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Basic Science

# Cervical total disc replacement exhibits similar stiffness to intact cervical functional spinal units tested on a dynamic pendulum testing system

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**Abstract**

**BACKGROUND CONTEXT:** The pendulum testing system is capable of applying physiologic compressive loads without constraining the motion of functional spinal units (FSUs). The number of cycles to equilibrium observed under pendulum testing is a measure of the energy absorbed by the FSU.

**OBJECTIVE:** To examine the dynamic bending stiffness and energy absorption of the cervical spine, with and without implanted cervical total disc replacement (TDR) under simulated physiologic motion.

**STUDY DESIGN:** A biomechanical cadaver investigation.

**METHODS:** Nine unembalmed, frozen human cervical FSUs from levels C3–C4 and C5–C6 were tested on the pendulum system with axial compressive loads of 25, 50, and 100 N before and after TDR implantation. Testing in flexion, extension, and lateral bending began by rotating the pendulum to 5°, resulting in unconstrained oscillatory motion. The number of rotations to equilibrium was recorded and the bending stiffness (Newton-meter/°) was calculated and compared for each testing mode.

**RESULTS:** In flexion/extension, with increasing compressive loading from 25 to 100 N, the average number of cycles to equilibrium for the intact FSUs increased from 6.6 to 19.1, compared with 4.1 to 12.7 after TDR implantation ($p<.05$ for loads of 50 and 100 N). In flexion, with increasing compressive loading from 25 to 100 N, the bending stiffness of the intact FSUs increased from 0.27 to 0.59 Nm/°, compared with 0.21 to 0.57 Nm/° after TDR implantation. No significant differences were found in stiffness between the intact FSU and the TDR in flexion/extension and lateral bending at any load ($p<.05$).

**CONCLUSIONS:** Cervical FSUs with implanted TDR were found to have similar stiffness, but had greater energy absorption than intact FSUs during cyclic loading with an unconstrained pendulum system. These results provide further insight into the biomechanical behavior of cervical TDR under approximated physiologic loading conditions. 

*Keywords:* Total disc replacement; Biomechanics; Pendulum testing system; Cervical radiculopathy; Functional spinal unit; Motion preservation technology

## Introduction

Anterior cervical decompression and fusion (ACDF) is a well-established procedure with proven clinical benefits for the treatment of symptomatic cervical disc disease [1–3]. However, evidence suggests that ACDF may ultimately lead to kinematic strain on adjacent spinal levels and consequent disc degeneration and mechanical instability over time [4–7]. Cervical total disc replacement (TDR) is a motion-preserving technology also indicated in the treatment of cervical spondylotic radiculopathy that is gaining popularity in use. Integral to the design of the TDR is its capacity to replicate normal spine motion and avoid

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limitations of fusion, therefore allowing patients to quickly return to routine activities. The primary goals of the procedure in the cervical spine are to restore disc height and segmental motion after removing local pathology. Short-to-midterm clinical follow-ups of cervical TDR have demonstrated that it provides significant improvement in pain and functional outcome scores over time, and may prevent adjacent-segment disease [8–12].

In addition to clinical study, biomechanical investigation into motion-preserving implants is essential to complement our understanding of the in vivo behavior. The biomechanical properties of the ligamentous cadaver cervical spine with and without implanted motion-preserving devices have been studied using a wide variety of experimental protocols, including displacement-controlled testing, constrained load-controlled testing, unconstrained load-controlled testing, and unconstrained pure moment load-controlled testing [13,14]. More recently, finite element analysis has also been used to model spinal biomechanics, both with and without motion-preserving device and at additional cervical levels [15–17]. Yet, many of the protocols used in these studies were limited in their ability to apply physiologic compressive loads or dynamic bending moments, while allowing unconstrained three-dimensional motion.

To address the aforementioned limitations, we developed a novel pendulum model as means to study the complex kinematics and dynamic nature of the cervical spine. Previous work has demonstrated that the pendulum system is capable of applying physiologic compressive loads dynamically without constraining the motion of the functional spinal unit (FSU) [18]. Initial investigation using the pendulum found that after an initial rotation, the FSUs behaved as a dynamic, under-damped vibrating elastic system. Significant increases in bending stiffness and decreases in natural frequency were found with increasing compressive loading. The number of cycles to equilibrium observed under pendulum testing is a marker of the energy absorbed by the FSU. We previously reported a dynamic biomechanical investigation of a lumbar TDR using the pendulum system that revealed that lumbar TDR was less stiff than intact FSU, but absorbed more energy with cyclic loading [19].

Accordingly, we hypothesized that the cadaveric cervical spine with implanted TDR would exhibit decreased dynamic stiffness and increased energy absorption compared with native cervical FSUs under simulated physiologic motion when tested with the pendulum system, similar to the lumbar spine testing. We additionally aimed to determine the effects of various axial compressive loads on the dynamic biomechanical properties of native cervical FSUs with implanted TDR as compared with native cervical FSUs.

## Methods

Nine unembalmed, frozen human cervical FSUs were obtained from six cadavers (three men and three women, average age 69.3 years, range 59–83 years). All human cadaveric specimens were acquired from a third party donation center and were also used in a previous study [20] (MedCure, Inc., Portland, OR 97230, USA, http://medcure.org).

Radiographic screening was performed to eliminate any samples with previous surgery, trauma, or pathologic lesion. Five separate FSUs from C3–C4 and four from C5–C6 were used for testing. Biomechanical testing of the FSUs was performed on a pendulum apparatus as described previously after modification for the cervical spine [18,19]. The pendulum system consists of the lower cervical vertebra mounted on a rigid platform via its potting cup and the pendulum arm (0.55 m) mounted to the upper vertebral body via its potting cup. Dead weights are fixed to the lower end of the pendulum arm. The pendulum (55 cm long, 35 cm wide) was mounted with its weights directly below the FSU (Fig. 1). The pendulum is mounted

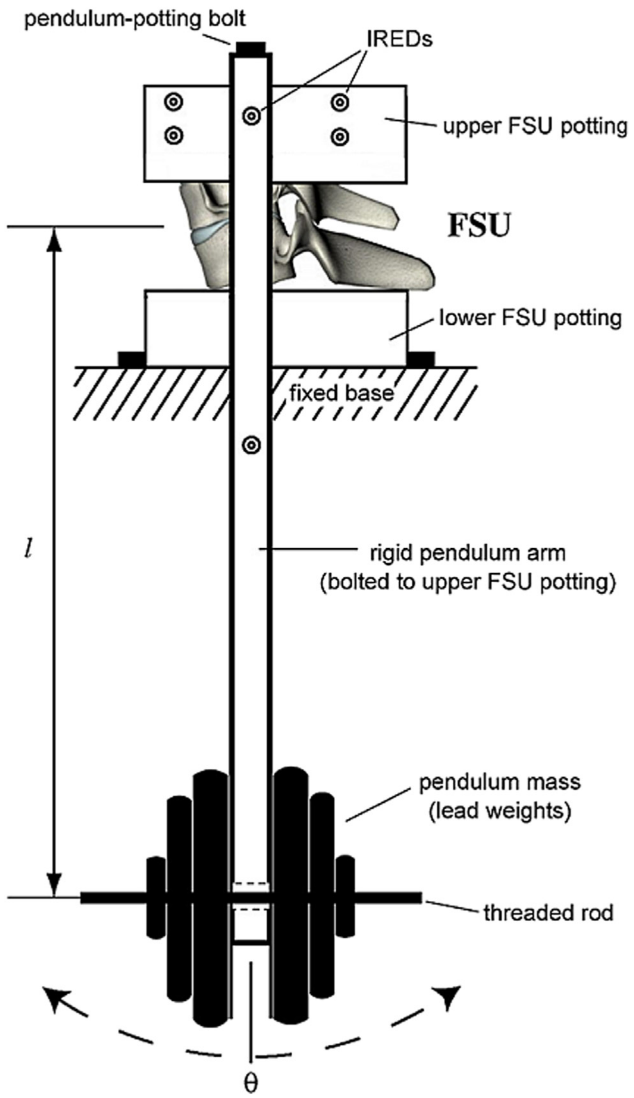


Fig. 1. Pendulum testing apparatus. FSU, functional spinal unit; IRED, Infrared Emitting Diode.