Gait & Posture 39 (2014) 372–377

Contents lists available at ScienceDirect

Gait & Posture

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

Crouch gait in persons with positive sagittal spine alignment resolves with surgery

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ARTICLE INFO

Article history:
Received 13 November 2012
Received in revised form 5 August 2013
Accepted 9 August 2013

Keywords:
Spinal deformity
Positive sagittal alignment
Reconstruction surgery
Gait analysis
Crouch gait

ABSTRACT

Objective: Degenerative spinal conditions often result in positive sagittal alignment which may be corrected using multi-segment spinal reconstructive surgeries. The purpose of this study was to investigate gait kinematics before and after spinal reconstructive surgery in persons with positive sagittal alignment.
Methods: Subjects presenting with positive sagittal alignment of greater than or equal to 7 cm who were treated with spinal reconstructive surgery were included in this study. Gait analyses were conducted pre- and 6 months post-operatively. Data were collected while subjects stood quietly for 20 s and walked at their normal self-selected walking speed.
Results: For 12 subjects, sagittal spine alignment during standing and walking was significantly decreased post-operatively ($p < 0.0001$ for standing and $p < 0.0005$ for walking). Prior to surgery, the subjects appeared to adopt a crouch gait with the knee flexion angle at mid terminal stance decreasing significantly after surgery ($p < 0.0$ for the dominant lower limb and $p < 0.0$ for the non-dominant lower limb). Additionally, dominant step length ($p < 0.003$) and non-dominant step length ($p < 0.001$) increased significantly after surgery.
Conclusions: Positive sagittal alignment resulted in crouch gait, which was resolved after multi-segment reconstructive spinal surgery that improved sagittal spinal alignment. Step and stride lengths also improved after surgical correction of the sagittal alignment.

1. Introduction

Regional spinal curvatures, including lumbar lordosis and thoracic kyphosis, allow humans to maintain an upright posture with minimal energy expenditure and efficient muscle activity [1–3]. These normal spinal curvatures result in a sagittal spine alignment wherein the anterior-posterior distance between C7 and S1 vertebrae is less than 5 cm when measured using static X-rays [2,4,5]. When a plumb line drawn from the midpoint of the C7 vertebral body is located at 5 cm or more anterior to the posterior superior aspect of the S1 vertebral body in the sagittal plane, the spine is considered to have a positive sagittal alignment [4].

Spinal conditions/pathologies such as degenerative disc disease, flat back syndrome, kyphoscoliosis and spondylolisthesis can all contribute to positive sagittal alignment. Positive sagittal alignment can also occur over time in persons with scoliosis treated with Harrington rods [6] and other distracting rod techniques [7]. Positive sagittal alignment can result in abnormal spino-pelvic alignment such as a higher pelvic tilt and pelvic incidence than in able-bodied adults [5,8], contribute to poor clinical outcomes [5,9], and lead to pseudoarthrosis [10]. Positive sagittal alignment leads to energy inefficient ambulation and an increase in muscle activity due to the effort required to maintain compensatory maneuvers such as retroversion of the pelvis [1]. Additionally, when able-bodied individuals were asked to walk with positive sagittal balance, they adopted a compensatory crouch gait [11] and, persons with positive sagittal balance as a result of flatback syndrome have been shown to walk in a crouch posture [12], which is likely to be energy expensive [3,13]. Generally, individuals with positive sagittal alignment reportedly have difficulty standing erect or walking for long periods of time [6]; they experience nearly constant fatigue in the back, thigh and buttock muscles from attempts to maintain an upright posture [4,6,14,15]. The spinal column plays an important role in human ambulation [16], and independent ambulation plays an important role in maintaining quality of life [17]. A study with 304 subjects showed that increase in positive sagittal spine balance resulted in an increase in 10 m gait time and decrease in quality of life [9].

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0966-6362/$ – see front matter
http://dx.doi.org/10.1016/j.gaitpost.2013.08.012

Spinal conditions that result in positive sagittal spine alignment are often treated by spinal reconstructive surgery. Goals of surgery include improvement in function and quality of life by optimizing spinal alignment and reducing pain. However, spinal fusion surgery may result in restricted pelvic motion especially when the pelvis is used to anchor instrumentation. Such restriction of the pelvis may result in abnormal pelvic kinematics. It has been shown in able-bodied subjects that restriction of the spine and pelvis with a fiberglass body jacket results in an increase in cadence and significant reductions in pelvic obliquity, pelvic rotation, and coronal plane hip motion [18].

Review of the literature pertaining to gait analysis of subjects undergoing spinal reconstructive surgery yields inconsistent results. One subject with cervical spondylosis was reported to have increased walking speed and a more normal gait pattern post-operatively [19]. However, another study of persons with adolescent idiopathic scoliosis [20] reported decreased walking speed, cadence and stride length post-operatively but did not observe any changes in hip or pelvic kinematics as a result of surgery. Overall, the effects of positive spine alignment and multi-segmental fusion surgery on human gait are not well understood.

Given the lack of consensus, the purpose of this study was to investigate the gait of persons with positive sagittal spine alignment before and after reconstructive spinal surgery. We hypothesized that (1) sagittal spine alignment during standing and walking would improve post-operatively, (2) post-operative lower limb gait kinematics would be similar to that of able-bodied people, and (3) post-operative temporospatial parameters such as walking speed, stride length, step length, step width and cadence would also be similar to that of able-bodied people.

Fig. 1. Sagittal plane view of one representative subject pre- and 6 months post-operatively while standing quietly. Marker placement is shown.

2. Methods

This study was approved by our Institutional Review Board (IRB). Subjects meeting the following inclusion criteria were recruited through the university's Department of Neurological Surgery: (1) the presence of thoracic or cervical kyphosis with positive sagittal alignment of $\geq$7 cm; (2) planned multi-segment spinal reconstructive surgery with fusion to the sacrum/ilium to correct positive sagittal spine alignment; (3) 18–80 years of age; and (4) the ability to walk without aids for at least short periods of time indoors on a smooth level surface. Excluded were individuals who were morbidly obese or who had presented with comorbidities that were likely to progress over the duration of the study, and change gait.

Spine alignment, kinematic, and temporospatial data were acquired pre-operatively and six months post-operatively. At the beginning of the testing session, subjects' height and weight were measured. In addition subjects' dominant limbs were identified by self-report [21].

Kinematic and temporospatial data were collected with an eight-camera, Eagle Digital Real-time motion capture system (Motion Analysis Corporation, Santa Rosa, CA). This system was used to determine the instantaneous position of reflective markers placed on the body using double-sided hypoallergenic tape (Fig. 1). The marker set consisted of a modified Helen Hayes arrangement [22] with additional markers on the spinous processes [23]. Markers were located on the dorsum of the foot between the second and third metatarsals immediately proximal to the metatarsal heads, the posterior calcaneus, lateral malleoli, lateral femoral condyles, right and left anterior superior iliac spines, and the sacrum at the superior aspect of the L5/sacral interface. Pedestal markers were placed on the lateral aspects of the thigh and calf. Triad markers, consisting of three non-co linear markers, were placed over the spinous processes at C5, T7, and L3 while single markers were located over the spinous processes of C1, C7 and L1. To ensure repeatability, marker placement on the spine was facilitated using fluoroscopy at the beginning of every data collection. Marker placement and data collection were conducted by a single researcher who has more than 12 years of experience in the use of motion capture systems.

Sagittal spine alignment is usually measured as the anterior-posterior distance between C7 and the posterior superior aspect of the S1 vertebrae on static X-ray [2,20]. Similar to radiographic assessment, sagittal spine alignment was calculated as the anterior-posterior distance between the center of the C7 and sacral markers during both quiet standing and dynamically during walking. A previous study demonstrated that motion analysis measurements of spine alignment were comparable to X-ray measurements [18].

Kinematic data were acquired at 120 Hz using Cortex software (Motion Analysis Corporation, Santa Rosa, CA). OrthoTrak software (Motion Analysis Corporation, Santa Rosa, CA) was utilized to calculate the temporospatial and lower body kinematic data, while custom Matlab (The Mathworks, Inc., Nattick, MA) programs were used to calculate spine alignment.

Data were collected while the subjects stood quietly for 30 s and walked along a 10 m walkway at their self-selected normal walking speed. Based on completeness of marker position data, three standing and five walking trials were then averaged and analyzed. The Shapiro Wilk test was used to assess whether the data were normally distributed. Consistent with our hypothesis, paired *t*-tests were then used to assess ten variables (walking speed, dominant and non-dominant limb step lengths, stride length, cadence, step width, sagittal plane dominant and non-dominant limb knee kinematics and static and dynamic spine sagittal alignment) with α set at 0.005 after Bonferroni correction for multiple comparisons.