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Biomechanical analysis of press-extension technique on degenerative lumbar with disc herniation and staggered facet joint

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Abstract This study investigates the effect of a new Chinese massage technique named "press-extension" on degenerative lumbar with disc herniation and facet joint dislocation, and provides a biomechanical explanation of this massage technique. Self-developed biomechanical software was used to establish a normal L1–S1 lumbar 3D FE model, which integrated the spine CT and MRI data-based anatomical structure. Then graphic technique is utilized to build a degenerative lumbar FE model with disc herniation and facet joint dislocation. According to the actual press-extension experiments, mechanic parameters are collected to set boundary condition for FE analysis. The result demonstrated that press-extension techniques bring the annuli fibrosi obvious induction effect, making the central nucleus pulposus forward close, increasing the pressure in front part. Study concludes that finite element modelling for lumbar spine is suitable for the analysis of press-extension technique impact on lumbar intervertebral disc biomechanics, to provide the basis for the disease mechanism of intervertebral disc herniation using press-extension technique.

1. Introduction

Lumber disc herniation is an important cause of lower back pains. Relevant research indicates that it is generally induced by the degenerated deformation of a disc due to too much labour or spine abnormality. The number of patients with intervertebral disc herniation is increasing. The lumbar discs in the spine make up a structure with a complex shape, which is the hinge and basis of spine activities. They can transfer labour loads, balance the body, stabilize the spine and absorb vibration (Lee and Teo, 2004). All the functions depend on the intact disc. In pathological cases such as disc herniation caused by too much load on the spine, anatomical morphology and biomechanical properties of the spine will have a series of changes.

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At present, there are several types of therapy for disc herniation. Patients with heavy symptoms generally undergo surgery, which will change the biomechanical characteristics of lumbar after operation. These changes will affect the following therapy and recovery.

Recently, there is a growing tendency for disc herniation with non-operation therapies. Chinese massage, usually named "Tuina" in China, is commonly used in China (Zhang et al., 2015; Yang et al., 2014; Hou et al., 2015). Our treatment group proposed new kind of massage technique named "press-extension", based on improvement of traditional extension massage technique for many years. However, the mechanism of this massage therapy for lumber disc herniation, e.g., the effectiveness and safety of press-extension Tuina, is not clear. Special biomechanical analysis in both lumbar disc herniation and changes of the disc stress–strain distribution states by this treatment is needed.

At present, there are two methods of biomechanical analysis in the lumbar. One is by experimentation and the other is creating a computational model. In vitro experiments conducted using fresh human specimens have inherent limitations (Mehta and Tewari, 2015). For example, human spinal specimens are difficult to get, often with poor bone quality thus not representing the conditions of a living individual. Moreover, there is always the risk of being infected by a virus. Thus, there is need for further models to be used in the field of spinal research. In the analyses of bone joints such as spines, which have complicated shape, load and boundary conditions, finite element (FE) methods can be a useful tool. Using special software, it allows the modelling of complex structures, and demonstrated detailed biomechanical characteristics of lumbar and provides intrinsic parameters (stress, strain, strain energy, etc.).

There were many research studies using FE modelling to investigate the spine biomechanics (Park et al., 2013; Dreischarf et al., 2014; Allison et al., 2015). Most of previous FE spine models mainly focused on spine bone, intervertebral disc and ligament, neglecting surrounding muscles, while the massage technique acts directly on the skin and muscles, which play the role of force transmission and diffusion. Besides, most lumbar disc degeneration models only considerate only changes of disc biomechanical properties (Park et al., 2013), ignoring related changes on the disc morphology, as well as facet joint dislocation in many cases.

In this study, we established a detailed FE model of complete normal lumbar integrated with surrounding muscles, and utilized graphics technique to build a degenerative lumbar model with disc herniation as well as facet joint dislocation, and then did biomechanical analysis on the press-extension massage technique for lumbar disc herniation. We believed that better understanding of the biomechanical characteristics of surgical procedures will ultimately lead to better diagnoses and treatments on intervertebral disc herniation.

2. Materials and methods

2.1. Hardware and software

Hardware employed was a standard desktop computer with Intel Pentium Core 2 Duo processor running at 2×2.83 GHz and 4 GB RAM, and an NVIDIA GeForce GTX 465 Graphics card. A specially designed modelling system – E-3D Biomedical Modeler (http://www.e-feature.net/content/fea) was employed to build a finite element model. ANSYS 12 was used as the finite element computation software.

2.2. Development of the FE model of the healthy lumbar spine

A young man with no history of present and past disc disease was selected as normal subject, with scan range of lumbar spine from L1 to S1. The CT slice images had a slice thickness of 0.8 mm, and the MRI slice images had a slice thickness of 1.5 mm. This study was approved by the Ethics Committee for the Protection of Human Subjects at Zhejiang Provincial Hospital of Traditional Chinese Medicine in accordance with the tenets of the Declaration of Helsinki, and informed consent was obtained from all participating individuals.

The scan images were exported to the E-3D Biomedical Modeler system in DICOM 3.0 format. Then, each vertebra region (L1–S1) was extracted from CT data by some semi-automatic segmentation tools, and corresponding 3D solid model was reconstructed precisely, such as in Fig 1, including the separation surfaces between cortical and trabecular regions. It should be noted that we ranged the thickness of cortical bone of 0.5–2.5 mm, taking consideration of the fact that CT tends to overestimate the thickness of cortical bone in this work (Silva et al., 1994). Then, these bony regions discretized to volumetric mesh elements of high quality.

Each intervertebral disc was extracted from MRI data, and modelled as a central nucleus surrounded by an annular ground substance reinforced by fibres acting at approximately $\pm 30°$ from the transverse plane, as shown in Fig 2(b). The upper and lower surfaces of each disc were covered with the end plate of 0.6 mm. The fibres were modelled using a rebar definition. The nucleus was modelled as an incompressible fluid whose volume was approximately 48% of the entire disc volume.

For each facet joint, the modelling tool first generated two layers of shell elements with thickness of 0.5 mm as the articular cartilage, as shown in Fig 2(b); frictionless 3D surface-to-surface soft contact and an initial gap of 0.5 mm were assumed to exist between the superior and inferior articular cartilage (Park et al., 2013).

Several major spine ligaments were incorporated into the model, such as the anterior longitudinal (ALL), posterior longitudinal (PLL), ligamentum flavum (LF), capsular ligaments (CL), interspinal ligament (IS), supraspinal ligament (SS) and transverse ligaments (TL). The ligaments were defined as 3D nonlinear spring elements acting nonlinearly in tension only (Park et al., 2013; Zheng et al., 2012).

The lumbar muscles surrounding the lumbar spine is necessary to investigate the massage technique. Based on anatomical knowledge of lumbar muscles surrounding the lumbar spine, e.g., paraspinal muscles, quadratus lumborum muscle, and psoas major muscle, were generated by interactive graphics modelling function in E-3D software. Fig. 2(c) shows the final lumbar model embedding in muscles.

The complete lumbar model contains 939,532 10-node solid elements, 82,756 6-node 3D shell elements, 896 3D nonlinear spring element, 41,321 surface target elements, and 41,228 surface contact elements. The material and physical properties were adopted from previous validated finite element and