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Original Article

Experimental research on the viscoelastic behavior of goat cervical vertebra after part of articular process resection

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Abstract: This study aims to investigate the influence of part of articular process resection on the viscoelastic behavior of goat cervical vertebra. To research the stress relaxation and creep properties of six cases of fresh goat cervical specimens, we measured the stress relaxation and creep properties of intact cervical spine (normal group) and the cervical spine with resection of 50% articular process of C4-C5 segment (control group). And the stresses, strain-time curves were calculated and analyzed with regression analysis, to calculate the normalized stress relaxation function, creep function and curves. There were no significant differences between normal group and control group. There was no significant difference in amount of 3600 s stress relaxation between normal group and control group ($P<0.05$); there was also no significant difference in amount of 3600 s creep between normal group and control group ($P>0.05$). The viscoelastic behavior of cervical vertebra was less affected when 50% articular process was removed but the soft tissue was preserved. The flexion and extension, and cushioning were also less affected, which would not increase the compensatory activities of other intervertebral discs and articular process. In conclusion, it was no need to use interbody fusion and internal fixation devices for the minor injury surgery, which could reduce the un-necessary costs and complications after surgery.

Keywords: Cervical spine, articular process resection, viscoelasticity, stress relaxation, creep

Introduction

Biomechanics is an interdisciplinary subject which is involved in biology, anatomy, physiology, medicine, mathematics, mechanics and other subjects [1, 2]. The main contents of biomechanics are composed of mechanics, biology and medicine to explain the various biological phenomenons in the view of mechanics. In which the bone mechanics is an important part of biomechanics.

Bone has special physical properties as its complex composition and structure. Bone maintains the greatest strength, the least materials and the lightest weight from the macroscopic, microscopic and submicroscopic structure. This is an optimal choice, and bone can satisfy the mechanical requirements. To research the mechanical properties of bone, we must consider that it is a biological material and a living tissue. In 2000, the experiment of viscoelastic properties of cancellous bone and its theoretical analysis. The creep and relaxation experiments found that human tibial cancellous bone had viscoelastic properties, and the creep and relaxation expressions were achieved with three-parameter model. In 2006, Bredbenner believed that the degree of injury was correlated with the viscoelastic change of spinal cancellous bone. The viscoelasticity is one important property of human cervical spine; and the fast creep sensitivity and fast stress relaxation sensitivity are important indicators for reflection of the flexion and extension and cushioning. As a type of biological viscoelastic solid, the cervical spine would be affected by both the change of flexion and extension and the reduction of cushioning [3-5], which would increase the compensatory activity of intervertebral disc and articular process, thereby leading to osteoarthritis, osteophyte and other complications, even paralysis of limbs. The cervical spine was connected with head and torso with weaker protection, therefore, the rate of injury was larger. Moreover, the cervical spine was prone to degeneration as high frequency activity [6], and the cervical spine injury had characteristics of severe symptoms, acute illness and poor prognosis. For the above reasons, we believe that study of viscoelastic properties of cervical spine can prevent and treat cervical spine injury. The previous reports were always about the vertebral plate and disc, but the articular process has not been reported. However, the articular process is the important part of maintaining spinal stability. In clinic, it is often to remove articular process, such as locked facet, nerve root decompression, and cervical cancer. With the development of minimally invasive surgery, it is important to study the viscoelasticity of the facet.

In this study, we performed the compression stress relaxation and creep experiments on goat cervical spine. Comparison of the viscoelasticity of lower cervical spine between intact cervical spine and the cervical spine with resection of 50% articular process, indirectly investigate the influence of human articular process surgery on the viscoelasticity of lower cervical spine. We also calculated the normalized stress relaxation function, creep function and curves with regression analysis. We quantitatively analyzed the influence of part of articular process resection on viscoelasticity of cervical spine.

Materials and methods

Specimen preparation

The fresh cadavers of normal goat aged 3-4 years old were used to collect 6 cervical vertebras of C2-T1 segments; there were no pathological changes by X-ray examination. The cervical vertebras were embedded with polymethyl methacrylate and stored at -20°C refrigerator. During experiments, the specimens were processed into a complete C2-T1 lower cervical spine (the ligaments and joint capsule were retained, and the left joint capsule was cut to reduce the experimental error). The six specimens were performed stress relaxation and creep test (normal group). Then the six cervical spines were resected 50% left articular process of C4-C5 segment, and performed stress relaxation and creep test again (control group). The mechanical tests were completed with 4 h after thawing and all experiments were completed within 72 h.

Test methods and equipment

The height and diameter of specimen were measured by microscope. The test device was automatically controlled electronic universal testing machine (AG210TA, Shimadzu, Japan), the strain was measured through differential transformer extensometer. The extensometer was clamped on both ends of the sample to measure the strain, and the results were automatically output. This machine can automatically control of the stress, strain speed and strain constant.

The compression stress relaxation test of C2-T1 segment

The length of six specimens was measured with 0.01 mm micrometer, and the length was 201.11-233.23 mm; the cross-sectional area was measured with planimeter, and the diameter was 22.32-30.04 mm according to formula $D = \sqrt{4A/\pi}$. The original data of specimens were input into computer of the machine. The data needs to repeat several times to reach a steady state as the flexibility of cervical spine. Under the condition of a maximum stress was 20% breaking stress, each sample was loaded and unloaded for 30 times firstly, and then the formal experiment. The sample was put into a plexi glass cylinder with saline, pH 7.4, and the cylinder was placed on the table of machine, the upper portion of specimen was contacted with the indenter of machine. The temperature was set 39±0.5°C to simulate the goat body temperature. The rate of strain increase speed was 50% min, and the stress should decrease with time when the load reached 0.1 kN, and stress reached 0.204 MPa. The data was collected from t (0), and 10 times every 10 s, 30 times every 20 s, 60 times every 50 s; a total of 100 data were collected within 3600 s. The experimental data and curves were printed automatically.

The creep test of C2-T1 segment

The load method and temperature were the same as the stress relaxation experiments. The rate of strain increase speed was 0.5 GPa/min, and the stress should increase with time when

Table 1. The general data of stress relaxation (MPa)

Group	Time (s)											
	0	90	150	300	600	900	1200	1800	2400	2700	3300	3600
Experimental group	0.204	0.126333± 0.026643	0.112333± 0.024105	0.096333± 0.020452	0.082000± 0.01873	0.07000± 0.013476	0.06350± 0.009731	0.05600± 0.006261	0.050833± 0.004167	0.050167± 0.005811	0.04750± 0.006686	0.046167± 0.007441
Control group	0.204	0.13800± 0.026758	0.11600± 0.024058	0.09650± 0.02152	0.081333± 0.019336	0.073833± 0.018214	0.06550± 0.012613	0.055833 0.009196	0.050667± 0.005076	0.047833± 0.005076	0.044667± 0.003724	0.04350± 0.003674

Table 2. Normanization data of stress relaxation (MPa)

Group	Time (s)											
	0	90	150	300	600	900	1200	1800	2400	2700	3300	3600
Experimental group	1	0.618833± 0.130512	0.550167± 0.11837	0.471667± 0.100596	0.401333± 0.091705	0.342667± 0.066193	0.310833± 0.047671	0.274167± 0.030636	0.248833± 0.020439	0.245667± 0.028682	0.232333± 0.033025	0.225667± 0.036806
Control group	1	0.67600± 0.13119	0.568167± 0.118163	0.47250± 0.105331	0.398333± 0.095051	0.34660± 0.091051	0.32050± 0.061831	0.273167± 0.045111	0.247833± 0.033481	0.233667± 0.025129	0.218167± 0.018225	0.21250± 0.018371

Table 3. The general data of stress creep (%)

Group	Time (s)											
	0	90	150	300	600	900	1200	1800	2400	2700	3300	3600
Experimental group	0.882333± 0.213719	1.196833± 0.290519	1.355333± 0.329263	1.57600± 0.391574	1.89100± 0.498359	2.156333± 0.582406	2.399333± 0.670982	2.797833± 0.792359	3.070833± 0.925239	3.274833± 0.956995	3.629833± 1.047744	3.806167± 1.10202
Control group	0.97350± 0.515946	1.33300± 0.597895	1.497167± 0.659157	1.730667± 0.751674	2.090167± 0.902614	2.36350± 1.020254	2.58650± 1.105163	2.944667± 1.219055	3.234167± 1.30162	3.360167± 1.33703	3.59000± 1.401964	3.73350± 1.439335

Table 4. Normanization data of stress creep (%)

Group	Time (s)											
	0	90	150	300	600	900	1200	1800	2400	2700	3300	3600
Experimental group	1.008823 ±0.002137	1.011968 ±0.002905	1.013553 ±0.003293	1.01576 ±0.003916	1.182243 ±0.406108	1.021563 ±0.005824	1.023993 ±0.00671	1.027978 ±0.007924	1.030708 ±0.009252	1.032748 ±0.00957	1.036298 ±0.010477	1.038062 ±0.01102
Control group	1.009735 ±0.005159	1.01333 ±0.005979	1.014972 ±0.006592	1.017307 ±0.007517	1.020902 ±0.009026	1.023635 ±0.010203	1.025865 ±0.011052	1.029447 ±0.012191	1.032342 ±0.013016	1.033602 ±0.01337	1.03590 ±0.01402	1.037335 ±0.014393

the load reached 0.1 kN, and strain reached 0.88%.

Statistical analysis

The stress relaxation, creep and normalization functions were processed by computer in each group. The data were analyzed by SPSS 19.0. The enumeration data were expressed as mean ± standard deviation ($\bar{x}$±s). The data were analyzed by using the t test for statistical analysis. A $P<0.05$ was considered as significance difference.

Results

The compression stress relaxation test of C2-T1 segment

The original data of stress relaxation in normal group and control group were calculated and the results were shown in **Table 1**, the data after normalized analysis were shown in **Table 2**.

The creep test of C2-T1 segment

The original data of creep test in normal group and control group were calculated and the results were shown in **Table 3**, the data after normalized analysis were shown in **Table 4**.

Discussion

Our results showed that the stress relaxation curves showed logarithmic changes and creep curves showed exponential changes. There were no significant differences in stress relaxation and creep experimental data between normal group and control group, suggesting that removal of 50% articular process of C4-C5 segment would not affect the viscoelasticity of lower cervical spine of goat.

It has been proved that the accuracy of viscoelastic experiment depended on the duration of stress relaxation and creep tests [7, 8]. Our study conducted 3600 s, which was enough, and the stress and strain changes were larger within 600 s either stress relaxation test or creep test. Then the stress relaxation curves showed logarithmic changes and creep curves showed exponential changes. And the stress relaxation curves and creep curves of 3600 s maintain basic balance and an upward trend; we believe the mechanical state of goat cervical spine reached stabilization, and the date accurately reflected the real viscoelastic change process.

The reason we chose cervical spine of goat was that the cervical spine was connected with head and torso with weaker protection, therefore, the rate of injury was larger. Moreover, the cervical spine was prone to degeneration as high frequency activity; and the cervical spine injury had characteristics of severe symptoms, acute illness and poor prognosis. It has been reported that C4-C5 segment had the maximum pressure value, and the disc with large load would appear degeneration [9]. Another study confirmed that in flexion and extension, the strain values of C4-C5 segment were the maximum, followed by C5-C6 segment, and C3-C4 segment [10].

In order to discharge the possible confounding factors, the temperature was strictly controlled 39±0.5°C. The simulated physiological environment could ensure the accuracy [11]. On the other hand, the change of temperature and moisture could affect the viscoelasticity of soft tissue, and our study avoided these confounding factors.

The modern biomechanical studies have showed that bone has special physical properties as its complex composition and structure [12]. Bone maintains the greatest strength, the least materials and the lightest weight from the macroscopic, microscopic and submicroscopic structure. This is an optimal choice; bone can satisfy the mechanical requirements. Therefore, to study the mechanical properties of bone, we must consider that it is a biological material and a living tissue.

In the organism's life, bone constantly improve itself, rebuild new bone tissue and absorb old bone tissue, which is its unique feature. However, this feature also leads to diseases. As a feedback control system, bone is in the state of equilibrium under the optimum stress value, that is the bone formation rate is equal as bone absorbing rate. When the strain and stress values are bigger than the optimum value and smaller than the upper limit of adaptation, the osteogenesis is dominant, causing bone hyperplasia; then the strain and stress values are decreased and returned to the optimal value. On the contrary, the strain and stress values are increased, which would lead to osteoarthritis, degeneration and other diseases. The two intervertebral joints play an important role in the stress conduction. It has been found that the disc bear 36% stress and the intervertebral joints bear 64% stress under axial stress [13]. The viscoelasticity is the parameter which reflects the strain rate under stress, is the important indicator of biomechanics. In home and abroad, the viscoelastic experiments were simulation of the anteroposterior surgery, such as single open-door, double door and disc removal, etc. Simple articular process resection was few reported [14], which was always combined with other surgery; therefore, it couldn't explain the viscoelasticity of articular process and the influence on cervical spine, which has small guiding significance on minimally invasive surgery.

Our study simulated removal of 50% articular process of C4-C5 segment without disrupting the lamina, ligaments and joint capsule, and the results showed that the viscoelasticity of samples was not significantly changed, suggesting there was no influence on the overall viscoelastic when removal of 50% articular process under retaining the soft tissue [15-17]. Our results also showed that the flexion and extension, and cushioning were also less affected, which would not increase the compensatory activities of other intervertebral discs and articular process. In clinic, we performed spinal surgery is to restore the original anatomy, relieve oppression and establish a stable mechanical structure; therefore, to restore and maintain the viscoelasticity of spine has great significance. We suggested that there was no need to use interbody fusion and internal fixation devices for the minor injury surgery, which could reduce the unnecessary costs and complications after surgery.

In this study, we used goat sample, which had some differences with human body from morphology and experimental load. On the other hand, our study only conducted 50% articular process resection; it still needs further 75% and 100% resection to confirm the results.

In the actual clinical work, we performed spinal surgery is to restore the original anatomy, relieve oppression and establish a stable mechanical structure. Therefore, to restore and maintain the viscoelasticity of spine has great significance. We suggested that there was no need to use interbody fusion and internal fixation devices for the minor injury surgery, which could reduce the unnecessary costs and complications after surgery.

Disclosure of conflict of interest

None.

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