Neuromonitoring in EOS Surgery: Is it Different than in AIS?

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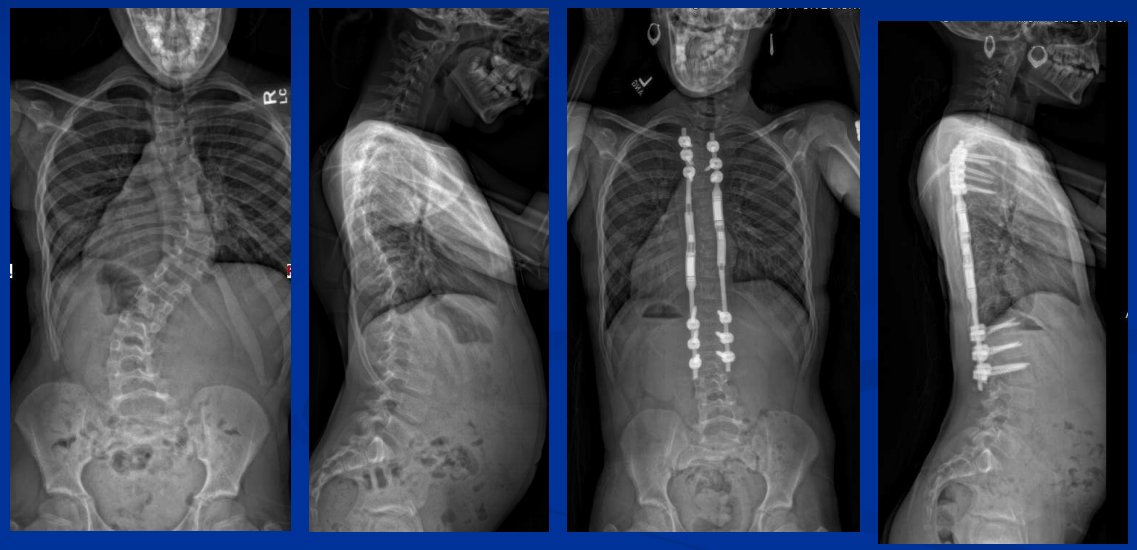
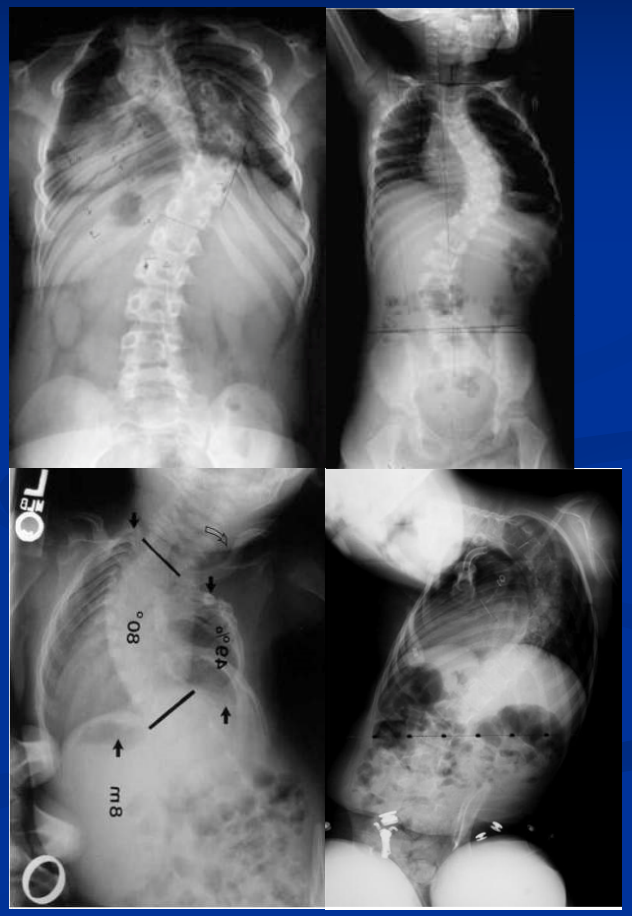
Patient L.S.

- 8-year-old child with JIS
  - Normal MRI
  - T6-L1: 46º curve
- IONM
  - Similar to AIS



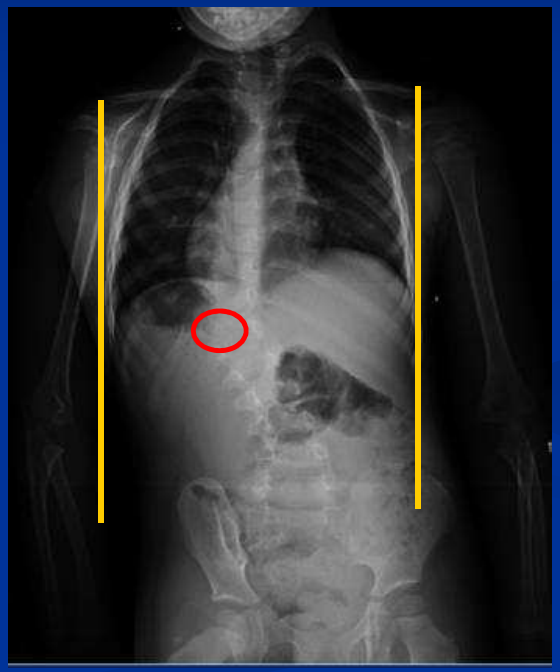
Factors to Consider

- Age
  - Can we get signals?
- Intraspinal anomalies
  - How do they impact signals?
- Diagnosis
  - Can we predict which patients may not have signals?
- Growth friendly instrumentation and neurologic risk



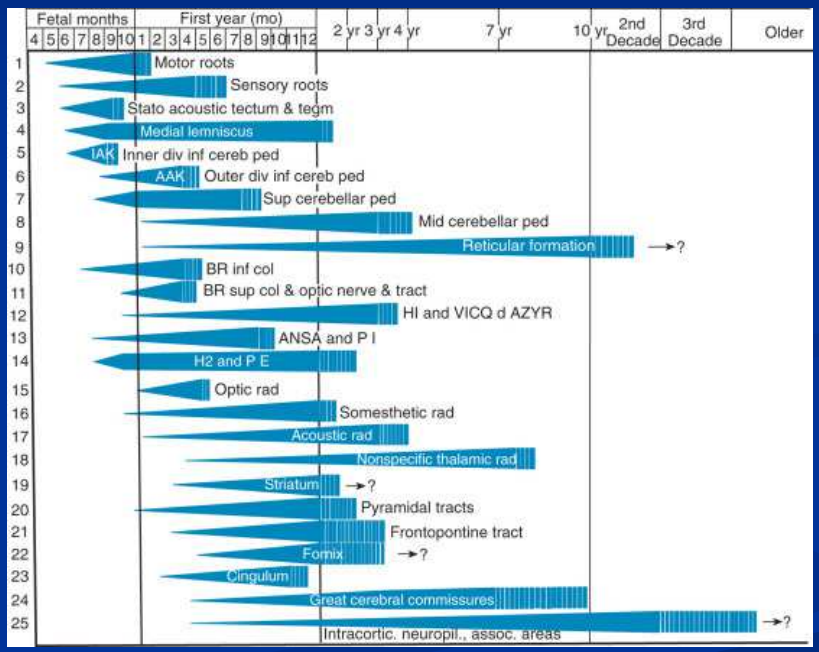
Patient E.E.

- 2.5 yo with congenital scoliosis and worsening curve
  - Trunk shift
  - Pain
- T12 hemivertebrae
- Will you have reliable signals to follow?



Very Young Age: Signals to Follow?

- MEPS
  - Underlying condition, anesthesia, myelination
- Several authors have shown an age-dependent decrease in MEPs reliability
- Corticospinal tracts undergo myelination into second decade of life (age 16, majority done by age 3)
- Conduction velocity 10m/s compared to 70m/s in adults
- Higher threshold voltage required to obtain signals



Volpe's Neurology of the Newborn, 2018
Fulkerson et al, JNS Peds, 2011

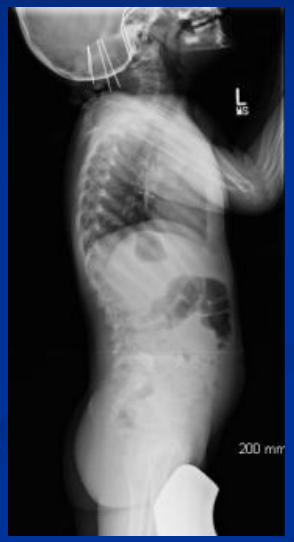
Intraoperative monitoring of motor evoked potentials in very young children

Fulkerson DH et al. JNS Peds 7(4):331-7, 2011

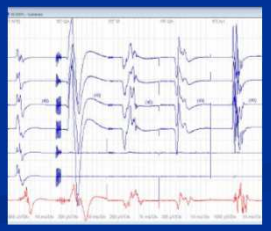
- 10 children average age 16.8 months
- TIVA
- MEPs obtained in all patients
  - Mean baseline stimulation threshold of 533V (AIS=300V)
  - 4 patients with IONM changes
    - 2 returned to baseline
    - 2 did not return to baseline, and this correlated with a deficit

Postoperative X-rays

10 year

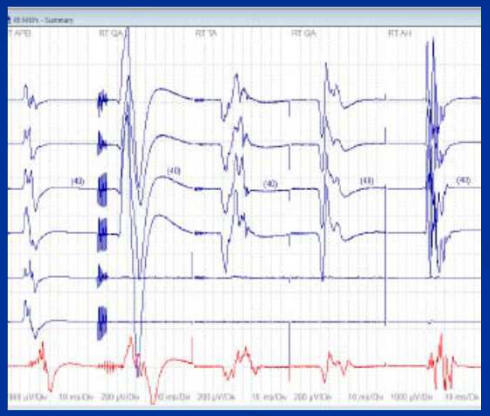


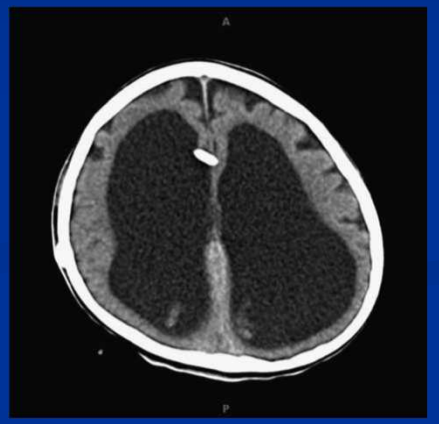
10 year



EOS Motor Evoked Potentials Underlying Diagnosis

- Wide spectrum of diagnosis
- Significance
  - Bowel and bladder
  - Spastic versus flaccid
- Mo et al: Why no signals? Cerebral anatomy predicts success of IONM during correction of scoliosis secondary to CP. JPO 37:2017
  - No signals in 31%
  - Hydrocephalus a predictor



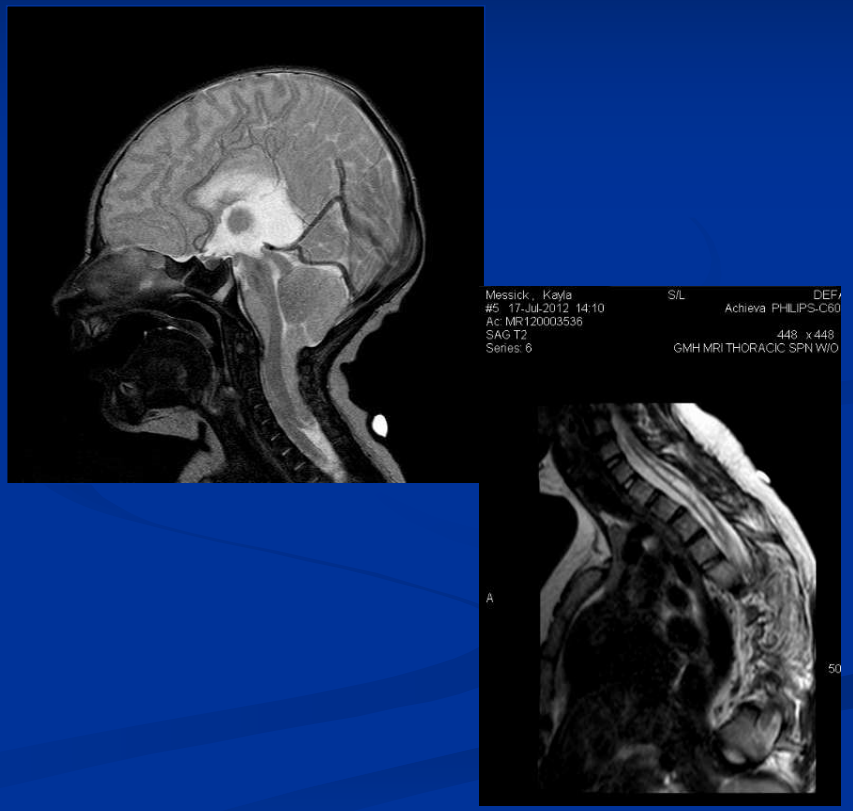


Case Presentation

- 8 yo girl presented with 30° right thoracic curve
  - MRI scan demonstrated Chiari malformation with holocord syrinx
- What kind of signals can we expect?

EOS and Intraspinal Anomalies

- Incidence can range from 13-60%
  - Shen et al, Spine 2013
    - 226 patients
    - 43% with intraspinal anomaly
      - Diastematomyelia most common
  - Basu et al, Spine 2002
  - 126 consecutive patients
    - Tethered cord most common
- Most common etiologies
  - Chiari
  - Tethered cord
  - Syrinx
  - Diastematomyelia



Intraspinal Anomalies and Increased Neurologic Risk

- Noordeen *et al,* Spine 1994
- Charry *et al*, J Pediatr Orthop 1994
- Ozerdemoglu *et al,* Spine 2003

Intraspinal Anomaly and Neuromonitoring

- Wilson-Holden TJ *et al*, Spine 1999
  - 38 patients
  - 93% SSEPs, 51% nMEPs
  - 27% false positive
- Muchow *et al*, Spine Deform 2013
  - 38 patients
  - Baselines in 95% (AIS 100%)
- Aleem *et al*, Spine Deform 2015
  - 82 patients
  - 18% no lower extremity signals

Outcomes of Patients With Syringomyelia Undergoing Spine Deformity Surgery: Do Large Syrinxes Behave Differently than Small?

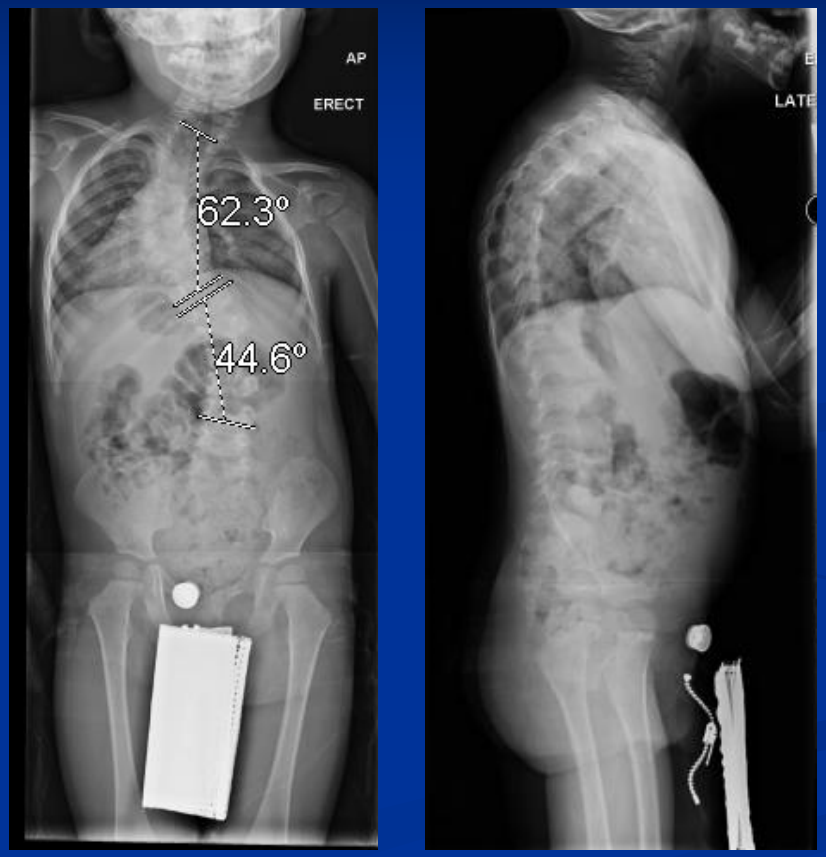
Spine Journal 2018

- Patients with larger syrinxes had larger curves, more kyphosis, and larger rib prominences
- These patients were fused longer with more blood loss
- Intraoperatively, neuromonitoring signals were less reliable and had a higher probability of change

Patient G.D.

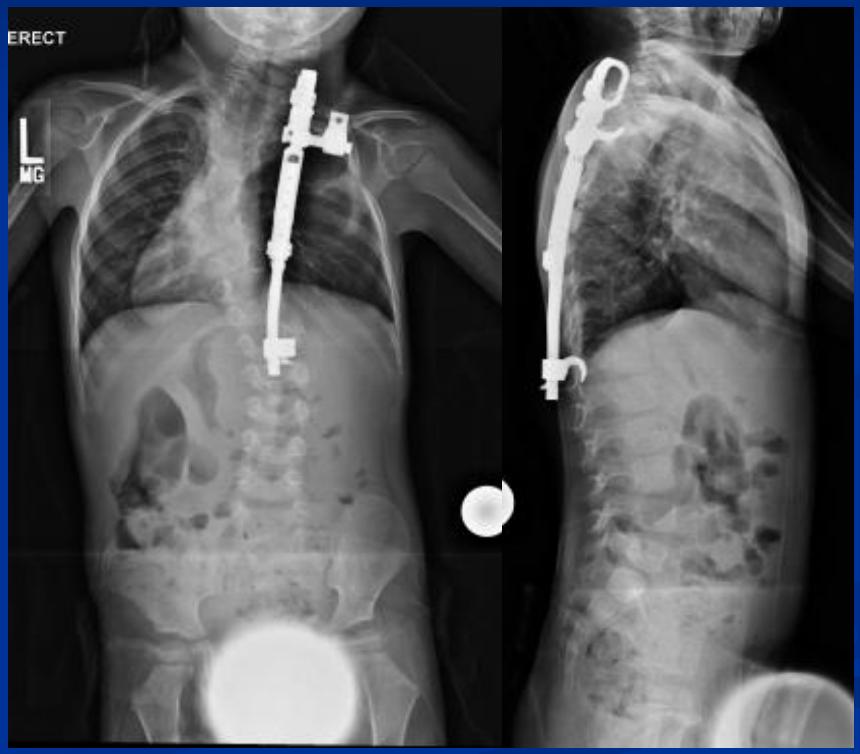
- 4 yo with progressive congenital scoliosis
  - Syndromic
  - Hearing loss
  - Low BMI
  - MRI normal

X-Rays



Surgery

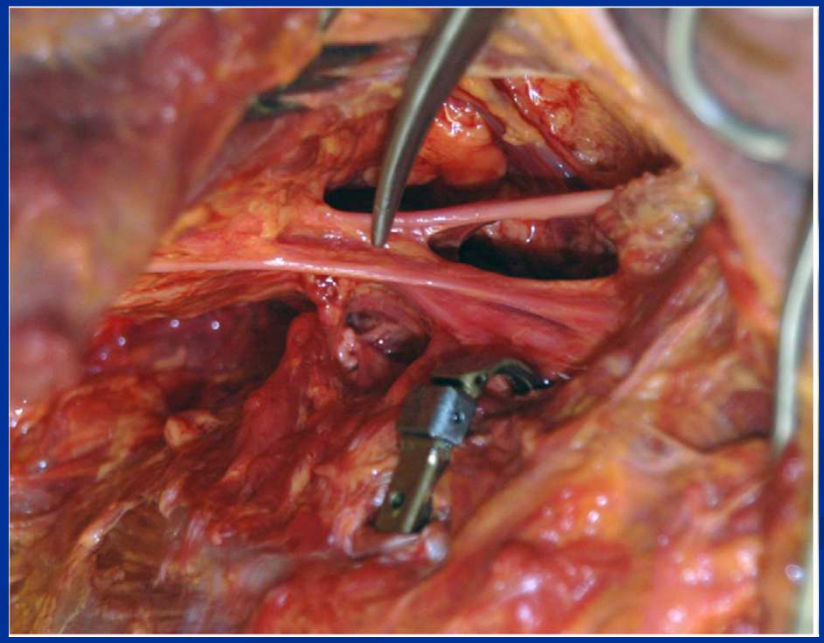
- T2/3 to L1
  - Thoracoplasty
  - Outrigger
  - Hook at L1
  - MEPs/SSEPs
  - In recovery could not move right hand
    - Returned to OR and decreased distraction
    - Recovered over one month



Mechanisms and Risk Factors of Brachial Plexus Injury in the Treatment of Early-Onset Scoliosis with Distraction-Based Growing Implants

Joiner ER, et al: JBJS 95:e161, 2013

- Distraction based rib anchors
- 4/41 (10%) experienced brachial plexus injury
- All patients with congenital scoliosis
- 3 mechanisms identified
  - First rib pushed superiorly
  - Superior pole of retracted scapula
  - Inferior mobilization of scapula for Sprengel's deformity



Neurologic Risk in Growing Rod Spine Surgery in EOS: Is Neuromonitoring Necessary for All Cases?

Sankar et al: Spine 34:1952-5, 2009

- 782 growing rod surgeries in 252 patients (rib based excluded)
  - 252 primary implantations
  - 168 exchanges
  - 362 lengthenings
- 569 (73%) monitored
  - Implantation 2/231 (0.9%)
  - Exchange 1/116 (0.9%)
  - Lengthening 1/222 (0.5%) - also change during initial implant
  - BUT anecdotal changes during simple lengthenings exist

The Recognition, Incidence, and Management of Spinal Cord Monitoring Alerts in Early-onset Scoliosis Surgery

Phillips et al, JPO 37(8):e581-7, 2017

TABLE 1. Spinal Cord Monitoring Alerts

Patients	Age	Sex	Diagnosis	Procedure	Outcome	Prior Alert	Surgery in Series
1	13	M	Coffin-Lowry syndrome	PSF	No deficit	No	6/6
2	9	M	Oral-facial-digital syndrome	GR primary implant	No deficit	NA	1/8
3	10	F	Juvenile scoliosis	GR lengthening	No deficit	No	2/3
4	4	M	Townes-Brocks syndrome	VEPTR lengthening	No deficit	No	3/12
5	4	F	Congenital scoliosis	VEPTR lengthening	No deficit	NA	1/2
6	4	F	Congenital scoliosis	VEPTR primary implant	Aborted	NA	1/2
6	5	F	Congenital scoliosis	VEPTR primary implant	Aborted	Yes	2/2
7	4	F	Cerebral palsy	GR primary implant	No deficit	NA	1/3
8	5	F	Atelosteogenesis type III	GR primary implant	No deficit	NA	1/10
8	5	F	Atelosteogenesis type III	GR lengthening	No deficit	Yes	2/10
8	7	F	Atelosteogenesis type III	GR lengthening	No deficit	Yes	4/10
8	8	F	Atelosteogenesis type III	GR lengthening	Aborted	Yes	7/10
8	11	F	Atelosteogenesis type III	PSF	No deficit	Yes	10/10
9	13	M	Myelomeningocele	GR lengthening	No deficit	No	2/7
10	8	F	Arthrogryposis	GR primary implant	No deficit	NA	1/7
10	10	F	Arthrogryposis	GR lengthening	No deficit	Yes	5/7
11	11	M	Unknown bone dysplasia	Reverse bilateral VEPTRs	No deficit	No	12/15
12	12	F	Myelomeningocele	PSF	No deficit	No	6/6

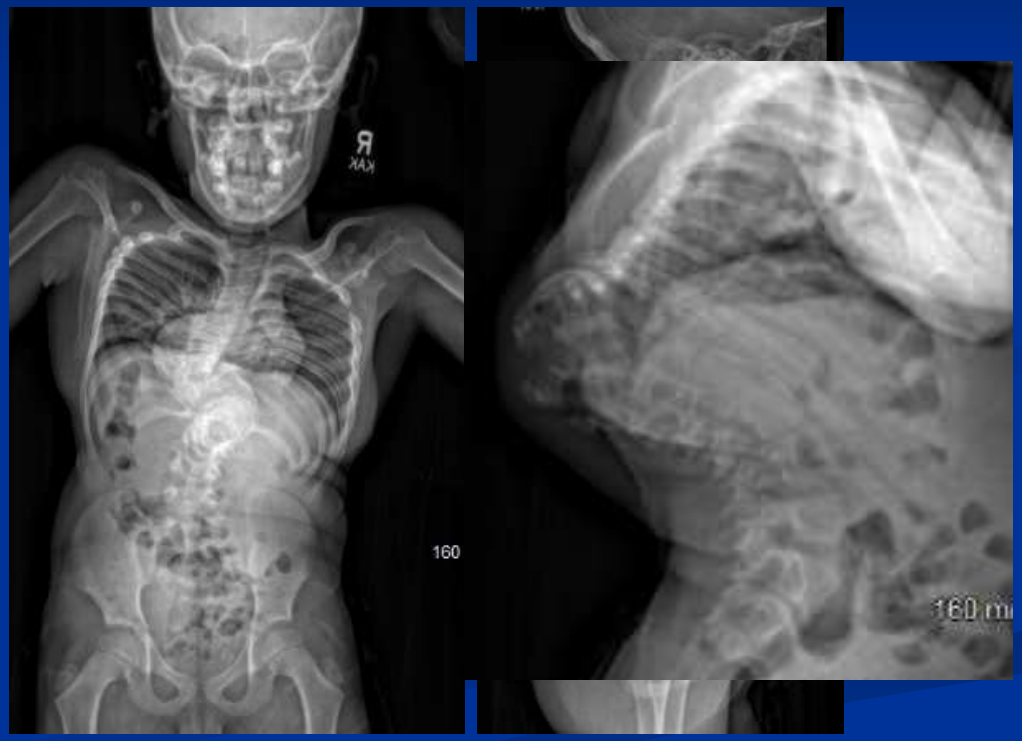
- 150 monitored surgical cases of EOS
- 18 (12%) neuromonitoring alerts
- Index implantation versus routine lengthening showed no difference
- A few patients with no alert during initial had an alert during routine lengthening

Growth Friendly Implants

- Gauthier et al, Spine Deformity 2014
  - 524 patients treated with rib based
    - 222 (42%) congenital
    - 9 (1.7%) with neurologic injury (8/9 congenital)
    - 5 patients with brachial plexus injuries
    - 7/9 patients recovered fully at 2 years
- LaGreca et al, JPO 2017
  - 2355 rib based procedures (352 patients)
    - 299 initial implant, 377 revision, 1587 expansion
    - 539 with IONM
      - 9 alerts
      - 3/192 (1.6%) initial implants
      - 3/58 (5.2%) revisions
      - 3/258 (1.2%) expansions

EOS Severe Curves

- 8-year-old patient with congenital scoliosis
  - Underwent anterior-posterior fusion at age 1
  - Severe kyphoscoliosis
  - Ambulatory but myelopathic
- Signals?
- Outcomes?



Comprehensive Assessment of Outcomes From Patients with Severe EOS Treated With a Vertebral Column Resection: Results From an SRS Global Outreach Site (FOCOS) in Ghana

Verma, et al: JPO 38:e393-8, 2018

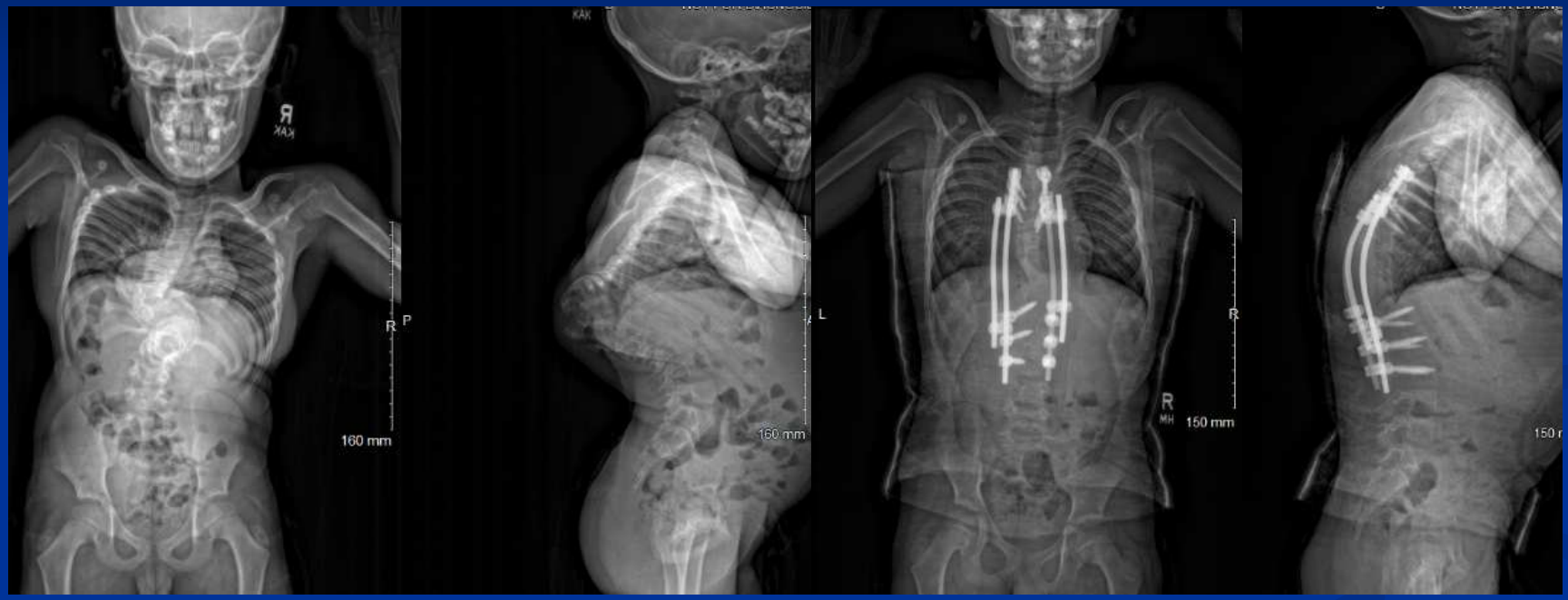
- 14 patients
  - 7 congenital
  - 7 post TB
- MEPs and SSEPs obtained on all
- 50% IONM changes
- All resolved intra-op
- No neuro deficits

TABLE 2. Coronal Radiographic Outcomes Preopreative Versus Postoperative

	Mean ± SD			
	Preoperative	**Postoperative**	**Change**	***P***
Primary curve	55.0 ± 24.9	20.6 ± 15.3	29.0 ± 25.2	**0.002**
Compensatory curve #1	36.5 ± 17.4	13.1 ± 7.9	23.3 ± 11.5	0.000
Compensatory curve #2	21.8 ± 13.8	20.2 ± 22.9	1.6 ± 11.3	0.767
C7 Shift (mm)	52.9 ± 38.9	26.2 ± 16.7	37.8 ± 28.9	0.116
T1-T12 length (mm)	136.6 ± 47.3	150.7 ± 33.6	22.2 ± 19.0	**0.065**
T1-S1 length (mm)	218.4 ± 51.2	270.7 ± 46.8	53.1 ± 35.8	0.000
Chest at T6 (mm)	174.7 ± 22.6	175.1 ± 26.1	16.1 ± 17.1	0.956

Bold values indicate statistical significance $P < 0.05$.

Post-ops



Summary

- Incomplete myelination can make obtaining MEPs difficult but with increased voltage can usually be obtained in children older than 18 months
- Intraspinal anomalies, which are common in these patients, may affect signals, particularly in patients with large syrinxes
- Rib based anchors require close monitoring of upper extremities
- The young spinal cord has tremendous ability to recover