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Case Series

Sagittal Spine Length Measurement: A Novel Technique to Assess Growth of the Spine

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Abstract

Study Design: The accuracy and repeatability of a novel sagittal spine length (SSL) radiographic measurement was examined using photographic and radiographic imaging.

Objectives: To validate the new SSL technique for measuring growth in early-onset scoliosis (EOS) patients.

Summary of Background Data: Current assessment of patient growth undergoing growth-friendly surgical treatment for EOS is the use of serial vertical spine height measurements (VH) on coronal radiographs. Spine-based distraction implants are able to control the coronal plane deformity of scoliosis, but exhibit a ''law of diminishing returns'' in the impact of each follow-up lengthening surgery. As these treatments are kyphogenic, we hypothesize that the increase in kyphosis is, in fact, growth out of plane, not captured by standard spine height measurements.

Methods: Measurement accuracy was assessed using 6 spine model alignments and clinical radiographs of 23 retrospective EOS patients. Inter- and intrarater reliabilities were assessed using interclass coefficient (ICC) analyses. The discrepancy between the VH and SSL was also investigated.

Results: The model assessment showed excellent accuracy, with a 1.54 mm (SD: 1.07, range: 0.03–3.14, $p = .226$) mean error and mean ICCs of 0.999. As the kyphosis increased, a progressive difference between the phantom VH and SSL was observed. Interrater reliability ICCs of the clinical radiographs averaged 0.981 and 0.804, whereas intrarater reliabilities averaged 0.966 and 0.826, for the coronal and sagittal radiographs, respectively. Mean clinical SSLs were 177.5 mm (SD: 28.5, range: 114.3–250.3), whereas the VH averaged 161.6 mm (SD: 31.8, range: 58.5–243.0), resulting in a 16.0-mm (SD: 16.7, range: 0.3–90.3, $p < .0001$) difference between the two measurements with a progressive difference as the kyphosis increased.

Conclusions: The novel SSL measurement is accurate, repeatable, and complements the current growth assessments for EOS treatments. Until sagittal spine lengths are taken into consideration, the ''law of diminishing returns'' should be interpreted with caution.

Level of Evidence: Level II - Prospective Comparative Study.

Keywords: Early-onset scoliosis; Spine length; Law of diminishing; Returns; Spine growth; VEPTR

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Introduction

Early-onset scoliosis (EOS) is defined as scoliosis with onset less than the age of 10 years, regardless of etiology [1-3]. One of the treatment goals for growth-friendly surgery is to allow for spine and chest growth while controlling spine and chest deformity [2]. To assess the ongoing growth of patients with posterior distraction−based growth-friendly treatments (ie, rib-based and spine-based growing rods), serial measurements of the vertical spine height are taken from standard of care, weight-bearing coronal radiographs. These measurements are one-dimensional length measurements, usually performed from the first thoracic vertebra to the first sacral vertebra (T1−S1), although alternatively measured from T1 to T12 if examining only the thoracic spine region [4,5].

The Children's Spine Study Group has published that rib-based distraction surgeries maintain 75% of the expected T1−S1 growth up to the age of 10 years [4,6]. This same group of subjects had a significant increase in their mean kyphosis (44.5 degrees at first lengthening to 64.8 degrees by the 15th lengthening surgery) [6]. It is hypothesized that these traditional coronal plane measurements of spine length may not account for any out-of-plane length increases that may lead to an underestimation of the growth effects of the surgical interventions. Sankar et al. [7] found that the use of spine-based distraction implants performed well at controlling the coronal plane deformity of the scoliosis but were found to exhibit a ''law of diminishing returns'' in the increase in vertical spine height imparted at each follow-up lengthening surgery. They attributed the diminishing returns to auto fusion that limited the ability for the spine to continue to grow with repeated attempts at surgical lengthening. This study has helped popularize an evolving trend toward the use of serial casting as a ''delay tactic'' for the treatment of EOS [8]; however, it did not comment on the effects of repetitive lengthening on thoracic kyphosis. As it has been demonstrated that spine-based distraction surgeries are kyphogenic by nature [6,9-11], there may be sagittal plane increases in length that may not be represented by his measurements and may have led to an underrepresentation of the growth effects of spine-based distraction surgery.

We hypothesize that because of the limitations of the vertical height measurement, the increase in kyphosis of these patients is in fact out-of-plane growth that may be occurring at the expense of vertical height. Therefore, the ''law of diminishing returns'' may not only be a loss of patient growth related to auto-fusion, it may in fact be a diminishing returns of the measurement technique; the tissues of the spine are still increasing in size (the vertebrae are getting taller, with their endplates getting farther apart), growth not reflected in the current measurements. To account for this potential ''loss of growth,'' we developed a custom software program to measure the curved arc length of the spine in the sagittal plane (sagittal spine length [SSL]; Fig. 1). The authors believe that the inclusion of the actual arc lengths of the spinal segments may add considerable value to the assessment of spinal growth over the traditional straight vertical measurements. The purpose of this study was to validate this new technique for measuring the sagittal spine length for patients with early-onset scoliosis.

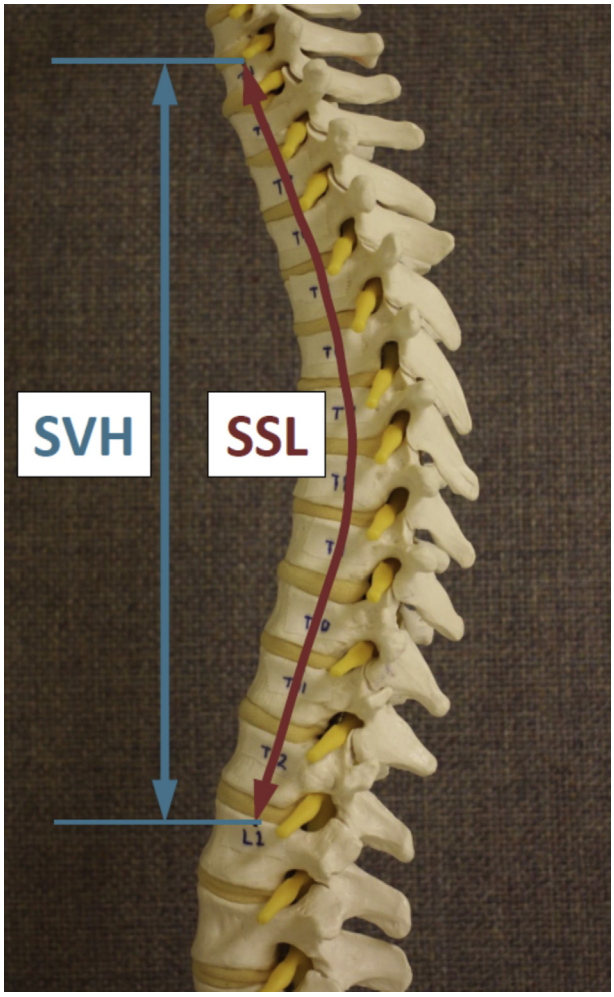

Fig. 1. Measurements of the physical spine model. SVH - the vertical height of the T1-L1 spine section; SSL - the sagittal spine length of the T1-L1 spine section. The SVH is equivalent to the traditional coronal plane measurements of spine vertical height of the same section when all magnification errors are taken into account.

Materials and Methods

Using the LabView software environment (National Instruments, Austin, TX), a research engineer created a custom spine curve length measurement program. The program allowed for the import of DICOM radiographic images, selection of the desired vertebral levels to be measured (any contiguous section between T1 and S1), and selection of the measurement points on the image using the computer mouse. The program instructs users to select measurement points that represented the center of the superior endplate for each vertebra. Therefore, to measure from T1 to T12 (inclusive), a user would select each