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Current State of Pedicle Screw Constructs in Children with Spinal Deformity

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Pedicle screw use in children is a balance of safety and efficacy. Regardless of patient age or technique, pedicle screws provide 3-column fixation, load sharing surgical correction, long-term fixation, and continued growth for growing constructs. Pedicle screws are essential for 3-column fixation associated with vertebral column resection, hemivertebra excision, or fracture fixation. For nonfusion techniques, pedicle screws are excellent foundations at ends of implant constructs. The unique needs of young children for nonfusion techniques, such as traditional growing rods, Shilla, and staples, with associated regulatory challenges have led to off-label use of adult devices.
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First developed for adults in the lumbar spine, pedicle screws have been successfully used in children extensively during the past 15 years.[1,2] A conservative estimate is that there are 20,000 pediatric scoliosis cases per year, with a similar number of procedures for other pediatric conditions, such as Scheuermann kyphosis, neuromuscular scoliosis, early-onset scoliosis (EOS), congenital scoliosis, kyphosis, spondylolisthesis, fractures, and tumors. Pedicle screw use in children is a balance of safety and efficacy. It allows for a secure 3-column fixation, more robust correction with secure fixation, and continued growth in the younger child. Pedicle screws used in children have a safety and efficacy profile at least as good as that of adults.[2] Even in the young child, pedicle screw fixation does not adversely affect individual vertebral growth, although it will affect longitudinal growth.[3,4] Pedicle screw fixation has the advantages of decreased fusion levels, less reoperation for implant-related problems, and less pseudarthrosis.[2] Although pedicle screws have been approved for marketing by one company for adolescent idiopathic scoliosis (AIS) in children older than 10 years and for vertical expandable prosthetic titanium rib as a humanitarian device exemption (HDE), the unique needs of growing children for nonfusion techniques, such as Shilla, staples, and traditional growing rods, have seen regulatory challenges, leading to the off-label use of adult devices in children.

Normal Growth Features

The child grows tremendously from conception to adulthood. By far, the fastest growth spurt is between conception and birth, with next greatest during the first year of postnatal life.[5] At birth, the spine is proportionately taller than the lower segments. Overall postnatal height increases 350% and the femur increases 300%, whereas the entire spine more than doubles in length (200%) between birth and adulthood. The length of the thoracic spine is 11 cm at birth, 18 cm at age 5 years, 22 cm at age 10 years, and approximately 27 cm at maturity.[5] Although the thoracic spine has reached 70% of its adult height by age 5 years, the chest has only achieved 30% of its eventual adult volume. By age 10 years, the thoracic volume is still only 50% of predicted adult volume. At one year of age, similar to increases in thoracic and spine height, rib height is one-half the adult rib height and the thickness of the rib is similar to that of an adult.[6] This early growth of the ribs allows for very substantial upper thoracic implant sites as an alternative to pedicle fixation.

The vertebral body enlarges in height by endosteal growth of the vertebral endplate. The anterior vertebral body enlarges forward and laterally by appositional growth. The pedicle angles remain constant throughout growth. However, the transverse plane pedicle angles varies with the vertebral level, convergent at the upper thoracic and lower lumbar spine and more straight ahead in the segments between

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Figure 1 T1 in a 4-year-old child with wide-open neurocentral synchondroses and relatively small vertebral body. Hamann Todd Collection, Cleveland, OH. (Color version of figure is available online.)

these ends. In the thoracic spine, the rib articulation angle with the vertebra influences the pedicle angle. The rib articulation angle defines an axis of rib rotation, which in turn determines thoracic motion. The pedicle undergoes a proportionate doubling in height and width during childhood, making pedicle insertion progressively easier with age in the nondeformed spine.

The neurocentral synchondrosis (NCS) is a growth plate between the pedicle and the vertebral body (Fig. 1). The NCS is a bipolar growth plate, remains open at various spinal levels until midchildhood, and contributes to anterior posterior (AP) growth of the spinal canal as well as to growth of the posterior vertebral body. The spinal canal enlarges early both through endosteal remodeling of the posterior elements and longitudinal growth of the pedicles. By age 5 years, the AP diameter of the spinal canal has reached its adult size (Fig. 2).

Human and animal studies have shown that although unilateral closure of the NCS can cause asymmetric spine growth and scoliosis, it is difficult to cause significant spinal canal stenosis. This is likely because of the large effect that posterior appositional growth has on the size and shape of the spinal canal. Canal growth has been described in greater detail in the lumbar than in the thoracic spine. As is generally true with all segments of the spine in general, the proximal segment of the lumbar spinal canal matures earlier than the distal portion.[7] In one study of 38 juvenile skeletons, by age 4 years, the midsagittal lumbar canal size was adult size and the interpedicular diameter was 87% of adult size.[7] In another study, the more proximal lumbar spine canal area and AP diameter matured by approximately age 1 year, although the interpedicular diameter continued to increase until adulthood.[8] Zhang and Sucato[9] (2011) in a pilot study using 1-month-old pigs placed unilateral screws across the NCS. This produced approximately 10% reduction in pedicle length. Total spinal canal area was also diminished with unilateral and bilateral screw placement in these very young animals. Longitudinal vertebral growth was not affected, and a unilateral screw caused rotational and coronal plane deformity that was reversed with placement of a contralateral screw.

As the immature spine is proportionally smaller, so too are the pedicles and the vertebral bodies. A study of 75 anatomical specimens from 3 museums in the age range from 3 to 19 years, measured C1-L5, using direct caliper measurements.[10] There was wide variation in morphology at each vertebra, especially in the younger spine specimens. The lower lumbar

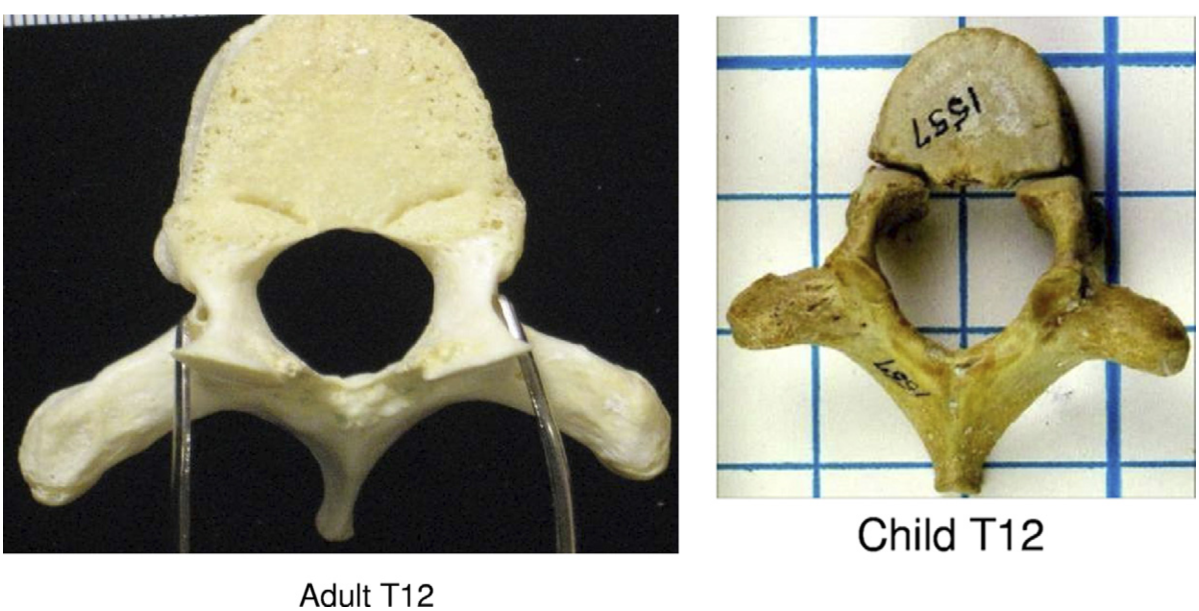

Figure 2 Note that in the young child (Hamann Todd Collection, Cleveland, OH), the spinal canal is as large as that of the adult's in the adult (Maxwell Osteology Collection, University of New Mexico, New Mexico). The posterior elements are similar in size, but the child's vertebral body is much smaller. (Color version of figure is available online.)