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Smaller Interval Distractions May Reduce Chances of Growth Rod Breakage Without Impeding Desired Spinal Growth: A Finite Element Study

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Abstract

Background: Growth rods allow regular distraction of the spine to compensate for growth. Traditionally such distractions are performed every 6 months via open surgery. However with the advent of minimally invasive techniques like magnetically controlled growing rods, the distractions can be performed non-surgically. This also implies that the interval of distraction could be changed or customized based on individual patient's need.

Hypothesis: In this study we have hypothesized that the distraction at shorter intervals reduces the stresses on the rods which in turn reduces the chance of rod failure.

Objective: A finite element model of a juvenile spine was instrumented with growth rods and distractions were applied at different frequencies (2 months, 3 months, 6 months, and 12 months) for a period of two years to study the effects of frequency of distraction on maximum von Mises stresses on the rods for different loading conditions were studied.

Results: The stresses on the rods were highest for 12-month distraction (2 distractions in 2 years) and lowest for 2-months distraction (12 distractions in 2 years).

Conclusion: It was found that the shorter intervals of distraction led to reduction of stresses on the rod for same spinal height gain in two years.

Keywords: Juvenile scoliosis; Distraction frequency; Magnetic growth rods; Interval of distraction; Finite element study

Introduction

Dual growth rods are the most commonly used distraction-based, ‘‘growth-friendly’’ surgical instrumentation [1,2]. Growth rods are used to limit the progression of scoliosis without restraining spinal growth. To date, growth is sustained by consecutive lengthening surgeries at intervals of 6 months because it is not feasible to undertake surgeries at shorter time intervals [3]. During such lengthening surgeries the proximal and distal rods at each side are distracted [4]. Despite the advantages of this system, there have been many instances of mechanical failure [5]. The major complication is rod fractures, with a 15% incidence failure rate [3,6-8]. The recent advent of magnetically controlled growing rods allows the surgeon to distract spines noninvasively after the initial surgery. With this new technology it is feasible to distract rods at shorter intervals without causing discomfort to the patient [9].

The authors hypothesized that distraction at shorter intervals, which can be achieved through magnetic growth rods, would decrease the incidences of rod breakage, because for the same growth over 6 months frequent distractions would require smaller distraction forces, and thus would induce lower stresses in the rods. Thus, the objective of this study was to quantify the maximum stresses on the rod for 24 months using different frequencies of distraction.

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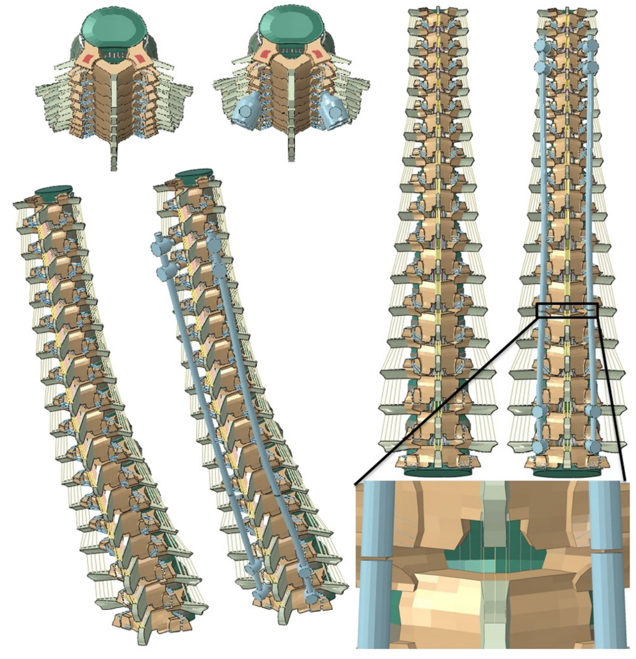

Fig. 1. The intact juvenile spine (T1−S1) model and the corresponding dual growth rod instrumented juvenile spine (T1−S1) model in different views. Tandem connectors have been modeled analytically between the proximal and distal rods [10].

To achieve this objective, the researchers used growth modulation incorporated within the finite element (FE) model of a normal juvenile spine. This article builds on the authors' earlier publication [10].

Materials and Method

An FE model of T1−S1 juvenile ligamentous spine (aged 9 years, weighing 22 kg) was used in this study [10]. The model was produced by personalizing the geometry of a previously validated adult spine model [11-15] to computed tomography data of a 9-year-old normal juvenile spine (Fig. 1). The material properties for the juvenile model were taken from the literature (Table 1) [16,17]. The model output was then compared with the only kinematic data (at 0.5 Nm) available in the literature for validation [17-19]. The model includes viscoelastic effects (Table 2) [20,21] and incorporates the Hueter−Volkmann principle of growth modulation [22,23]. Follower load was applied as reported by Schultz et al. that is, the spine was loaded with 14% body weight at T1 with a 2.6% body weight increase between succeeding vertebrae [24]. A detailed description of the incorporation of viscoelasticity, the Hueter−Volkmann principle of growth modulation, follower load application, and so forth is provided in the authors' previous publication [10]. Boundary conditions included restraining of the inferior surface of S1 vertebra in all degrees of freedom [24].

Spine instrumented with growth rods exhibits diminished lengthening with subsequent distraction [25]. This aspect was incorporated into the current model by increasing the stiffness of the spine as a function of time, using the available data on diminished lengthening on subsequent distractions (Fig. 2) [25]. The data pertain to an increase in distraction force with subsequent distraction surgery. The duration between each distraction was 6 months. Data are presented as distraction versus months following surgery over a period of 24 months at 6-monthly interval. The stiffness was calculated based on the mean values of distraction forces and the corresponding distractions. The mean value of distraction forces was 143, 102, 170, 201, and 373 N at 0, 6, 12, 18, and 24 months, respectively. The corresponding mean values of distraction were 17 mm, 10 mm, 11 mm, 9 mm, and 8 mm, respectively. Stiffness was calculated as the distraction force divided by distraction: 8.4, 10, 15.4, 22.2, and 46.3 N/mm at 0, 6, 12, 18, and 24 months, respectively. The researchers used these values to find a polynomial equation establishing a relation between stiffness and the time after implantation. The percent increase in stiffness at each time point was found and incorporated into the spine model by increasing the modulus of elasticity of nucleus pulposus and annulus fibrosus. The authors calculated the slopes of increase in longitudinal stiffness of the spine (in tension) with respect

Table 1
Material properties used in the model for bone, ligament, intervertebral disc, and instrumentation [10].

Component	Element formulation	Modulus (MPa)/Poisson ratio
Cortical bone	Isotropic, elastic hex elements (C3D8)	75/0.29 [16-19]
Cancellous bone	Isotropic, elastic hex elements (C3D8)	75/0.29 [16-19]
Growth plate	Isotropic, elastic hex elements (C3D8)	25/0.4 [17]
Posterior bone	Isotropic, elastic hex elements (C3D8)	200/0.25 [16-19]
Nucleus	Isotropic, elastic hex elements (C3D8H)	1/0.4999 [16-19]
Annulus (ground)	Neo-Hookean, hex elements (C3D8)	C10=0.348, D1=0.3 [11]
Annulus (fiber)	rebar	357−550 [11]
Apophyseal joints	Nonlinear soft contact, GAPPUNI elements	12,000 [11]
Ligaments	Tension-only, truss elements (T3D2)	90% of adult ligament values [11,17]
Titanium pedicle screws	Isotropic, elastic hex elements (C3D8)	115,000/0.3
Titanium Growth rods	Isotropic, elastic hex elements (C3D8), 4.5-mm diameter	115,000/0.3
Cobalt-chromium growth rods	Isotropic, elastic hex elements (C3D8), 4.5-mm diameter	210,000/0.3
Stainless-steel growth rods	Isotropic, elastic hex elements (C3D8), 4.5-mm diameter	190,000/0.3