Manual Therapy 19 (2014) 527–533

Contents lists available at ScienceDirect

Manual Therapy

journal homepage: www.elsevier.com/math

Original article

Biomechanical analysis of two-step traction therapy in the lumbar spine

Won Man Park [a], Kyungsoo Kim [b], Yoon Hyuk Kim [a,*]

[a] Department of Mechanical Engineering, Kyung Hee University, Yongin-si, Gyeonggi-do 446-701, Republic of Korea
[b] Department of Applied Mathematics, Kyung Hee University, Yongin-si, Gyeonggi-do 446-701, Republic of Korea

ARTICLE INFO

Article history:
Received 25 November 2013
Received in revised form
9 April 2014
Accepted 9 May 2014

Keywords:
Lumbar spine
Traction therapy
Finite element analysis
Biomechanics

ABSTRACT

Traction therapy is one of the most common conservative treatments for low back pain. However, the effects of traction therapy on lumbar spine biomechanics are not well known. We investigated biomechanical effects of two-step traction therapy, which consists of global axial traction and local decompression, on the lumbar spine using a validated three-dimensional finite element model of the lumbar spine. One-third of body weight was applied on the center of the L1 vertebra toward the superior direction for the first axial traction. Anterior translation of the L4 vertebra was considered as the second local decompression. The lordosis angle between the superior planes of the L1 vertebra and sacrum was 44.6° at baseline, 35.2° with global axial traction, and 46.4° with local decompression. The fibers of annulus fibrosus in the posterior region, and intertransverse and posterior longitudinal ligaments experienced stress primarily during global axial traction, these stresses decreased during local decompression. A combination of global axial traction and local decompression would be helpful for reducing tensile stress on the fibers of the annulus fibrosus and ligaments, and intradiscal pressure in traction therapy. This study could be used to develop a safer and more effective type of traction therapy.

1. Introduction

Low back pain is one of the most common complaints in the general population, affecting about 80% of the population at some point in life (Kelsey and White, 1980; Manchikanti, 2000). Conservative treatments, such as rest, exercise, and anti-inflammatory drugs, are often used to treat spinal pain (Hilibrand and Rand, 1999; Gluck et al., 2008; Majid and Fischgrund, 2008). Traction therapy is one of the most common conservative treatments for low back pain. Traction therapy is proposed to relieve pain and to recover joint functions by reducing pressure on discs or nerves (Harrison et al., 2002a,b; Paulk and Harrison, 2004; Horseman and Morningstar, 2008; Apfel et al., 2010; Gagne and Hasson, 2010; Kurutz and Bender, 2010; Diab and Moustafa, 2012). Even though there is a controversy regarding the efficacy of traction for back pain (Maher, 2004) and a case study in which the occurrence of large disc protrusion during motorized traction therapy was reported (Deen et al., 2003), the clinical reliability of traction therapy has been investigated in a number of studies (Harrison et al., 2002a,b; Paulk and Harrison, 2004; Macario and Pergolizzi, 2006; Daniel, 2007; Kurutz and Bender, 2010; Kurutz and Oroszvary, 2010; Diab and Moustafa, 2012).

A small number of studies has investigated the biomechanical effects of traction. Ramos and Martin (1994) measured changes in intradiscal pressure during axial traction with a motorized traction device. They have reported quantitative reduction in intradiscal pressure using a cannula inserted pressure transducer at L4–L5 disc, and inverse relation between intradiscal pressure and applied tension was shown in the study. Kurutz and Oroszvary (2010) analyzed the biomechanical effects of hydrotraction therapy on the intervertebral discs using finite element (FE) models that incorporated age-related intervertebral disc degeneration. They reported that direct traction deformations are 15–90% of the indirect one, while the direct traction load is 6% of indirect one in hydrotraction therapy consisting indirect and direct traction loads. Nonetheless, relatively little is known about the effects of traction therapy on lumbar spine biomechanics, including the stresses on the fibers of the annulus fibrosus and ligaments and the forces on the facet joints.

The purpose of this study was to investigate the biomechanics of the spine in a two-step traction therapy, which consists of global axial traction and local decompression, using FE analysis. Changes

* Corresponding author. Tel.: +82 31 201 2028; fax: +82 31 202 8106.
E-mail address: yoonhkim@khu.ac.kr (Y.H. Kim).

http://dx.doi.org/10.1016/j.math.2014.05.004
1356-689X/

in the lordosis angle, tissue stress on the fibers of the annulus fibrosus, ligaments stress, intradiscal pressure, and facet joint contact forces during two-step traction therapy were determined. Because it is difficult to measure the amount of stress on the fibers of the annulus fibrosus and ligaments that is related to the damage in these soft-tissues, FE analysis was chosen for this biomechanical study.

2. Materials and methods

In order to measure biomechanical behaviors of the lumbar spine, such as lordosis angle, intradiscal pressure, stresses on the fibers of annulus fibrosus and ligaments, and facet joint forces, with traction, a validated three-dimensional FE model of the lumbar spine was used (Park et al., in press). Computed tomographic scans in 1 mm slices were taken from a healthy male volunteer (170 cm, 66 kg). Three-dimensional FE models of the lumbar vertebrae from L1 to the sacrum were reconstructed from the CT scans. Intervertebral discs were modeled between the vertebrae based on a previously developed modeling technique that used hyperelastic solid elements (annulus ground substance), linear elastic solid elements (end plates), tension-only truss elements (fibers of the annulus fibrosus), and fluid elements (nucleus pulposus). The initial intradiscal pressure was set to zero in this study.

Stiffness of the annulus fibers was increased from the center to the outer region and stress–strain curves of the annulus fibers were adapted from literatures (Shirazi-Adl et al., 1986; Schmidt et al., 2006). Cross-sectional areas of annulus fibers were calculated that makes fiber content of 19% of the annulus volume (Natarajan and Andersson, 1999). Seven major ligaments – the anterior longitudinal ligament (ALL), posterior longitudinal ligament (PLL), ligament flavum (LF), interspinous ligament (ISL), supraspinous ligament (SSL), intertransverse ligament (TL), and capsular ligament (CL) – were attached on the basis of anatomical information using tension-only truss elements. Non-linear stiffnesses were used for seven major ligaments (Rohlmann et al., 2006). Articular cartilage was modeled using linear elastic solid elements, and surface-to-surface contact conditions were applied for the facet joints. All material properties of the bones and soft-tissues were adapted from previously published studies (Table 1) (Shirazi-Adl et al., 1986; Ueno and Liu, 1987; Goel et al., 1995; Lu et al., 1996; Natarajan and Andersson, 1999; Natarajan et al., 2000; Wagner and Lotz, 2004; Rohlmann et al., 2006; Schmidt et al., 2006, 2007a,b; 2009; Guan et al., 2007; Park et al., 2009; Ruberte et al., 2009; Kim et al., 2010). Spinal muscles were not included in the developed FE model. In previous computational studies by using FE analysis, developed FE models were validated by comparing intersegmental ranges of motions (ROMs) and/or moment rotation curves (Shirazi-Adl et al., 1986; Ueno and Liu, 1987; Natarajan and Andersson, 1999; Zander et al., 2001; Eberlein et al., 2004; Guan et al., 2006; Rohlmann et al., 2006; Ruberte et al., 2009; Moramarco et al., 2010). The model used in this study also validated on the aspects of moment rotation curves and ROMs at all motion segment units (MSUs) in various loading conditions.

For two-step traction therapy, we determined the interaction between the bed and the patient as 1) the patient was lying on the bed, 2) the patient's hip and trunk were both on the bed during two-step traction therapy due to the patient's body weight (BW) and/or tightening bands, 3) the bed on which the patient's hip was lying was separate from the bed on which the trunk was lying, and 4) two-step traction therapy was symmetric across the mid-sagittal plane. The relative motions of the L1 vertebra and sacrum could be generated with motions of the upper body and lower body, respectively. Thus, all translational movement of the sacrum was constrained in all directions, and translation of the L1 vertebra in the axial direction was allowed for axial traction. In addition, only flexion–extension rotational movements of the L1 vertebra and the sacrum were allowed in order to avoid over-constraint (Fig. 1).

Two-step traction therapy consisted of the following. The first step was global axial traction. An axial traction force of 216 N (which is about one-third of body weight of the volunteer) was applied in the axial direction at the center of the L1 vertebra toward the superior direction. The second step was local decompression. The reverse side of the lower facet joint of the L4 vertebra was pushed during the second step as much as 7.0 mm, which is about 20% of the anterior–posterior length of the vertebral body of the L4 vertebra. Kinematic boundary condition was used generate anterior translation of the L4 vertebra. The axial traction force and translation of the L4 vertebra were applied in 10% increments.

During two-step traction, we investigated the changes in the lordosis angle, intradiscal pressure, stress on the fibers of the annulus fibrosus and ligaments, and facet joint forces for each MSU. The annulus fibrosus was divided into anterior, lateral, and posterior regions, and the change in the average stress in each region was analyzed. The commercial FE analysis software Abaqus Standard v. 6.10 (Simulia, Providence, RI, USA) and pre- and post-processing software FEMap 10.1.1 (MSC.Software Co., Santa Ana, CA, USA) were used for this study.

3. Results

3.1. Lordosis angle

The lordosis angle between the superior planes of the upper and lower vertebrae was measured at each MSU in the sagittal plane during two-step traction therapy (Fig. 2). The initial angles were 5.4°, 5.3°, 9.0°, 8.1°, and 16.6° at the L1–L2, L2–L3, L3–L4, L4–L5, and L5–S1 MSUs, respectively. When 1/3 BW was applied for global axial traction, the angles at the L1–L2, L2–L3, L3–L4, L4–L5, and L5–S1 MSUs decreased to 5.1°, 3.5°, 6.4°, 5.1°, and 15.1°, respectively; these values changed to 5.5°, 5.4°, 9.9°, 9.1°, and 16.4°, respectively, in the second step.

Table 1
Material properties of the FE model of the lumbar spine (Shirazi-Adl et al., 1986; Ueno and Liu, 1987; Goel et al., 1995; Lu et al., 1996; Natarajan and Andersson, 1999; Natarajan et al., 2000; Wagner and Lotz, 2004; Guan et al., 2006; Rohlmann et al., 2006; Schmidt et al., 2006, 2007a,b, 2009; Park et al., 2009; Ruberte et al., 2009; Kim et al., 2010).

Component	Element type	No. of element	Young's modulus E (MPa)	Poisson ratio (ν)
Cortical bone	Solid	67,939	12,000	0.3
Cancelous bone	Solid	14,160	100	0.2
Post bone	Solid	21,261	3,500	0.25
Cartilaginous Endplate	Solid	4,040	23.8	0.4
Articular cartilage	Solid	496	11	0.4
Nucleus pulposus	Fluid	3,190	Compressibility: 0.0005 mm^2/N	
Annulus ground substance	Solid	8,250	Hyperelastic material (Mooney-rivlin; $C_1 = 0.18$, $C_2 = 0.045$)	
Annulus fibrosus	Truss	19,800	Non-linear elastic	
Ligaments	Truss	186	Non-linear elastic	