IMMATURE SPINE and thorax
The growing spine: What we have learned?

- The thorax is the heart of the problem in severe scoliosis
- Growth of the spine, thorax, lung are intricated
- The spine and ribs dictate lung function
- The cranckshaft phenomenon is an uncontrollable factor
The growing spine: What we have learned?

Mosaic of growth plates
Changes in rhythm
All parameters do not progress at the same speed
The thorax is the fourth dimension

Challenging the growing spine: to maintain spinal growth, thoracic growth, lung growth and keep the spine supple
ONE DEFICIT LEADS TO ANOTHER DEFICIT

- Consider the complete life span
- What is the functional benefit?
- What is the morbidity risk?
- What quality of Life?

Domino effect

The goal is to break up the vicious circle.
The growing spine now

- Still high morbidity
- The first priority is the pulmonary growth
- Differents etiologies, different strategies
- Keep the spine supple
- Avoid thorax retraction
- Have a pediatric approach
The final dream?

- Avoid arthrodesis

The final goal

- Weight : 40 Kg
- T1 – T12: 22 cm
- T1 – S1 : 30 cm
- VC : 50 %
No ideal device!

Shilla…Phenix…Ellipse…Staples…Vertebral body tethering
The growing spine

130 growth plates working in a perfect synchronisation

EOS breaks

Harmony  Hierarchy  Synergy

With the growing spine EOS becomes a growth plate disorder
Ossification starts at the third month of intra-uterine life
3 months intra-uterine life

Lentil

4 months intra-uterine life

Ovoid

8 years

Rectangular
Closure at eleven years

Zang Sucato 2008
At age 5 years, the spinal canal has grown to 95% of its definitive size.

The growing spine before age five. J Pediatric ortho B 1993
GROWTH IS A VOLUMETRIC REVOLUTION

AT BIRTH 30% OF THE SPINE IS OSSIFIED
Repeat the measurements

...To understand the dynamic of growth and to anticipate
SITTING HEIGHT INCREASES BY 29 CM IN BOYS AND 28 CM IN GIRLS FROM BIRTH TO AGE OF 5 YEARS

The growing spine  Springer 2009
Girls sitting Height

% of girls reaching different heights at different ages:

- Birth: 38%
- 1 year: 53%
- 5 years: 70%
- 10 years: 83%
- 15 years: 100%

The diagram shows the percentage of girls reaching various heights as they age from birth to 15 years.
GROWTH ACQUIRED

REMAINING GROWTH

REMAINING GROWTH AT 5 YEARS SITTING HEIGHT
All parameters do not progress at the same speed
WEIGHT : an excellent parameter

Many children are hypotrophics!

Birth: 3.5 Kg
5 years: 20 Kg
10 years: 30 Kg

After 1 year, the annual gain is 2.5 Kg / year…up to puberty
ANNUAL GROWTH VELOCITY WEIGHT

Kg

Puberty: weight > 40 Kg
Thorax is the heart of the problem

Deformities change the shape of the thorax and reduce its normal mobility.

The rib-vertebral-lung complex should be considered as a whole, it is an elastic structural model,

scoliosis it becomes rigid preventing from normal development lungs.
VOLUMETRIC GROWTH
The thorax: the fourth dimension of the spine

New born  5 years  10 years  15 years

6%  30%  50%  100%

The growing spine, Springer Velarg 1990
Physiotherapy

20 muscles
10 insertions by rib
Birth

- AP: 70 mm
- FL: 80 mm
- Volume Right: 70 cm³
- Volume Left: 60 cm³

5 years

- AP: 130 mm
- FL: 180 mm
- Volume Right: 400 cm³
- Volume Left: 350 cm³

Frontal diameter grows faster than AP Diameter

Thoracic volume X5

Gollogly spine 2004
The gain is particularly important the first 5 years (24 cm) with a slow down after 5 years and a new peak at puberty.
Infantile scoliosis, 16 Years
Deficit on the sitting height 25 cm
Weight 22 kg
Normal Length of the lower limbs
Thoracic deformity in severe scoliosis

- Thoracic insufficiency Syndrome
- Congenital scoliosis and fused ribs

- Spinal penetration index

Neuromuscular scoliosis Syndromes

Influence of idiopathic scoliosis on volumetric thoracic growth and proportions?
Follow the different stages of growth

• The first five years: crucial period

• After five years: a slowing down

• Puberty: thoracic peak
## Annual Growth Velocity T1 – L5

<table>
<thead>
<tr>
<th>Age</th>
<th>Velocity (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth – 5 yr</td>
<td>2.2</td>
</tr>
<tr>
<td>5 yr – 10 yr</td>
<td>1.1</td>
</tr>
<tr>
<td>10 yr – Puberty</td>
<td>1.8</td>
</tr>
</tbody>
</table>

### Curves of growth velocity

![Diagram showing growth velocity curves](image)

Magnetic device?
PUBERTY IS A TURNING POINT

STANDING HEIGHT
ANNUAL VELOCITY > 7 cm/year

Girls: remaining sitting height is 12 cm (14%)

Boys: remaining sitting height is 13 cm (15%)
Curves $> 30^\circ$ at onset of puberty

$\n = 40 / 205$

- 73% rapid progression
- 27% slow progression

- 100% operated

Elbow closure

Spine August 2006
Annual gain: 5 Kg

Remaining growth: 13%
Remaining weight: 40%
3 Periods in growth
/ Standing height

Standing height
Thorax
Sitting height
Lower limb
THE THORACIC VOLUME DOUBLES BETWEEN 10Y AND SKELETAL MATURITY
Constant relationships during growth

Thoracic perimeter

- birth = 100%
- 5y = 90%
- 15y = 96%

five years: remaining growth of the thorax is 70%
remaining sitting height is 35%

Sitting height

Risser 1
Arm span

Sitting height = 50%

T1 - S1 = 25%
T1 – S1 a strategic segment

T1 – S1 : 50% of the sitting height
T1 – T12 : 32%
L1 – S1 : 18%
GROWTH CURVE  T1 – S1

BOYS

GAIN

T1 – S1 : 25 cm
T1 – T12 : 16 cm
L1 – L5 : 9 cm

From birth to skeletal maturity
A peri-vertebral arthrodesis in the T1-S1 segment at 5 years causes a sitting height deficit of 15 cm

T1 – T12 = 10 cm;  L1 – L5 = 5 cm
Evolution of T1-T12 Segment

Thoracic vertebrae in boys

Newborn 5 years 10 years Adult

The growing spine, Springer Verlag 2009
Evolution of L1-L5 Segment

Birth                     5 years             10 years               Adult

L1

1.6

0.65

7 cm

10.5

12.5

16

The growing spine, Springer Verlag 2009
Conversion to final instrumented fusion is possible at the beginning of puberty.
Conversion to final instrumented fusion is possible at the beginning of puberty
Avoid early arthrodesis
POSTERIOR ARTHRODESIS OF THE THORACIC SPINE IN PRE-PUBERTAL RABBITS: EFFECTS ON THORACIC GROWTH

Does a posterior arthrodesis influence the thoracic growth patterns, the length of the sternum and the thoracic volume?

MATERIAL AND METHODS

• 12 female White New Zealand pre pubertal rabbits 9 weeks old

• Implant of 2 “C” shaped titanium bars placed beside the spinous processes of the first 6 thoracic vertebrae

• 3 CT SCAN: day 10 (T1)
  day 55 (T2)
  day 139 (T3)

• Myran Pro® program: Thoracic Diameters
  Lung Volume
  Vertebral Body Size

*Canavese, Dimeglio Spine 2007.*
RESULTS

Vertebral Body Size

• In the complete fusion group:
  • decrease in the length of the vertebral body.
  • reduction of thoracic kyphosis due to Crankshaft Phenomenon
  • Decrease the growth of lungs

*Canavese, Dimeglio* *Spine* *July* 2007.
Growing rabbit model: a unilateral deformity of the spine or the thorax induces both scoliosis and thoracic cage deformity with asymmetric lung volumes.

_Karol JBJS A. 2008_

Early arthrodesis reduces AP diameter, shortens T1-T12 index.
- Fusion causes respiratory insufficiency.
- Optimum length T1-T12: 22 cm
- Respiratory insufficiency worsens after skeletal maturity

_Metha spine 2006_
The growing spine tomorrow

- We must go to the ideal by taking in consideration the reality
- We have to believe in the magic of the impossible
- Repetitive surgery leads to fibrosis
- Magnetic rod is the future
- The maximum is not the optimum
- The grey matter is more important than the material
E. O. S is not an orthopedic disease. It’s a Pediatric disease!

- Annual trunk velocity?
- Annual weight velocity?
- Respiratory status?

Don’t stick on X Ray

More attention to vital capacity and spinal penetration index
Distance T1 – T12

Height T1 – T12 = thoracic frontal diameter

Thoracic perimeter

T1

D12

N born

32 56 66 89

5 y 10 y 15 y

h

diameter
Thorax: volumetric expression of the growing spine
More growth on the horizontal plan
We can overcome the issue of EOS by the summation of ours intelligences.

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Influence of idiopathic scoliosis on three-dimensional thoracic growth

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Scoliosis - 3D spinal deformity

- Frontal plane
- Sagittal balance
- Vertebral rotation
Thorax - fourth dimension of scoliosis

- Brace concepts
- Surgical strategies
Thoracic growth

Newborn 5 years 10 years 15 years

6% 30% 50% 100%
Assessment of thoracic growth

- **Transversal diameter**
  \[= \text{30\% sitting height}\]

- **AP diameter**
  \[= \text{21\% sitting height}\]

- **Thoracic perimeter**
  \[= \text{95\% sitting height}\]
Thoracic deformity in severe scoliosis

- **Thoracic insufficiency Syndrome**
  Congenital scoliosis and fused ribs
  
  **Campbell et al.**
  J Bone Joint Surg (Am) 2003

- **Spinal penetration index**
  Neuromuscular scoliosis Syndromes
  
  **Dubousset et al.**
  J Orthop Sci 2003
Influence of idiopathic scoliosis on volumetric thoracic growth and proportions?
Optical data acquisition
Orten System
Thoracic growth parameters

- AP diameter
- Transversal diameter
- Thoracic perimeter
- Sternal length
- T1-T12 length
- *Thoracic volume*
Patient groups

- Reference group: n = 126
  61 boys / 65 girls

- Scoliosis group: n = 130
  20 boys / 110 girls

- Age range: 4 - 16 years
Clinical growth parameters

- Standing height
- Sitting height
- Weight
Spinal deformity assessment

- Frontal standing radiographs
  Cobb angle range: 15° - 45°
  Average = 24°

- Rib hump
  Range: 5 - 25 mm
  Average = 11 mm
### Average thoracic parameters in reference and scoliosis < 45° groups

<table>
<thead>
<tr>
<th></th>
<th>Boys</th>
<th></th>
<th>Girls</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>normal scoliosis</td>
<td>normal scoliosis</td>
<td>normal scoliosis</td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>8.9 dm³</td>
<td>7.9 dm³</td>
<td>7.4 dm³</td>
<td>8.3 dm³</td>
</tr>
<tr>
<td>Perimeter</td>
<td>68.3 cm</td>
<td>66.5 cm</td>
<td>64.1 cm</td>
<td>66.8 cm</td>
</tr>
<tr>
<td>AP diameter</td>
<td>17.0 cm</td>
<td>16.2 cm</td>
<td>15.8 cm</td>
<td>16.0 cm</td>
</tr>
<tr>
<td>Transv. diameter</td>
<td>24.5 cm</td>
<td>23.0 cm</td>
<td>22.9 cm</td>
<td>24.1 cm</td>
</tr>
<tr>
<td>T1-T12 length</td>
<td>24.6 cm</td>
<td>23.4 cm</td>
<td>23.2 cm</td>
<td>24.4 cm</td>
</tr>
<tr>
<td>Sternum</td>
<td>16.0 cm</td>
<td>15.8 cm</td>
<td>15.3 cm</td>
<td>16.4 cm</td>
</tr>
</tbody>
</table>

- **No significant difference**: Wilcoxon test $p > 0.05$
Thoracic growth - Boys
Average volumes

**Normal**

- 4 years: 4.9 dm³
- 10 years: 8.0 dm³ (x 1.7)
- 16 years: 14.1 dm³ (x 1.8)

**Scoliosis**

- 4 years: 4.7 dm³
- 10 years: 8.1 dm³
- 16 years: 14.8 dm³
Thoracic growth - Girls

Average volumes

**Normal**

- 4 years: 3.8 dm³ (33%)
- 10 years: 6.4 dm³ (55%)
- 16 years: 12.2 dm³ (100%)

**Scoliosis**

- 4 years: 3.8 dm³
- 10 years: 6.4 dm³
- 16 years: 11.5 dm³

Comparisons:
- Normal: 6.8 dm³ (x 1.7)
- Scoliosis: 6.8 dm³ (x 1.7)
- Normal: 6.8 dm³ (x 3)
- Scoliosis: 6.8 dm³ (x 3)
- Normal: 12.2 dm³ (x 1.8)
- Scoliosis: 12.2 dm³ (x 1.8)
### Regression analysis

**Thoracic volume - growth parameters**

<table>
<thead>
<tr>
<th></th>
<th>Boys</th>
<th>Girls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>normal</td>
<td>scoliosis</td>
</tr>
<tr>
<td>Age</td>
<td>$r = 0.73$</td>
<td>$r = 0.43$</td>
</tr>
<tr>
<td>Standing height</td>
<td>$r = 0.84$</td>
<td>$r = 0.87$</td>
</tr>
<tr>
<td>Sitting height</td>
<td>$r = 0.85$</td>
<td>$r = 0.88$</td>
</tr>
<tr>
<td>Weight</td>
<td>$r = 0.92$</td>
<td>$r = 0.92$</td>
</tr>
</tbody>
</table>

➢ **Growth parameters better than chronological age**
Constant relationships during growth in reference and scoliosis < 45° groups

AP diameter

\[ r = 0.78 \]

Sternal length

\[ r = 0.88 \]

20% sitting height
Constant relationships during growth in reference and scoliosis < 45° groups

Frontal diameter

$r = 0.85$

$30\%$ sitting height

T1-T12 length

$r = 0.89$
Constant relationships during growth in reference and scoliosis < 45° groups

Thoracic perimeter

\[ r = 0.93 \]

Sitting height
Conclusions

- Thoracic parameters need to be related to sitting height
- Thoracic volume triples from 4 to 16 years and doubles during pubertal growth
- No significant difference of thoracic volume between normal subjects and scoliosis < 45°
Clinical relevance of three-dimensional thoracic concept

- Conception of optimised braces
- Analysis of surgical strategies
- Further investigation on major scoliosis leading thoracic deformity
GROWTH IS A VOLUMETRIC REVOLUTION

AT BIRTH 30% OF THE SPINE IS OSSIFIED
Deformities change the shape of the thorax and reduce its normal mobility.

The rib-vertebral-lung complex should be considered as a whole, it is an elastic structural model,

scoliosis it becomes rigid preventing from normal development lungs.
AT BIRTH 30% OF THE SPINE IS OSSIFIED

GROWTH IS A VOLUMETRIC REVOLUTION

Newborn  5 years  Sk. maturity
Physiotherapy

20 muscles
10 insertions by rib
RESULTS

Vertebral Body Size

• In the complete fusion group:
• decrease in the length of the vertebral body.
• reduction of thoracic kyphosis due to Crankshaft Phenomenon
• Decrease the growth of lungs

The vertebrae volume triple after ten.
Where are we going?

1. There is a normal interaction between the spine, the thoracic cage and the lungs.

2. Deformities of the spine adversely affect the development of the thorax by changing its shape and reducing its normal mobility.

3. The rib-vertebral-lung complex should be considered as a whole; it is an elastic structural model; in the presence of scoliosis it becomes rigid thus preventing from normal development lungs.