What is True Normal Growth of the Spine … and How Do We Measure it?

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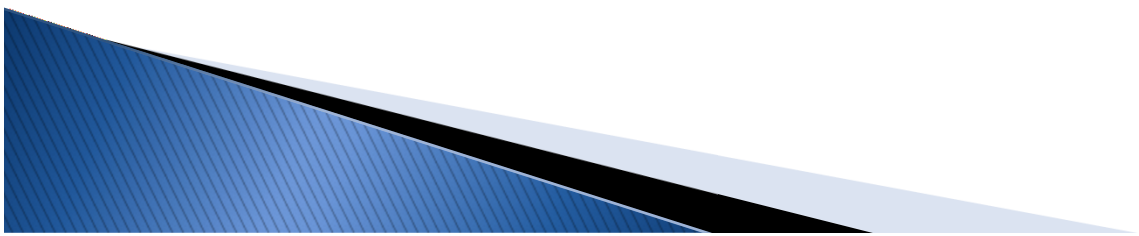
Disclosures

- Grants / Research Support
  - Depuy-Synthes Spine
  - Medtronic Canada
  - EOS Imaging

- Consultant
  - Depuy-Synthes Spine
  - Medtronic Canada
  - Halifax Biomedical Inc.



Summary

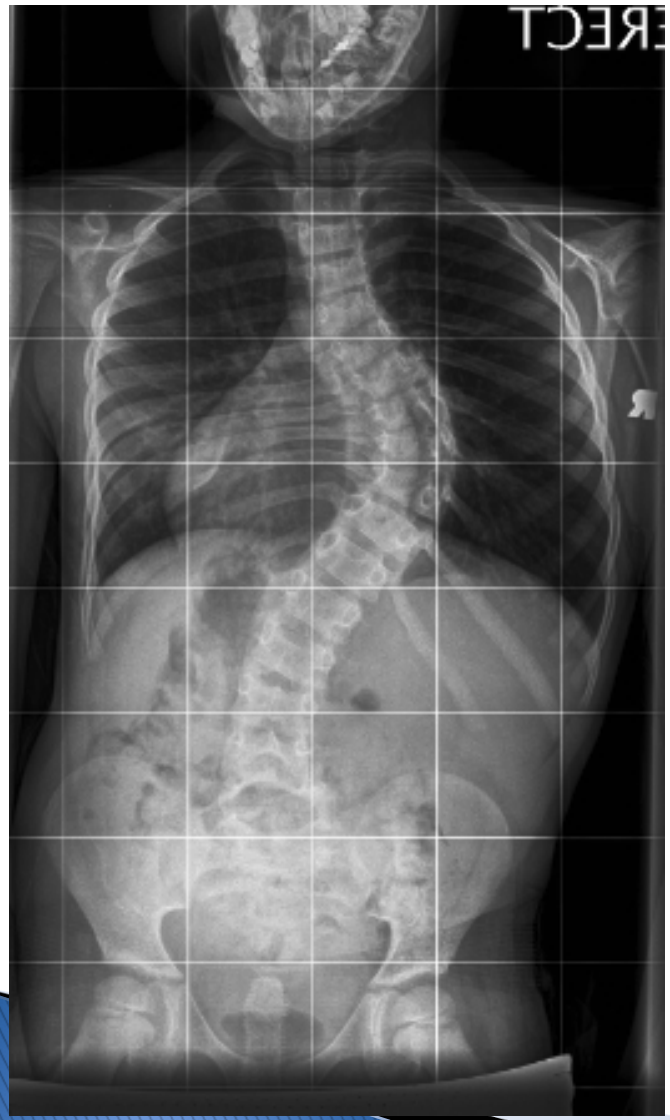
- Traditional Measures of Spine Growth
- Spine-Based Distraction
  - Law of Diminishing Returns?
- Rib-Based Distraction
- Growth Guidance
- Magnetic Control Growth Rods

Summary

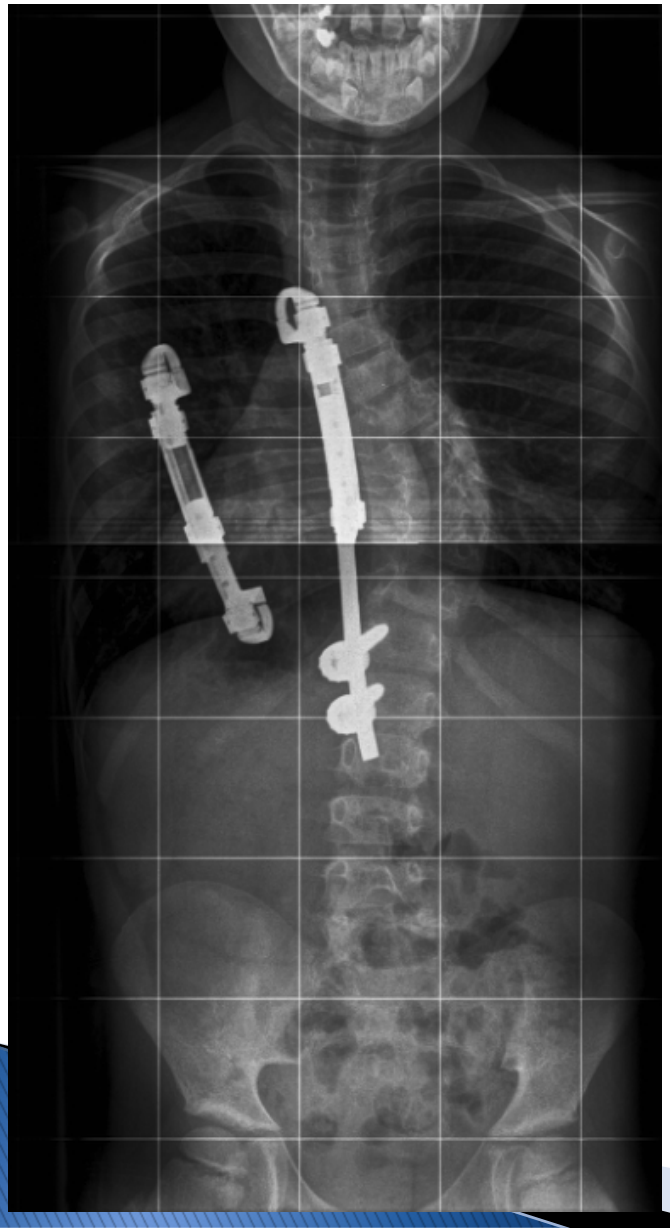
- Novel Techniques for Measurement
  - Sagittal Spine Length (SSL)
  - Three Dimensional True Spine Length (3D-TSL)
- Novel 2D / 3D References
  - Optical Imaging (Surface)
  - EOS Imaging
  - CT Data
  - Anthropometrics

2007: 6 yo boy with NF-1

2007: 6 yo boy with NF-1

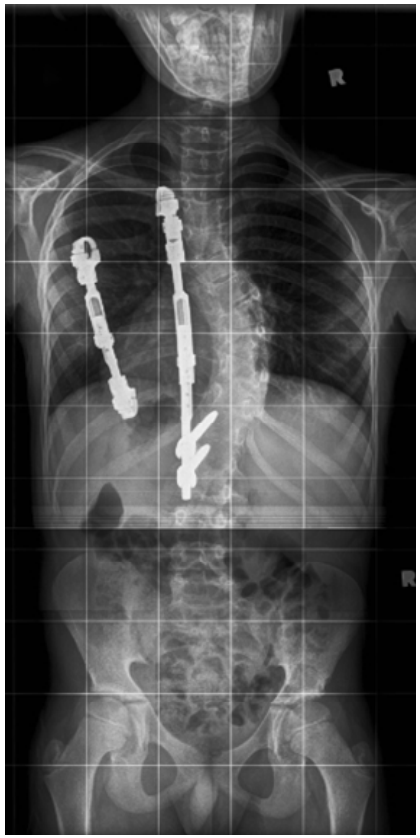


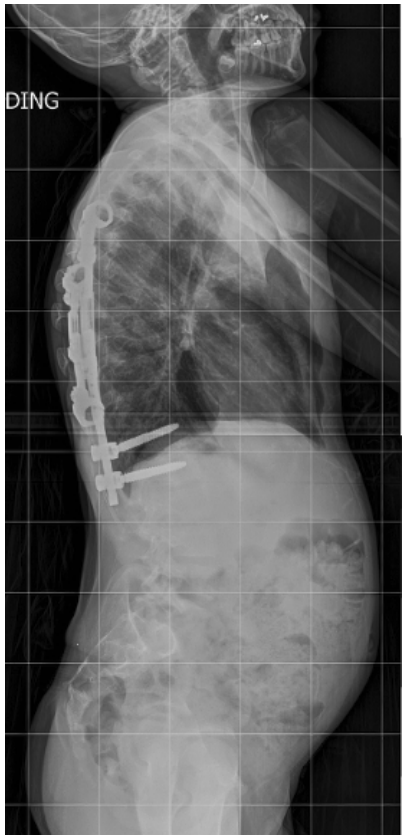
2007: 6 yo boy with NF-1



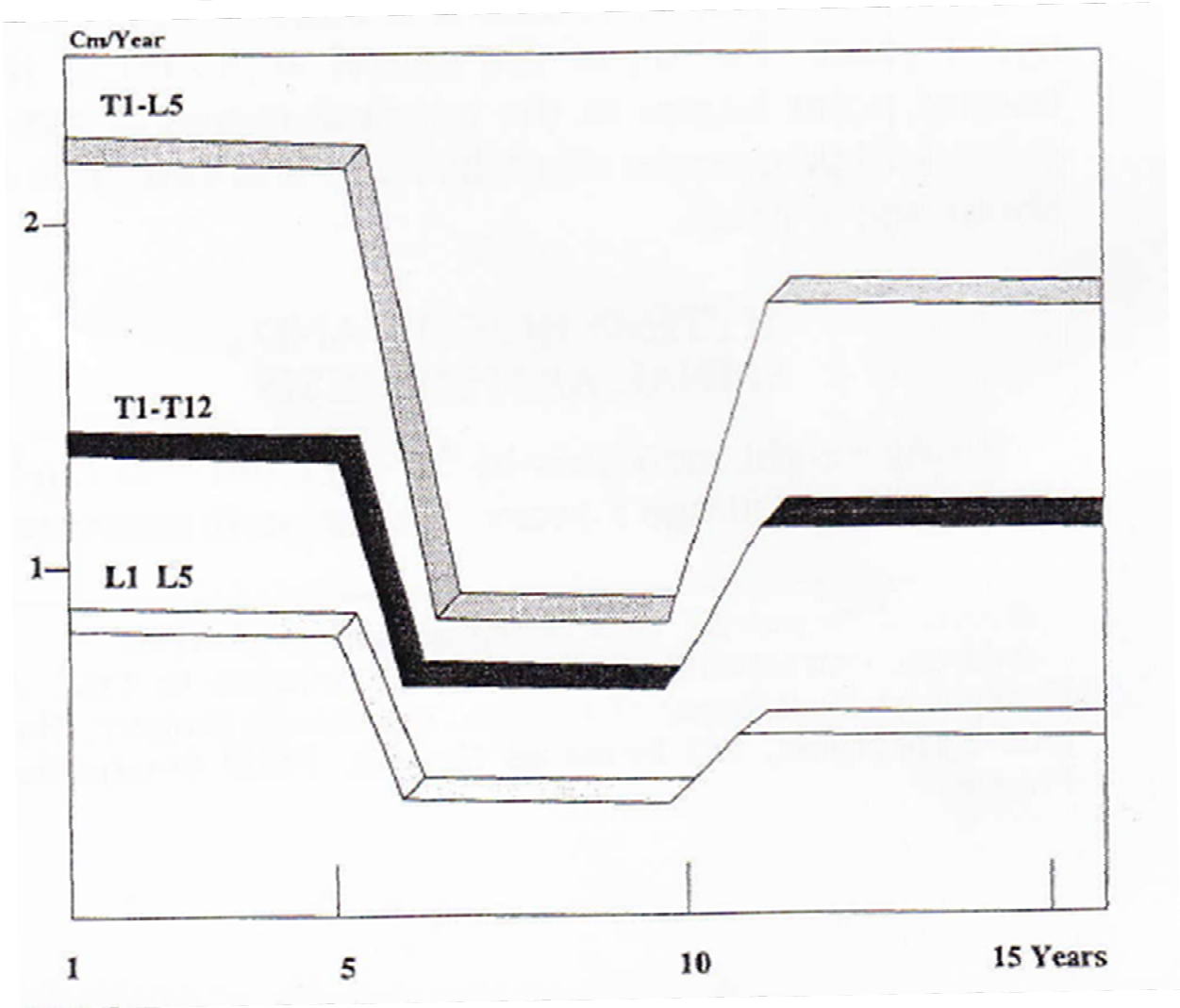
2013: 5 yrs post-op

- Age 12
- 9 Lengthenings
- 1 Rod Exchange
  - Both rods
- No complications
- Growth?



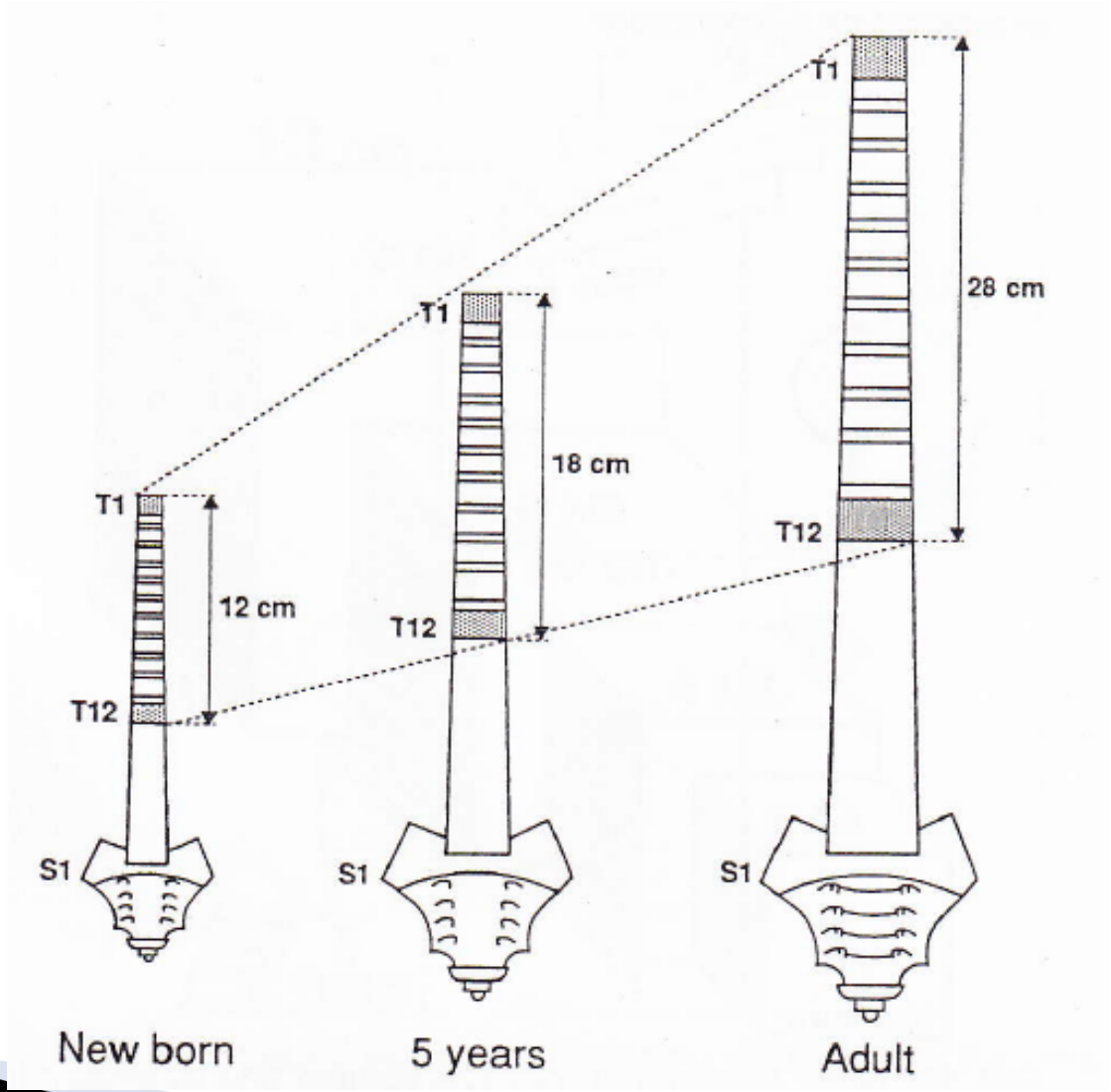


Normal Spine Growth



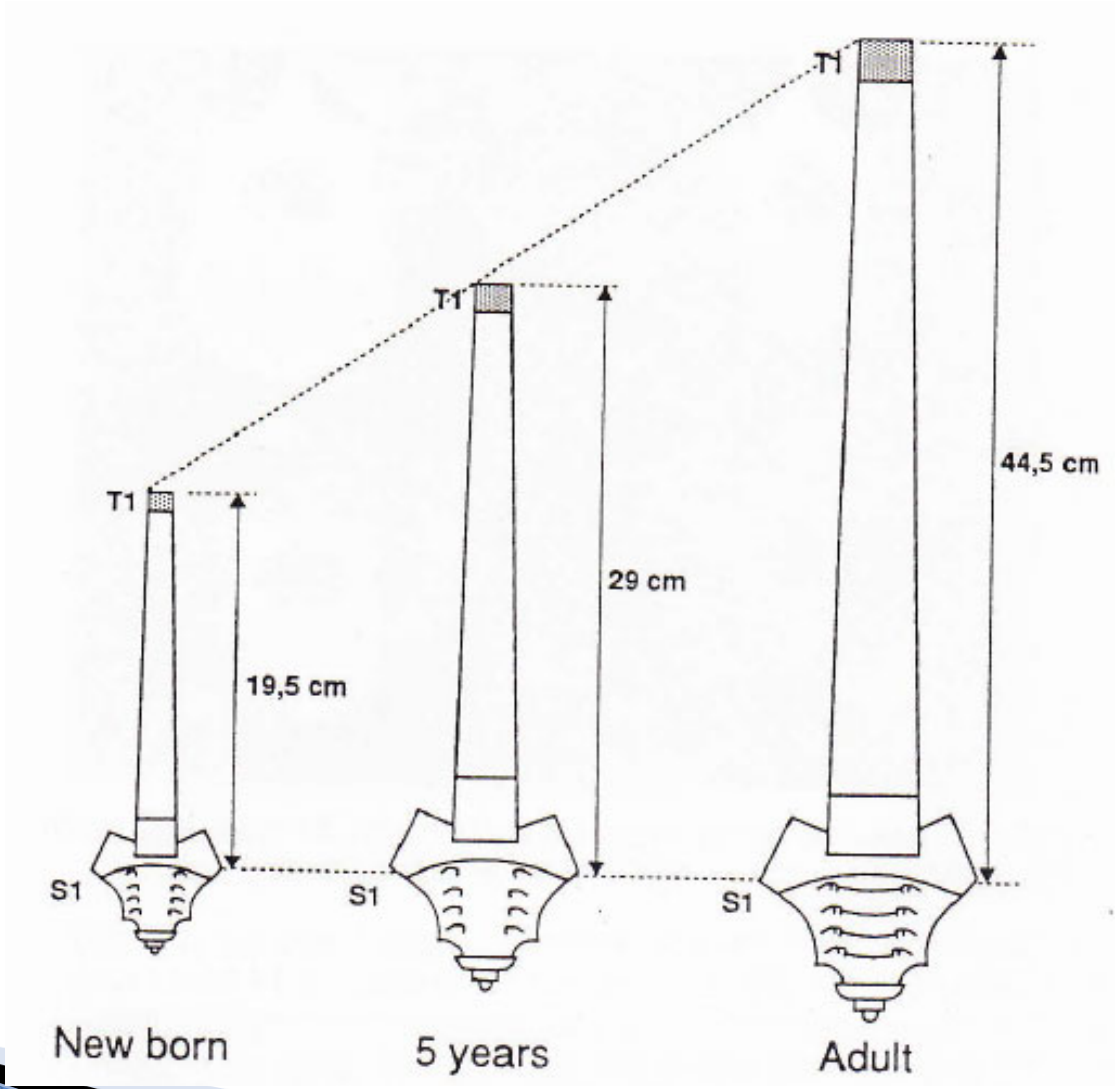
Dimeglio, JPO-B 1993

Normal Spine Growth



Dimeglio, JPO-B 1993

Normal Spine Growth

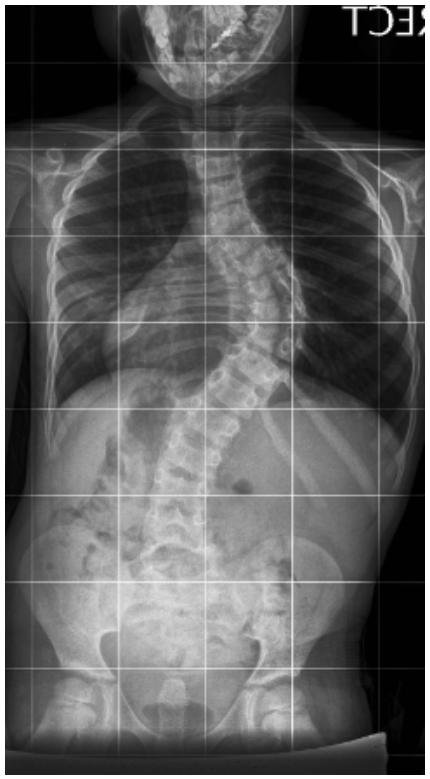


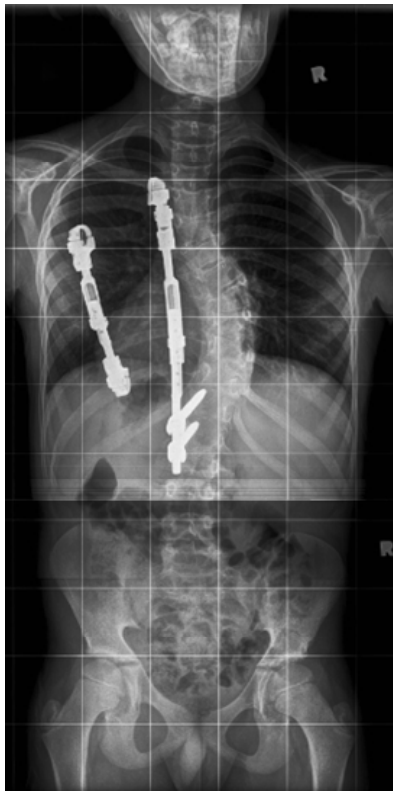
Dimeglio, JPO-B 1993

Date	Age	T1–T12	T1–S1
May 2007	6 yrs	17 cm	27 cm
Jan 2013	12 yrs	23 cm	34 cm

- Delta T1–S1 = 7cm

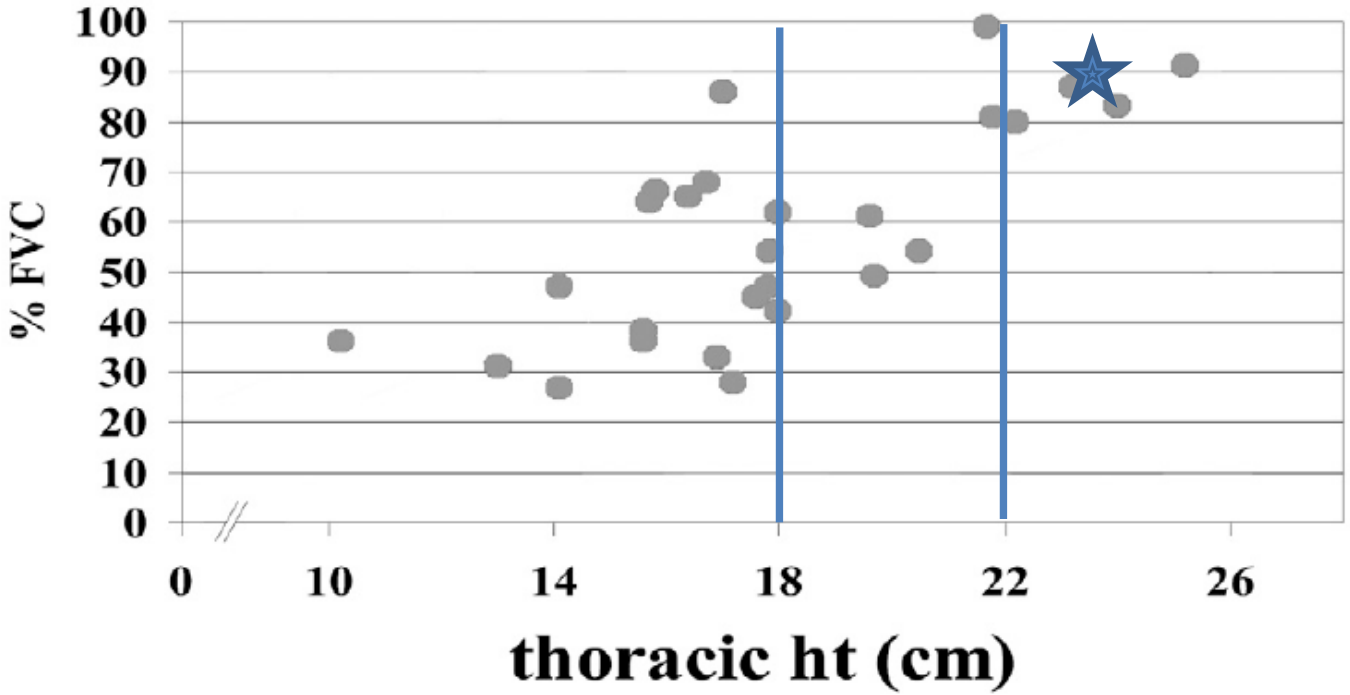
- Expected:
  - Age 6–10 yrs
    - 0.9cm/yr = 3.6 cm
  - Age 11–12 yrs
    - 1.8cm/yr = 3.6 cm
  - Total = 7.2 cm



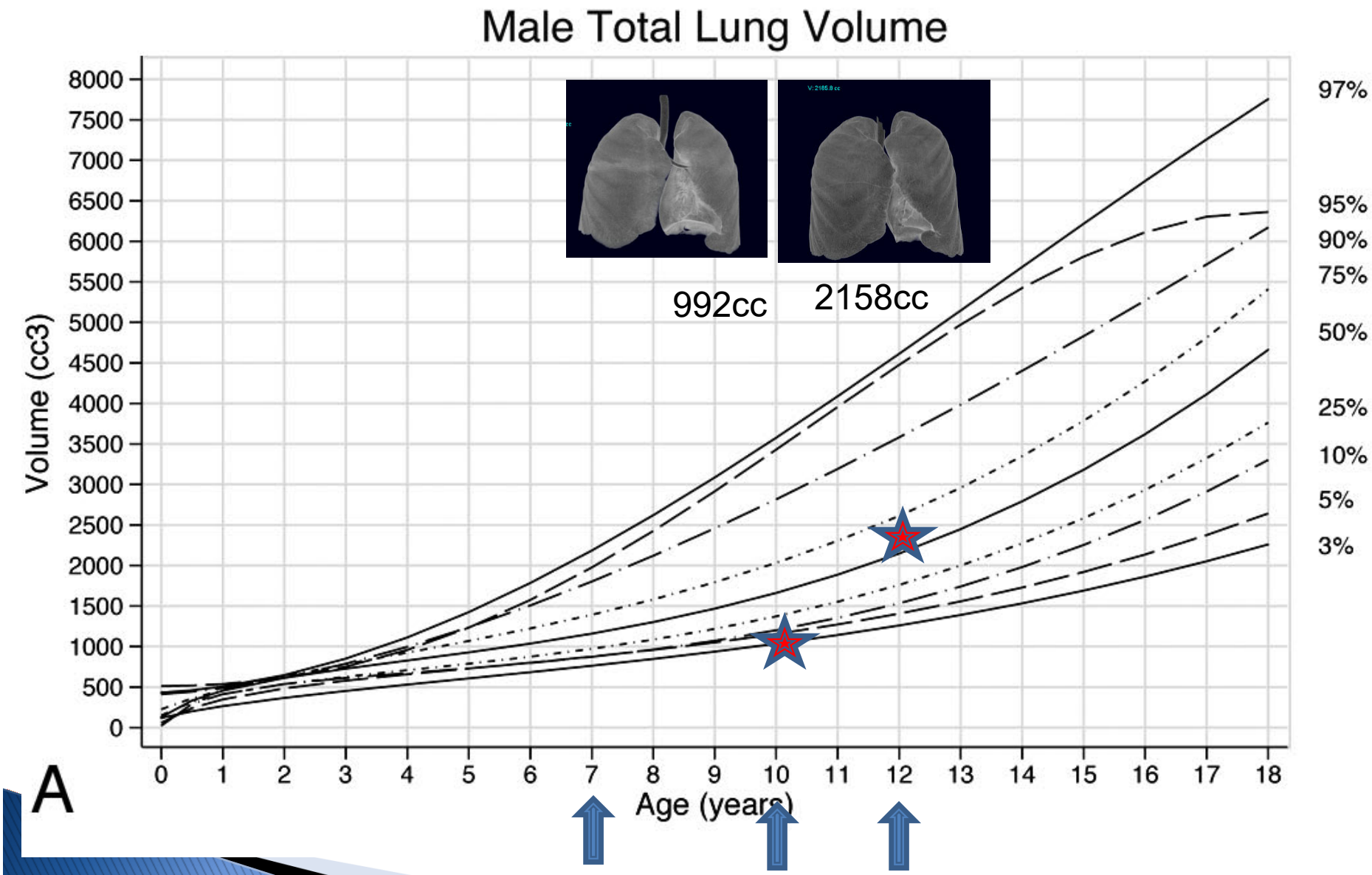


18 cm Rule

- Outcomes
  - T1-T12 23 cm
  - % FVC 87%

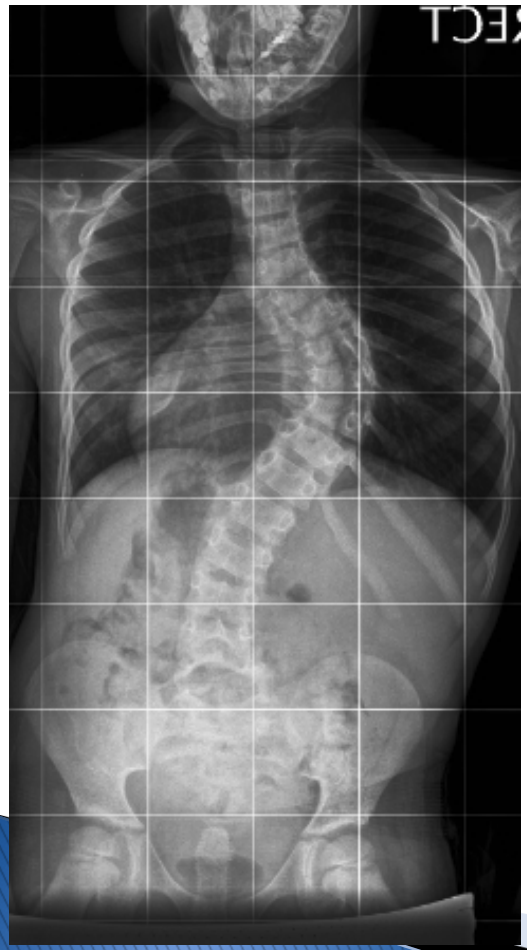


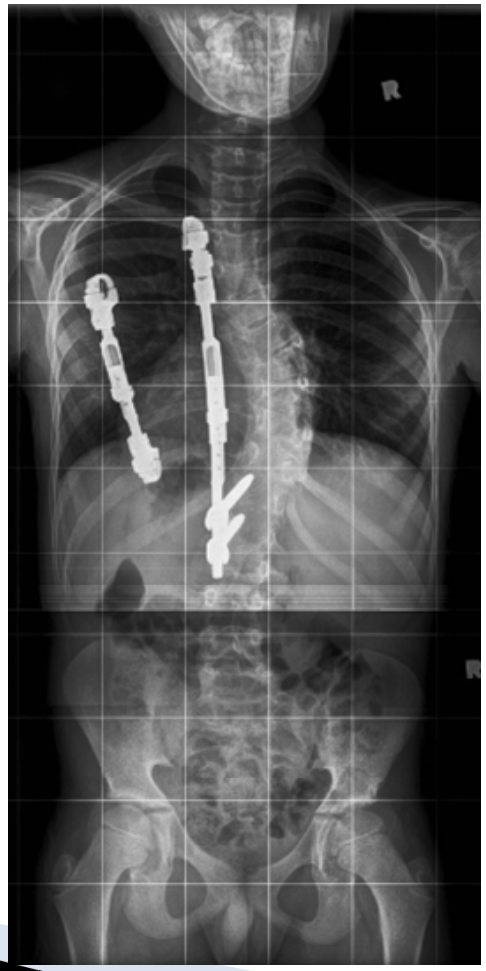
Karol et al., JBJS 2008


Male Total Lung Volume
Volume (cc3)
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Age (years)
97%
95%
90%
75%
50%
25%
10%
5%
3%
992cc
2158cc
A

2015: Graduation

- Age 14

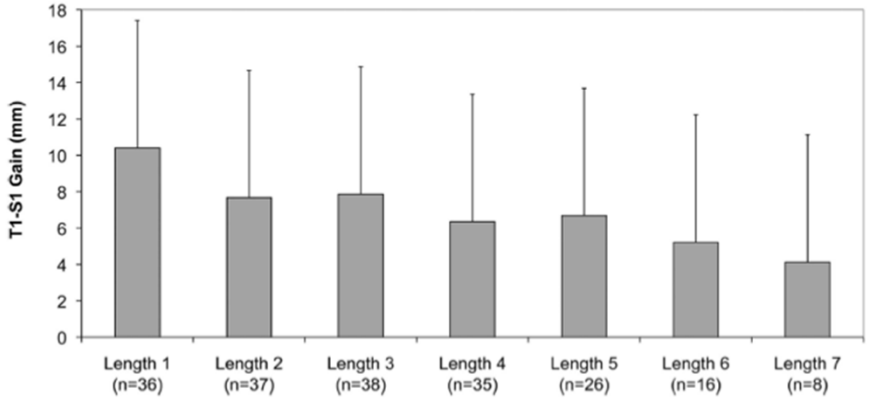




Spine Based Distraction

Lengthening of Dual Growing Rods and the Law of Diminishing Returns

Wudbhav N. Sankar, MD, David L. Skaggs, MD, Muharrem Yazici, MD, Charles E. Johnston II, MD, Suken A. Shah, MD, Pooya Javidan, MD, Rishi V. Kadakia, BS, Thomas F. Day, MD, and Behrooz A. Akbarnia, MD



SPINE Volume 36, Number 10, pp 806–809

- Auto fusion?
- Supports delay tactic with casting

Spine-Based Distraction

- Auto fusion?
- 99 Growing Rod Graduates – Subset of 58
- 19% had a mobile spine
- 19% had areas of autofusion
- 62% had completely autofused

Flynn et al., JBJS 2013

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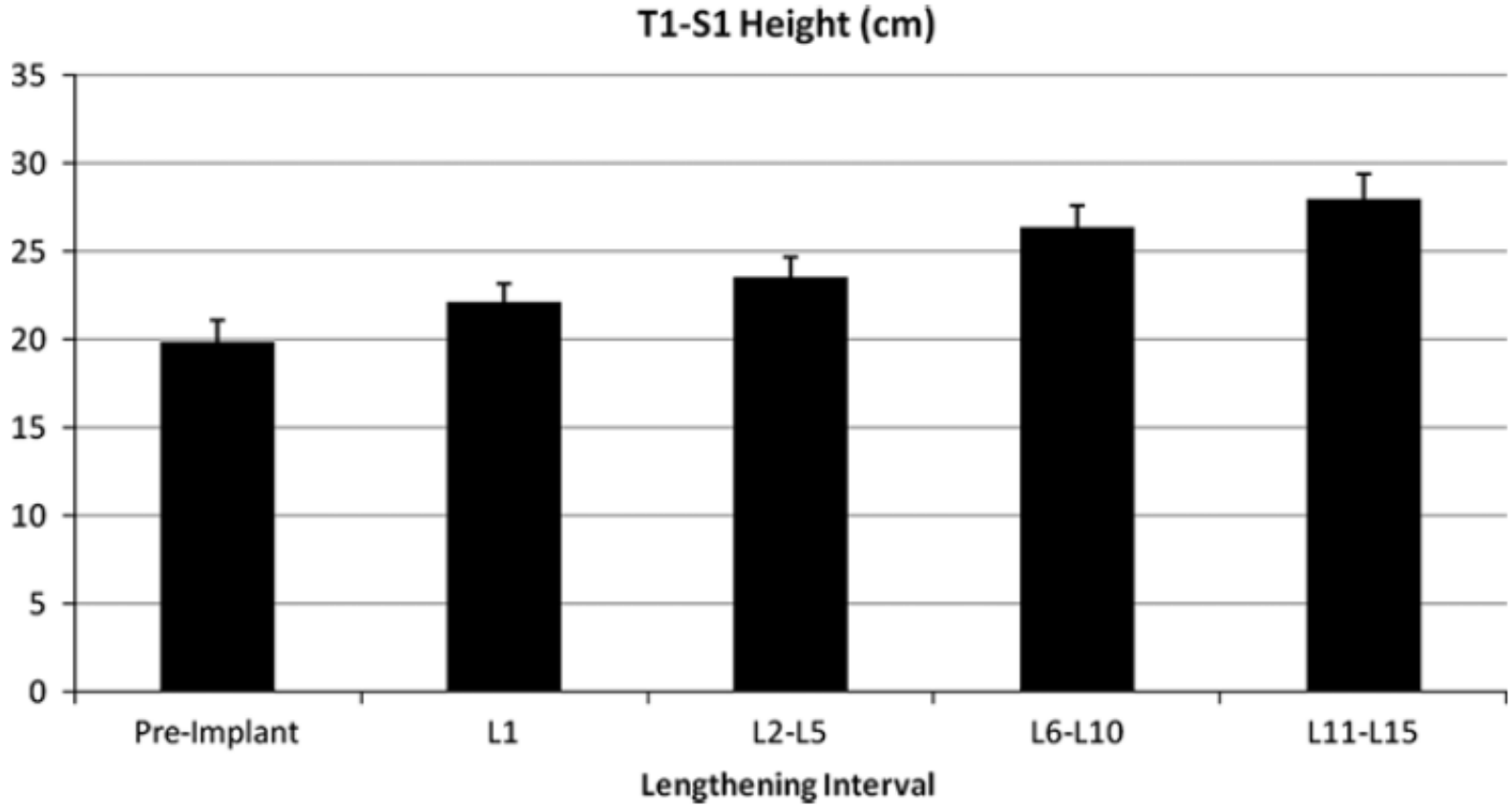
- T1–S1
  - Pre-Op 24.9 cm
  - Post-Implant 28.1 cm
  - Final F/U (mean 3.3 yr) 33.1 cm
  - Total Length Gained 8.2 cm
  - % Gained 33%

Spine 2011

Rib-based Distraction Surgery Maintains Total Spine Growth

Ron El-Hawary, MD, MSc, FRCS(C), Amer Samdani, MD,† Jennie Wade, BS, CCRP,‡ Melissa Smith, NP,‡ John A. Heflin, MD,‡ Joshua W. Klatt, MD,‡ Michael G. Vitale, MD,§ John T. Smith, MD,‡ and Children's Spine Study Group*



JPO 2015

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- T1-S1
  - Pre-Op 19.9 cm
  - Post-Implant 22.1 cm
  - Final F/U (> 5 yr) 28.0 cm
  - Total Length Gained 8.1 cm
  - % Gained 41%

JPO 2015

Rib-based Distraction Surgery Maintains Total Spine Growth

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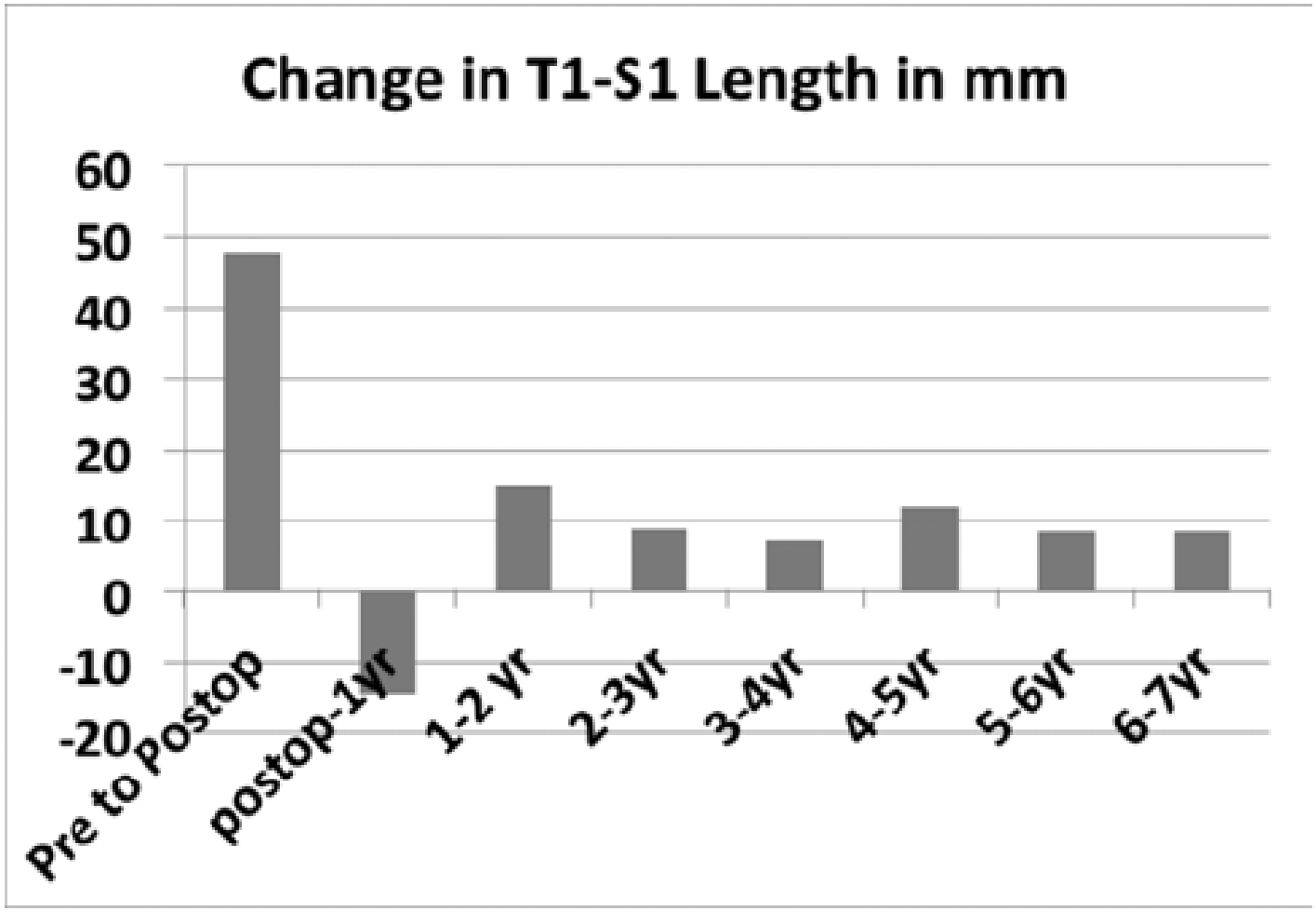
- Lengthenings < 5 yo age
  - 82% of Expected Growth
- Lengthenings 6-10 yo age
  - 76% of Expected Growth
- Lengthenings > 10 yo age
  - 14% of Expected Growth

JPO 2015

Growth Guidance



Andras et al., SRS 2015

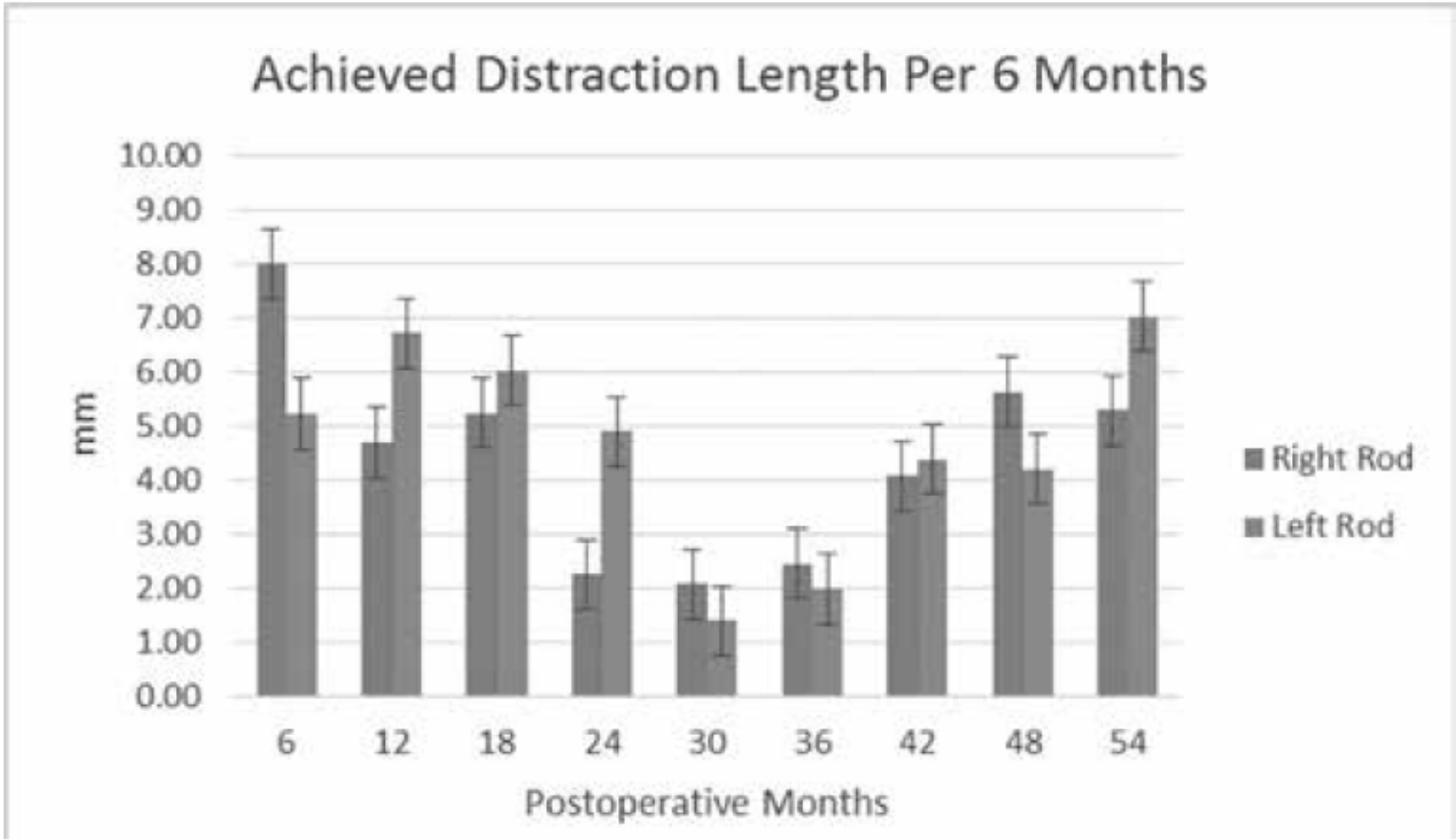
Growth Guidance

With mean follow-up of 5 years, statistically significant annual increases in T1-S1 length were sustained in patients treated with Shilla constructs.

The law of diminishing returns observed in growing rods does not appear to affect guided growth Shilla constructs in the same manner.

Andras et al., SRS 2015

Magnetic Control Growth Rods



Cheung et al., SRS 2015

Magnetic Control Growth Rods

Conclusion

There was no significant reduction in ability to distract over the period of study. This would suggest that frequent and small amounts of distraction is less likely to result in tissue damage at the time of distraction leading to autofusion of the spine, which may account for reduction in length gain over time for TGR patients.

Cheung et al., SRS 2015

Rib-based Distraction Surgery Maintains Total Spine Growth

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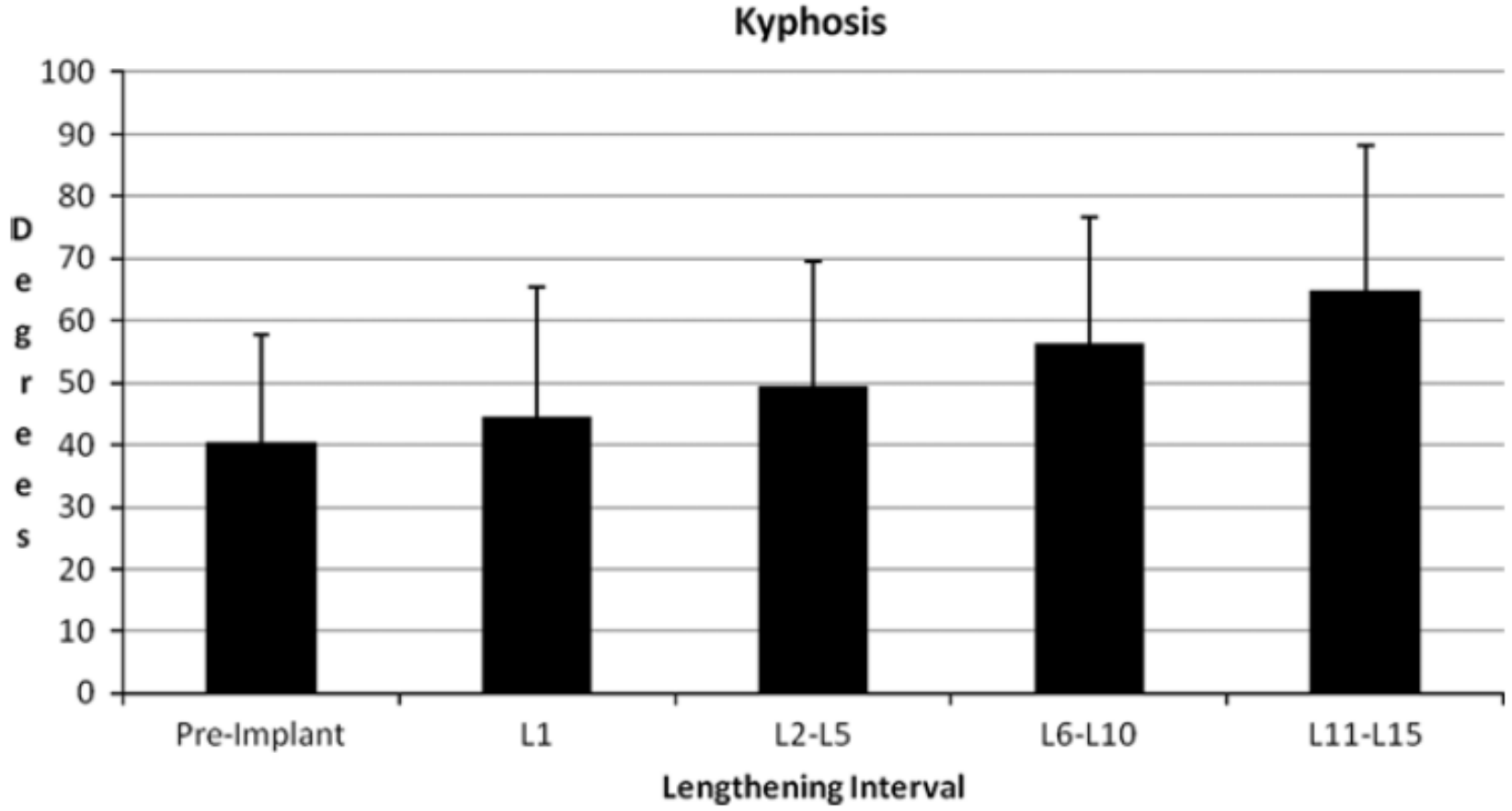
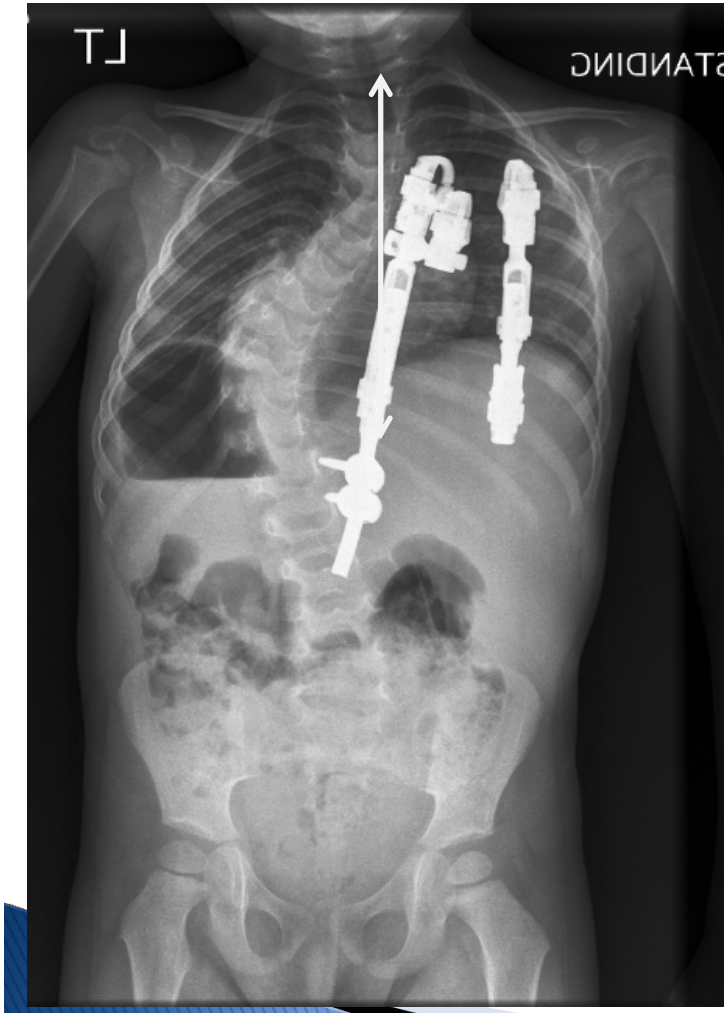
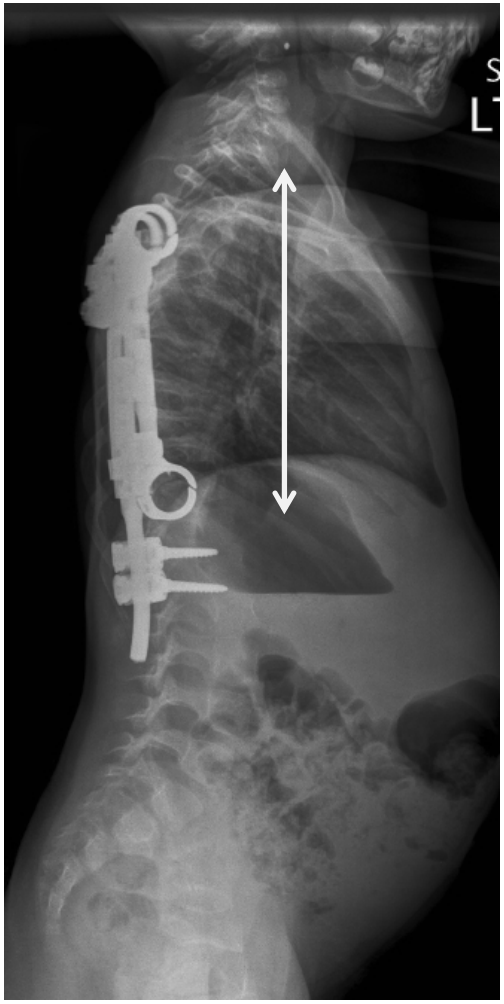
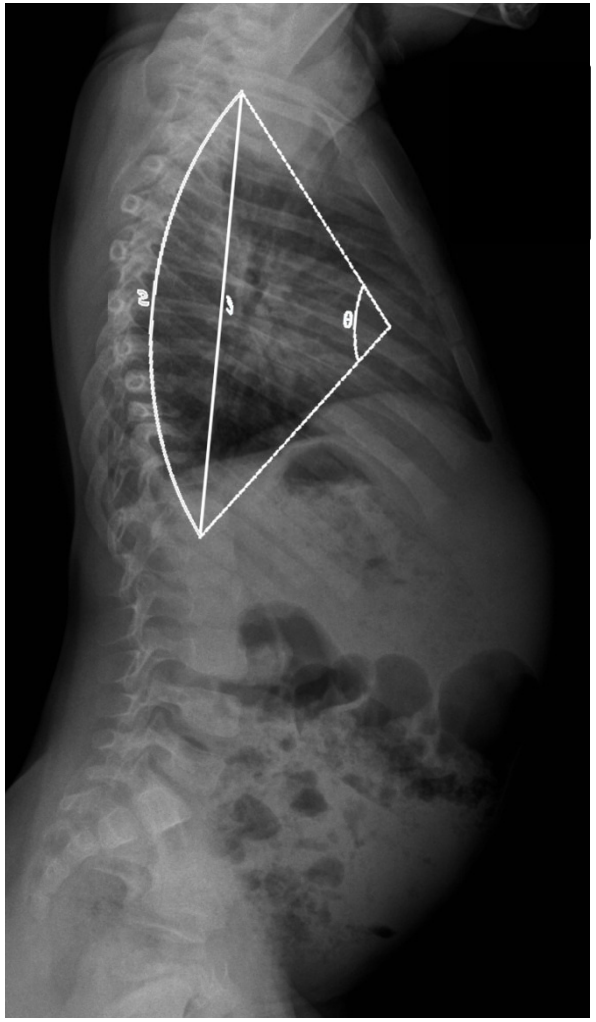


JPO 2015

Out of Plane Growth?

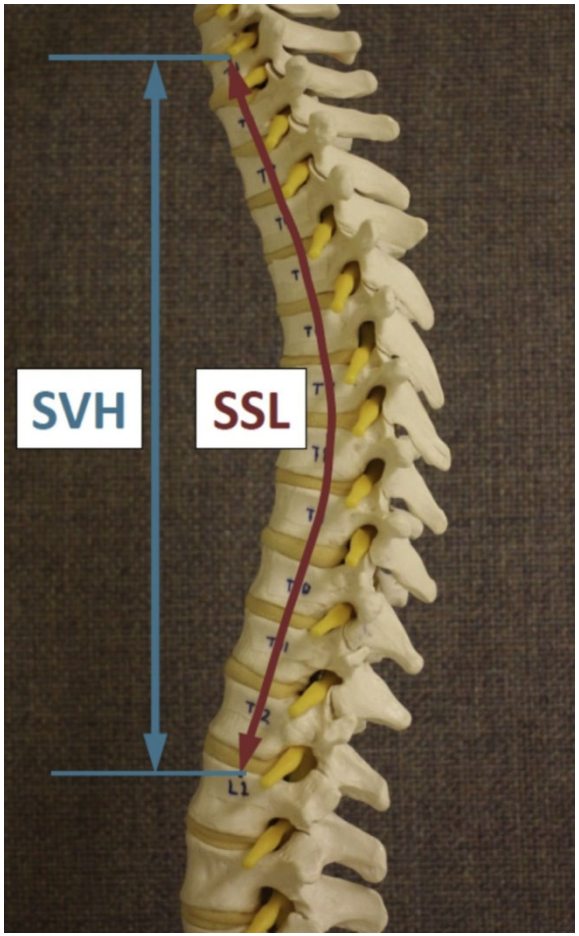


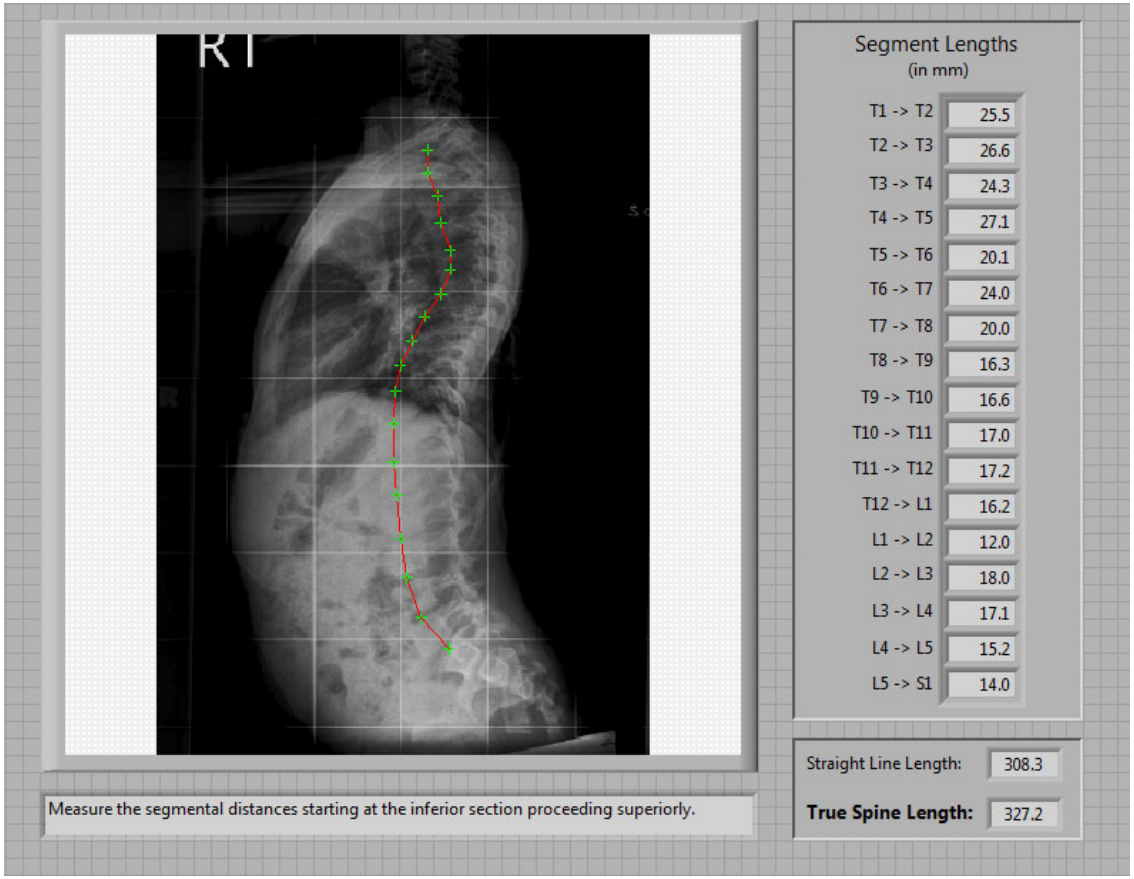




Sagittal Spine Length Measurement: A Novel Technique to Assess Growth of the Spine

Alan J. Spurway, PEng, MSc*, Chukwudi K. Chukwunyerenwa, MD, MCh, FRCS (C)[1], Waleed E. Kishta, MD, PhD, FRCS (C)[2], Jennifer K. Hurry, MSc, Ron El-Hawary, MD, MSc, FRCS (C)





Spine Deformity 2016

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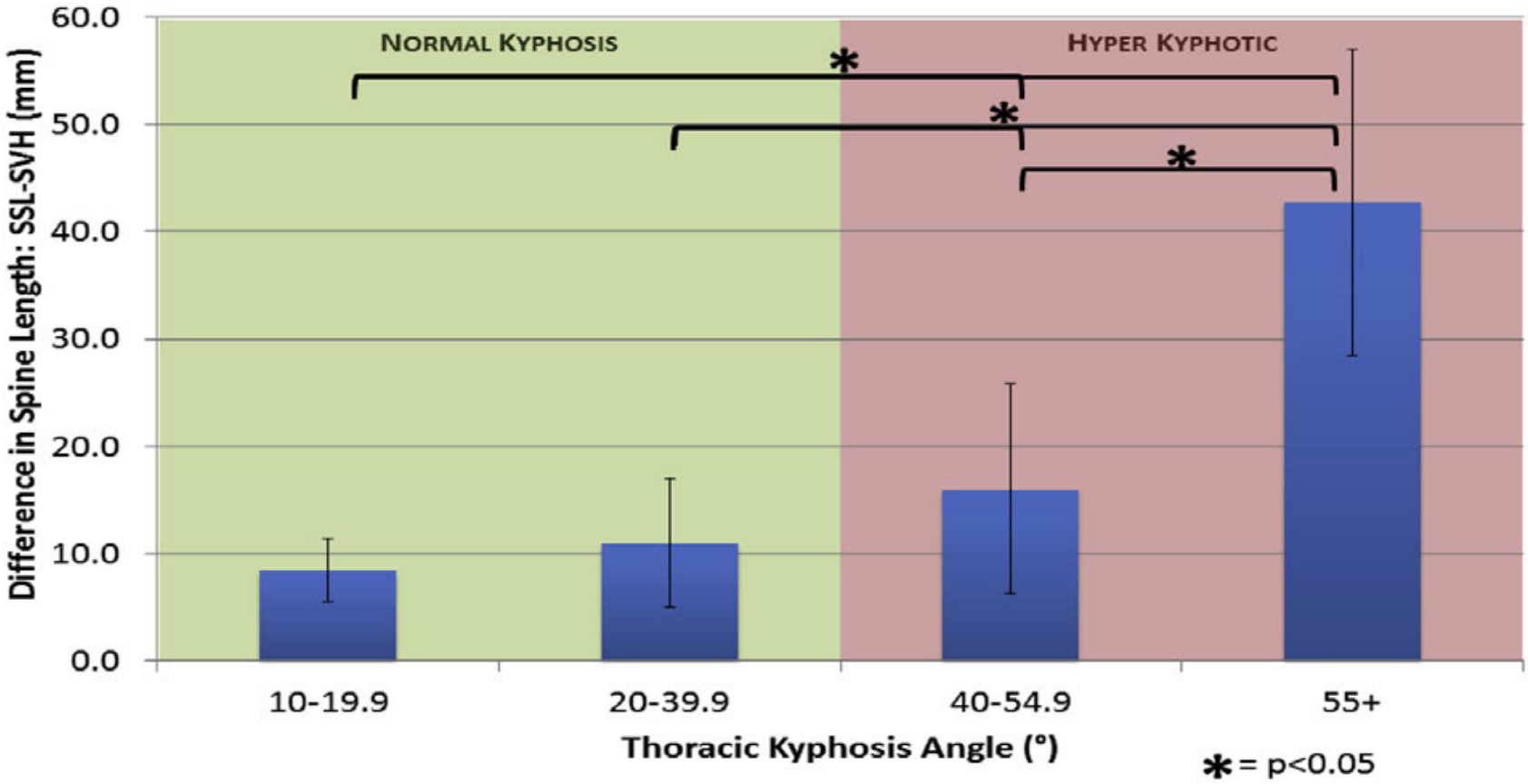


Spine Deformity 2016

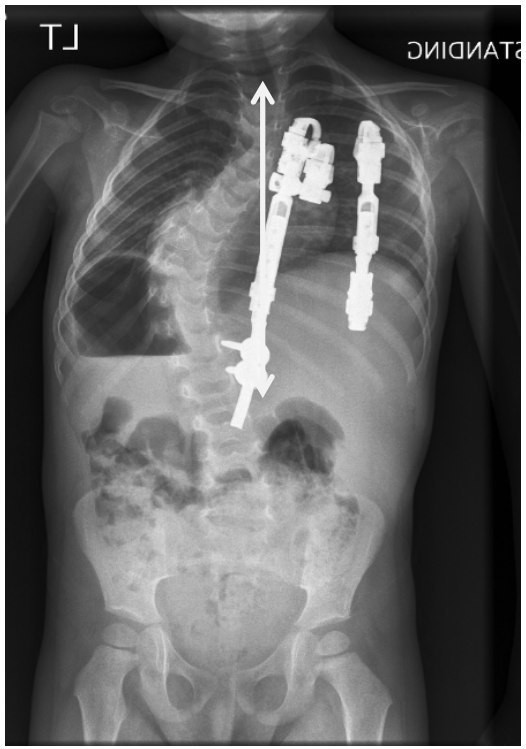
Idiopathic

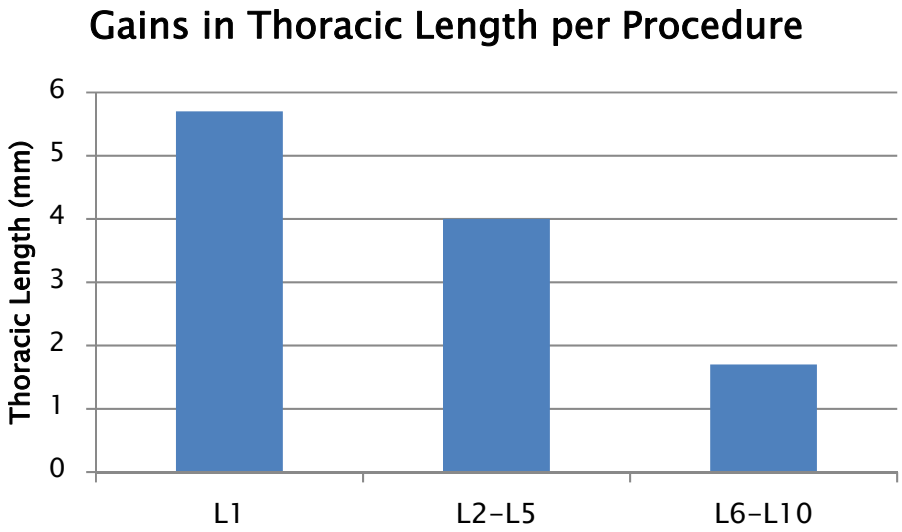
- 18 patients
  - 9 Growing Rod and 9 Rib-based (VEPTR)
- Mean age of 4.1 years
- Three groups were compared:
  - Post Implantation (L1)
  - 2nd through 5th lengthenings (L2-L5)
  - 6th through 10th lengthenings (L6-L10)

Results

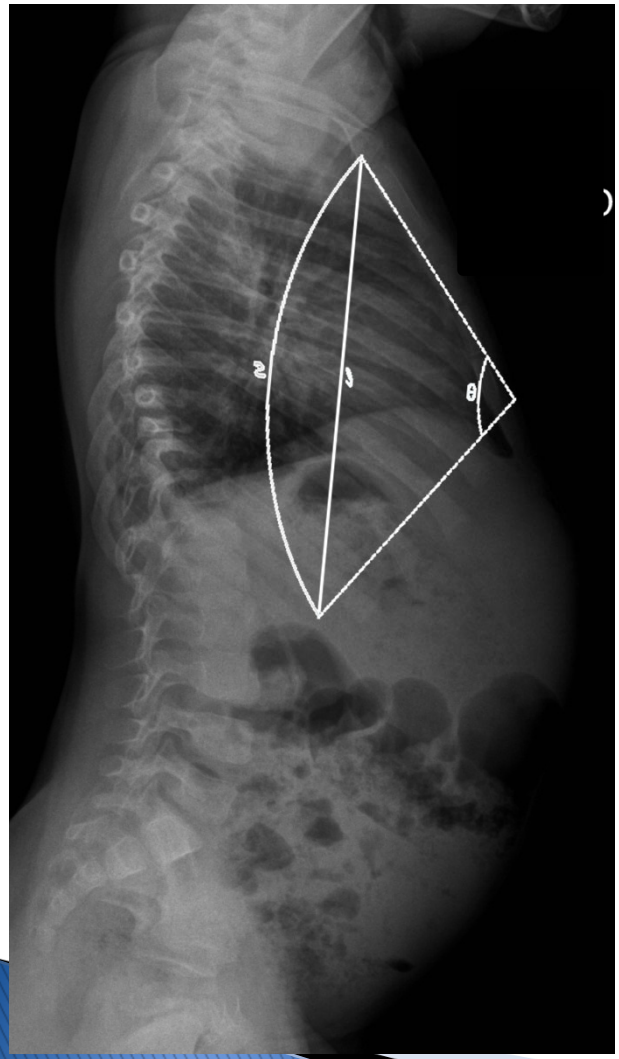
	Pre-Implant	L1	L2 – 5	L6 – 10
Cobb angle	52.6°	45.0°	44.7°	48.6°
Kyphosis	40.9°	32.1°	45.3°	47.5°
Coronal T1-T12	16.4cm	16.0cm	17.6cm	17.8cm
Sagittal T1-T12	16.8cm	16.4cm	17.4cm	18.3cm
True T1-T12	18.6cm	18.4cm	19.5cm	20.8cm
Change coronal T1-T12 per lengthening	Not applicable	5.7mm	4.0mm	1.7mm
Change in sagittal T1-T12 per lengthening	Not applicable	4.0mm	3.3mm	3.1mm
Change in true T1-T12 per lengthening	Not applicable	2.8mm	4.4mm	4.4mm

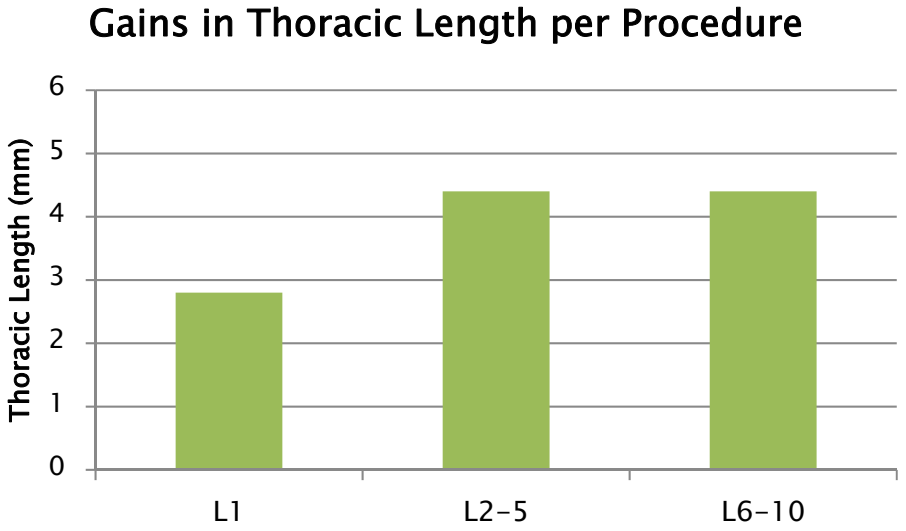
Coronal T1–T12





Sagittal Spine Length T1–T12

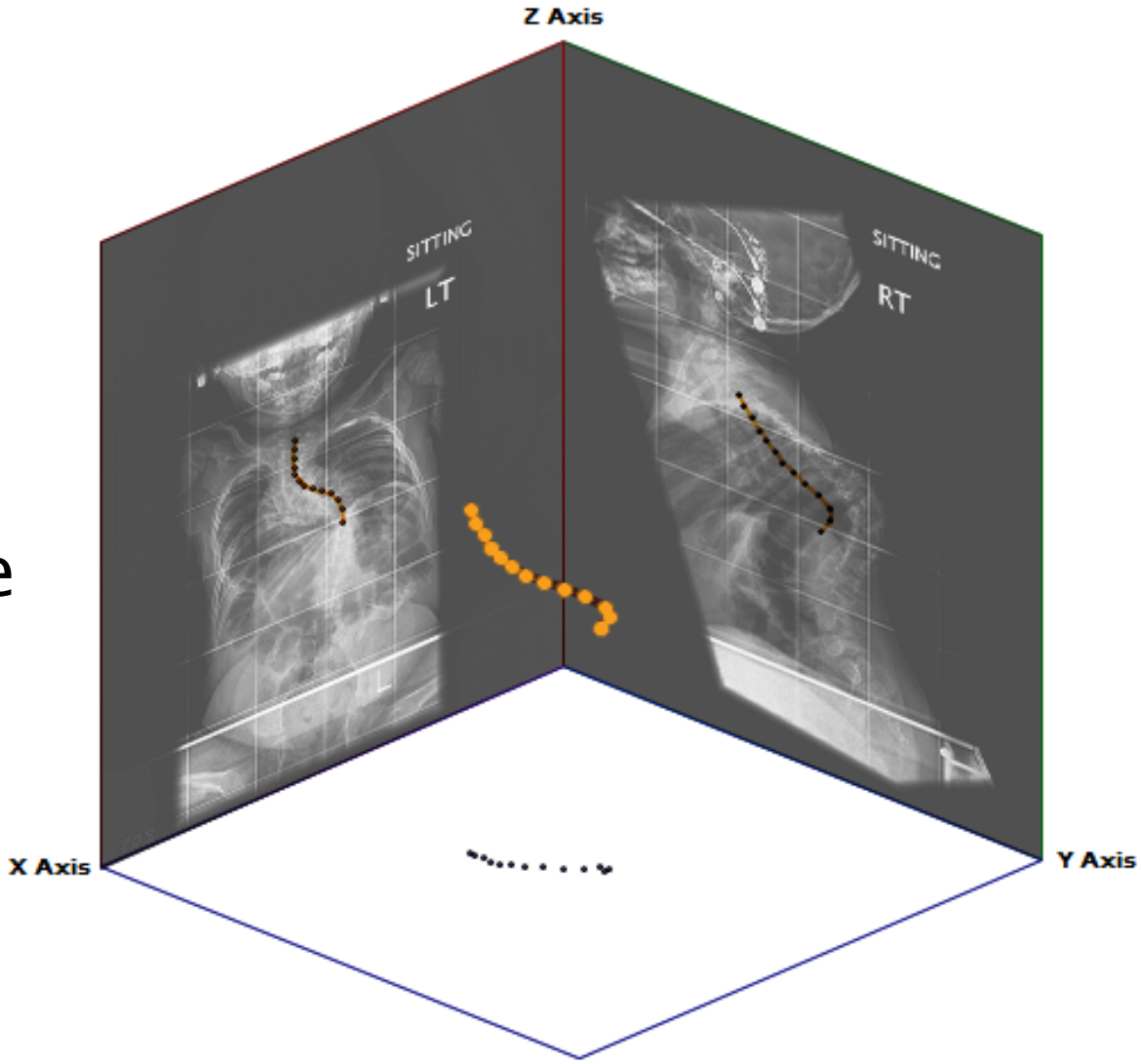




CSSG / GSSG, ICEOS 2014

3D True Spine Length (3D-TSL)

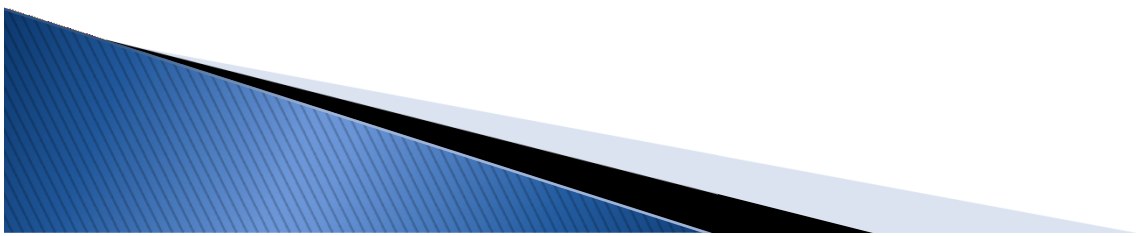
- Biplanar, Three Dimensional Measurement Technique
- Follows the True Path of the Spine



3D True Spine Length (3D-TSL)

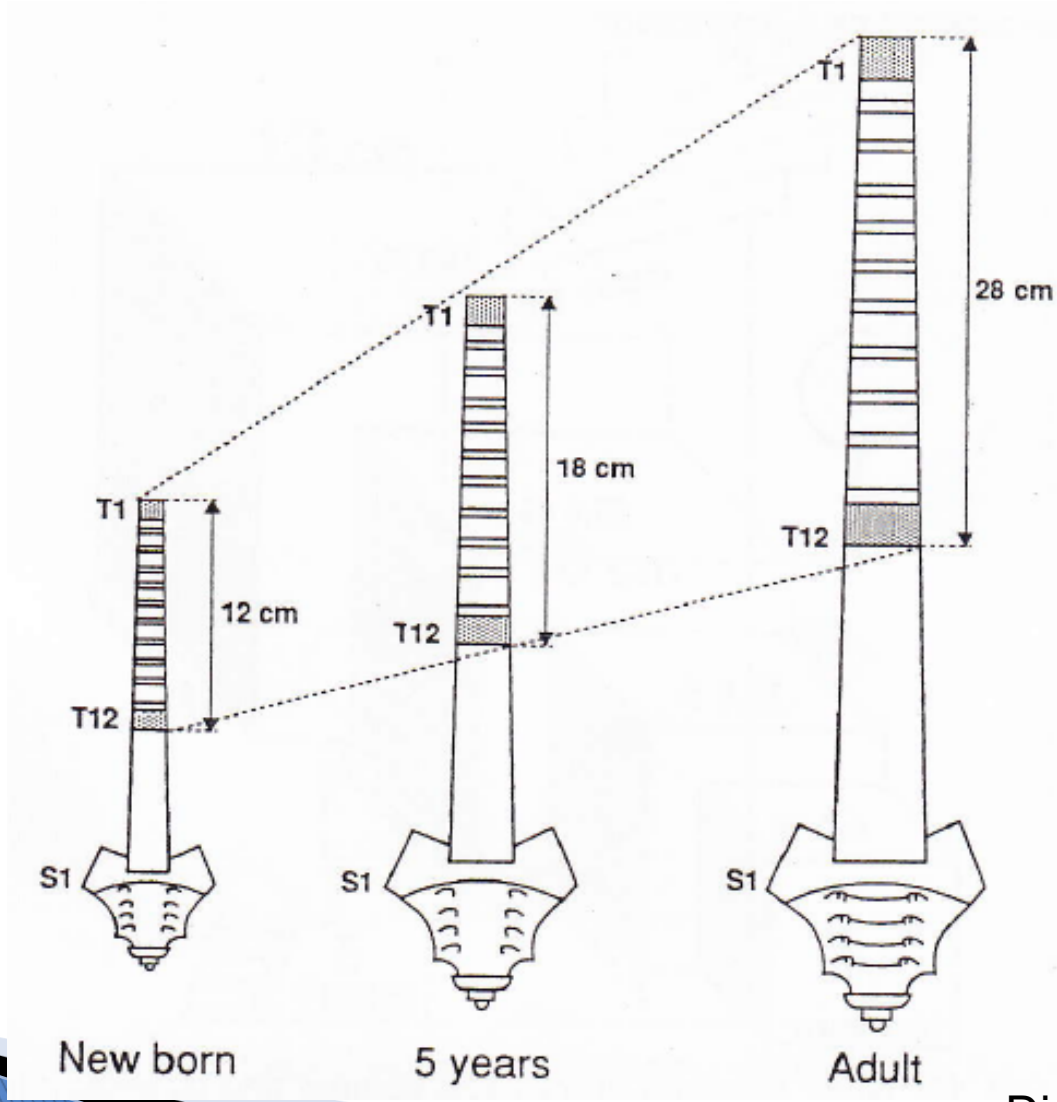
- 3D-TSL is
  - Accurate (0.4% error).
  - Reliable (0.952).
  - Repeatable (0.944).

- 3D-TSL results in greater spine length as compared to traditional coronal plane measures.



We can measure in 3D...

What about 3D References?



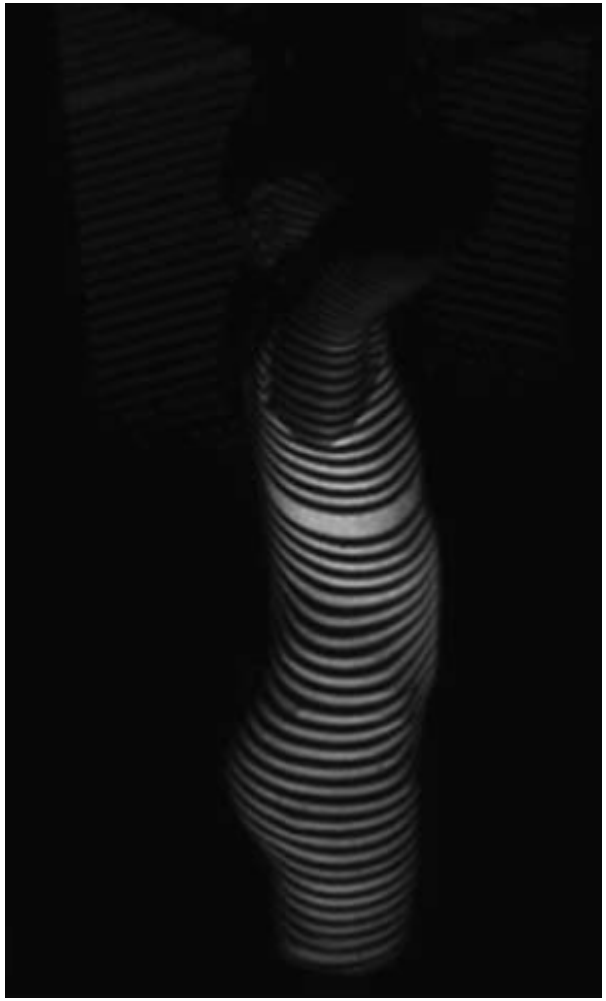
Dimeglio, JPO-B 1993

Three-dimensional and volumetric thoracic growth in children with moderate idiopathic scoliosis compared with normal

Yann Philippe Charles[a], Amélie Marcoul[c], Mickaël Schaeffer[b], Federico Canavese[e] and Alain Diméglio[d]

- <u>ORTEN trunk surface</u>
  - 294 Healthy Subjects
  - 557 Idiopathic Scoliosis

- As compared to Sitting Ht
  - Transverse 30%
  - AP 20%
  - Perimeter 100%



Journal of Pediatric Orthopaedics B 2016

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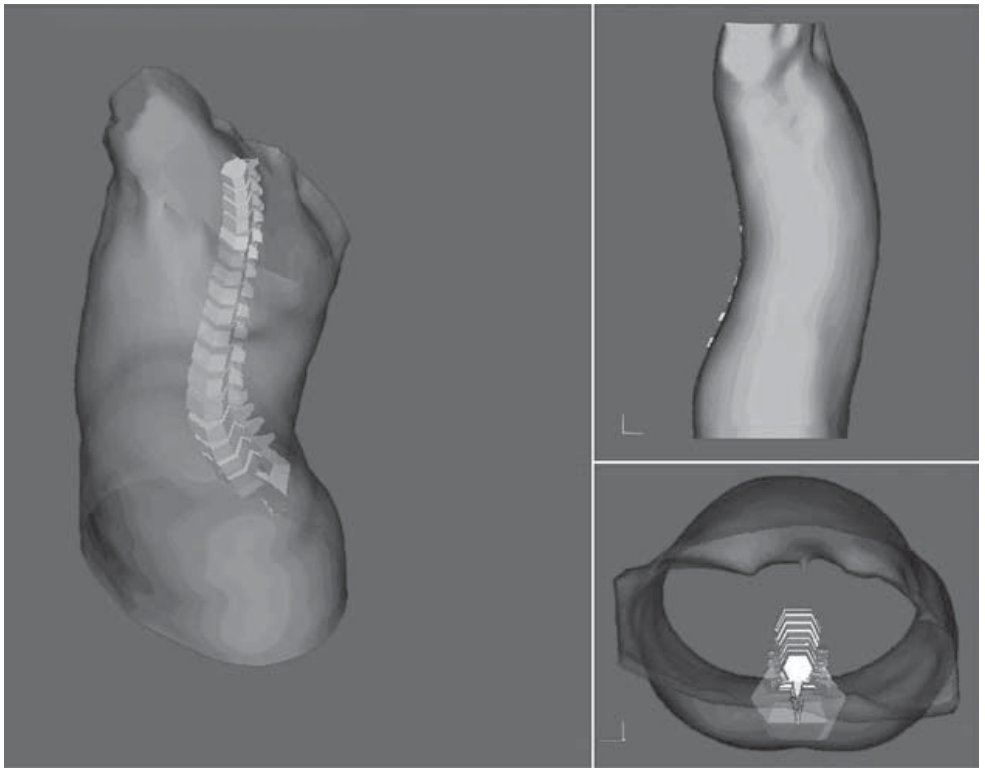
Yann Philippe Charles[a], Amélie Marcoul[c], Mickaël Schaeffer[b], Federico Canavese[e] and Alain Diméglio[d]

- Mild to moderate scoliosis does not affect thoracic dimensions or volume at any stage of growth.

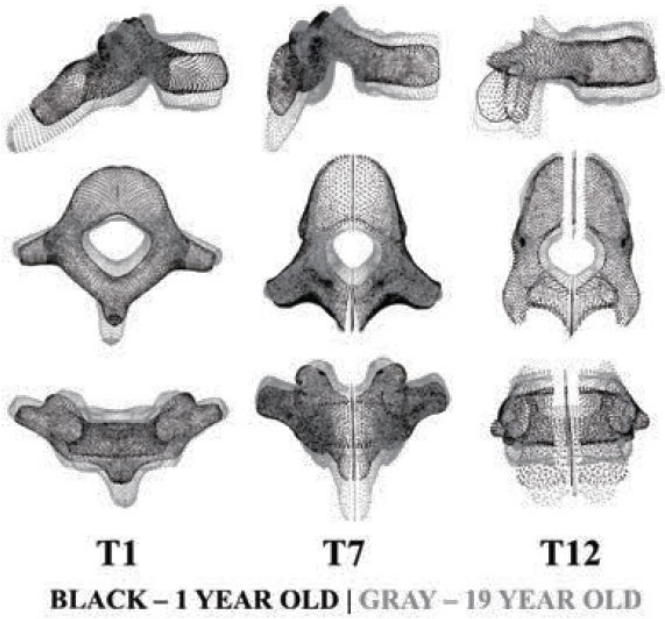


Journal of Pediatric Orthopaedics B 2016

109. Age-Related Shape Characterization of the Pediatric Thoracic Spine Using Generalized Procrustes Analysis

James Peters, BS; Evan Bisirri; Robert M. Campbell, MD; Sriram Balasubramanian, BS, PhD, MS

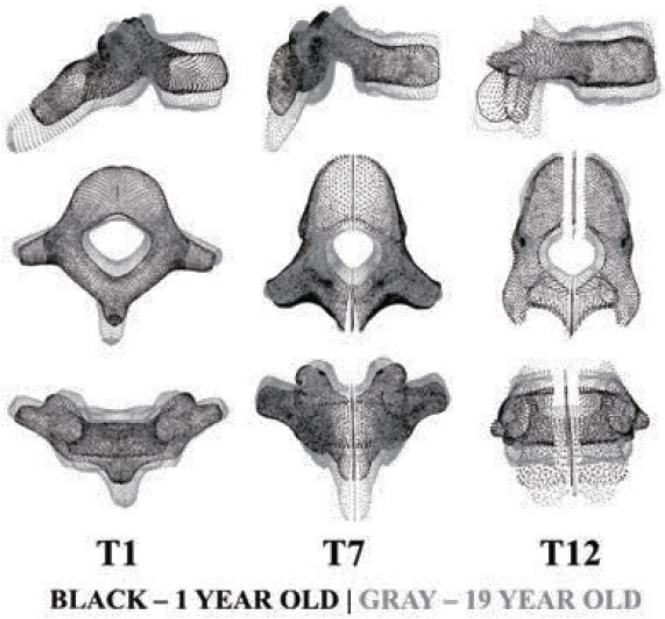
- Chest CT's of 100 healthy children
- Reconstructed
- Generalized Procrustes Analysis



109. Age-Related Shape Characterization of the Pediatric Thoracic Spine Using Generalized Procrustes Analysis

James Peters, BS; Evan Bisirri; Robert M. Campbell, MD; Sriram Balasubramanian, BS, PhD, MS

- Age-related variations in vertebral shape were seen for all levels of the thoracic spine.
- Minimal gender differences could be observed.



35. Normal Human Spine Growth and Prediction of Final Spine Height Developed from a Longitudinal Cohort of Children Followed Through Their Growth Until Completion

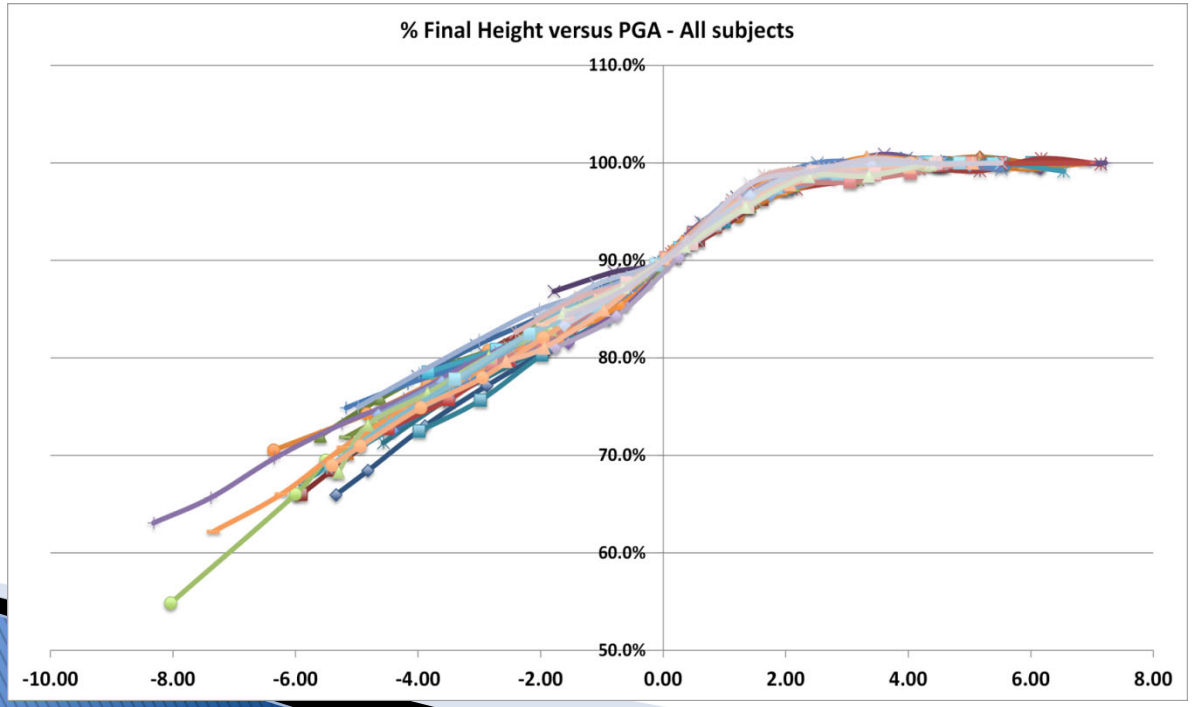
James O. Sanders, MD; Lauren Karbach, MD; Thomas Osinski, BS; Raymond Liu, MD; Xing Qiu, PhD; Daniel Cooperman, MD

- Anthropometrics
  - Bolton Brush Study
- Longitudinal Cohort
  - 54 subjects
- Normalized spine length and height as a percentage of length / height at maturity.

35. Normal Human Spine Growth and Prediction of Final Spine Height Developed from a Longitudinal Cohort of Children Followed Through Their Growth Until Completion

James O. Sanders, MD; Lauren Karbach, MD; Thomas Osinski, BS; Raymond Liu, MD; Xing Qiu, PhD; Daniel Cooperman, MD

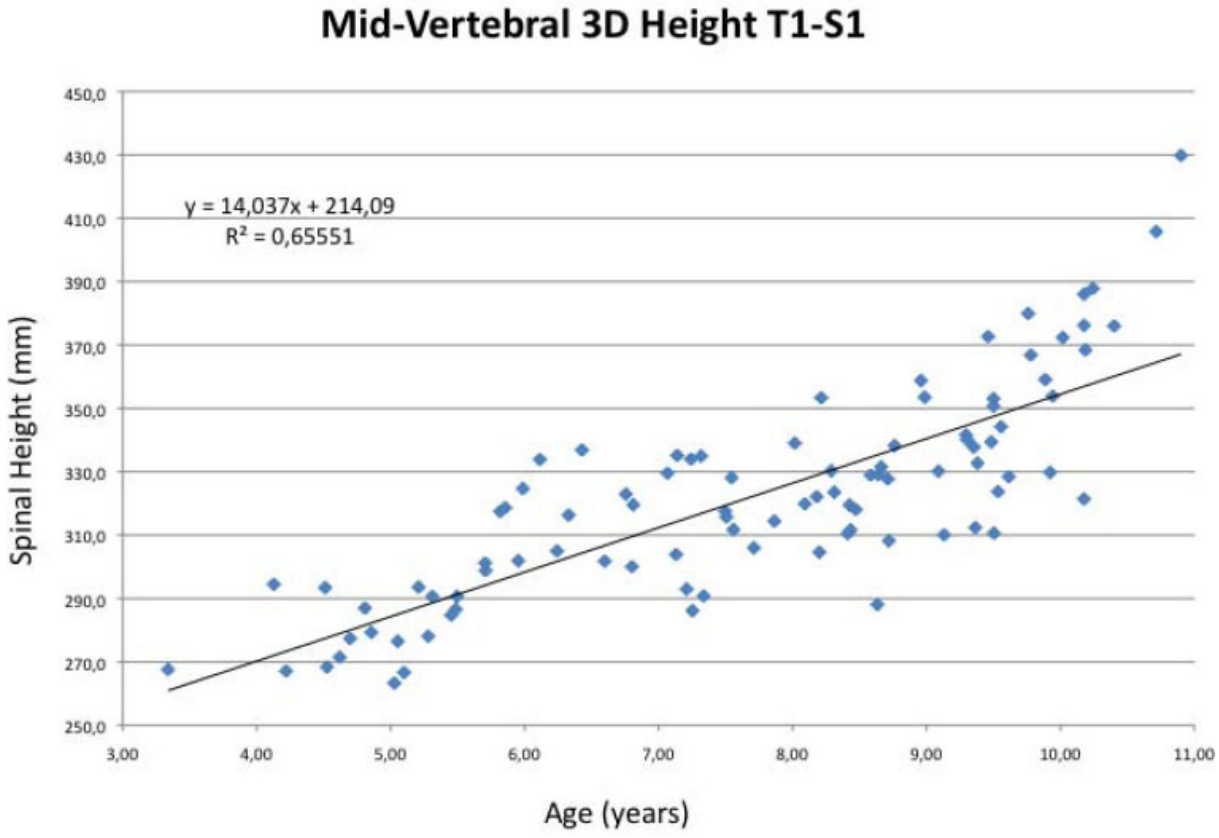
- At Peak Height Velocity:
  - Spine Height = 90% Maturity
  - Spine Length = 85% Maturity



248. Spinal Growth in Normal Children Between 3 and 11 Years Old Using 3D Reconstruction: A Longitudinal Study

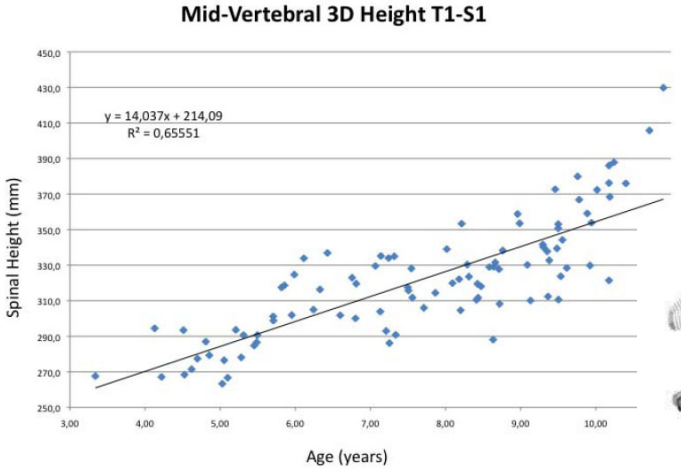
Leonie Tremblay; Patrick Tohmé; Marjolaine Roy-Beaudry, MS; Marie Beauséjour, PhD; Hubert Labelle, MD; Stefan Parent, MD,

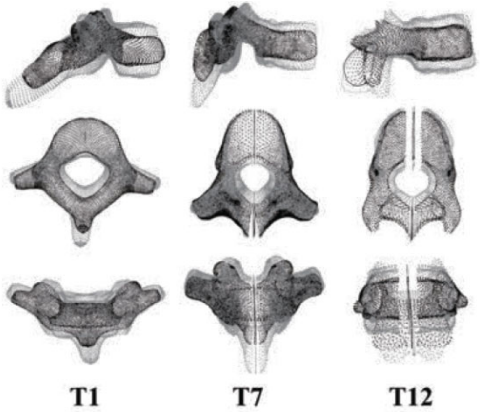
- 3D Spine Growth – EOS Imager

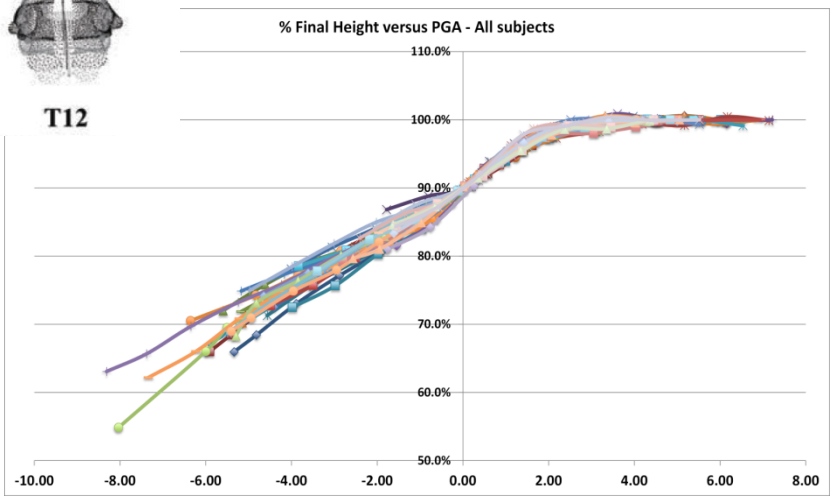


The Future

- Combine data sets.

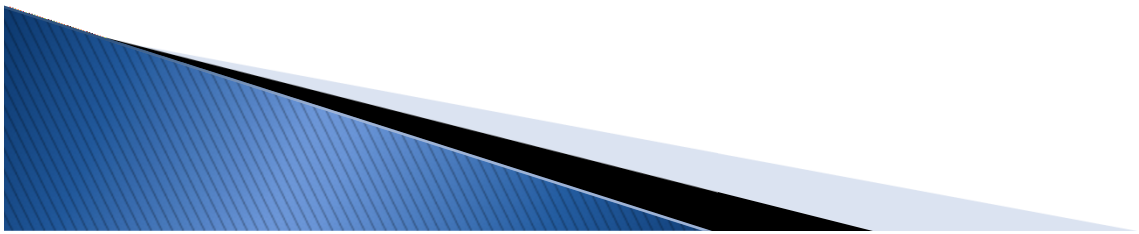






The Future

- Combine data sets.
- Develop longitudinal spine growth as a function of chronological and physiological age and gender for "normal" children and those with scoliosis.
- Ideally, this can then be used to derive growth remaining charts.



Conclusions

- Traditional methods of assessing spine growth is based on linear coronal plane images.

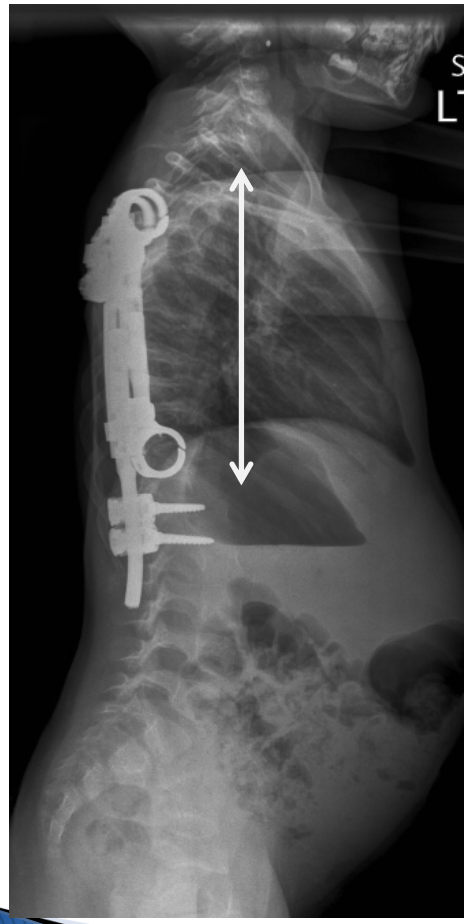
- Growth Friendly surgeries maintain spine growth
  - Spine-Based
  - Rib-Based
  - Growth Guidance
  - MCGR

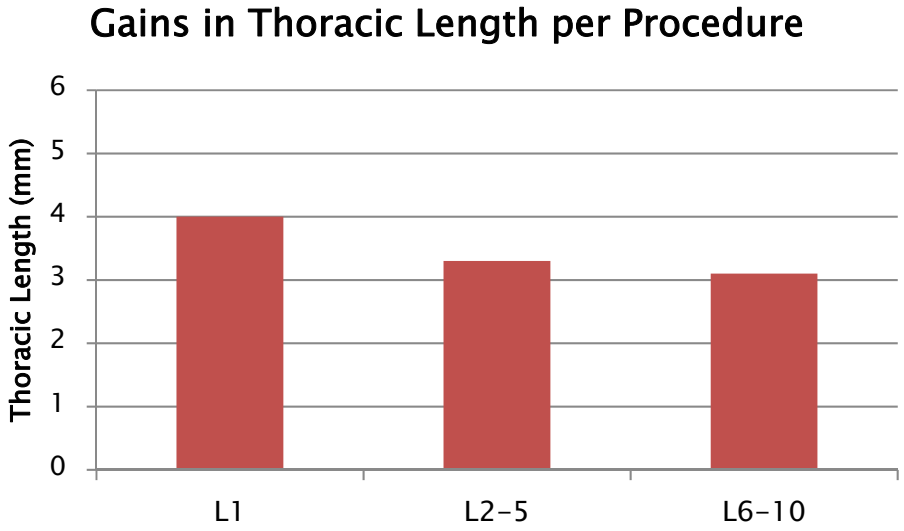
Conclusions

- Novel techniques for **assessing** spine growth in 3D have been developed.
- New **3D references** for spine growth are being developed.
- Growth remaining curves for growth modulation surgery will be developed.

Thank You

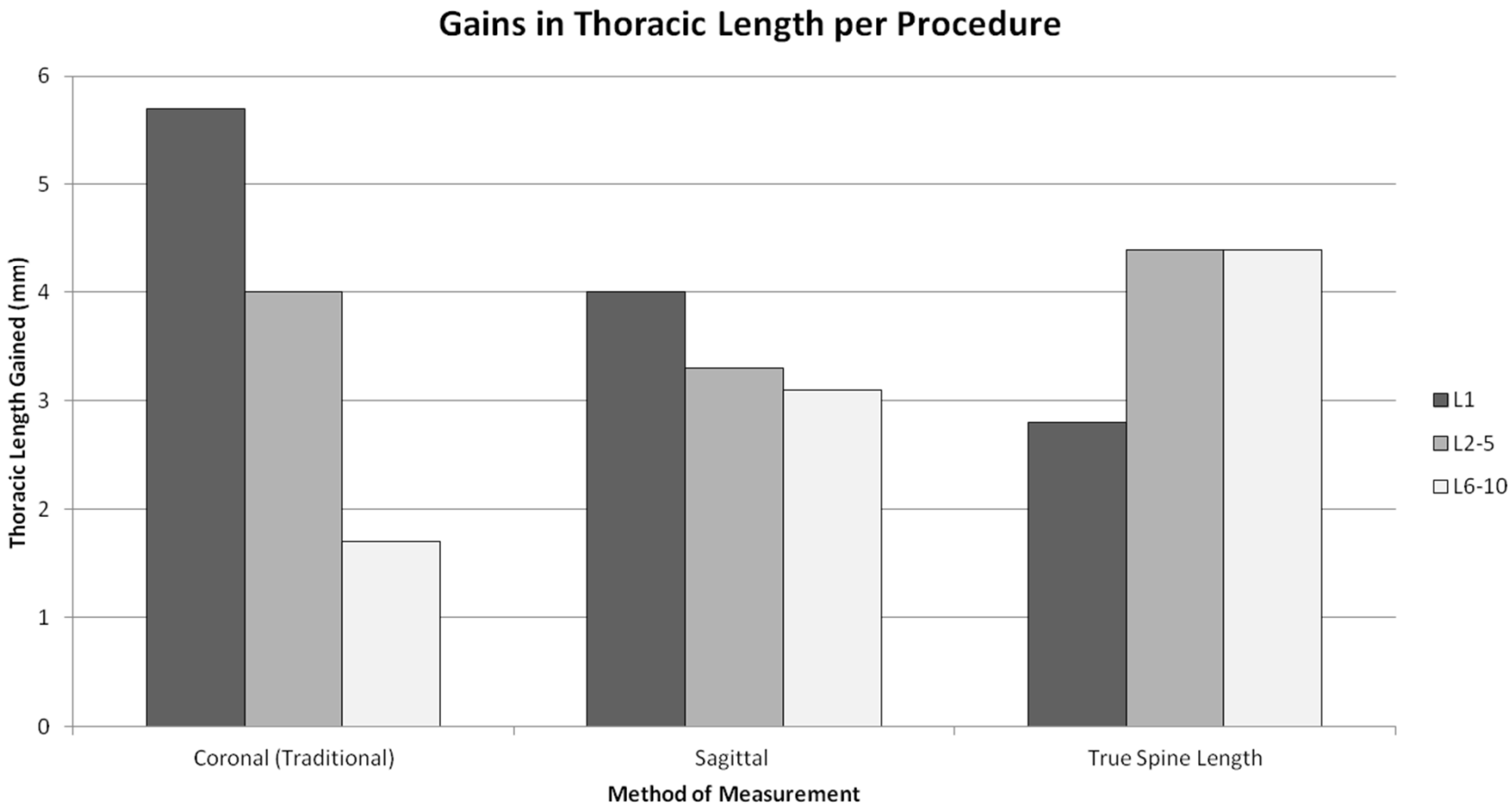
Sagittal T1–T12





CSSG / GSSG, ICEOS 2014

Results


Gains in Thoracic Length per Procedure
Thoracic Length Gained (mm)
0
1
2
3
4
5
6
Coronal (Traditional)
Sagittal
True Spine Length
Method of Measurement
L1
L2-5
L6-10