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Study on Mechanical Characteristics of Lumbar Spine for Snatch Action in Weight Lifting Based on Finite Element Method

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Abstract: Objective: To establish the three-dimensional finite element model (FEM) of lumbar motion segment (L1-L2), to investigate mechanical characteristics of lumbar spinal motion segment for application of clinical diagnosis and therapy in weightlifters snatch. Methods: The three-dimensional FEM of lumbar spinal motion segment (L1-L2) with material properties and geometrical behaves was established, the biomechanical characteristics of lumbar spine was analyzed based on the finite element method at neutral position in snatch. Results: The three-dimensional FEM of lumbar spine (L1-L2) was directly established by Dicom data, the biomechanical characteristics of lumbar spine was studied at neutral position in snatch. Conclusion: the advantages of the method in the paper: fast speed of modeling, high precision of model; the FEM simulated the structure and materials properties of lumbar spine with geometrical, materials and nonlinear contact properties. In the standing position in snatch, stress acted on vertebral body was distributed on facet joints and pedicle of vertebral arch, stress concentration on inervertebral disc was found on middle-posterior location of annulus fibrosus, displacement centered mainly around posterior exterior location of intervertebral disc; at the moment, if the weight of barbell is too heavy and the lumbar muscle lacks of strength, it can cause lumbar joint instability and induce intervetebral disc excessive extrusion. The forward excessive shear stress on isthmus from the effects of gravity can cause isthmus injury. The three-dimensional finite element model of lumbar spine L1-L2 can be applied as a good tool in many fields in vertebral column biomechanics.

Keywords: Biomechanics; Model; Finite element method; Vertebral column; Snatch

1. Introduction

The weightlifting has a higher incidence of trauma among sports. The athletes must repeatedly and quickly raise and pull, squat, uprise and jerk during special technical training and assistant training, and exert their maximum power in the best times, the loads on the waist, knee, hip, shoulder and elbow are great, consequently, the athletes will get injured easily, especially on waist. Experts and scholars[1-4] studied the reasons and rules about waist trauma, but, few people studied mechanical characteristics of vertebral body and intervertebral disc in waist to the weightlifters based on finite method, and no correlative studies were reported in our country at present.

The advantages of finite element method for diagnosing weightlifters' waist injuries lie in the accurate calculation of the stress value between vertebral body and intervertebral disc, and show vividly the dynamic process of its stress. But, to achieve the objective of analysis, it is necessary to establish the accurate and reliable three-dimensional FEM of lumbar spine first, and then, to define boundary conditions and loading mode to the finite element analysis. The snatch can be divided into six phases in *Competitive Weightlifting*[5], preparing phase, raising barbell, stretching knee, exerting, squatting and uprising. The biomechanical characteristics of lumbar spine were analyzed based on the finite element method at standing position in snatch in the paper. Therefore, the mechanical characteristics between vertebral body and intervertebral disc in waist were studied based on the finite element method at standing position in snatch by the help applying CT data and medical image processing software and establishing three-dimensional FEM of lumbar spine.

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Reasons of injuries in waist were investigated for application of clinical diagnosis and therapy in weightlifters snatch.

2. The materials and methods in the paper

2.1. Object of experiment

One healthy male volunteer, height 165cm, weight 60kg, without pain experience and former injury in waist, received X-ray examination in lumbar vertebrae and no degeneration and deformity was found in Figure 1.

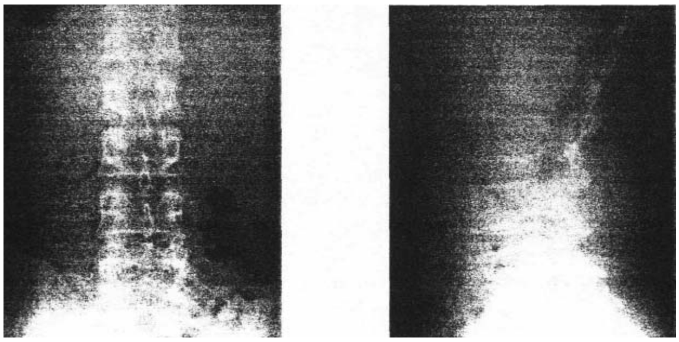

Fig.1: X-rayed photograph in waist vertebras check

2.2. The collection of experiment data

Consecutive CT scanning to the volunteer's the upper edge of first lumbar vertebrae to the lower edge of the second lumbar vertebrae was fulfilled through spiral CT (Siemens Somatom Sensation 10) with fine definition and function of post photograph processing and out-putting. The volunteer has to keep one position to lie on his back and scanning data were directly stored according to standard of Dicom3.0, bone structure window was selected, a total of 123 CT scan slices of the lumbar spine were taken, the distance between two consecutive slices was 0.75 mm.

3. Establishment and analysis of lumbar spine FEM

The finite element method enables numerical solutions to a wide variety of problems involving soft and hard tissues. Estimating the stress distributions in various bones or cartilages, quantifying the contact stresses in joints, or assessing prosthesis performance are but a few topics in which finite element method proved to be a powerful method. It also offers a powerful validation tool for experimental procedures. Studies and analysis of biological tissue behavior and response are conducted using the finite element approach in conjunction with experimental methods. The large number of commercially available finite element codes, addressing a very rich diversity of mechanical problems, makes this method practical.

In the field of biomechanics, currently many finite element models of human bones and joints exist. A finite element model is superimposed on the geometrical model; material properties assigned and loading conditions prescribed. The desired analysis is then performed. Depending on the level of sophistication of the software used and the requirements of the specific research, the geometry and the finite element mesh are more or less detailed and accurate.

3.1. Establishment of lumbar spine FEM

- Construction of three-dimensional geometrical model for the lumbar spine segment

The Dicom data were directly inported into the medical processing disposal software, the software can process any number of two dimensional image slices (CT images as well as MRI images) and render three-dimensional objects.

The individual elements of CT scans are called voxels, units of graphic information that define points in three-dimensional space. Each voxel has a density value referred to in Hounsfield units based on the density of the structure. The density of structures within an image is absolute and can be used to differentiate and characterize different tissues. Ranges of gray scale values define different regions of interest. Threshold is the action performed in order to create a region. A region of interest is selected by defining a range of gray scale values.

The CT mages positioning and organizing were fulfilled. In order to extract accurately contour of the vertebrae, the range of gray scale values of the segmentation object was defined first so as to distinguish obviously the vertebra and surrounding tissue in the voxels. Therefore, the "threshold" of bone tissue was defined as 212-3071Hounsfield and bone tissue was distinguished from the surrounding tissue, and than, the contour of bone tissue to every layer was extracted, the region that local gray value was similar was extracted by artificial identification, different regions were segmented through region growing, the vertebral tissue was segmented to the all CT images. Three-dimensional geometric models of lumbar spine segment L1-L2 are constructed through 3D calculation based on 3D interpolation methods, deleting redundant data, selectively editing and cavity filling as well as edge segmentation to each layer of one target photograph.

The intervertebral disc was defined the soft tissue of annulus fibrosus and nucleus pulposus, its threshold was defined as -134-1695Hounsfield, the three-dimensional images segmentation was completed with disc as the center, redundant data were removed, the three-dimensional geometrical model of intervertebral disc L1/L2 was established by 3D calculation. The more accurate three-dimensional geometrical model of lumbar spine L1-L2 to the weightlifter was reconstructed (Fig.2) through remeshing, smoothing, shells and triangles reduction respectively for the elimination of small inclusions and the reduction of grids to improve the quality of the triangle, triangle self-intersection test without intersecting triangles and bad edges.

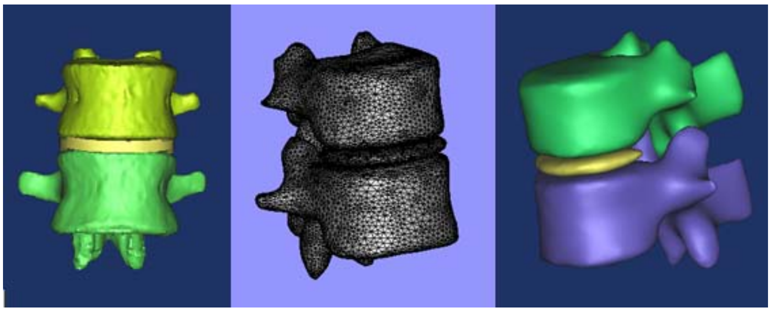

Fig. 2: The three-dimensional geometrical model of lumbar spine after remeshing and smoothing

- Construction of three-dimensional FEM for the lumbar spine segment

The surface mesh was converted to the volumetric mesh by using the finite element software. The density, E-Modulus and Poisson Coefficient of different materials were calculated based on the gray value of CT images, and realized material assignment of the bone tissue with non-uniform material properties and anisotropic mechanical properties. The density of spongy bone 0.9*10-6 kg/mm3, E-Modulus 2764MPa, Poisson Coefficient 0.29; the density of compact bone 1.9*10-6kg/mm3, E-Modulus 16800MPa, Poisson Coefficient 0.22. The material properties of intervertebral disc and ligaments were from the previous studies[6], the density of disc 1.02*10-6 kg/mm3, E-Modulus 3.4MPa, Poisson Coefficient 0.39; the material properties of ligaments was nonlinear.

The anterior and posterior longitudinal ligament, interspinal ligament, supraspinal ligament and the intertransverse ligament were established referencing the physical form of human body specimen[7], and then, the three-dimensional FEM of L1-L2 was fulfilled. The veterbae and intervertebral disc were adopted the element of SOLID185, the ligaments were adopted element of BEAM188 with nonlinear material property, and the model were consisted of elements of 83223 and nodes of 54626(Fig.3).

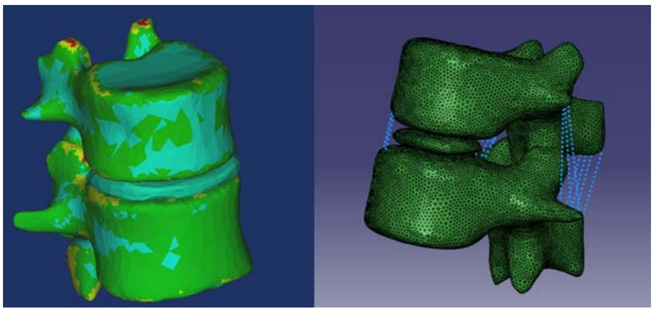

Fig. 3: The three-dimensional FEM of lumbar spine L1-L2

3.2. Analysis of mechanical characteristic of lumbar by finite element method in snatch

- Boundary condition and loading

According to the parameters of part of Chinese human body from literature[8], the weight of upper trunk accounted for 17 percent of the total body weight, and that of head, neck and arms accounted for 17 percent of the total body weight. Therefore, the weight above lumbar (L1) approximates 20.4kg; weight of barbell approximates 165kg. The axial compressive load on the upper endplate, 1854N, was evenly distributed on the surface of endplate so as to simulate the equivalent stress of lumbar motion segment L1-L2.

- Finite element analysis of lumbar in uprising position in snatch

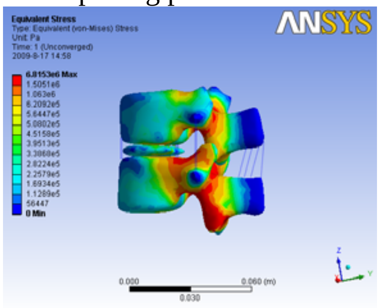

Fig. 4: Stress of lumbar L1-L2 in uprising position in snatch

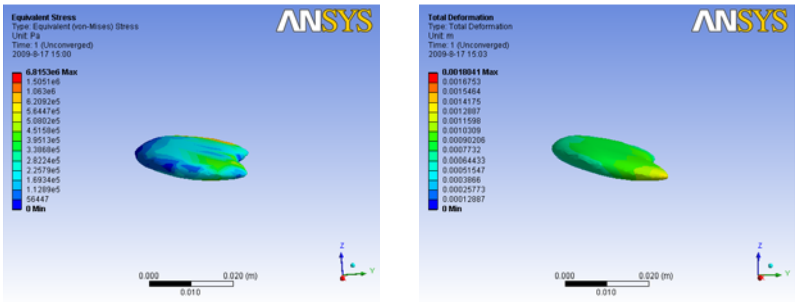

Fig. 5: contact compression and displacement of intervertebral disc in uprising position in snatch

In the standing position in snatch, stress acted on vertebral body was distributed on facet joint and pedicle of vertebral arch, stress concentration on inervertebral disc was found at middle-posterior location of annulus fibrosus, displacement happened at posterior exterior location of intervertebral disc in Figure 4-5. The loads on the lumbar spine existed different forms when athletes were in different pose of motion in sport. The power was generated in two forms from the axial loads; one perpendicular downward power acted on the upper endplate of vertebral body, the other was the forward shear force from the center of vertebral body. The downward torque made the vertebral body rotate in the sagital plane, horizontal power made the vertebral body move in the horizontal plane. Therefore, both the vertical downward torque and the shear force acted on the facet joint.

Facet joints, intervertebral disc and ligaments have close relationship in term of load bearing among the lumbar motion segment. In the neutral position, the posterior ligaments relax, so intervertebral disc and facet joint together support the axial loads. It is believed that abnormal high compression can lead to the disease on the facet joint, which will cause the low back pain. Most people think that it is the degeneration of intervertebral disc that causes the degeneration of facet joint[9-10].

Therefore, if the weight of barbell is too heavy, the strength of muscles from the waist isn't enough, and the muscles in the waist and back can't fully contract, lumbar joints may be instable and intervetebral disc may be extruded excessively. The forward excessive shear stress on isthmus from the effects of gravity can cause isthmus split and injury.

This model can be applied to lumbar spine biomechanics of theoretical study and simulation research in snatch. The ultimate aim of finite element model is to provide the mechanical basis and theoretical reference for the clinical, but, due to limitations of study conditions, this study didn't consider that the muscles affected the biomechanics of the spine, meanwhile, only one motion segment of lumbar spine is adopted as the model, the results of the analysis in this study and that for the several motion segments may be different, so the model needs continuous improvement.

4. Conclusion

The three-dimensional FEM of lumbar spine L4-L5 was established by inputting directly the data of Dicom format in the paper, and featured by fast speed of modeling and high precision of the FEM, the FEM fully imitated the structure and the material properties of the lumbar spine, with integrate structure, vivid appearance and similar geometry, the FEM can be used to simulate a realistic range of spinal movement, to research finite element analysis in snatch.

In the standing position in snatch, stress acted on vertebral body was distributed on facet joint and pedicle of vertebral arch, stress concentration on inervertebral disc was found at middle-posterior location of annulus fibrosus, displacement focused mainly on posterior exterior location of intervertebral disc.

If the weight of barbell is too heavy, the strength of muscles from the waist isn't enough, and the muscles in the waist and back can't fully contract, lumbar joint may be instable and intervetebral disc may be extruded excessively. The forward excessive shear stress on isthmus from the effects of gravity can cause isthmus split and injury.

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