Spine Deformity
www.spine-deformity.org
Spine Deformity 6 (2018) 529−536

Relationship Between Lumbar Lordosis and Pelvic Incidence in the Adolescent Patient: Normal Cohort Analysis and Literature Comparison*

T. Barrett Sullivan, MD[a], Nikolas Marino, BA[b], Fredrick G. Reighard, MPH[b], Peter O. Newton, MD[a,b,*]

[a]*University of California, San Diego, 9500 Gilman Dr, La Jolla, CA 92093, USA*
[b]*Rady Children's Hospital, San Diego, 3020 Children's Way, MC 5260, San Diego, CA 92123, USA*

Received 31 July 2017; revised 28 November 2017; accepted 2 February 2018

Abstract

Study Design: Retrospective review; literature comparison.
Objectives: To review the literature on the relationship between lumbar lordosis (LL) and pelvic incidence (PI) and evaluate this relationship in asymptomatic adolescents while testing the validity of previously reported adult correlation models between LL and PI in an adolescent population.
Summary of Background Data: Accurate understanding of the normal spinopelvic relationship is critical when considering surgical fusion of the lumbar spine. Many studies have reported relationships between pelvic measurements and LL in adult populations, but data in pediatric populations is lacking.
Methods: A literature search was performed to identify previously reported relationships between pelvic parameters and LL in adults and pediatric patients. A cohort of 125 asymptomatic adolescent patients evaluated at our institution was evenly split into two cohorts for model development and validation. Linear regression between LL and PI was performed. The resultant regression model was tested in the validation cohort along with previously reported formulae with LL as a function of PI. Mean absolute error (MAE) was calculated and compared between prior models and the newly developed adolescent model using analysis of variance and post-hoc testing.
Results: In our adolescent cohort (mean age: 13 ± 2), there was a strong correlation between PI and LL ($r = 0.53$). Regression analysis in the development cohort produced the following predictive model: $LL = 0.66(PI) + 24.2$. Testing in the validation cohort revealed a good correlation between predicted and actual LL ($r = 0.51$) and an MAE of 8.3. All but three previously reported models functioned with similar accuracy in the adolescent population, with only two methods having an MAE over 10.
Conclusions: The majority of previously published formulae for predicting LL as a function of PI developed in adults can be extrapolated to adolescent populations. These relationships are important in understanding how to surgically restore the sagittal alignment in adolescents with spinal deformity.
Level of Evidence: Level IV.

Keywords: Lumbar lordosis; Pelvic incidence; Adolescent spine

This study was conducted at Rady Children's Hospital, San Diego, CA.

Author disclosures: TBS (none), NM (none), FGR (none), PON (grants and other from the Setting Scoliosis Straight Foundation, other from Rady Children's Specialists, grants and personal fees from DePuy Synthes Spine, personal fees from Law firm of Carroll, Kelly, Trotter, Franzen & McKenna, personal fees from Law firm of Smith, Haughey, Rice & Roegge, grants from NIH, grants from OREF, grants and other from SRS, grants from EOS imaging, personal fees from Thieme Publishing, other from NuVasive, personal fees from Ethicon Endosurgery, other from Electrocore, personal fees from Cubist, other from International Orthopedic Think Tank, other from Orthopediatrics Institutional Support, personal fees from K2M, outside of the submitted work; in addition, a patent "Anchoring systems and methods for correcting spinal deformities" (8540754) with royalties paid to DePuy Synthes Spine, a patent "Low profile spinal tethering systems" (8123749) issued to DePuy Spine, Inc., a patent "Screw placement guide" (7981117) issued to DePuy Spine, Inc., and a patent "Compressor for use in minimally invasive surgery" (7189244) issued to DePuy Spine, Inc.).

Research support is gratefully acknowledged from the Rady Children's Foundation Assaraf Family Research Fund and a Surgical Department grant from Rady Children's Specialists of San Diego.

*Corresponding author. 3020 Children's Way, MC 5260, San Diego, CA 92123, USA. Tel.: (858) 966-6789; fax: (858) 966-8519.
E-mail address: pnewton.rady@gmail.com (P.O. Newton).

2212-134X/$ - see front matter
https://doi.org/10.1016/j.jspd.2018.02.002

Introduction

Deformity and imbalance of the spine can lead to profound disability and loss of independence both in the pediatric and adult population, and there is great value to clinicians in understanding normal alignment of the spine and pelvis in order to facilitate the best realignment of spinal deformities [1,2]. Although the determination of normal coronal and axial spinal alignment is straightforward, determination of the "normal" sagittal profile of the spine is quite complex. Segmental sagittal curvatures vary between patients and are complicated by interdependence of the spine and pelvis. Patient-specific variation in sagittal spinal contour leads to challenges in characterization and quantification of sagittal spinal deformity.

The spine has a substantial capacity to accommodate deformity in the sagittal plane while maintaining overall balance, but with increasing derangement of sagittal alignment comes increasing energy requirements to maintain such balance. This was first outlined by Dubousset with his description of the "cone of economy," a range within which compensatory mechanisms could efficiently maintain standing balance [3]. As compensatory mechanisms are stressed to failure, requirements for external support increase. Prior work has shown that loss of global sagittal alignment negatively impacts a patient's quality of life [1,4-6]. Accurate understanding of the normal relationship between the lumbar spine and pelvic geometry is critical when considering instrumented fusion of the spine as surgical fixation of a region of the spine restricts flexibility and induces compensatory changes of the remaining spine in attempts to achieve global sagittal balance.

Many prior studies have sought to delineate the relationship between parameters of pelvic geometry and lumbar lordosis (LL) for calculation of patient specific surgical targets [7-25]. As pelvic incidence (PI) is a pelvic parameter that is unaffected by patient posture, this measurement has been a primary focus for many such investigations [7-9,11,13-15,17-21,24-26]. Nearly all of this work has been in the adult population, whereas there are few studies on the subject in pediatric populations. Given the frequency of surgical fusion treatment of pediatric spinal deformity, an adequate characterization of the relationship between LL and pelvic sagittal morphometry is of critical importance. Although fusion to the sacrum or pelvis is less common in the pediatric patient than in the adult, long fusions to lumbar vertebrae, the sacrum, and the pelvis remain a component of the treatment algorithm for pediatric and adolescent scoliosis. A recent analysis of sagittal alignment following posterior fusion for adolescent idiopathic scoliosis identified that patients undergoing long fusion to L3 through L5 had significantly altered postoperative lumbar lordosis, which resulted in a relationship to pelvic incidence outside of that recommended in the management of adult spinal deformity [27]. Such findings not only provide evidence of the potential impact of long fusion on global sagittal alignment but also rely on the validity of adult surgical correction target models in the adolescent population. No work to date has examined these previously reported adult models in pediatric and adolescent cohorts.

Explorations of spinopelvic relationships in the pediatric and adolescent patient have an additional layer of complexity given prior studies that have identified substantial changes in the sagittal plane of adolescent idiopathic scoliosis patients when assessed in 3D [28] as well as age-related changes in LL and PI. However, results of these analyses have been mixed, with some studies reporting stability of PI after age 10 and others reporting a change in PI throughout adolescence [29,30]. Inconsistency in these reported findings further highlights the importance of assessing the validity of use of adult-derived sagittal alignment models in the pediatric or adolescent patient.

This study aimed to review previously published work on the relationship between LL and PI in adult and pediatric populations, and in addition present an analysis of this relationship in a population of "normal" adolescent patients evaluated at our institution. Finally, we sought to compare previously reported models established to predict LL from PI to test extrapolation of adult-derived formulae to the adolescent population.

Methods

A Medline search of key words including "lumbar lordosis" and "pelvic incidence" was performed in an attempt to identify articles published in the English language pertaining to the relationship of sagittal alignment and pelvic sagittal parameters, specifically PI. All articles reporting a statistical correlation between LL and PI, a prediction of global sagittal alignment on the basis of PI, or a predictive model for LL with an input variable of PI were reviewed. Both single-input and multi-input models were included.

As a part of an IRB-approved study, 125 patients referred to our institution for evaluation of scoliosis or back pain and subsequently found to be free of spinal or pelvic pathology on clinical and radiographic evaluation were included. Each patient underwent upright posterior-anterior and lateral radiographic imaging with an EOS imaging system (EOS Imaging, Paris, France). Two-dimensional measures of LL (T12−S1) and PI were made by a single, trained individual. Linear regression analysis was performed and Pearson correlation coefficients were calculated for the relationship between LL and PI as well as between each of these values and patient age. Patients were subsequently divided into two cohorts for model development ($n = 63$) and validation ($n = 62$) using the holdout method for cross validation. Given the general lack of validation analyses in previously reported models in both adult and pediatric patients, all previously reported methods for determining LL on the basis of PI were also tested in our validation set. Mean absolute error (MAE) values were