A Novel Vertebral Numbering System Using EOS Imaging

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Background

- Congenital spinal abnormalities include anomalies of the cervical region, unilateral failure of vertebral segmentation, greater or less than 12 ribbed segments, and lumbosacral transitional vertebrae. Failure to detect congenital spinal anomalies can lead to inconsistencies with vertebral numbering. Vertebral numbering inconsistency, mislabeling, and errors can have devastating implications for patients, including catastrophic intraoperative events such as wrong-level spinal surgery.
- Variation in detection methods, regions of the spine imaged, and patient populations have prevented radiologists and surgeons from reaching a consensus on how to best identify and label anomalous spinal anatomy. EOS (whole spine) imaging may allow more comprehensive detection all patients with congenital cervical, thoracic, and lumbosacral anomalies of the spine, allowing us to generate a method that can easily and accurately applied to segmental radiographs when full-body EOS imaging is not available.

Incidence and Patterns of Vertebral Anomalies of the 3147 images analyzed:
- 8.8% had Lumbosacral Transitional Anatomy (LSTA); of these, 62.4% had 25 pre-sacral mobile segments and 37.3% had 23 pre-sacral mobile segments.
- No patients had an abnormal number of cervical vertebrae.
- All observed transitional anatomy was lumbosacral.

Incidence and Patterns of Congenital Rib Anomalies of the 3147 images analyzed:
- 5.4% had an abnormal number of ribs (> or < 12); of these, 83.6% had 11 ribs and 16.4% had 13 ribs.
- 3.5% had incomplete or hypoplastic ribs.
- Location of first ribbed vertebrae: at the 8th pre-sacral mobile segment for 99.6%; remainder at the 7th or 9th.
- Location of last ribbed vertebrae: at the 19th segment (normal anatomic level) in 94.7% of patients, 4.5% at the 18th segment, 0.76% at the 20th segment.

Vertebral Counting Method in the Setting of Transitional Anatomy:
- 1.8% had both LSTA and a rib anomaly (either rib number or rib location) in this subset:
  - 67.9% had 23 pre-sacral mobile segments + abnormal number of ribs; 30.4% had 25 pre-sacral mobile segments + abnormal number of ribs.
  - 70% had LSTA + 11 ribs; 30% had LSTA + 13 ribs.
  - Three patients had both LSTA and abnormal rib location (not abnormal rib #) first ribbed vertebrae at the 7th (opposed to 8th) pre-sacral segment.

Patients with four non-ribbed lumbar pre-sacral segments were more likely to have 23 pre-sacral mobile segments and 12 ribs (2.1%) than 24 pre-sacral segments and 13 ribs (0.3%).

Patients with six non-ribbed lumbar pre-sacral segments were more likely to have 25 pre-sacral mobile segments and 12 ribs (5.0%) than 24 pre-sacral segments and 11 ribs (3.3%).

Research Questions

1. How common are congenital rib and vertebral anomalies and in what patterns do they most often occur in EOS full-length spine imaging?
2. What vertebral counting method best accounts for transitional anatomy of the spine and can provide the lowest error when utilizing limited imaging of the spine?

Methods

- Retrospective, single institution, image analysis study of 3250 images from patients >18 years old who obtained full-length EOS spine imaging at UCH.
- 5 labelers; Discrepancies in 63 images resolved by musculoskeletal radiology attending.
- Counting and Labeling Criteria (determined by musculoskeletal radiologists, neurosurgical spine surgeons, and orthopedic spine surgeons):
  - The sacrum (S1) considered to be the endpoint of mobile segments.
  - Starting at the skull base, count caudally until reaching the sacrum to identify # of pre-sacral mobile segments.
  - In normal (absence of transitional) anatomy, there are 24 pre-sacral mobile segments (L5 being the last).
  - Identified first and last ribbed segments.
  - Recorded hypoplastic, incomplete, and unilateral ribs, in addition to failure of formation or failure of segmentation.

Figure 3. An AP lumbar radiograph demonstrating four non-ribbed pre-sacral lumbar segments numbered in two different ways. The method on the right accounts for the more common abnormality (having 23 pre-sacral mobile segments) rather than the less common abnormality (having 13 ribs).

Figure 4. An AP lumbar radiograph demonstrating six non-ribbed pre-sacral lumbar segments numbered in two different ways. The method on the right accounts for the more common abnormality (having 25 pre-sacral mobile segments) rather than the less common abnormality (having 11 ribs).

Limitations

- Single-institution study.
- Images analyzed were obtained in a population being seen in a clinical setting for evaluation.
- None of our patients had extra cervical vertebrae contributing to their transitional anatomy.

Discussion

- While classification systems exist that describe different anomalies, they do not aid in accurate labeling of vertebral levels in the setting of variable anatomy.
- Conventional methods of counting and numbering vertebrae do not consistently account for patients with congenital rib and vertebral anomalies.
- They inaccurately assume that the most caudal pre-sacral segment in the lumbar spine is indeed L5 and that patients will always have 12 ribbed vertebrae (not always the case in patients with congenital spinal anomalies).
- Our study shows that patients with < or > 5 nonribbed (traditionally called "lumbar") vertebrae are more likely to have an abnormal total number of pre-sacral mobile segments (23 or 25) than to have an abnormal number of ribs (11 or 13).
- New method for when EOS is not available: label first non-ribbed vertebrae as the first segment of the lumbar spine (L1).
- Then, if four or six lumbar segments are identified, they label the spine in a manner that accounts for the most likely form of congenital anomaly: one with an abnormal number of lumbar vertebrae, not an additional or missing rib segment.

Conclusions

- Transitional lumbosacral anatomy is more common than ribbed vertebral body anatomic variations.
- New numbering system: count in a cranial to caudal direction, with the first ribbed vertebra labeled as thoracic (T1) and the first non-ribbed vertebra in the lumbar spine labeled as lumbar (L1).
- Goal of the new method: improve consistency between radiologists and surgeons and decrease the risk of wrong level surgery in the setting of transitional anatomy.
- Future directions: test this method at multiple institutions beyond UCH.

References