Clinical Biomechanics 32 (2016) 220–228

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Understanding how axial loads on the spine influence segmental biomechanics for idiopathic scoliosis patients: A magnetic resonance imaging study

J.P. Little *, M.J. Pearcy, M.T. Izatt, K. Boom, R.D. Labrom, G.N. Askin, C.J. Adam

Paediatric Spine Research Group, Institute for Health and Biomedical Innovation - Centre for Children's Health Research, Queensland University of Technology and Mater Health Services Ltd., Brisbane, Australia

ARTICLE INFO

Article history:
Received 28 March 2015
Accepted 17 November 2015

Keywords:
Adolescent idiopathic scoliosis
Spine biomechanics
Joint compliance
Flexibility
Magnetic resonance imaging
Axial loading

ABSTRACT

Background: Segmental biomechanics of the scoliotic spine are important since the overall spinal deformity is comprised of the cumulative coronal and axial rotations of individual joints. This study investigates the coronal plane segmental biomechanics for adolescent idiopathic scoliosis patients in response to physiologically relevant axial compression.

Methods: Individual spinal joint compliance in the coronal plane was measured for a series of 15 idiopathic scoliosis patients using axially loaded magnetic resonance imaging. Each patient was first imaged in the supine position with no axial load, and then again following application of an axial compressive load. Coronal plane disc wedge angles in the unloaded and loaded configurations were measured. Joint moments exerted by the axial compressive load were used to derive estimates of individual joint compliance.

Findings: The mean standing major Cobb angle for this patient series was 46°. Mean intra-observer measurement error for endplate inclination was 1.6°. Following loading, initially highly wedged discs demonstrated a smaller change in wedge angle, than less wedged discs for certain spinal levels (+2,+1,−2 relative to the apex, ($p < 0.05$)). Highly wedged discs were observed near the apex of the curve, which corresponded to lower joint compliance in the apical region.

Interpretation: While individual patients exhibit substantial variability in disc wedge angles and joint compliance, overall there is a pattern of increased disc wedging near the curve apex, and reduced joint compliance in this region. Approaches such as this can provide valuable biomechanical data on in vivo spinal biomechanics of the scoliotic spine, for analysis of deformity progression and surgical planning.

1. Introduction

Scoliosis is a three dimensional deformity of the spine, involving rotation of the vertebrae in both the coronal and transverse planes. Adolescent idiopathic scoliosis (AIS) is the most common type of deformity, for which there is no known cause or cure. The spinal deformity is characterised clinically using the Cobb method (Cobb, 1948) which provides an angular measurement of the overall deformity, as defined by the spinal levels at the cephalic and caudal limits of the major curve.

There is still much to learn regarding biomechanical factors which define and characterise AIS deformity, particularly since mechanical loading on the spine has been implicated as a contributing factor in AIS aetiology (Asher and Burton, 2006) and deformity progression (Adam et al., 2008; Roaf, 1966). While clinically, the Cobb method measuring spinal curvature in the coronal plane is an important and straightforward parameter for assessing deformity; this provides no quantitative information on the flexibility or biomechanics of the spinal segments (Berger et al., 2015; Buchler et al., 2014; Hasler et al., 2010). To better understand level-wise spinal joint mechanics, Berger et al. (2015) and Buchler et al. (2014) presented results for the preoperatively measured mechanical flexibility of individual spinal joints in AIS patients. These data were measured using a controlled traction force and presented new information on the variation in coronal plane flexibility throughout the major curve.

In the upright posture, gravitational loading aligned with the longitudinal axis of the AIS spine is a significant component of the forces applied to the spine. The coronal curvature and axial rotation in the AIS spine change when patients move from a supine to a standing position (Little et al., 2012; Torell et al., 1985; Wessberg et al., 2006). Moreover, gravity-induced torque active on the spine during axial loading has been proposed as a biomechanical cause for the increase in axial vertebral rotation which is observed during growth of the AIS spine (Adam et al., 2008).

While prior studies have demonstrated the crucial role played by biomechanical loading in influencing AIS deformity (Drevelle et al.,

* Corresponding author at: Gardens Point Campus, Queensland University of Technology, 2 George Street, Brisbane QLD 4000, Australia.
E-mail address: j2.little@qut.edu.au (J.P. Little).

http://dx.doi.org/10.1016/j.clinbiomech.2015.11.007
0268-0033/

2008; Kleinman et al., 1982; Lamarre et al., 2009; Little et al., 2012; Takahashi et al., 1997; Torell et al., 1985; Wessberg et al., 2006), rarely do they consider this influence in terms of the biomechanical behaviour of individual spinal joints (i.e. spinal segments). Rather, assessment methods that measure the behaviour of the overall deformity are employed, such as use of the Cobb method (Cobb, 1948) and spinal shape classifications (Lenke et al., 2001) to characterise coronal deformity. These provide information on only one aspect of the overall deformity. Conversely, segmental biomechanics are important since the overall spinal deformity is comprised of the cumulative coronal and axial rotations of individual joints, which themselves often deviate from the normal alignment of the spine. Hasler et al. (2010) note that an understanding of how the three dimensional deformity of the spinal joints changes when loaded is essential in order to understand how the biomechanics of the spine changes in response to surgical treatment.

In this study we investigate the segmental biomechanics of the scoliotic spine in response to axial compression. Axial compression is a physiologically relevant load case occurring due to body weight in the upright position. Although several prior studies have explored the change in Cobb angle between supine and standing (axially loaded) positions, to our knowledge there is no existing data on the relative segmental *compliance* in the scoliotic spine under axial compressive loading, despite this being a primary direction of loading. (*Compliance*, the inverse of *stiffness*, is a measure of the deformation produced by a given force.) Hence, the current study investigates the segmental compliance for a series of AIS patients who underwent supine MRI scanning, both with and without an axial compressive load.

2. Methods

A series of 15 AIS patients who attended the spinal deformity clinic at the Mater Children's Hospital in Brisbane, Australia underwent supine magnetic resonance imaging (MRI) scans unloaded and while simultaneously being subjected to axial compression using a custom-developed pneumatic compression device. The compression device and the MRI scanning procedure have previously been described in detail (Adam et al., 2010), so it will be reported here only briefly.

2.1. Compression device

The compression device was custom-developed to apply a user-defined axial compressive load along the length of the spinal column, and to maintain this load while the patient underwent a supine MRI scan (Fig. 1). The device consisted of: a pneumatic actuator which was attached to a polyurethane footplate in which the patient's feet were located; knee supports to ensure the patient did not hyperextend during the compression loading procedure; and nylon straps which attached the pneumatic actuator to a neoprene vest fitted to the patient's torso. The device applied an axial compressive load to the spine primarily through contact between the straps of the vest and the patient's shoulders. The compression device was activated remotely from the MRI control room imposing a pre-defined compressive force (maximum 500 N) oriented axially along the spine. The device was manufactured from non-metallic components to permit operation within the magnetic field of the MRI scanner.

2.2. MRI scanning procedure

Ethical approval was granted by the Mater Hospital Human Research Ethics Committee to conduct this study and informed patient consent was obtained from all subjects and their parents prior to participation in the study. The patients were scanned in both an unloaded and loaded position in the same session using a Siemens Sonata 1.5T scanner (Siemens AG, Munich, Germany) using a T1 turbo spin echo sequence with acquisition time 9 min per sequence, a scan window of $21 \times 28 \times 8$ cm and 1.1 mm isotropic voxel resolution. A preliminary scout film was obtained first, in order to identify the relevant spinal region. Following this, the scan window was selected to ensure spinal levels included the major curve for each patient, which usually encapsulated both the thoracic and proximal lumbar spine. The patients were positioned supine and the pelvis was in a neutral position during the unloaded scan procedure. A removable oil capsule was attached to the patient's skin at the bony prominence of T2, to provide an external anatomical reference on both the unloaded and loaded MR images.

Following the unloaded scan a compressive axial load equivalent to 50% body weight was applied. To ensure relaxation of the spinal tissues,

Fig. 1. A patient positioned supine on the MRI scanner bed prior to undergoing axially loaded MRI. Patient is wearing the neoprene vest with nylon straps connecting the vest to the pneumatic actuator at their feet.