

Are Deer and Boar Spines a Valid Biomechanical Model for Human Spines?

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Abstract

Objective: To examine the validity of using cadaveric spines of deer or boars for biomechanical experiments as substitutes for the cadaveric spine of humans.

Materials and Methods: Five specimens of the L3-4 functional spinal unit of human cadavers, mature deer and mature boars were prepared according to 3 models: 1) normal model, 2) injured model and 3) pedicle screw fixation model and they were evaluated in 8-direction bending and 2-direction rotation tests. The mean ROM in bending and rotation tests of each specimen and the rate of relative change of ROM were calculated.

Results: Flexibility of cadaveric spine of deer and boars was slightly higher than that of cadaveric spine of humans in the bending and rotation tests, but the rates of relative change of ROM in the rotational and bending tests were similar across species.

Conclusions: It is reasonable to use cadaveric spines of deer and boars as a model of the human cadaveric spine in biomechanical experiments.

Keywords: Biomechanics; lumbar spine; In vitro testing; Animal models; Spinal instrumentation

Introduction

Recently there have been many biomechanical studies of spinal decompression, fusion and spinal instrumentation [1-3]. Ideally these studies should be performed employing a human cadaveric spine, but in many countries or institutions human cadaveric specimens cannot be obtained. In such situations, bovine or porcine spines are frequently used instead [4-7]. Deer and wild boars inflict harm on humans, and 500 thousand boars and 400 thousand deer were hunted in Japan in 2011 [8]. In our institution, deer and wild boar specimens are available for research studies. However, there are very few reports comparing the biomechanical properties of the spines of deer and boars to those of humans [9-12]. In the current study, we compared the biomechanical properties of the lumbar vertebrae obtained from deer, boars and human cadavers to examine the validity of using cadaveric spines of deer or boars for biomechanical experiments as a substitute for the cadaveric spine of humans.

Subjects and Methods

Five lumbar vertebrae from human cadavers, five lumbar vertebrae from deer (Sika deer, *Cervus nippon*) and five lumbar vertebrae from boars (Japanese wild boar, *Sus scrofa leucomystax*) were used. The specimens were removed from cadavers after dissection of the bulk of the muscle mass and were frozen at -20°C until required for testing. Specimens were thawed out 8-12 h before testing. The functional spinal unit consisted of L3-4 vertebral bodies, including the

intervertebral disc, the facet joint and the supraspinatus and interspinous ligaments. The human cadavers (n=5) were 35-58 years old (mean age, 44.7 years, weight 50-75 kg) and the mean estimated age of the mature deer and boars was 2 years (weight 80-110 kg). Computed tomography findings of L3-4 of cadaveric deer and boars are shown in Figures 1 and 2, respectively. Regarding anatomical differences from humans, the spines of deer and boar have the intervertebral disk of about 3 mm in height and the size of vertebral body of about 2/3, and the shape of intervertebral joint is ellipsoid different from facet joint in humans, which is large anatomical different from humans. A normal model, an injured model, and a pedicle screw fixation (PS-fixed) model were prepared in a stepwise manner for each specimen. The normal model preserved all stabilized elements such as intervertebral disc and facet joints. In the injured model, holes were bored into the front of the L3/4 intervertebral disc at three sites (1/4, 1/2, and 3/4 of the width of the disc) using a 3-mm-diameter drill, and total bilateral intervertebral joints were resected. Since the size of vertebral body and pedicle is different between humans and deer or boar, moreover, the pedicle screw different from humans has been used for deer and boars in the present experiment. We prepared the pedicle screw system of which the design is the same but the length and thickness were downsized to about 2/3 with reference to the pedicle screw (Texas Scottish Rite Hospital System, Reduced Profile Spinal System, Medtronic Sofamor Danek, Co., Ltd., Memphis, TN) for humans; namely 6.5-mm diameter and 35 mm long in humans and 3.0-mm diameter and 25 mm long in deer and boars) and a rod system (5.5 mm in humans and 4 mm in deer and boars) for L3-4 fixation of PS-fixed model. Its fixed power is of course different between that for humans and that for animals, but it is sure that any system gives

stability to the functional spinal unit, so it is considered possible to know approximate biomechanical characteristics.

from side to side, and in the intermediate direction). Rotational tests were performed under a load of 3 Nm at an angular velocity of 0.1 deg/s in two directions: leftward and rightward. The six-axis material tester is equipped with six drive sources and a dynamic sensor on each independently controlled actuator and motion can be voluntary controlled in six dimensions. The material tester was limited to three degrees of freedom for the bending tests (speed control on the x-axis and displacement along the y- and z-axes) and to four degrees of freedom for the rotational tests (speed control on the x- and y-axes and displacement along the x- and y-axes).

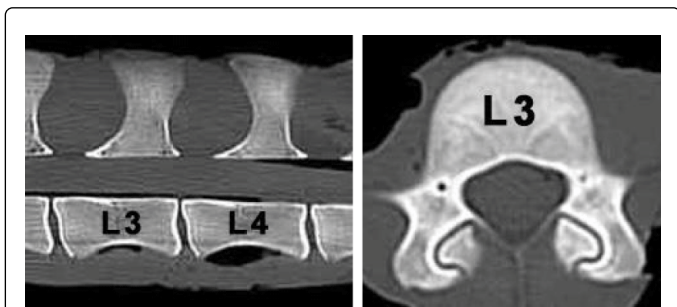


Figure 1: Lumbar spine of a deer in sagittal view and axial view.

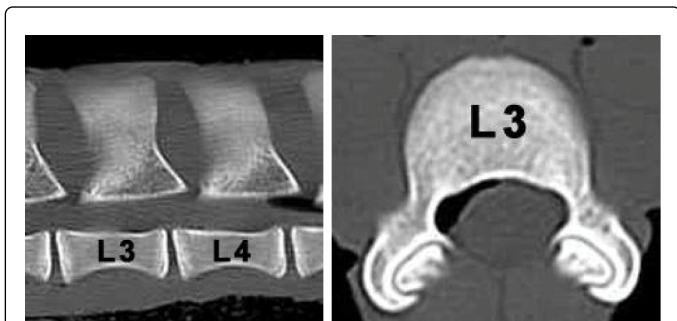


Figure 2: Lumbar spine of a boar in sagittal view and axial view.

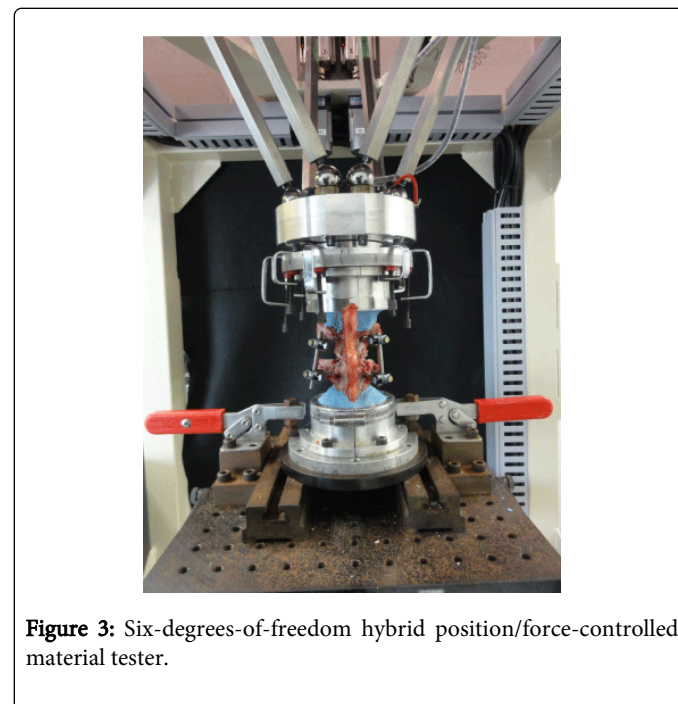


Figure 3: Six-degrees-of-freedom hybrid position/force-controlled material tester.

A six-degree-of-freedom hybrid position/force-controlled material tester that was custom made by the Faculty of Engineering, at Mie University, Japan [13], was used to perform the bending and rotational tests (Figure 3). Bending tests were performed under a load of 3 Nm at an angular velocity of 0.1 deg/s in eight directions (from front to back,

Humans (degree)								
	anterior	anteroright	right	posteroright	posterior	posteroleft	left	anteroleft
normal	4.7 ± 2.8	4.6 ± 2.9	4.5 ± 3.1	4.3 ± 3.3	4.1 ± 2.5	4.2 ± 2.6	4.4 ± 3.0	4.5 ± 3.2
injured	6.5 ± 3.9	6.3 ± 4.1	6.5 ± 4.3	6.1 ± 3.8	6.3 ± 4.2	6.0 ± 3.5	6.4 ± 4.1	6.2 ± 3.8
PS-fixed	1.5 ± 1.0	1.4 ± 0.9	1.5 ± 1.1	1.4 ± 0.8	1.4 ± 1.0	1.3 ± 0.9	1.4 ± 1.0	1.5 ± 1.1
Deer (degree)								
normal	6.2 ± 3.8	6.3 ± 4.1	6.8 ± 4.3	6.6 ± 4.2	6.1 ± 4.0	6.4 ± 3.9	6.9 ± 3.5	6.7 ± 4.3
injured	9.2 ± 4.5	9.5 ± 4.3	10.1 ± 4.8	9.9 ± 5.3	9.6 ± 5.1	9.9 ± 5.0	10.2 ± 4.9	9.4 ± 5.1
PS-fixed	2.2 ± 1.5	2.1 ± 1.7	1.8 ± 1.4	1.9 ± 1.2	2.2 ± 1.5	1.9 ± 1.0	1.8 ± 1.1	2.1 ± 1.4
Boars (degree)								
normal	5.8 ± 3.7	6.2 ± 4.0	6.4 ± 3.2	6.2 ± 3.5	6.2 ± 3.7	6.3 ± 3.8	5.9 ± 3.6	5.8 ± 3.8
injured	8.5 ± 4.1	8.7 ± 4.3	9.2 ± 4.8	9.1 ± 4.3	8.7 ± 5.0	9.0 ± 5.1	9.3 ± 4.9	8.7 ± 4.6
PS-fixed	1.8 ± 1.2	1.6 ± 1.4	1.4 ± 1.0	1.5 ± 1.1	1.8 ± 1.3	1.6 ± 1.1	1.4 ± 1.0	1.7 ± 1.2

Table 1: Mean range of motion in each direction for humans, deer and boars in the bending test.

The interspinal motion in each direction under a load of 3 Nm was considered the ROM. The mean bending ROM in each of the eight directions and the mean rotational ROM in each of the two directions were calculated for each species (n=5 cadaveric specimens per species). The rate of relative change of ROM in the injured model in both the bending and the rotation tests was calculated according to the following formula: (mean ROM of injured- mean ROM of normal model data)/mean ROM of normal model data × 100(%). The rate of

relative change of ROM in the PS-fixed model in both the bending and the rotation tests was calculated according to the following formula: (mean of PS fixed model-mean ROM of injured model data)/mean ROM of injured model data × 100(%). The ROM and the rate of relative change of ROM of each model were compared among the three species using a Kruskal-Wallis test. P<0.05 was used as the level of statistically significant difference.

Change from normal model to injured model (%)										
	anterior	anteroright	right	posteroright	posterior	posteroleft	left	anteroleft	right-rotation	left-rotation
human	-76.9 ± 22.6	-77.8 ± 15.1	-76.9 ± 18.1	-77.0 ± 21.8	-77.8 ± 9.4	-78.3 ± 10.8	-78.1 ± 14.6	-75.8 ± 18.2	-11.8 ± 1.5	-21.5 ± 1.3
deer	-76.1 ± 25.7	-77.9 ± 17.7	-82.2 ± 17.6	-80.8 ± 12.2	-77.1 ± 20.0	-80.8 ± 17.9	-82.4 ± 21.4	-77.7 ± 16.9	-11.2 ± 2.2	-8.8 ± 2.1
boar	-78.8 ± 16.8	-81.6 ± 20.5	-84.8 ± 18.8	-83.5 ± 15.7	-79.3 ± 13.3	-82.2 ± 18.1	-84.9 ± 22.8	-80.5 ± 9.1	-13.4 ± 1.3	-12.9 ± 1.5
Change from injured model to PS fixed model (%)										
human	38.3 ± 11.4	37 ± 12.6	44.4 ± 17.3	41.2 ± 8.7	53.7 ± 14.1	42.9 ± 13.8	45.5 ± 7.6	37.8 ± 8.2	53.2 ± 19.1	64.6 ± 22.3
deer	48.4 ± 17.5	50.8 ± 16.9	48.5 ± 15.8	50.0 ± 18.3	57.4 ± 13.4	54.7 ± 17.8	47.8 ± 13.3	40.3 ± 9.1	53.2 ± 16.5	55.1 ± 20.1
boar	46.6 ± 14.5	40.3 ± 16.6	43.8 ± 13.6	46.8 ± 10.8	40.3 ± 7.9	42.9 ± 18.1	57.6 ± 10.5	50.0 ± 8.9	57.1 ± 13.6	46.6 ± 19.7

Table 2: Rate of relative change of range of motion

Left direction (degree)			
	human	deer	boar
normal	1.1 ± 0.3	1.7 ± 0.6	1.5 ± 0.4
Injured	2.5 ± 0.7	3.8 ± 1.6	3.4 ± 1.0
PS-fixed	1.7 ± 0.4	2.7 ± 0.7	2.3 ± 0.8
Right direction (degree)			
normal	1.1 ± 0.4	1.9 ± 0.5	1.5 ± 0.4
Injured	2.6 ± 0.9	4.0 ± 1.1	3.6 ± 0.8
PS-fixed	1.7 ± 0.3	2.6 ± 0.9	2.3 ± 0.8

Table 3: Mean range of motion in right and left direction for humans, deer and boars in the rotation test.

Results

Bending tests

The mean ROMs in each direction for humans, deer and boars are shown in Table 1.

The flexibility was higher in deer and boars than in humans, but ROM did not differ significantly among the three species statistically. In all three species, ROM in all directions was greater in the injured model than in the normal model and the PS-fixed model. The mean rate of relative change of ROM in the injured model from the normal model and the mean rate of relative change of ROM in the PS-fixed model from the injured model in each of the eight directions are

shown in Table 2. The rates of relative change of ROM in the injured and the PS-fixed model were not significantly different in the three species statistically.

Rotational tests

The mean ROM in the right and left rotational directions for humans, deer and boars is shown in Table 3.

Flexibility was higher in deer and boars than in humans, but ROM did not differ significantly across the three species statistically. In all three species, ROM in both directions was greater in the injured model than in the normal model and the PS-fixed model. The mean rate of relative change of ROM in the injured model from the normal model and the mean rate of relative change of ROM in the PS-fixed model from the injured model in both directions are shown in Table 2. The rates of relative change of ROM in the injured and the PS-fixed models were not significantly different in the three species statistically.

Discussion

A search of the existing literature that we conducted in Pubmed with the following key words: biomechanical study, spine, spinal instrumentation, animal, and in vitro, identified 173 studies conducted between 1983 and 2013: 51 human, 41 bovine, 26 porcine, 14 sheep, 12 goats, 5 canine, 3 baboon, 4 other animals and 17 finite element methods. There was a tendency for a higher proportion (about 60-70%) of recent biomechanical studies to use human cadaveric spines and finite element methods. In some countries, such as Thailand, human cadaveric spines can be obtained from donor patients; however, in Japan it is difficult to obtain human cadaveric spines due to ethical and religious issues. We conducted this study to

evaluate deer and boars spines as an alternative model for in vitro biomechanical testing.

A systematic review [14] concluded that bovine, porcine and sheep were suitable experimental animals for in vitro and in vivo experimental studies of the lumbar spine, and then, the advantages and disadvantages of each animal for biomechanical studies are summarized in Table 4. Porcine spine was proposed to provide the best representation of a human spine in anatomical and biomechanical studies [2,3,5], and Wilke et al. [15] demonstrated the biomechanical similarities of bovine and human spines for in vitro evaluation of an implant system, and Wilke et al. [16] also found similarities in the biomechanical properties of sheep and human spines. There is no obviously significant point in the deer and boar used in this study compared with porcine, bovine and sheep from the viewpoint of the data of biomechanical study. In recent Japan, however, the number of

wild deer and boars, destructive animals, has increased, agricultural damages are occurring frequently, and the number of captured destructive animals is increasing drastically to prevent the damages. Therefore, the merits of the use of cadaveric spines of deer and boars are that the resource of destructive animals can be utilized effectively and that the spines can be obtained easily at very low prices compared with other animals. Some biomechanical studies have used the cervical spine of goats to evaluate the intervertebral disc, interbody fusion device or ventral plate [1,14] and canine spines were rarely used for biomechanical studies due to the variety of breeds and size of dogs and the unique anatomy of the posterior component of their spine [17,18]. The anatomy of the vertebral body of all these animals, with narrower width and taller height 16 is significantly different to that of humans, so the results can be interpreted as a trend rather than quantitatively [7].

Animals	Advantages	Disadvantages
Porcine	Closely resembled those of human vertebrae, ROM Most similar facet orientation esp.T10-11 level facet became similar to human lumbar facet joint orientation	Cervical level: limited lateral bending due to lack of uncinat process and uncovertebral joints Erysipelothrix rhusiopathiae infection
Bovine	similar ROM less variability in bone quality	Bovine Spongiform Encephalopathy (BSE) infection
Sheep	Mature sheep comparable bone mineral density to average young adult male for corresponding column	Hook-shaped facet very small size of sheep's pedicles scrapie infection
Goat	Comparable size, shape, geometry of Human intervertebral disc, very useful in degenerative process of intervertebral disc testing C2-3 are most appropriate level for intervertebral body device testing	Hook-shaped facet Narrower mean pedicle width Tuberculosis, brucellosis, Q-fever, rabies
Canine	similar ROM in flexion and extension	Ethical implication of being companion Animals unique anatomy of facet

Table 4: Advantages and disadvantages of each animal for biomechanical studies

In the experiments using animals, the individual difference is generally large and it is difficult to make the procedures such as destruction and fixation constant, so the data may be variable, but it is considered possible to know approximate biomechanical tendency. In our study, the flexibility of the cadaveric spine of deer and boars was slightly higher than the flexibility of the cadaveric spine of humans in both bending and rotation tests, but the rate of relative change of ROM was not significantly different in the three species statistically.

The largest advantage of this study over previous studies was that we compared biomechanical characteristics of the vertebrae from deer, boars and humans using the same set-up test and protocol. After a thorough anatomical and biomechanical study, Kumar et al. [9,10] recommended deer spines as an alternative model for lower thoracic and upper lumbar human spines. Liu et al. [11] compared deer, sheep and human spines and concluded that the deer lumbar spine was more appropriate than the sheep lumbar spine for use in vertebral internal fixation studies. In the biomechanical study in the final stage for clinical application in humans, the fresh human cadaveric spine must therefore be used [19]. In the biomechanical study in the stage of

inspiration of new idea, however, the biomechanical experiment using animals is useful, and as shown in our present study particularly, it is considered good application in determination of instability after destruction of functional spinal unit and checking of the stability after fixation with implants. In biomechanical studies, however, recently in Japan, the research using human fresh spine can be performed at Sapporo Medical University, Keio University and Chiba University as of 2014, so the number of institutions in such environment will increase to 10 in the future. Limitations of this study are the small number of specimens of each species and the age of the human cadaveric specimens (35–58 years), which may limit the extrapolation of our conclusions to older patients with osteoporosis. Repeated performance of the test procedures on the same vertebrae may have interfered with the bony microstructure and influenced the results. We did not analyze bone mineralization or bone density because many factors, for example hormones, can influence these variables.

Conclusions

It may be reasonable to use the cadaveric spine of deer and boars as a model of the human cadaveric spine in biomechanical experiments.

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