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Basic Science

Biomechanical analysis of the upper thoracic spine after decompressive procedures

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Abstract

BACKGROUND CONTEXT: Decompressive procedures such as laminectomy, facetectomy, and costotransversectomy are routinely performed for various pathologies in the thoracic spine. The thoracic spine is unique, in part, because of the sternocostovertebral articulations that provide additional strength to the region relative to the cervical and lumbar spines. During decompressive surgeries, stability is compromised at a presently unknown point.

PURPOSE: To evaluate thoracic spinal stability after common surgical decompressive procedures in thoracic spines with intact sternocostovertebral articulations.

STUDY DESIGN: Biomechanical cadaveric study.

METHODS: Fresh-frozen human cadaveric spine specimens with intact rib cages, C7–L1 (n=9), were used. An industrial robot tested all spines in axial rotation (AR), lateral bending (LB), and flexion-extension (FE) by applying pure moments (±5 Nm). The specimens were first tested in their intact state and then tested after each of the following sequential surgical decompressive procedures at T4–T5 consisting of laminectomy; unilateral facetectomy; unilateral costotransversectomy, and subsequently instrumented fusion from T3–T7.

RESULTS: We found that in all three planes of motion, the sequential decompressive procedures caused no statistically significant change in motion between T3–T7 or T1–T12 when compared with intact. In comparing between intact and instrumented specimens, our study found that instrumentation reduced global range of motion (ROM) between T1–T12 by 16.3% (p=.001), 12% (p=.002), and 18.4% (p=.0004) for AR, FE, and LB, respectively. Age showed a negative correlation with motion in FE (r=−0.78, p=.01) and AR (r=−0.7, p=.04).

CONCLUSIONS: Thoracic spine stability was not significantly affected by sequential decompressive procedures in thoracic segments at the level of the true ribs in all three planes of motion in intact thoracic specimens. Age appeared to negatively correlate with ROM of the specimen. Our study suggests that thoracic spinal stability is maintained immediately after unilateral decompression at the level of the true ribs. These preliminary observations, however, do not depict the long-

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term sequelae of such procedures and warrant further investigation.

Keywords: Thoracic; Spine; Decompression; Costotransversectomy; Biomechanics; Cadaver

Introduction

Decompressive procedures of the thoracic spine (ie, laminectomy, facetectomy, and costotransversectomy) are performed for numerous pathologies, including disc herniation, infection, tumor, and trauma. Unlike the cervical and lumbar spines, however, there is little evidence that quantifies the biomechanical consequences of these types of procedures in the thoracic region.

The thoracic spine is unique, in part, because of the stenocostovertebral articulations that afford increased stiffness and stability relative to the cervical and lumbar spines. The intervertebral discs, supra/interspinous ligaments (SIL), and rib cage contribute to a majority of the stability of the thoracic spine [1–5]. The SIL mainly contributes to the flexion range of motion (ROM) and may be specifically important at levels adjacent to long constructs [4]. The rib cage, or "the fourth column," [6] has been shown to contribute up to 78% of the thoracic spinal stability [2]. Specifically, it limits the ROM of the thoracic spine by 40% in flexion-extension (FE), 35% in lateral bending (LB), and 31% in axial rotation (AR) [5]. During decompressive surgeries in the thoracic spine, stability is compromised at a presently unknown threshold. The decision regarding the use of an instrumented fusion in such cases can substantially affect the patient's outcome by either providing insufficient stability or causing unnecessary additional surgery (ie, instrumented fusion). Cost considerations are also a concern, and it is possible that costly procedures are currently being performed on the thoracic spine, absent of data that proves their mechanical usefulness. Presently, there exist no guidelines delineating indications for a fusion procedure after the various thoracic spine decompression procedures.

The purpose of the present study was to define the angular ROM in the thoracic spine after laminectomy, laminectomy with unilateral facetectomy, laminectomy with unilateral costotransversectomy, and the subsequent addition of pedicle screw instrumentation. With this information, we intended to provide an algorithm for the use of fusion after thoracic decompressive surgery.

Methods

Specimen preparation

Nine (n=9) fresh-frozen human cadaveric spine specimens, spanning C7–L1, were used that included the sternum, ribs, and all articulations intact. Computed tomography and dual-energy X-ray absorptiometry scans of each specimen were carried out to determine preexisting spinal pathology or fusion and the bone mineral density (BMD) of each specimen before biomechanical testing. Specimens with previous spinal surgery, spinal implants, soft-tissue abnormalities, or fractures were excluded from this study. Specimens with kyphosis (more than 65°) or severe scoliosis were excluded from the sample. The average age of the specimens was 59 years (±9.5 years) with an average height of 170 cm (±8.6 cm) and an average BMD of 0.941 g/cm^2 (±0.11 g/cm^2). There were five female and four male specimens. The existing conditions, in addition to the documented cause of death of each specimen, are listed in Table 1. One patient had been diagnosed with rheumatoid arthritis; however, no gross or radiographic changes characteristic of rheumatoid arthritis were found with this specimen.

Before testing, the specimens were removed from a −20°C freezer, thawed, and the surrounding musculature was meticulously dissected, leaving all ligamentous and articular attachments preserved. Custom-designed spinal fixtures were used to secure the spine cranially and caudally onto a robotic spine testing system. The cranial (C7–T1) and caudal (T12–L1) levels were mounted onto the custom test fixtures using pedicle screws and rods. The test setup was further secured using wood screws inserted into the cranial and caudal vertebral bodies and embedded in Cereband, a liquid metal alloy (HiTech Alloys, Squamish, WA, USA).

Multidirectional biomechanical testing

An industrial robot (KUKA, GmbH, Augsburg, Germany) capable of motion in six axes was used as the spine testing apparatus for implementing in vitro multidirectional flexibility tests. It was used to apply pure moments on the spinal segments through custom-designed mounting fixtures (Fig. 1). Multidirectional testing was carried out in three orthogonal directions. These three test directions corresponded to FE, bilateral LB, and bilateral AR of the thoracic spine. The specimens were unconstrained so as to allow for natural coupled motion of the spine.

A six-axes, force-moment sensor (GAMMA; ATI, Apex, NC, USA) was used to measure the applied load and provide feedback for the robot. The sensor also measured the off-axis forces and moments to provide feedback to ensure that a pure moment was being applied along the primary axis of motion of the spine. Three-dimensional motion was monitored continuously using an optoelectronic camera system (Optotrak Certus; Northern Digital, Inc., Waterloo, ON, Canada) at a rate of 20 Hz. The camera system measured the vertebral motion by tracking the relative motion between the infrared markers placed on rigid body