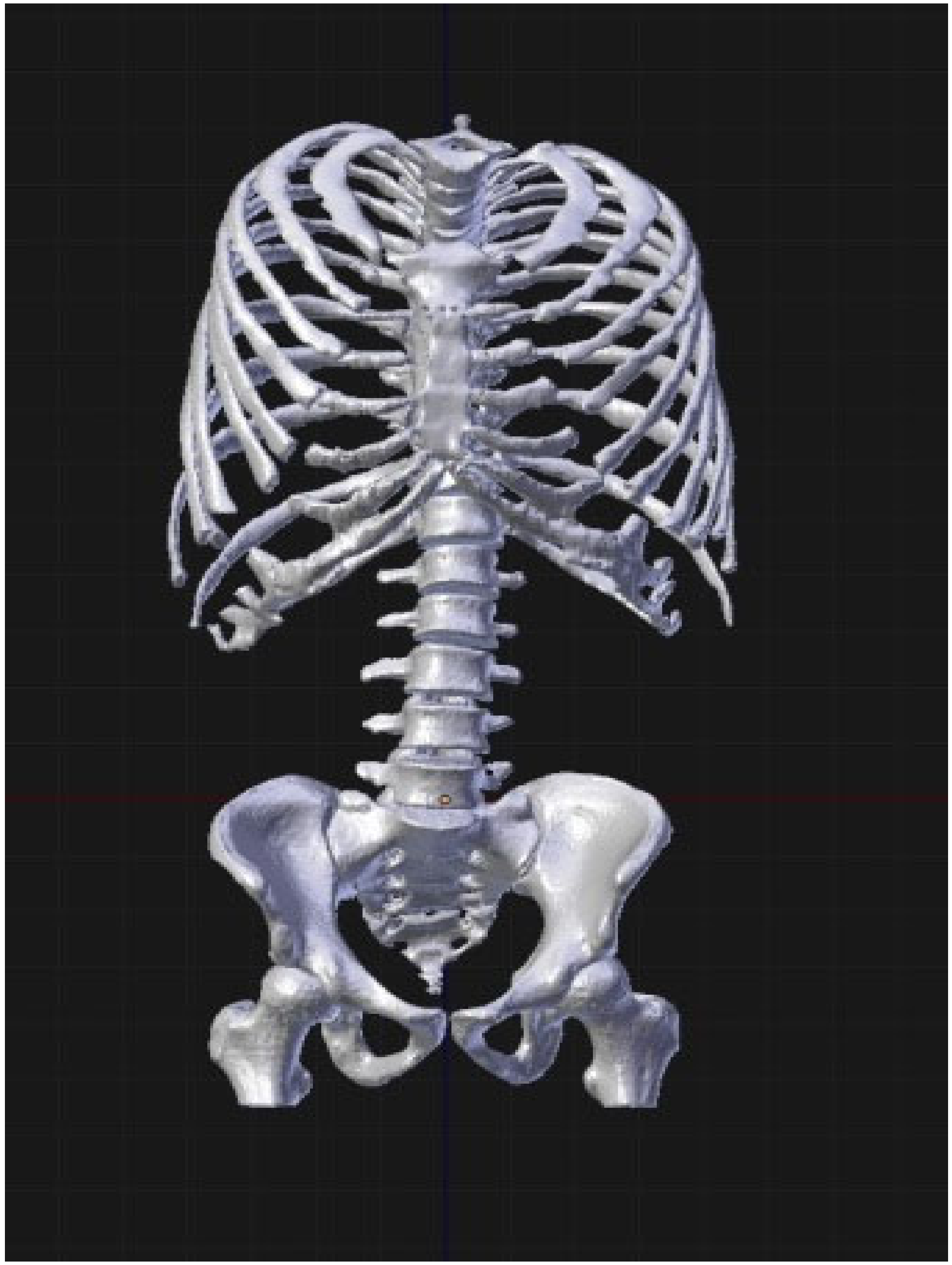


Virtual thoracic volumes in Scheuermann's Kyphosis
Thoracic volume (cm3)
1800
1600
1400
1200
1000
800
600
400
200
0
1679
1594
1529
1476
1329
1218
Virtual 50
Virtual 60
Virtual 70
Virtual 80
Virtual 90
Virtual 100



Virtual Thoracic Volumes in Osteoporotic Wedging Model
Thoracic Volume (cc)
4000
3500
3000
2500
2000
1500
1000
500
0
3643
3496
3253
3058
2700
2472
Virtual 50
Virtual 60
Virtual 70
Virtual 80
Virtual 90
Virtual 100





Hope for the Future?

- Define how patient specific deformity is expected to behave
- Compare intervention strategies
- Rigorous critique of outcomes
- Analysis of risks and complications associated with growth guidance strategies

Challenges

- Regulatory approval
- Payer approval
- Minimizing intervention morbidity
- Funding for quality work

Excitement Remains

- We are so much further ahead
- There is so much more to do
- Collaboration around the world is accelerating our understanding
- We want the right intervention for the right patient at the right time- that's all

- What will the next 50 years bring?

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The Growing Spine

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Second Edition

Springer