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Basic Science

Toward a better understanding of direct vertebral rotation for AIS surgery: development of a multisegmental biomechanical model and factors affecting correction

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Abstract

BACKGROUND CONTEXT: The direct vertebral rotation (DVR) technique involves vertebral manipulation by the application of force in the transverse plane using a pedicle screw as the anchor point. The biomechanics of this technique has not been well studied, and the applied derotation force may affect cosmetic outcome and potential complications.

PURPOSE: The purpose of the study was to develop an in vitro biomechanical model replicating DVR and examine the effects of screw placement, derotation direction, and segmental versus en bloc rotation on correction.

STUDY DESIGN: This study is based on a cadaveric spine model examining the biomechanics of DVR.

METHODS: Short three vertebral segments were dissected from thoracolumbar cadaveric spines (T5–L4). Each pedicle of the central vertebra received a unicortical, bicortical, or in-out-in screw. Unconstrained biomechanical tests were performed in an axial rotation (medial and lateral directions) mimicking DVR surgery. Nondestructive tests were performed examining peak force and rotational stiffness with/without a contralateral rod. A destructive failure test was performed on each pedicle screw with a contralateral rod connecting via the contralateral pedicle screw. Repeated-measures analysis of variance and post hoc Student *t* tests were used to detect significance with screw placement and loading direction as main factors.

RESULTS: Without the contralateral rod, the rotation direction was significant ($p=.004$, medial stiffness more than lateral). With the contralateral rod, in-out-in placement demonstrated lower stiffness than unicortical or bicortical screws ($p=.009$), and the rotation direction was significant ($p=.003$, medial stiffness more than lateral). There was no interaction effect between main factors. Peak force with and without a contralateral rod resulted in a similar pattern of significance as stiffness. Destructive failure tests showed that the placement was significant ($p<.02$) with in-out-in resulting in lower stiffness than unicortical- and bicortical-placed screws. In-out-in (25 ± 6 N) and unicortical (35 ± 16 N) placements resulted in lower peak load ($p<.001$) than bicortical (48 ± 17 N) screws.

CONCLUSIONS: The biomechanical characteristics of DVR are dependent on the derotation direction and screw placement. Correction for adolescent idiopathic scoliosis can be attempted irrespective of the type of pedicle screw placement, more efficiently if performing derotation

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maneuvers en bloc on bicortical screws in the medial direction.

Keywords: Adolescent idiopathic scoliosis; Thoracic spine; Pedicle screw; Coupled motion; Failure test; Bone-screw interface

Introduction

Scoliosis is a three-dimensional deformity affecting the spine. Based on the severity and the potential for progression, the treatment of adolescent idiopathic scoliosis (AIS) is observation, bracing, or surgical correction. The last 30 years have seen the evolution of numerous posterior and anterior spinal instrumentation techniques for scoliosis correction. Currently, pedicle screw constructs have gained popularity with multiple reports citing the superior frontal, sagittal, and rotational corrections achieved through their use [1–4]. Recently, the technique of direct vertebral rotation (DVR) has been described by Lee et al. [5] as a means of achieving a true axial correction of the vertebral and chest wall deformity.

Direct vertebral rotation involves the use of long tube derotators to apply a transverse rotational torque to the spine via pedicle screw fixations. The force is transmitted through the pedicle screws to the vertebral bodies to obtain rotational correction in an axial plane. The vertebral rotation can either be segmental involving a single vertebra or en bloc involving multiple vertebrae. Based on the technique described by Lee et al. [5], the DVR maneuver for a thoracic curve involves the use of four to eight screw derotators inserted onto the pedicle screws of the juxta apical vertebrae, both on the concave and convex sides. During or after the rod derotation, the screw derotators are rotated to the opposite direction of rod derotation. The lower most pedicle screws are rotated in a direction depending on the unfused lumbar curve. This is followed by the locking of the concave rod and the insertion of the convex rod, which is locked in situ [5].

Direct vertebral rotation has been reported to produce improved correction of thoracic and lumbar coronal curves compared with traditional rod derotation techniques. The improved transverse plane control of the spine with the DVR technique allows for the management of the rib hump and, in some cases, eliminating the need for a thoracoplasty [5]. Direct vertebral rotation attempts to uncoil the deformed spine both at the instrumented and the uninstrumented levels [5]. The phenomenon of three-dimensional correction with DVR can be explained on the basis of coupled motions of the spine. A biomechanical study by Gregerson and Lucas [6] has demonstrated an axial rotation to be an integral part of lateral bending in the thoracolumbar spine. During a scoliosis correction, when the thoracolumbar spinal segments are rotated, lateral bending also occurs. This phenomenon is termed as ‘‘coupled motion of the spine’’ [7,8]. Direct vertebral rotation appears to take advantage of the concept of coupled motions of the spine in achieving a more anatomically true three-dimensional correction. As curves become larger and more rigid, it would seem obvious that more force must be placed on these screws in the transverse plane to achieve an acceptable vertebral derotation. A recent study by Parent et al. [9] has examined the biomechanics of the screw-bone interface in the transverse plane, based on a completely encased and anchored vertebral body model. The study calculated the rotational force that could lead to the anatomic failure of the pedicle in the transverse plane with standard pedicle screw placement. In a radiographic study comparing thoracic fusion of Lenke Type I AIS curves with monoaxial versus multiaxial pedicle screws, Kulko et al. [3] found superior derotation and restoration of symmetry with monoaxial screws. In a biomechanical analysis of derotational load to failure of pedicle screw instrumentation in cadaveric thoracic spinal segments, Cheng et al. [10] investigated the derotational torque that can be applied to the thoracic spine through different linked constructs and also evaluated the modes of failure. A special potting technique was used to secure the vertebral bodies to allow testing while preventing polymethylmethacrylate (PMMA) from contacting the lateral walls of the vertebrae, thus keeping it unbutressed. They found that a near linear increase in the relative torque applied before failure was found with each additional pedicle screw linked.

There are insufficient data about the different variables that appear to influence the amount of force that can be safely applied during the process of DVR. In particular, the role of screw placement technique and the depth of pedicle screw placement on the biomechanics of vertebral derotation are currently unexplored. The purpose of this study is to develop a more practical multilevel cadaveric model that will allow for study of DVR. It also seeks to examine the biomechanics of unicortical-, bicortical-, and in-out-in (tricortical)–placed pedicle screws in the transverse plane rotation using this model. In addition, the role of the direction of derotation and the use of contralateral rod are studied. To our knowledge, there are no published studies that have examined these aspects of DVR.

Materials and methods

Specimen preparation

Fresh thoracolumbar spine specimens, T4–L5, were dissected from six cadavers (two females, four males; age, 49±18 years) and frozen until use. Specimens were thawed