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A biomechanical investigation of dual growing rods used for fusionless scoliosis correction

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ABSTRACT

Background: The use of dual growing rods is a fusionless surgical approach to the treatment of early onset scoliosis which aims to harness potential growth and correct spinal deformity. The purpose of this study was to compare the in-vitro biomechanical response of two different dual rod designs under axial rotation loading.

Methods: Six porcine spines were dissected into seven level thoracolumbar multi-segment units. Each specimen was mounted and tested in a biaxial Instron machine, undergoing nondestructive left and right axial rotation to peak moments of 4 Nm at a constant rotation rate of 8 deg. s^{-1}. A motion tracking system (Optotrak) measured 3D displacements of individual vertebrae. Each spine was tested in an un-instrumented state first and then with appropriately sized semi-constrained and 'rigid' growing rods in alternating sequence. The range of motion, neutral zone size and stiffness were calculated from the moment–rotation curves and intervertebral range of motion was calculated from Optotrak data.

Findings: Irrespective of test sequence, rigid rods showed a significant reduction of total rotation across all instrumented levels (with increased stiffness) whilst semi-constrained rods exhibited similar rotational behavior to the un-instrumented spines ($P < 0.05$). An 11.1% and 8.0% increase in stiffness for left and right axial rotation respectively and 14.9% reduction in total range of motion were recorded with dual rigid rods compared with semi-constrained rods.

Interpretation: Based on these findings, the Semi-constrained growing rods were shown to not increase axial rotation stiffness compared with un-instrumented spines. This is thought to provide a more physiological environment for the growing spine compared to dual rigid rod constructs.

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1. Introduction

Current treatment options for managing scoliosis are limited to observation, bracing and surgery. Although there are some scoliotic curves in the very young that do not progress, others can deteriorate significantly despite non-operative management. It is these progressive curves that impose significant health risks for developing children and present dilemmas for the treating surgeon. Adolescents who fail bracing or conservative treatment options can obtain acceptable deformity correction through instrumented spinal fusions. However in the younger child or early onset scoliosis (EOS) group, fusing the spine for deformity correction can consequently limit chest wall and lung growth (Karol et al., 2008).

Normal growth rate slows significantly between the ages of 5 and 10 years, having peaked in the first five years of age during which the thoracolumbar spine has already achieved up to two thirds of its adult height (Dimeglio, 2001). Surgical treatment of EOS without arthrodesis, usually occurs in this period and has the potential to allow continued spinal growth until maturity, without the deleterious outcomes of spinal fusion (Akbarnia and Marks, 2000). Known as "fusionless" growth modulation, Skaggs (Skaggs et al., 2010) divided these procedures into two categories consisting of either distraction (tension based) or growth guiding procedures. By harnessing the patient's potential growth, correction can be achieved through initial instrumentation and redirection, so as to achieve near maximal potential length and maintain spinal motion.

Harrington originally reported the technique of growing rods in 1962 (Harrington 1962), which was further developed by Moe et al. through the use of 'subcutaneous rods', with rod lengthenings at set time intervals (Moe et al., 1984). These early constructs typically used only a single rod. Akbarina et al. incorporated a dual/bilateral rod modification to the original design, with several studies reporting superior deformity correction and maintenance with dual rods (Akbarnia et al., 2005, 2008; Thompson et al., 2005). Subsequent improvements were made and rods redesigned. Luque (Pratt et al., 1999) introduced a growth guidance system utilizing sublaminar wires along several spinous processes, a technique which removed the need for repeated lengthenings. This construct has been reported to achieve 90% of expected spinal growth across the instrumented spine (Ouellet, 2011). However, design concerns still exist, even with the modernized Luque

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trolley. These include the inability to control for rotational deformity and the occurrence of spontaneous fusion, possibly due to subperiosteal exposure during initial instrumentation and inferred from the loss of deformity correction in documented cases (Luque and Cardoso, 1977; Mardjetko et al., 1992; Moe et al., 1984; Ouellet, 2011). An alternative and more recent growing rod design is the semi-constrained growing rod (Medtronic, Memphis TN, USA). It improves on previous designs with the preservation of soft tissues through submuscular instrumentation and the ability to enable telescopic lengthening via interconnecting male and female components. Similar to the Shilla technique (McCarthy et al., 2010), semi-constrained growing rods enable growth, but do not eliminate the need for repeated lengthenings entirely. It is believed that this new design of growing rod is more physiological in function during corrective growth management of patients with EOS, when compared with conventional rigid rods. Unlike rigid rods which have been shown to constrain rotation (Fricka et al., 2002), the primary rationale for design of the semi-constrained growing rod was to reduce the degree of rotational constraint, allowing axial rotation similar to un-instrumented spines. Little is known, however, about the biomechanical effect of semi-constrained growing rods during axial rotation and in particular the effect on the commonly instrumented thoracolumbar region.

The aim of this study was to measure the response in axial rotation of the newer semi-constrained growing rods (Fig. 1) in comparison with rigid rods. We hypothesize that in axial rotation the overall MSU construct would be significantly less stiff with the semi-constrained rods than with rigid rods. We also hypothesized that with the semi-constrained growing rods the intervertebral rotations at each level of instrumentation would be similar to those of the un-instrumented MSUs, while the rigid rods would significantly reduce these intervertebral rotations.

Fig. 1. Semi-constrained growing rod and telescopic sleeve component.

2. Methods

2.1. Specimen preparation and surgical procedure

Six fresh frozen immature spines from English Large White pigs were used in this study. The specimens were obtained from a local abattoir and ranged in age from 16 to 22 weeks with a weight range of 40–60 kg. Each specimen was harvested and frozen immediately following euthanasia and kept frozen at minus 20 °C until required for testing. To exclude any anatomical anomalies each specimen underwent pre-test CT scanning. There was no radiological evidence of any spinal pathology in the spines tested. Each vertebral column was sectioned once thawed to room temperature (a process which entailed 12–15 h at 4 °C and a further 1–2 h at room temperature), to give a multi-segment unit (MSU), consisting of seven vertebrae and six intervertebral discs, from thoracic vertebrae ten through to fifteen and the first lumbar vertebrae (T10–15 and L1). All musculature was carefully removed leaving the ligaments intact, including preservation of the costotransverse and costovertebral articulations with approximately 3 cm of ribs on either side (Oda et al., 1996). The zygapophysial joints were localized and exposed at the second and sixth vertebral level of the MSU. Two 4.5 mm × 25 mm multi-axial screws (Medtronic CD Horizon ® Legacy ™, Sofamor Danek Memphis, TN, USA) were inserted into the pedicles at levels 2 and 6 of the MSU, using standard instruments and surgical procedure. All instrumentation and testing were performed by one person. Note that, the terms 'instrumented' and 'un-instrumented' are used to refer to the presence or absence of growing rods secured by break-off set screws. Accurate positioning of the multi-axial screws was confirmed on post-test CT scanning. During instrumentation outlined below, levels 1 and 7 of the MSU were always left intact and embedded in stainless steel cups using poymethylmethacrylate (PMMA) with three screws driven into the upper and lower end vertebrae to optimize fixation of the cephalic and caudal vertebrae in the PMMA. All zygagpophysial joints were kept free from PMMA fixation. Specimens were then wrapped in plastic bags and stored again at minus 20 °C. After a minimum of 48 h the MUS specimens were re-thawed (using the same process as described above) to room temperature for a second time prior to testing. Rigid body markers containing three LEDs were attached to each spinous process of the MSU for detection by the optical tracking system and separate markers were kept aside and attached to the rod construct during testing. During MSU preparation and testing the spines were kept moist by being wrapped in saline soaked gauzes. All tests were performed at room temperature (21 °C).

2.2. Experimental test setup

A custom built dynamic spine testing apparatus mounted in an Instron MTS 8874 biaxial testing machine (Instron, Norwood, MA, USA) was used to test each specimen. Pilot studies showed that the response of the un-instrumented spine was not affected following repeated testing with rigid rods attached. There being less than 7% increase in the range of motion for the whole specimen. Each test as outlined in Table 1 consisted of five fully reversed cycles of non-destructive axial

Table 1
The order of testing for each specimen, comprised of 5 continuous cycles at a constant 8 deg s^{-1} to maximum moment of ±4 Nm. There was a 5 minute rest between each test.

Specimen	Test 1	Test 2	Test 3	Test 4	Test 5
1	UN-IN	GR	UN-IN	RIGID	UN-IN
2	UN-IN	RIGID	UN-IN	GR	UN-IN
3	UN-IN	GR	UN-IN	RIGID	UN-IN
4	UN-IN	RIGID	UN-IN	GR	UN-IN
5	UN-IN	GR	UN-IN	RIGID	UN-IN
6	UN-IN	RIGID	UN-IN	GR	UN-IN

(UN-IN; un-instrumented. RIGID; dual rigid rods. GR; dual semi-constrained growing rods).

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