The Pediatric Spine: Anatomical and Dynamic Considerations Preceding Manipulation

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INTRODUCTION
Unlike the skeletally mature vertebrae of the adult, the skeletally immature spine of the child is composed of vertebrae that are still being influenced by the processes responsible for growth and development (osteogenesis). This dynamic column reflects anatomical and biomechanical diversity. The configuration of the immature vertebra is derived from a complex set of separate ossification centers and chondrous regions (growth plates) that model and maintain the integrity of the spinal column.1 Despite the seemingly "plastic" osseous component of the child’s vertebrae, the cartilaginous growth plates have been shown, in both humans and other large mammals, to be the primary sites of mechanical energy absorption during trauma. The potential for acquired growth plate injuries is very real, and for this reason, it is important that the physician trained in spinal manipulation be acquainted with the structural and functional differences between individuals of different skeletal ages. Awareness of such dissimilarities may persuade the physician to treat the pediatric spine more conservatively than the adult spine in an effort to avoid damaging the cartilaginous growth mechanisms.

DEVELOPMENTAL ANATOMY OF THE SKELETALLY IMMATURE SPINE
Each segment of the spinal column (cervical, thoracic, lumbar, sacral, and coccygeal) has distinguishing developmental features that must be considered during the routine assessment of a child’s spine prior to manipulation. An understanding of the processes involved in growth and development is essential to this interpretation.

At birth, a typical vertebra (C3–C7, thoracic, lumbar) consists of a single ossification center within

ORIGINAL ARTICLE
Spinal manipulation is effective for the treatment of many conditions, albeit not without possible complications. The incidence of subtle growth plate fractures following high-velocity techniques in children is surely under-appreciated because of the occult nature of these injuries.

REPRINTS
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the body (centrum) and one within each of the two neural arches. These three primary ossification centers are separated from each other by hyaline cartilage growth plates that are responsible for chondroosseous expansion. These unique junctions are known as synchondroses: the two neurocentral synchondroses are located between the centrum and each neural arch, and the posterior synchondrosis is located between the two neural arches (Figure 1A). The synchondroses feature distinct cellular organization in which two opposing growth plates share a common reserve zone of chondrocytes. Progressive enlargement of the spinal canal occurs via endochondral bone transformation at each of these sites. This allows the vertebra to increase in girth while maintaining a central vertebral foramen.

Cranial and caudal to the centrum and the neural arches are plates of hyaline cartilage that are influenced by both compression (typical of epiphyses) and tensile forces (typical of apophyses). Despite the uniqueness of this area, recent scientific nomenclature commonly refers to this region as the apophyseal end-plate. These regions contain growth plates that contribute to longitudinal growth of the vertebral centrum.

Secondary centers of ossification develop within the end-plates during puberty with varying potential to ossify, but are largely reduced to peripheral circumferential rings (apophyseal rings). More inconspicuous secondary ossification also occurs within the ends of the spinous, transverse, accessory, and mammillary processes.

In contrast to the synchondrosis, the end-plate physis does not exhibit bimodal growth. Its growth plate characteristics resemble those of the physis of a long bone with the hypertrophic cells located adjacent to the centrum and the reserve zone initially abutting the intervertebral disk cartilage. In the transverse plane, the apophyseal end-plate extends beyond the neurocentral synchondroses (Figure 1B). In the immature spine, the vertebral body is defined by the circumference of the two apophyseal plates.

Humans develop thin peripheral rings of ossification that are restricted to the circumferential aspect of each end-plate (ring apophyses). In a coronal plane through the vertebral centrum it becomes quite obvious that the network of chondrous growth plates comprises a large portion of the developing vertebrae. Two horizontal end-plate physes (large arrows) lie cranial and caudal to the centrum of the vertebra and below the end-plate ossification center (E). The vertical neurocentral synchondroses (asterisks) anastomose with the end-plate physes while separating the central ossification center of the centrum from the postero-lateral ossification centers of the two neural arches (n). Internal ossification within the dens, neural arches, and centrum is complete before the first decade of life, whereas the longitudinal contribution of the end-plate physis continues until age 16–18 years. A better understanding of the tortuous path of the neurocentral synchondroses (asterisks) is seen in the transverse plane. Similar to the end-plate physes, these growth mechanisms are closely associated with the periosteum surrounding the vertebral foramen and the periosteum at the junction of the neural arch and centrum. Such a relationship could predispose the peripheral aspect of each growth-plate (Zone of Ranvier) to avulsion injury if an extreme force was propagated through the ligamentous attachments in these areas. Less significant, but important, contributors to vertebral modeling are located at the ends of the mammillary, transverse, and spinous processes. Note the experimental fracture pattern easily produced in the distal, left transverse process which was subjected to a posterior-directed force. As is the case with any bone-cartilage interface, this intersection acts as the site of energy absorption and subsequent structural failure. Similarly, subtle facet injuries can also occur.