Gait & Posture 66 (2018) 181–188

Contents lists available at ScienceDirect

Gait & Posture

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

Motion analysis in the axial plane after realignment surgery for adolescent idiopathic scoliosis

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A R T I C L E I N F O

Keywords:
Adolescent idiopathic scoliosis
Gait analysis
Motion analysis
Axial plane
Posterior spinal fusion
Postoperative changes

A B S T R A C T

Background: This study aimed to define changes occurring in axial plane motion after scoliosis surgery in patients with adolescent idiopathic scoliosis (AIS) using gait analysis. Pre- and postoperative axial plane motion was compared to healthy/control subjects. This may potentially improve our understanding of how motion is impacted by deformity and subsequent surgical realignment.
Methods: 15 subjects with AIS underwent pre- and postoperative radiographic and gait analysis, with focus on axial plane motion (clockwise [CW] and counterclockwise [CCW]). Age, weight, and gender-matched controls (n = 13) were identified for gait analysis. Control, preoperative and postoperative groups were compared with paired student's t-tests.
Results: Surgical realignment resulted in significantly decreased in upper thoracic, thoracic, thoracolumbar and lumbar Cobb angles pre-to-postoperatively (36.7° vs. 15.2°, 60.1° vs. 25.6°, 47.7° vs. 17.7° and 27.2° vs. 4.8°, respectively) (all $p < 0.05$), with no significant change in thoracic kyphosis, lumbar lordosis, central sacral vertical line, pelvic incidence, and sagittal vertical axis. However, pelvic tilt significantly increased from 4.9° to 8.1° (p = 0.035). Using gait analysis: preoperative thoracic axial rotation differed (mean CW and CCW rotation was 1.9° and 3.1° [p = 0.01]), whereas mean CW & CCW pelvic rotation remained symmetric (2.0° and 3.0°; p = 0.44). Postoperatively, CCW thoracic rotation range of motion decreased (CW: 0.6° and CCW: 1.4°; p = 0.31). No significant difference in postoperative pelvic rotation occurred (1.1° and 3.4°; p = 0.10). Compared to controls, AIS patients demonstrated no significant difference in total CW & CCW thoracic motion relative to the pelvis both pre- (14.9° and 12.3°, respectively; p = 0.45) and postoperatively (12.9° and 12.3°, respectively; p = 0.82).
Significance: AIS patients demonstrated abnormal gait patterns in the axial plane compared to normal controls. After surgical realignment and de-rotation, marked improvement in axial plane motion was observed, highlighting how motion analysis can afford surgeons three-dimensional perspective into the patient's functional status.

1. Introduction

Spinal realignment and fusion are the mainstays of treatment for severe adolescent idiopathic scoliosis (AIS). Operative goals include limiting the number of vertebral levels fused while achieving stabilization of the deformity and maintaining spinal balance in the coronal and sagittal planes. It is typical for scoliosis fusions to span 8–10 intervertebral levels when using the posterior approach [1]. Thus, it is logical that these long thoraco-lumbar constructs would result in functional changes in the postoperative AIS patient. This has been

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https://doi.org/10.1016/j.gaitpost.2018.08.015
Received 22 April 2018; Received in revised form 5 July 2018; Accepted 18 August 2018
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demonstrated when assessed using force plate and opto-electronic gait analyses.

Previous research has confirmed loss in overall flexion, lateral bending, and rotation of the spine in the fused postoperative AIS patient [2–4]. Naturally, a loss of segmental motion over the fused segments would result in an overall reduction in range of motion in all three planes. On the other hand, spinal realignment and fusion during scoliosis treatment may also produce favorable changes in function. Our previous work has demonstrated improvements in center of mass (COM) – center of pressure (COP) inclination angles, a surrogate measure of global balance during gait, in postoperative AIS patients. Improvements in balance and reductions in COM excursions in the coronal plane indicate a tighter cone of economy [5] and improved energy expenditure during gait [6–9].

Vertebral rotation in the axial plane is recognized by some surgeons as the primary deformity of an AIS curvature and previous studies have demonstrated that vertebral rotation, as seen in AIS, may result in an asymmetric left-right gait pattern in the axial plane [10–12]. Intraoperative maneuvers during AIS realignment are pursued to de-rotate the spine and improve overall radiographic symmetry; however, our understanding of the postoperative impact of vertebral de-rotation and its impact on gait (function) in the axial plane is still very limited.

This investigation aimed to study axial plane motion before and after scoliosis correction. Our study sought to investigate the following: 1) the preoperative axial plane motion in AIS patients, and 2) the postoperative motion in the axial plane, the changes from preoperative motion, and comparisons to normal controls. The goal of identifying any axial plane changes is to offer dynamic data and afford surgeons a three-dimensional perspective into the patient's functional status in order to optimize surgical treatment.

2. Methods

2.1. Study Population

This was a prospective study of patients with AIS presenting for treatment at a single institution. Data was collected in compliance with our Institutional Review Board. Any AIS patients who underwent posterior spinal realignment and fusion, with pre- and postoperative radiographic and gait data, were included in this study. Patients were excluded if they had a spinal deformity from an etiology other than an adolescent idiopathic curve (neuromuscular, adult degenerative, infantile), gait pathology or neurological dysfunction assessed during physical examination, or demonstrated a > 1 cm leg-length discrepancy on scanogram evaluation. Subjects without spinal deformity (matched for age and sex) were recruited to serve as a control group from our institutions pediatric clinic.

2.2. Radiographic analysis

For each patient, full-length 36″ coronal and sagittal radiographs were taken preoperatively and one year postoperatively. Images were downloaded in DICOM format and analyzed using Surgimap Spine (NEMARIS Inc., New York, USA). As with our standard AIS workup, each patient underwent preoperative MRIs to rule out further neural pathology. Various parameters were then measured in the coronal and sagittal planes (Fig. 1). Operative technique was consistent for each patient regarding fluoroscopically-guided poly-axial screw insertion. An effort toward vertebral translation and segmental vertebral de-rotation was pursued prior to final tightening of the set screw.

2.3. Gait capture

Whole-body gait analysis was performed for each subject before and at one year following surgery. Each subject walked on a level, unobstructed surface in a dedicated motion lab with a 24 ft. walkway. Two AMTI OR-6 force-plates (Advanced Mechanical Technology Inc., Watertown, MA) were installed on the walkway, and subjects were instructed to walk over these force-plates. Ten to twenty trials at a self-selected speed were performed in order to obtain clean force-plate strikes. Each patient underwent three trials, which were averaged and used for analysis. Marker positions were recorded with a seven-camera system (Vicon 512, Vicon Peak, Oxford, UK) at 100 Hz using 34 retro-reflective markers applied according to the Helen Hayes Marker and Plug-In-Gait Model (Fig. 2). The Helen Hayes Marker set is a simple external marker set designed for time-efficient video analysis of lower extremity kinematics [13]. The Vicon system is highly reliable and accurate, with a reported margin of error less than 1.5° [14,15].

2.4. Data analysis

2.4.1. Point of data capture

Raw/unformatted reflective marker positional data in all three planes at each phase of the gait cycle was obtained from three walking trials, creating a triplicate data set for each patient. The gait cycle was defined as heel-strike to heel-strike (e.g. left heel to left heel). Each discrete point in the gait cycle was defined as a percentage of the complete gait cycle (0–100%), with 0% corresponding to the first heel-strike and 100% corresponding to the second heel-strike. Additionally, within the gait cycle there was one heel-strike of the contralateral foot occurring at the cycle midpoint. All data was exported and analyzed utilizing custom algorithms to compute the final gait data parameters (see below).

2.4.2. Axial plane analysis

Axial plane motion (rotation) of the thorax was assessed by measuring individual rotation, in degrees, of the thorax and the pelvis throughout the gait cycle. Rotation to the right (clockwise/CW) was defined as a positive angular displacement, whereas rotation the left (counterclockwise/CCW) was assigned a negative value. Major data points that were assessed included: 1) maximum and minimum rotation of the thorax and pelvis, 2) angular difference between rotation of the thorax and pelvis (pelvic-thorax rotational difference), and 3) the phase shift between thoracic and pelvic rotational movement (defines gait pattern and serves as a surrogate value for the coordination of trunk and pelvic motion during ambulation). Rotational parameters were assessed in AIS patients both pre- and postoperatively and then compared to control (non-AIS) group. Raw angular data was reported as positive (+) and negative (-) measurements; these have been adjusted using clockwise (+) and counterclockwise (-) as terminology for clarity.

2.4.3. Statistical analysis

Mean values and 95% confidence intervals were calculated for each data range. The Shapiro–Wilk test was used to test normality of the data. Paired student t-tests were used to compare pre- and post-operative radiographic and gait measurements, while unpaired t-tests were used for comparison of AIS and control subjects. Correlation coefficients were used to analyze differences in gait patterns. Statistical analysis was performed with a Bonferroni corrected p-value of $p < 0.05$ for significance.

3. Results

The control group was comprised of 13 subjects (7F:6 M) with a mean age of 16.6 years old (range: 10–24). Mean height and weight of the patients were 64.0 kg and 162.6 cm. The research group was comprised of 15 patients (10F:5 M) with a mean age of 14.13 years (range: 11–19). Mean height and weight of the patients were 58.3 kg and 162.2 cm. There was no difference between the groups regarding sex, and age. Preoperative Lenke classification of each individual in the research group yielded Type 1 – 5; Type 2 – 1; Type 3 – 0; Type 4 – 8;

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