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Sequential Magnetic Resonance Imaging Reveals Individual Level Deformities of Vertebrae and Discs in the Growing Scoliotic Spine

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Abstract

Study Design: The aim of this study was to measure contributions of individual vertebra and disc wedging to coronal Cobb angle in the growing scoliotic spine using sequential magnetic resonance imaging (MRI). Clinically, the Cobb angle measures the overall curve in the coronal plane but does not measure individual vertebra and disc wedging. It was hypothesized that patients whose deformity progresses will have different patterns of coronal wedging in vertebrae and discs to those of patients whose deformities remain stable.

Methods: A group of adolescent idiopathic scoliosis (AIS) patients each received two to four MRI scans (spaced 3−12 months apart). The coronal plane wedge angles of each vertebra and disc in the major curve were measured for each scan, and the proportions and patterns of wedging in vertebrae and discs were analyzed for subgroups of patients whose spinal deformity did and did not progress during the study period.

Results: Sixteen patients were included in the study; the mean patient age was 12.9 years (standard deviation 1.7 years). All patients were classified as right-sided major thoracic Lenke Type 1 curves (9 type 1A, 4 type 1B, and 3 type 1C). Cobb angle progression of $\geqslant 5°$ between scans was seen in 56% of patients. Although there were measurable changes in the wedging of individual vertebrae and discs in all patients, there was no consistent pattern of deformity progression between patients who progressed and those who did not. The patterns of progression found in this study did not support the hypothesis of wedging commencing in the discs and then transferring to the vertebrae.

Conclusion: Sequential MRI data showed complex patterns of deformity progression. Changes to the wedging of individual vertebrae and discs may occur in patients who have no increase in Cobb angle; therefore, the Cobb method alone may be insufficient to capture the complex mechanisms of deformity progression.

Keywords: Adolescent idiopathic scoliosis; Cobb angle; Magnetic resonance imaging; Curve progression; Spine deformity

Introduction

Adolescent idiopathic scoliosis (AIS) is a complex deformity of the spinal column and trunk for which the cause has not yet been identified. A key problem with the assessment and treatment of scoliosis is the current lack of understanding of the mechanisms governing deformity progression. In current clinical practice, scoliosis severity and progression is assessed through repeated radiographic measurements of the Cobb angle, a single angle that describes the severity of the lateral scoliotic curve (usually containing 6−8 intervertebral joints) on coronal plane standing radiographs [1]. However, the use of clinical radiographs in exploring underlying patterns of deformity progression during growth is not desirable, because they involve repeated exposure to ionizing radiation and suffer from poor contrast when imaging soft tissues. The combined dose for full spine posteroanterior (PA) and lateral standing radiographs is in the order of 1.0 mSv, and the annual background radiation in Queensland, Australia, is approximately 2.0−2.4 mSv [2,3]. Patients diagnosed with AIS have historically undergone an average of 12 to 22

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plain radiographs during a 3-year surveillance period, exposing the patient to significant levels of radiation [4,5], which in the modern era is being reduced as alternative surveillance and imaging techniques are developed. Nonionizing imaging modalities such as magnetic resonance imaging (MRI) are favorable, but are currently only used routinely for preoperative AIS patients to detect suspected intracranial and intraspinal anatomic or neurologic abnormalities rather than for assessment of the deformity itself.

When studying the progression of scoliotic deformities during skeletal growth, it is imperative to explore changes occurring at the level of individual vertebrae and discs (ie, not just the overall Cobb angle), because the degree of local deformity varies with location in the major scoliotic curve [6-8], and the biomechanical forces driving deformity progression are also not uniformly distributed within the major curve [9].

Several previous studies have suggested that there is a relationship between vertebral wedging and spinal growth in scoliosis, and that wedging initiates in the discs and later in the vertebrae [6,8,10,11]. Vertebral wedging and scoliosis progression have been reported in both mild and moderate curves, with wedging increasing primarily in the three levels inferior to the curve apex [7].

With the increasing awareness surrounding radiation doses in children, and the strong relationship of scoliosis curve progression with growth, it is important to assess the growing scoliotic spine with a nonionizing imaging modality. For this reason, the aims of this study were (1) to measure the individual deformations of the vertebrae and discs in the growing scoliotic spine using sequential MRI; (2) to examine the differences at the vertebra/disc level between those patients whose curve progressed and those whose did not; and (3) to consider the clinical implications of these findings.

Since the coronal plane Cobb angle is the current standard for clinical assessment of scoliosis progression, this study looked at the wedging and height changes of the vertebrae and discs only in the coronal plane. It was hypothesized that there is a consistent pattern of increasing coronal plane deformity in the vertebrae and discs with curve progression during growth, and that this pattern will differ between patients whose deformity progresses and those whose does not.

Methods

MRI protocol

A 3D MRI protocol was developed using a 3-Tesla (3T) MRI scanner (Philips Achieva 3.0T TX Dual Transit system, Amsterdam, Netherlands) at the Mater Hospital, Brisbane, Australia. A coronal "scout" image stack (a low-resolution scan containing 9–10 slices) was taken to capture the whole spine and identify the major scoliotic curve. The protocol used to perform the scout scan was a T_1-weighted 2D gradient echo sequence with an acquisition time of 5 minutes. The time to repetition (TR) and the time to echo (TE) were set as 6.9 and 4.6 milliseconds, respectively, with a flip angle of 20°. The protocol for the high-resolution 3D scan of the major scoliotic curve was a T_1-weighted 3D gradient echo sequence, with an isotropic voxel size of 0.49 mm, TR of 5.9 milliseconds, TE of 2.7 milliseconds, flip angle of 5°, and an acquisition time of 15 minutes. The field of view was adjusted according to the patient's deformity to ensure the whole of the major curve was captured. The 3D volume acquired using this sequence was 250 × 250 × 95 mm. Patients were in the supine position with arms by their side for all scans.

Patient demographics and clinical data collection

MRI scans were obtained for a group of AIS patients from the Mater Children's Hospital Spinal Clinic in Brisbane, Australia, over a 14-month period. Standing coronal Cobb angle and Risser Grade [12] were assessed on each patient's clinical standing radiograph, at routine spine clinic appointments, usually within a month of the MRI scan date. Standing height, rib hump, and menarche status were recorded from the patient's spine clinic records. Suitable patients were identified as those who had been diagnosed with AIS, aged a minimum of 10 years (to the nearest 0.1 year). Participants' clinical care was not altered as a result of their participation in the project and therefore could be either braced or unbraced, but never having received operative treatment. As our Center draws patients from a large geographical area, patients also had to be willing to commit to attend our Center for the research scans and travel the sometimes long distances that were involved to participate. As the primary focus was on curve progression during the adolescent growth phase, only patients who were Risser grade <3 were included, to ensure there was still remaining spine growth until skeletal maturity. Leg length differences of up to 1 cm were considered acceptable. Patients underwent an initial MRI scan after recruitment to the study, then received up to three more scans during growth until they either went on to surgery or were discharged from the clinic.

To capture the rapid growth spurt of the patient, the time periods between the scans varied according to the stage of growth of individual patients, determined during their clinical appointments with the spinal orthopaedic surgeons as part of their standard care. Informed consent was received from all participants and parents, and ethical approvals were obtained from the Mater Human Research Ethics Committee and Queensland University of Technology Human Research Ethics Committee.

Image analysis

To assess the change in coronal plane deformity during the adolescent growth phase, the MRI scans for each patient