Scoliosis in the Growing Child

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Disclosures

John Faust, M.D., has no financial relationships to disclose

Learning Objectives

At the end of this presentation the participant will be able to:
1. Describe the challenges in treating scoliosis in the growing child
2. Define thoracic insufficiency syndrome (TIS)
3. List current methods for assessing skeletal maturity
4. Discuss the current treatment options for scoliosis in the growing child and their pros and cons
**Pre-test**

2 questions from the most recent OITE

- Yearly exam for orthopaedic residents

**Orthopaedic In-Training Exam (OITE)**

The function of the starred structure is?

Preferred answer:

b. Pump Ancef to bones

**Orthopaedic In-Training Exam (OITE)**

The function of the starred structure is?

Preferred answer:

d. Inflate the chest to keep the spine straight

**Why this topic?**

Most conditions in pediatric orthopaedics aren’t life threatening

But there are a few to worry about:

- Infection
- Malignancy
- Early-onset scoliosis
- Radial deficiency
- Marfan syndrome
- Cervical spine instability
  - Skeletal dysplasia
  - Down syndrome

**Why this topic?**

EOS demonstrates the heart of orthopaedics ... using growth to re-shape anatomy

and the spectrum of tools we have

- Serial casting
- “Growth friendly” surgery
- Definitive spine fusion

Pediatric orthopaedics is more like gardening than mechanics

**Why this topic?**

Texas is important in the history of spine surgery

- Harrington rods: Paul Harrington (Houston)
- EDF casting: Al and Jim Sanders (San Antonio)
- VEPTR: Robert Campbell, Melvin Smith, Tom Mayes, Donna-Beth Wiley-Courand, Victor German, et al. (San Antonio)
Scoliosis and Thoracic Deformity

Scoliosis (Latin, 1706): lateral curvature of the spine
- Skoliosis (Greek): crookedness
- Skolio (Greek): bent or curved

SRS definition of scoliosis: a lateral curvature of the spine

This incorrectly implies a one-dimensional deformity

Translator’s Preface.

“This book is a translation of “Die Orthopädie in der inneren Medizin,” and is not intended as a text-book on orthopaedic surgery, which, as a rule, is largely devoted to matters that have little direct interest for the physician. But a glance at its contents, however, is sufficient to show how few are the diverse branches of medicine on which orthopaedics has not at least some bearing.

As may be gathered from the introduction written by Professor Lorenz, its object is to provide the medical practitioners with fuller information as to the present-day developments in this special field, so that he may make personal use of this knowledge in his practice or, noting what specialist treatment is capable of achieving, be guided to avail himself of the services of the orthopaedic surgeon. At the same time, the subject of diagnosis in orthopaedic conditions as they present themselves to the physician is dealt with fully.

Scoliosis and Thoracic Deformity

“the trunk under goes in severe scoliosis
• not only a considerable shortening in the vertical direction
• and a complete deformation in the other directions;
• but is also altered as a whole
• in that it is displaced laterally
• while its whole structure is twisted.”

“The lungs, being
• must accordingly at
• both in position and
• to the thoracic wall
• and so many as
• conformation.”


Scoliosis and Thoracic Deformity

Eur Spine J. 2014;23(12):2594-602.
• the combined spine and rib cage deformity in scoliosis is best described as a thoracic deformity, and recent advances in imaging have enabled better definition of three-dimensional (3D) deformity of the thorax in scoliosis. However, a comprehensive report that summarizes the published thorax deformity quantification parameter studies is lacking in the orthopaedic literature.

This talk

Like Lorenz’s book:
• less about “surgery”
• more about “medicine”

Scoliosis in growing children

The problem:
• Unlike adolescent scoliosis... scoliosis in the very young can be fatal

The natural history:
• Severe spinal deformity
• Creates limited chest volume
• And limits lung growth
• Causing extrinsic restrictive lung disease
• Leading to early mortality
  - Thoracic insufficiency syndrome
  - Cor pulmonale

TIS (Thoracic Insufficiency Syndrome):
• “The inability of the thorax to support normal respiration or lung growth”
  

Scoliosis mortality

Pehrsson K, Spine, 1992;17(7):1091-6
Similarly, Branthwaite reported that disabling dyspnea or cardiorespiratory failure were associated with scoliosis first noticed before the age of 5 but rarely in adolescent scoliosis.


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**Scoliosis in growing children**

**Before age 6-10:** mortality
- Chest wall growth and lung development

**After age 8-10:** deformity
- Deformity surgery not the same as cosmetic surgery

**Scoliosis in growing children**

**So what’s the problem?**
- Fuse the spine
- Arrest progression of chest deformity

**Okay, great but you also...**
- Arrest further chest growth
- Limiting chest volume and lung growth
- Causing extrinsic restrictive lung disease
- Still potential for early fatality
- Thoracic insufficiency syndrome
- Cor pulmonale

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**Lung and chest development**

**Lungs**
- Grow by alveoli multiplication through age 6-8 (OKU ped 4)
- Alveolar hypertrophy after that

**Thoracic growth**
- Different than that (OKU ped 4)
- Postnatal alveolar growth and development primarily occurs peripherally in the distal aspects of the pulmonary tree. Impaired thoracic growth and lung volume growth inhibit alveolar development and lung function. Thoracic insufficiency syndrome (TIS) is the inability of the thorax to support normal respiration or lung growth (Campbell 2003).
A severe scoliosis causes compression of the lungs with consequent difficulty in aeration of the alveoli and right heart hypertrophy because of the difficulty in circulating blood through the lungs. There is then a gradual failure of both respiratory and cardiac function.

Cardiopulmonary is right-sided heart failure from long-term pulmonary hypertension. This is caused by chronic lung disease causing prolonged low oxygen levels.

Thoracic insufficiency syndrome (TIS) is the inability of the thorax to support normal respiration or lung growth (Campbell 2003). TIS can occur when a spine deformity compromises thoracic growth, volume and function and consequently negatively impacts the growth, development, and function of the lungs.

**When is it safe to fuse the spine?**

**Skeletal maturity**

And before that?

- **Real answer:** We don’t know.
- **Mike Schmitz answer:** Depends.
  - How many levels?
  - What age?
  - Functional demand

**When is “early” fusion safe?**

“Early” meaning before skeletal maturity

**Current orthopaedic understanding of the literature:**

**Age 10 yo – 1980s**

- 18-20 cm – carroll

**Hold your horses**

Before planning treatment you need to know the “why”

**Why is there a curve in the spine?**

- Other medical issues to attend to
- Risk of progression
- Treatment
  - Choices
  - Expectations

**So a word on:**

- Terminology
- Evaluation

**Scoliosis terminology**

**Idiopathic:**

- No underlying cause
- Lateral curvature ≥10° Cobb with rotation
- James 1954, SRS
- Infantile idiopathic
- Juvenile idiopathic
- Adolescent idiopathic
- Dickson, 1994:
  - Early-onset
  - Late-onset

**Congenital:**

- Malformed bones
- Failure of formation or/and segmentation
  - Spine
  - Ribs

**Neuromuscular:**

- Due to either a neurologic or muscular disorder
**Idiopathic scoliosis classification**

"Three peak periods of onset"
- Infantile idiopathic
- Spontaneous correction noted by 13/30
- Terming resolving and progressive in 1935
- SRS: diagnosed 4-10 yo
- Originally described as age of onset "at the age of five" 
- Adolescent idiopathic
- SRS: diagnosed 10 yo to skeletal maturity
- Originally described as age of onset "from five to eight"
- Females, right thoracic curve

"Significant thoracic deformity" early enough to risk "cardiopulmonary compromise"


**Early-onset**
- SRS: Diagnosed before 10 yo
- Originally described as "0-5 years"
- Late-onset
- After age 10
- Originally described as "after the age of 5"

**Scoliosis terminology**

**Current common terminology**

- **Early Onset Scoliosis (EOS)**
  - Variably defined (to some confusion)
  - *Before age 10 or sometimes prepubescent*
  - Regardless of etiology (now includes non-idiopathic scoliosis)
- **Infantile idiopathic subset**
  - Onset before age 3 years (usually 6-18 months)
  - Boys with left thoracic curves
  - Curve may resolve spontaneously or with casting
- **Adolescent idiopathic scoliosis (AIS)**
  - Truly idiopathic
  - Onset after age 10 years
  - Congenital
  - Neuromuscular
  - Some crossover with EOS

**Congenital scoliosis**

Failure of formation
- with fused ribs: failure of thoracic formation

Failure of segmentation
- with fused ribs: failure of thoracic segmentation

Failure of both formation and segmentation

Jumbled spine / jumbled thorax
- "Extensive congenital scoliosis"

**Neuromuscular scoliosis**

- Cerebral palsy
- Myelodysplasia
- Muscular dystrophy
- Spinal muscular atrophy
- Arthrogryposis
- Amyotonia congenital
- Friedreich ataxia
- Poliomyelitis
- Syringomyelia
- Tethered cord
- Spinal cord trauma

**Classification of Early-Onset Scoliosis (C-EOS)**


<table>
<thead>
<tr>
<th>Age</th>
<th>Etiology</th>
<th>Major Curve Angle</th>
<th>Kyphosis</th>
<th>APR Modifier</th>
<th>Cobb Angle (Major Curve)</th>
<th>Maximum Total Kyphosis</th>
<th>Progression Modifier (optional)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Prefix</td>
<td>Congenital/Structural</td>
<td>1: &lt;20°</td>
<td>&lt;20°</td>
<td>P2 &lt;10°/yr</td>
<td>1: ≤20°</td>
<td>N: 20-50°</td>
<td>P2: 10-20°/yr</td>
</tr>
</tbody>
</table>

**C-EOS**

Cobb Angle: Measurement of major spinal curve in position of most gravity

Maximum Total Kyphosis: Between any 3 levels

Annual Progression Ratio Modifier (current):

- Progression per year; min. 6 months between observation

(Cobb Angle) = (Cobb Angle) X 12 months / [t1-t0]
**Scoliosis Evaluation in Young Children**

A radiograph makes the diagnosis

The exam is for the “why”?  
- Underlying neurologic cause  
- Underlying syndrome

**Scoliosis Evaluation in Young Children**

The power of observation  
- Little children often cannot help with your exam  
- Manual motor testing impossible  
- Watch them in action  
- Give them games/tasks  
- Lean back, all attention

Evidence of neurological involvement  
- Skin changes over the spine  
  - Color change, hairy spots (long enough to braid), etc.  
- Differing size of one thumb, hand, limb, or foot to the other  
- Facial asymmetry  
- Abnormal tone in any extremity  
- Abnormal reflexes (especially abdominal)

**Look closely**

Just because it all looks new and strange doesn’t mean you won’t recognize something

*Albert Einstein*

At the Grand Canyon  
In Native American headdress
Scoliosis Evaluation in Young Children

Congenital scoliosis and VACTERL association
- Other organ systems form at the same time as the spine
  - Heart (10%): clinical or echocardiogram
  - GU (25%): renal evaluation
  - US or same MRI done to evaluate spinal cord

- Spinal Cord:
  - XR of entire spine
  - Klippel-Feil (25%): congenital cervical spine fusions
  - MRI
  - Abnormal neuro exam or before surgery
  - Arnold-Chiari malformation, syringomyelia, tethered cord

Look for syndromes:
- Low set ears
- Loose joints
- Long fingers
- Any feature not quite right

If you suspect something, use a geneticist

MRI of spine in all children < 10 yr (infantile/juvenile, early-onset)
Incidence of neural axis abnormalities in presumed “idiopathic" scoliosis
- Infantile: 19.2%
- Juvenile: 15.6% patients aged 10-12 yr in curve > = 10°, retrospective
  - USA study, 15% of patients of diaphragm, some 10°, normal neurology examination, and absence of any syndrome or congenital anomaly
- Congenital: 23%
  - Abnormalities: neural tube, Chiari malformation, syringomyelia, cardiovascular anomalies
  - 6.9% had left-tilted curve
  - 1.4% with unilateral absence of abdominal reflexes
  - 22% with normal MRI
  - 54% (6/114) patients newborn to 10 yr with idiopathic scoliosis > = 20° without neurological findings
  - 55% (6/113) patients in the infantile age range had a neural axis abnormality

Exceptions:
- Resolving infantile curves
- Possibly certain syndromes without neural axis involvement
- Muscular dystrophy
- Down syndrome?

Scoliosis Evaluation in Young Children

If you suspect:
- Radial deficiency:
  - CBC, chromosome breakage study, renal US, echocardiogram
  - Genetics
- Marfan syndrome:
  - MRI of spine
  - Genetics, Cardiology (echocardiogram)
- Neurofibromatosis:
  - MRI of spine
  - Genetics, Ophthalmology
- Muscular dystrophy:
  - Genetics, Cardiology, Pulmonology
- Skeletal dysplasia (Morquio):
  - Flexion/extension lateral C-spine radiographs
  - Genetics

Curve Progression

Which curves get worse?
Why do curves get worse?
When do curves get worse?

Progression: congenital scoliosis

<table>
<thead>
<tr>
<th>Site of Curvature</th>
<th>Black Yorktown</th>
<th>White Yorktown</th>
<th>Single</th>
<th>Double</th>
<th>Unilateral Unsegmented Bar</th>
<th>Unilateral Lateral Hemivertebrae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper thoracic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower thoracic</td>
<td></td>
<td></td>
<td>1°-4°</td>
<td>5°-10°</td>
<td>5°-8°</td>
<td></td>
</tr>
<tr>
<td>Thoracic-lumbar</td>
<td></td>
<td></td>
<td>1°-6°</td>
<td>6°-10°</td>
<td>6°-10°</td>
<td></td>
</tr>
<tr>
<td>Lumbar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- No treatment required
- May require spinal fusion
- Requires spinal fusion
  - Too few or no curves
  - Age

Median survival rate of American spina bifida without treatment for each type of single congenital scoliosis in each region of the spine (207 patients). The survival rate of 5° or worse crooked was in patients who were more than the age of 20 years, the median age of the age in patients who were more than the age of 20 years.

Progression: congenital scoliosis

<table>
<thead>
<tr>
<th>Site of Curvature</th>
<th>Black Vertebrae</th>
<th>Wedge Vertebrae</th>
<th>Hemivertebrae</th>
<th>Unilateral Unsegmented Bar</th>
<th>Bilateral Unsegmented Bar and Corresponing Hemivertebrae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Thoracic</td>
<td>-1° - 1°</td>
<td>-2° - 2°</td>
<td>-1° - 1°</td>
<td>2° - 4°</td>
<td>5° - 7°</td>
</tr>
<tr>
<td>Lower Thoracic</td>
<td>-1° - 1°</td>
<td>-2° - 2°</td>
<td>-1° - 1°</td>
<td>2° - 4°</td>
<td>5° - 7°</td>
</tr>
<tr>
<td>Thoracic Lumber</td>
<td>-1° - 1°</td>
<td>1° - 2°</td>
<td>-1° - 1°</td>
<td>2° - 4°</td>
<td>5° - 7°</td>
</tr>
</tbody>
</table>


Infantile scoliosis: natural history

**Resolving**

**Progressive**

Natural History of Infantile Scoliosis

**Incidence of resolving curve varies between reports:**

  - 12% resolving (4/33), 55% progressive (18/33)
  - 33° “stationary” (11/33) with observation (most less than 2 yrs)
  - 17% resolving (9/52), 83% progressive (43/52)
  - 20% resolving (7/35), 80% progressive (28/35)
  - 12% resolving (4/33), 55% progressive (18/33)
  - 33° “stationary” (11/33) with observation (most less than 2 yrs)
  - 36% resolving (77/212), 64% progressive (135/212)
  - 92% resolving (92/100), 8% progressive (8/100)
  - All were <1 year of age – younger than in other reports

Infantile scoliosis: resolution

**Reported rates of spontaneous resolution:**

- 12% – James, 1951
- 17% – James, 1954
- 20% – Scott, Morgan, 1955
- 36% – James, Lloyd-Roberts, Pilcher, 1959
- 92%* – Lloyd-Roberts, Pilcher, 1965
*These children were younger than in the other studies (all <1 year old)
Natural History of Infantile Scoliosis

Incidence of resolving curve varies between reports:

  - 77% (92/127) resolving. 23% (28/127) progressive
  - Not clear if some resolving cases were treated based on Mehta's criteria

Progression: infantile idiopathic

4 criteria distinguish progressive from resolving curves

- Rib-vertebra angle difference (RVAD)
  - Apical vertebra
  - Concave RV angle minus convex RV angle
  - Initial radiographs:
    - RVAD <20°: 80% of cases resolve
    - RVAD ≥20°: 80% of cases progress
  - After 3 months:
    - Resolving: RVAD reduced (even if curve increased)
    - Progressive: RVAD same or greater

Progression: infantile idiopathic

4 criteria distinguish progressive from resolving curves

- RVAD
  - Rib phase: phase 2 is the hall-mark of progressive scoliosis

Progression: infantile idiopathic

4 criteria distinguish progressive from resolving curves

- Rib-vertebra angle difference (RVAD)
  - Rib phase
  - Double curve: all progress
    - Apical RVAD small ("nil or even a negative figure")
    - Concave 12th rib "drops" downward
    - RVAD at T12 always negative
    - Lumbar rotation opposite the thoracic rotation
    - Lumbar rotation present even before the curve apparent radiographically


The literature we were all taught

<table>
<thead>
<tr>
<th>Study</th>
<th>Definition of progression</th>
<th>Worse prognosis if</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nachemson</td>
<td>≥ 5°</td>
<td>Larger Cobb and Older patient (10-12 vs. 13-15 years)</td>
</tr>
<tr>
<td>Lonstein and Carlson</td>
<td>≥ 5°, Premenarchal and with larger curves Risser 0 or 1: 36% progressed Risser 2-5: 11% progressed</td>
<td></td>
</tr>
<tr>
<td>Bunnell</td>
<td>≥ 5° and ≥ 10°</td>
<td>Younger age at diagnosis, larger curve magnitude, pre-menarche, lesser Risser sign</td>
</tr>
<tr>
<td>Duval-Beupere</td>
<td>≥ 6°</td>
<td>Larger supine Cobb, Larger rib prominence</td>
</tr>
<tr>
<td>Perdriolle and Vidale</td>
<td>Not stated</td>
<td>Larger Cobb angle</td>
</tr>
<tr>
<td>Upadhyay</td>
<td>≥ 6°</td>
<td>Worse if curve worsened in brace</td>
</tr>
<tr>
<td>Noonan</td>
<td>≥5°, ≥10°, and ≥50°</td>
<td>Less correction in brace, younger age</td>
</tr>
</tbody>
</table>

Curvature Acceleration Phase (CAP)

Curves worsen during peak height velocity (PHV)

The CAP acts like a prism
- A period of rapid curve acceleration
- Specific curves behave differently

At the CAP, curves divided into 3 types

- Pre-acceleration
  - Average 0.2 degrees/month
- Rapid Acceleration
  - Average 1.6°/month
  - Reach >60°
  - Lenke 1 and 3 (or King 2 and 3)
- Moderate Acceleration
  - Average 0.8°/month
  - Final Range 44-59°
  - Lenke 2, 4, 5 and 6
- Low Acceleration
  - Average 0.3°/month
  - Max of 35°
  - No particular curve pattern

Scoliosis Progression

What we really know:
- Immaturity and larger curves carry a worse prognosis
- Curve pattern matters

But,
- What is “larger” and “smaller”?
- What is “mature” and “immature”?

Skeletal maturity

Since maturity matters, how can you measure it?
**Skeletal Maturity: chronological age**

Timing of the growth spurt is not homogeneous to chronological age

- 2 year standard deviation

Age is a poor indicator of maturity during adolescence

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**Peak Height Velocity (PHV)**

Excellent maturity indicator

Prognostic for curve progression

- Girls: progression of at least 10° to ≥45°
  - <30° at PHV: 4% (1/28 patients)
  - >30° at PHV: 83% (50/60 patients) despite bracing
- Boys: progression to surgery (Cobb >45°)
  - <30° at PHV: 34% (4/29 patients)
  - >30° at PHV: 100% (13/13 patients)

Issues:

- A pain to measure
- Only useful retrospectively

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**Skeletal Maturity**

Risser sign (American version)

- Risser 3: getting late for bracing
- Risser 4: growth within 13 mm of completion (Sanders, POSNA, 2014)
- Risser 5: growth cessation

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**Triradiate cartilage**

Complements the Risser sign

- Not all Risser 0’s are the same

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**Tanner Staging**

Less variability than chronological age

More stages make measurement more precise

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**Orthopedists who check Tanner Stages are:**

French

or

Suspect
Elbow (the other French way)

Olecranon matures (Diméglio 5) near end of PHV not skeletal maturity
- Humeral epicondyle
- The hand and physis continue to mature after the olecranon completes fusion.


Gruelich and Pyle atlas

Standard for determining skeletal AGE

Thomas Wingate Todd, M.D. (1885-1938)
- Born in England
- Professor of Anatomy, Western Reserve University School of Medicine in Cleveland

Interested in the growth of bone
- Hamann-Todd Osteological Collection
  - 3,000 skeletons with the name/alias, age, sex, ethnicity, cause of death, and more than 70 anthropomorphic measurements
  - Source for more than 1,000 publications
  - The year before Todd’s arrival in Cleveland, Ohio passed legislation (drafted in part by Carl Hamann, later dean of the medical school) that allowed medical school to receive cadavers otherwise destined for a potter’s field.

- The “Brush Inquiry”
  - 13 year longitudinal study of 4,483 children
  - Created the largest and most complete extant collection of skeletal radiographs obtained from a longitudinal cohort of children through their growth

Brush Foundation for Human Betterment
- Established in 1938 by the wealthy inventor, Charles Francis Brush, in memory of his son
- T.W. Todd made chairman of the foundation
- Deed of gift stated: “Whereas, in my opinion the most urgent problem confronting the world today is the rapid increase of population which threatens to overwhelm the earth in the not distant future, with resultant shortage of food and lower standards of living, which must certainly lead to grave economic disturbances, famines and wars, and threaten civilization itself...”
- The income of this trust shall be used by the board of Managers to finance efforts contributing toward the betterment of the human stock, and toward the regulation of the increase of population, to the end that children shall be brought up only under conditions which make possible a heritage of mental and physical health, and a favorable environment. These purposes include the furtherance of scientific research in the fields of demography and in regulation of the increase of population; the education of the people to the importance of the betterment of this stock and to the economic and social evils which result from too great increase of population and any activities which shall serve the intent set forth in this instrument and its preamble.”
- Interesting in the context of 1928 (post-WWI and pre-WWII)
- T.W. Todd postulated that it would be first necessary to know definitely what the well-born child was like

Brush Foundation Study (“Inquiry”)

T.W. Todd’s study of 4,483 children
- Healthy children from Cleveland
- From 1929 to 1942, recruited children from 3 mo. to 14 yrs. of age
- Children examined:
  - Every 3 months until 1 year old
  - Every 6 months until 5 years old
  - Then annually
  - This becomes important later
- Each visit had:
  - Radiographs: left hand, elbow, shoulder, foot, knee, hip
  - Anthropometrics: height, weight, segment measurements

Male White Hand Standard 1
Brush Foundation Study

Resulted in 2 atlases
- **Atlas of Skeletal Maturation**
  - Published by Todd in 1937

- **Radiographic Atlas of Skeletal Development of the Hand and Wrist**
  - a.k.a. the Gruelich and Pyle atlas
  - A representative left hand radiograph selected as a standard for each age
  - Published by William Gruelich and S. Pyle in 1950

Skeletal age atlases

Both atlases average appearance for specific ages and called it a “skeletal age”
- The concept of timing relative to the PHV was not described until the 1960’s by Tanner
- Maturity near adolescence is better based on timing relative to the PHV
- Adolescents have up to a four-year variation in the timing of their growth spurt

Concept of skeletal Maturity: better
- Bones do not have different ages than patients
- Bone maturity differs just as it does in children

Gruelich and Pyle: issues

Highlights subtle radiographic changes
- Rather than simplicity and reliability

Applicability to all children questioned
- 1930s
- White children
- Upper-class (better nutrition)

Maturity stages separated by 1 year time during the pubertal growth spurt
- No female 11.5 and 12.5 skeletal ages, no male 14.5 skeletal age
- In the Sanders’ simplified skeletal maturity assessment:
  - Progression from Sanders’ stage 2 to stage 8 occurs over 4 years
  - 12 months before the CAP and lasting 3 years after the start of the CAP
  - Stages 4 through 7 progress rapidly, typically within 6 months
  - Stage 3 (most important stage) corresponds with Gruelich and Pyle female skeletal age of both
    11 and 12 years

Sanders, J.B., 2008: 50-540

Shorthand Bone Age

**Table 1. Description of Radiographic Criterium Used for Determination of Skeletal Age in Females, Aged 10 to 16 Years, and Males, Aged 12.5 to 16 Years, According to the Shorthand Bone Age Assessment Method**

<table>
<thead>
<tr>
<th>Radiographic Criterium</th>
<th>Bone Age (Yr)</th>
<th>Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance of harmen sternum midline</td>
<td>12.5-13</td>
<td>Females</td>
</tr>
<tr>
<td>Appearance of 12th thoracic vertebra</td>
<td>12.5-13</td>
<td>Males</td>
</tr>
<tr>
<td>Width of upper end of distal radius</td>
<td>12-13</td>
<td>Females</td>
</tr>
<tr>
<td>Width of upper end of 1st metacarpal</td>
<td>12-13</td>
<td>Males</td>
</tr>
<tr>
<td>Capping* of distal radius epiphysis</td>
<td>14-15</td>
<td>Females</td>
</tr>
<tr>
<td>Closure of phalangeal epiphysis</td>
<td>15-16</td>
<td>Males</td>
</tr>
<tr>
<td>Closure of index metacarpal epiphysis</td>
<td>15-16</td>
<td>Females</td>
</tr>
<tr>
<td>Closure of 1st metacarpal epiphysis</td>
<td>15-16</td>
<td>Males</td>
</tr>
<tr>
<td>Closure of index metacarpal epiphysis</td>
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*“Capping” indicated by presence of a rounded uneven peak oriented proximally at a joint.

Heyworth, J Pediatr Orthop, 2013: 569-574

Tanner-Whitehouse-II Staging (TW3)

**TW3 RUS**
- Sum of individual scores for
distal Radius
  - Ulna
  - Small bones (1st, 3rd, and 5th metacarpals and phalanges)
- More closely related to curve behavior and the timing of curve take-off in early adolescents (curve acceleration phase or CAP) than:
  - Risser sign
  - Oxford staging
  - Gruelich and Pyle
- Multiple serologic skeletal maturity markers

Sanders JO, J Bone Joint Surg Am, 2007; 89:64-73

Rapid acceleration corresponds to digital capping

Digital Skeletal Age (DSA)

- **TWIII without radius and ulna** gives a digital skeletal age
- Radius and ulna correlate poorly with the CAP
  - Sanders JO, J Bone Joint Surg Am, 2007; 89:64-73
- DSA most closely correlates with the CAP
- But it is clinically cumbersome:
  - Need the TW3 atlas
  - 5 individual scores have to be given and then totaled
Sander’s SSMA: CAP

Stage 3: curve acceleration phase
- Digital capping
- Small bend of the epiphysis over the metaphyseal edge

Capped digits correlates with the CAP

Sander’s SSMA: skeletal maturity

Stage 7
- Digital physis closed
- Growth within 13 mm of completion
(Sanders POSMA 2014)

Stage 8
- Distal radius and ulna physis closed
- Growth ceased
**Issues to look up and research ideas:**

- Plot graph by cm/year for each Sanders stage (shape will probably look different)
- Confirm that other studies say the curve accelerates in a delayed fashion (purple line) so maybe the CAP is in the wrong place

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**Skeletal maturity progression**

**It's not all worked out yet**

- Sanders JO, Spine, 1997;22(12):1352-6
- Sanders JO, Spine, 2006;31(20):2289-95

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