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REVIEW ARTICLE

Anatomy of large animal spines and its comparison to the human spine: a systematic review

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Abstract Animal models have been commonly used for in vivo and in vitro spinal research. However, the extent to which animal models resemble the human spine has not been well known. We conducted a systematic review to compare the morphometric features of vertebrae between human and animal species, so as to give some suggestions on how to choose an appropriate animal model in spine research. A literature search of all English language peer-reviewed publications was conducted using PubMed, OVID, Springer and Elsevier (Science Direct) for the years 1980–2008. Two reviewers extracted data on the anatomy of large animal spines from the identified articles. Each anatomical study of animals had to include at least three vertebral levels. The anatomical data from all animal studies were compared with the existing data of the human spine in the literature. Of the papers retrieved, seven were included in the review. The animals in the studies involved baboon, sheep, porcine, calf and deer. Distinct anatomical differences of vertebrae were found between the human and each large animal spine. In cervical region, spines of the baboon and human are more similar as compared to other animals. In thoracic and lumbar regions, the mean pedicle height of all animals was greater than the human pedicles. There was similar mean pedicle width between animal and the human specimens, except in thoracic segments of sheep. The human spinal canal was wider and deeper in the anteroposterior plane than any of the animals. The mean human vertebral body width and depth were greater than that of the animals except in upper thoracic segments of the deer. However, the mean vertebral body height was lower than that of all animals. This paper provides a comprehensive review to compare vertebrae geometries of experimental animal models to the human vertebrae, and will help for choosing animal model in vivo and in vitro spine research. When the animal selected for spine research, the structural similarities and differences found in the animal studies must be kept in mind.

Keywords Comparative anatomy · Animal models · Human · Spine

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Introduction

Various large animals, such as pig, calf, sheep, baboon, deer, goat and dog spines as models have been used for in vivo and in vitro spinal research [1, 7, 11, 12, 17, 18, 21, 22]. In vitro models consisting of cadaveric spine specimens are useful in providing basic understanding of the functioning of the spine. In vivo models provide the means to model living phenomena, such as fusion, development of disc degeneration, instability and adaptive responses in segments adjacent to spinal instrumentation. Basically, human specimens are more suitable for these models than are animal specimens whenever anatomy, size (for instrumentation) and kinematics are important. However, there are some disadvantages in using the human model. One problem is the difficulty in obtaining fresh human specimens, especially from the younger population. Another problem with the use of human specimens is the large variation in geometry and mechanical properties due to differences in age, sex, bone quality and disc and bone degenerative changes. These disadvantages of human specimens force a search for alternative animal models; and, most in vivo and in vitro experiments have been performed in animal spines, which are more easily available and have more uniform geometrical and mechanical properties. To mimic the clinical situation, an appropriate animal should have similar characteristic anatomical dimensions of spine to those in humans as possible.

Up til now, basic studies about the anatomical suitability for several large animal spines exist [2–6, 8–10, 20, 23, 24]. However, in nearly all these studies, only single animal was used to do the comparative anatomical study with the human spine. Therefore, a systematic review is needed to analyze the differences and similarities of vertebrae between human and all large animals studied, so as to determine the extent to which animal models more resemble the human spine. Thus, the purpose of this study is to summarize the differences and similarities of anatomy between human and animal models, and give some suggestions on how to choose a better animal model in vivo and in vitro experiment.

Methods

PubMed, OVID, Springer and Elsevier (Science Direct) were searched using the keywords: animal(s), human, spine (spinal), lumbar, thoracic, cervical, anatomy, anatomic, anatomical, morphometry, sheep, pig (swine, porcine), calf (bovine), baboon, deer, goat (ovine) and dog (canine). The search was limited to studies on spine anatomy of large animals, published in English and in the period from January 1980 up to August 2008. References of retrieved articles and of relevant overview articles were checked to identify additional studies.

Two reviewers independently checked eligible articles on title, keywords and abstract. A consensus meeting was used to discuss disagreements. Reports on studies were included if they met the following inclusion criteria: (1) large animal used in spine research: sheep, pig, calf, baboon, deer, goat and dog, (2) anatomical study of cervical, or thoracic or lumbar spine, (3) at least three vertebral levels were measured in the study. Two reviewers then extracted data from all the included papers relating to the anatomy of animal spines. We compare the spinal anatomy of these animal models with that of human from seven anatomical parameters: vertebral body width (VBW), vertebral body depth (VBD), vertebral body height (VBH), spinal canal width (SCW), spinal canal depth (SCD), pedicle width (PW) and pedicle depth (Table 1, Fig. 1). The comparative human parameters were taken from published literature, for various regions of the spine—cervical (Panjabi et al. [13]), thoracic (Panjabi et al. [14]) and lumbar (Panjabi et al. [15]) were recorded.

Table 1 Anatomical parameters

Abbreviation	Dimension
Vertebral body	
VBW	Vertebral body width
VBD	Vertebral body depth
VBH	Vertebral body height
Spinal canal	
SCW	Spinal canal width
SCD	Spinal canal depth
Pedicle	
PW	Pedicle width
PH	Pedicle height
Suffixes	
a	Anterior
p	Posterior
u	Upper
l	Lower

Results

Among the 544 papers found, 510 papers were not considered, because they do not include any relevant anatomical information on animal spine. Furthermore, 37 papers were discarded because they did not meet the inclusion criteria mentioned above. In total, seven eligible studies were reviewed for further analysis. There was one report on baboon cervical spine [20], two papers on sheep spine [8, 23], two papers on porcine spine [2, 6], one paper on calf spine [4] and one paper on deer spine [9]. These studies are summarized in Table 2. Comparisons of each anatomical parameter of human [13–15], baboon [20], sheep [23], porcine [2, 6], calf [4] and deer [9] are shown in Figs. 2, 3, 4, 5, 6, 7, 8, 9, 10 11 and Tables 3, 4, 5, 6 7, respectively. The sheep, porcine and deer have more than 12 thoracic vertebrae, and the human has only 12 thoracic vertebrae, therefore, we just compared the parameters from T1 to T12 between them.

Vertebral body

In cervical region, the baboon spine is nearly half of human, and the increase trend of spine is similar to that in humans. The sheep spine is larger than human, particularly in VBH, and the trend is opposite to that in humans. In thoracic and lumbar regions, the mean human VBW and

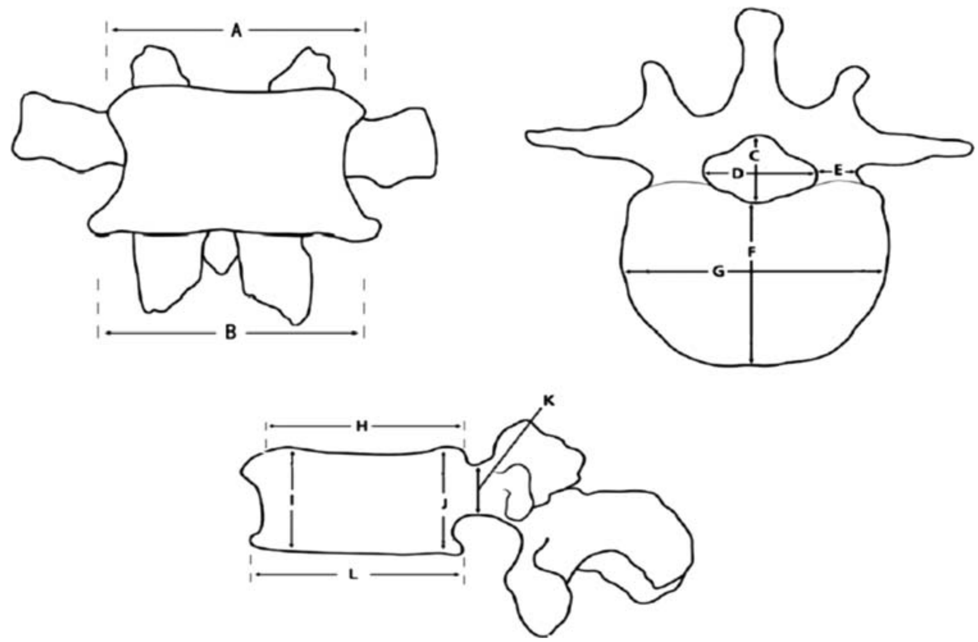

Fig. 1 Measurement of anatomical parameters. *A* vertebral body width upper (VBWu), *B* vertebral body width lower (VBWl), *C* spinal canal depth (SCD), *D* spinal canal width (SCW), *E* pedicle width (PW), *F* vertebral body depth (VBD), *G* vertebral body width (VBW), *H* vertebral body depth upper (VBDu), *I* vertebral body height anterior (VBHa), *J* vertebral body height posterior (VBHp), *K* pedicle height (PH), *L* vertebral body depth lower (VBDl)

VBD are greater than that of the animals, except in upper thoracic segments of the deer; the mean VBH is lower than that of all animals (Tables 3, 4, 5; Figs. 2, 3, 4, 5, 6, 7).

Spinal canal

The human spinal canal is wider and deeper in the anteroposterior plane than any of the animals. The human is similar to the all animal model in increase trend of SCW, but the increase trend of SCD is opposite, except the sheep, deer and porcine lumbar spine (Table 6; Figs. 8, 9).

Pedicle

The mean pedicle height (PH) of all animals is greater than the human pedicles. There is similar mean PW between animal and the human specimens, except in thoracic segments of sheep (Table 7, Figs. 10, 11).

Discussion

Basic spine research and preclinical testing of new surgical methods often involve animal experiments because most tests cannot be carried out on humans or the availability of human specimens is limited. Currently, large animal models, such as sheep, pig, calf, baboon, deer, goat and dog spines have been used to substitute for human spine [1, 7, 11, 12, 17, 18, 21, 22]. Before using animal models, it is necessary to study how the parameters of interest differ between species to be aware of the limitations of any particular animal model and to ensure conclusions reached are applicable to human. The current review shows although qualitatively, the anatomy of the spine of these species is similar to that of human, the sizes of some parameters differ considerably, including greater VBHs, lower VBW and VBD, smaller spinal canal and greater PH. Therefore, the ideal animal model for human spine does not exist. The differences between human and quadruped spines may affect the consequences for the interpretation of experimental results. These differences and similarities should be kept in mind, when choosing an animal model for study of human spinal conditions and treatments.

Although based on such comparative data of these animal models, it is difficult to interpret, whether a certain species is most suitable to be used as the human spine, we can choose an appropriate animal model based on the factors such as, anatomy, availability and cost, etc. Kandziora et al. [8] concluded that the sheep cervical spine is suitable as a model for cervical spine research. An analysis of existing data in the present study shows that only considering VBH, the baboon cervical spine is the best model to substitute for human, while the VBH of sheep cervical spine is significantly greater than that of human spine [23]. In terms of VBW, the trend of the sheep cervical spine is the opposite to that in humans from C2 to C7. Although the baboon cervical spine is smaller than human's, the VBW trend is similar to human. Therefore, in cervical region, spines of the baboon and human are more similar as compared to sheep, indicating the baboon may be a better substitution for human cervical spine in anatomy, which might be their closely shared gene homology [20]. In lower thoracic and upper lumbar regions, deer may be used as an alternative to human specimens, if the differences are taken

Table 2 Characteristics of the included studies

Authors	Year of publication	Animal names	Number of animals	Anatomical segments	Specimen properties	Measurement tools	Comparison of anatomical differences	Conclusions
Tominaga et al. [20]	1995	Baboon (mean age 16.7 years)	9	Cervical spine	Fresh	Digitized caliper	Comparison with the values of six adult cadaver cervical spines	The geometry and anatomy of the baboon cervical spine closely resemble that of the human cervical spine
Kandziora et al. [8]	2001	Sheep (mean age 2 years; average weight, 64.6 ± 3.7 kg)	20	Cervical spine	Fresh	Digitized ruler	Comparison with 20 fresh human cadaver cervical spines	The small intergroup standard deviations and the good comparability with the human spine encourage the use of the sheep cervical spine as a model for cervical spine research
Wilke et al. [23]	1997	Sheep (age 3–4 years; average weight, 72.1 ± 7.3 kg)	5	Cervical, thoracic and lumbar spines	Fresh	Hand-held micrometer	Comparison with reported values of the human spine	Sheep spine may be a useful model for experiments related to the gross structure of the thoracic or lumbar spine, with certain limitations for the cervical spine
Bozkus et al. [2]	2005	Pig (age 6 months; average weight, 30 kg)	10	Thoracic spine	Fresh	Digitized caliper and ruler	Comparison with the values of ten human cadaver Thoracic spines	Thoracic spine from T6 toT10 probably is most similar to that in the human anatomically
Dath et al. [6]	2007	Pig (age 18–24 months; weight, 60–80 kg)	6	Lumbar spine	Fresh	Digitized caliper	Comparison with the values of six human lumbar spine specimens	Porcine lumbar vertebrae may be used as an alternative to human specimen if the anatomical differences are taken into account
Cotterill et al. [4]	1986	Calf (age 6–8 weeks)	10	Thoracic (T6 and T12) and lumbar (L3) spines	Fresh	Hand-held micrometer	Comparison with the values of ten human thoracic lumbar spine specimens‘	Differences in column length and curvature were observed. These significantly different measurements were considered important factors that influence experimental results when using the bovine spine as a model
Kumar et al. [9]	2000	Deer (age 20–27 months; weight, 46–52 kg)	6	Cervical, thoracic and lumbar spines	Fresh	Hand-held micrometer	Comparison with reported values of the human spine	The deer and human vertebrae show many similarities in the lower thoracic and upper lumbar spine, although they show substantial differences in certain dimensions. The cervical spine was markedly different in comparison

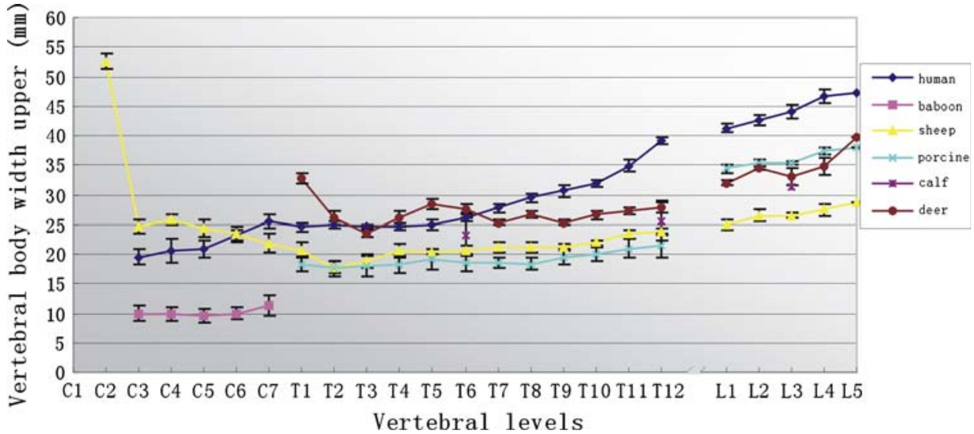

Fig. 2 Comparisons of upper vertebral body width (mean ± SD) (human [13–15], baboon [20], sheep [8, 23], porcine [2, 6], calf [4] and deer [9])

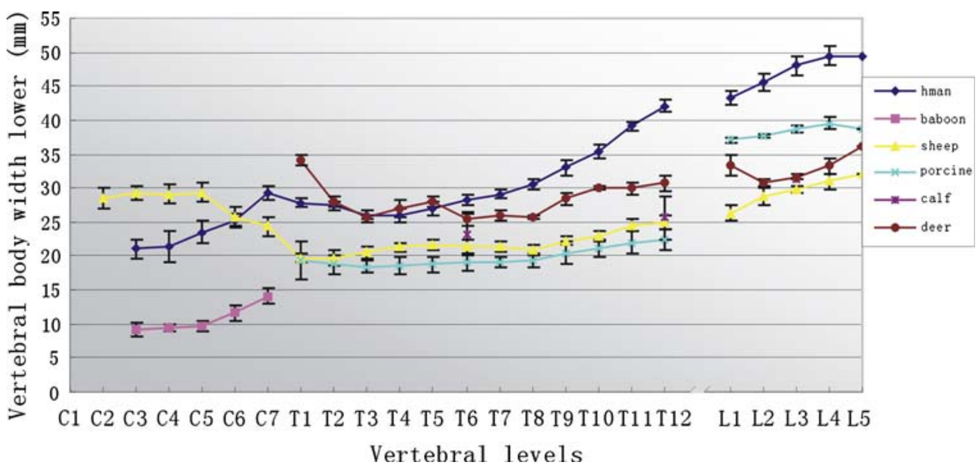

Fig. 3 Comparisons of lower vertebral body width (mean ± SD) (human [13–15], baboon [20], sheep [8, 23], porcine [2, 6], calf [4] and deer [9])

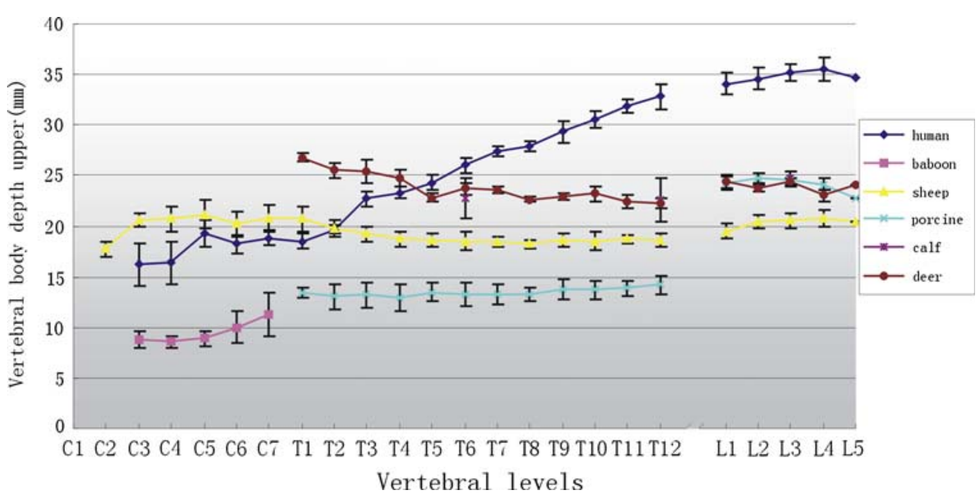

Fig. 4 Comparisons of upper vertebral body depth (mean ± SD) (human [13–15], baboon [20], sheep [8, 23], porcine [2, 6], calf [4] and deer [9])

into consideration. Sheep spine may be a useful model for experiments related to the gross structure of the thoracic or lumbar spine, with certain limitations for the cervical spine [23]. The most suitable for human spine of porcine is from T6 to T10, and the lumbar spine of porcine is an alternative to human specimens. The calf is an alternative to human thoracic and lumbar specimens, if the differences are taken into consideration. When compared with human spine, another relevant issue of using animal models is difference in size, which is important for the used implants and screw lengths. The VBH is larger for most animals, which results in a larger corpectomy size. For the PH, most animal

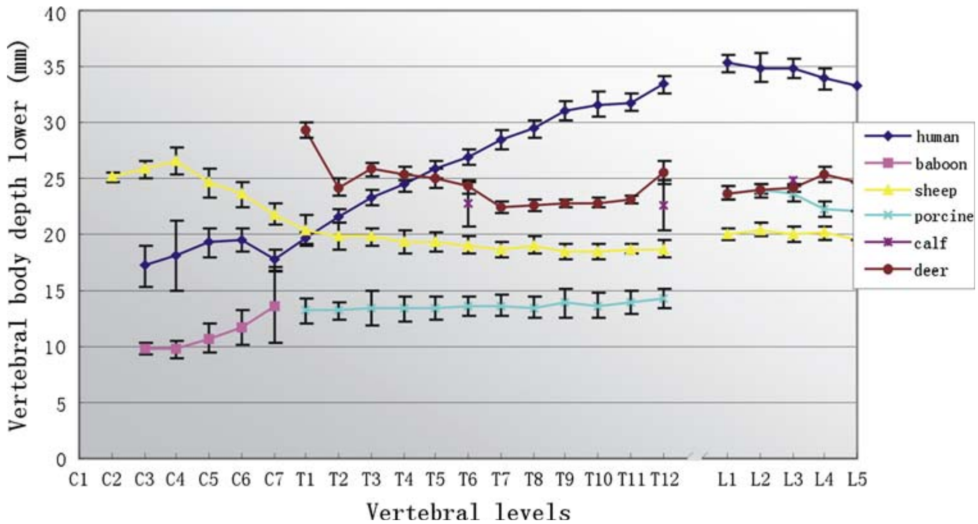

Fig. 5 Comparisons of lower vertebral body depth (mean ± SD) (human [13–15], baboon [20], sheep [8, 23], porcine [2, 6], calf [4] and deer [9])

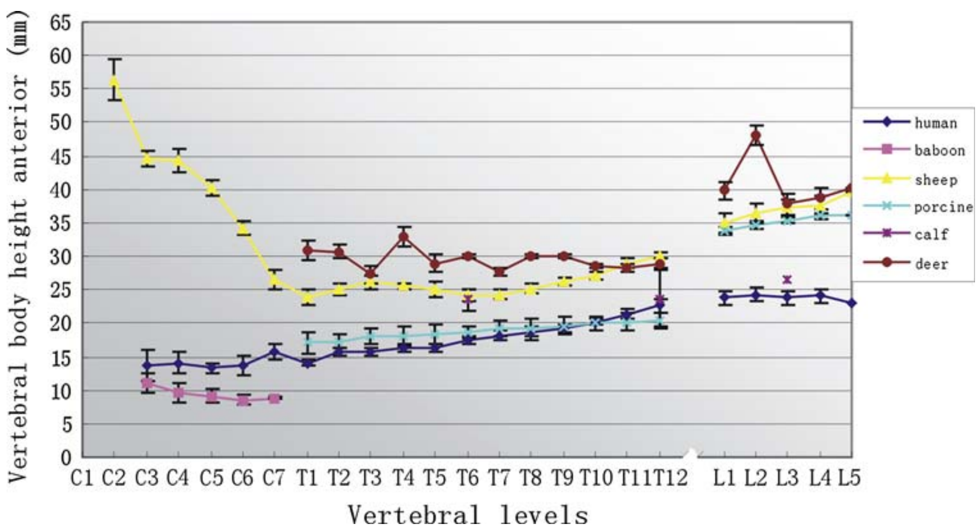

Fig. 6 Comparisons of anterior vertebral body height (mean ± SD) (human [13–15], baboon [20], sheep [8, 23], porcine [2, 6], calf [4] and deer [9])

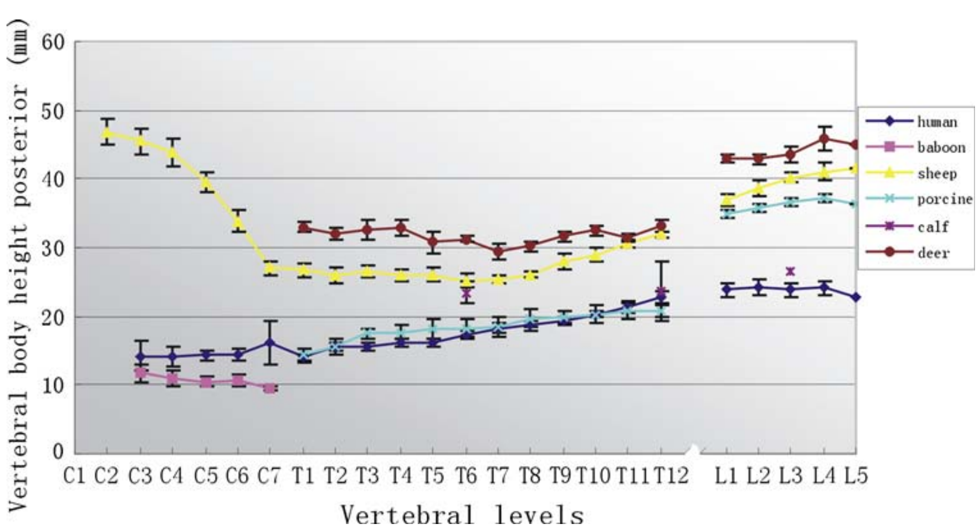

Fig. 7 Comparisons of posterior vertebral body height (mean ± SD) (human [13–15], baboon [20], sheep [8, 23], porcine [2, 6], calf [4] and deer [9])

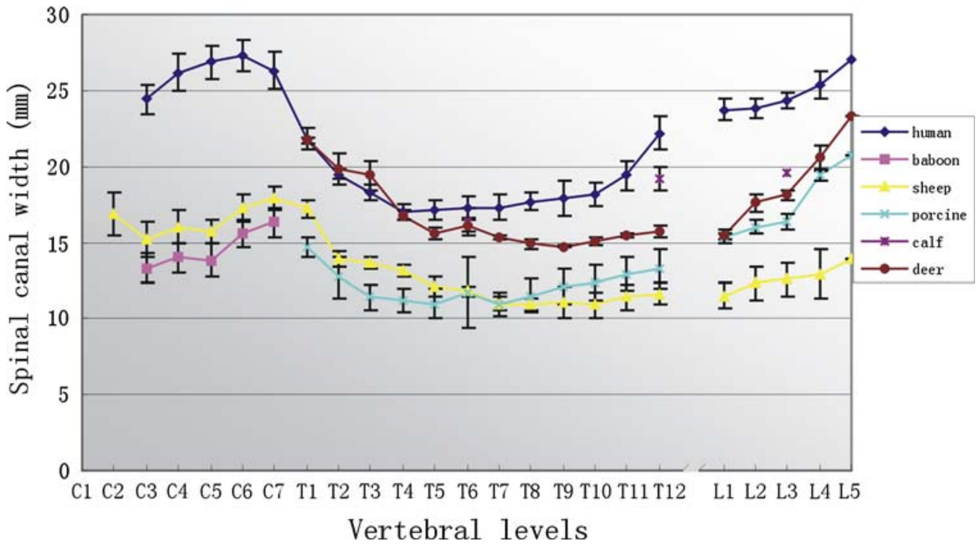

Fig. 8 Comparisons of spinal canal width (mean ± SD) (human [13–15], baboon [20], sheep [8, 23], porcine [2, 6], calf [4] and deer [9])

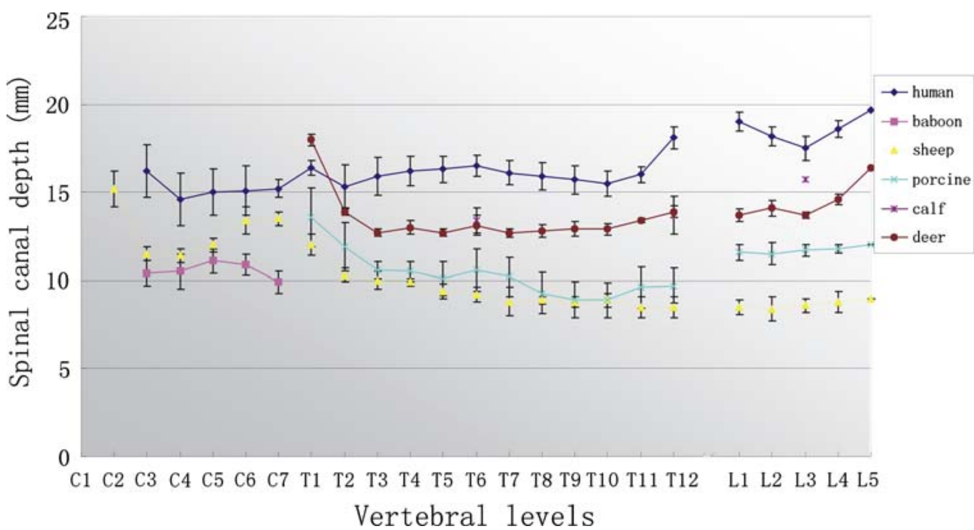

Fig. 9 Comparisons of spinal canal depth (mean ± SD) (human [13–15], baboon [20], sheep [8, 23], porcine [2, 6], calf [4] and deer [9])

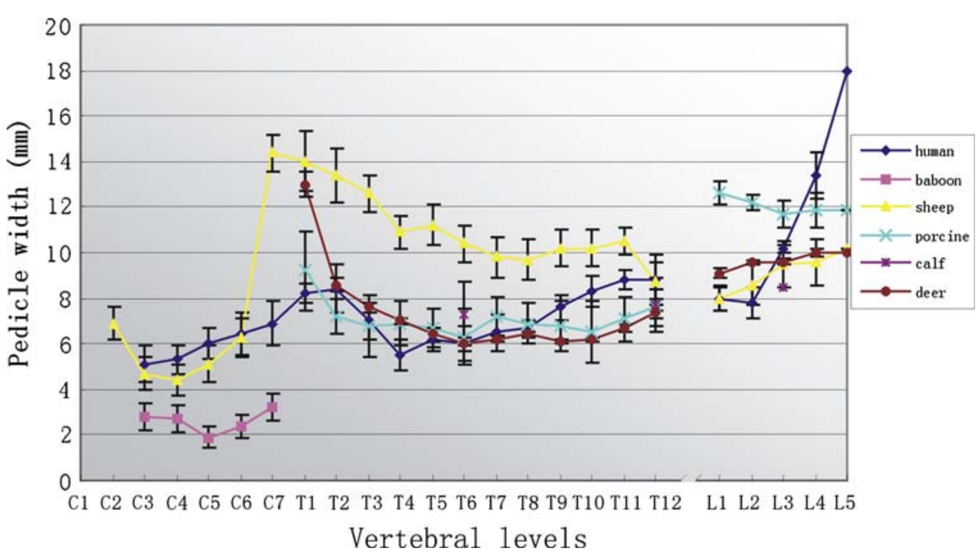

Fig. 10 Comparisons of pedicle width (mean ± SD) (human [13–15], baboon [20], sheep [8, 23], porcine [2, 6], calf [4] and deer [9])

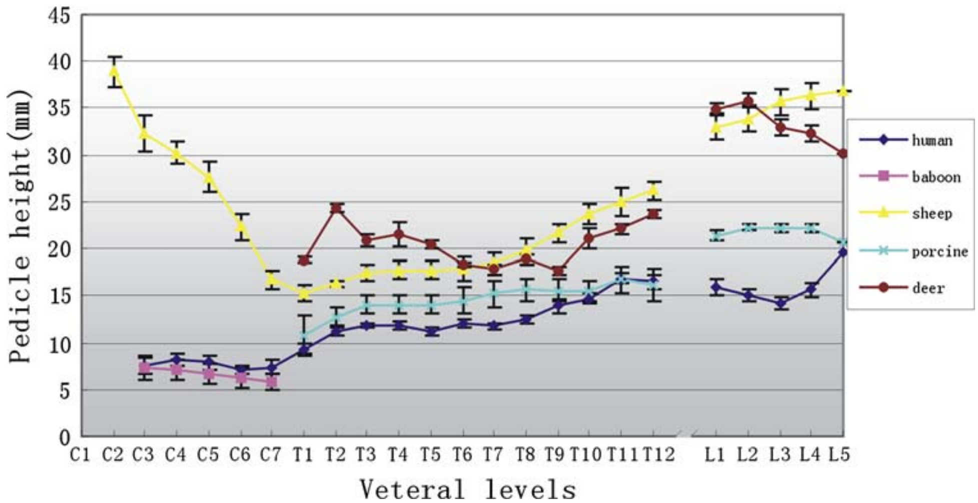

Fig. 11 Comparisons of pedicle height (mean ± SD) (human [13–15], baboon [20], sheep [8, 23], porcine [2, 6], calf [4] and deer [9])

Table 3 Comparisons of vertebral body of cervical spine

	The average percent of those in the human						The change trend compared with human (from C2 to C7)					
	VBWu (%)	VBWl (%)	VBDu (%)	VBDl (%)	VBHa (%)	VBHp (%)	VBWu	VBWl	VBDu	VBDl	VBHa	VBHp
Baboon	45–47	Nearly 50	54–61	54.1–77.4	Nearly half	82.3–59.6	Similar	Similar	Similar	Similar	Similar	Opposite
Sheep	101–127	85–138	109–127	123–150	Nearly two to three times	320–167	Opposite	Opposite	Opposite	Opposite	Opposite	Opposite

Table 4 Comparisons of vertebral body of thoracic spine

	The average percent of those in the human						The change trend compared with human (from T1 to T12)					
	VBWu (%)	VBWl (%)	VBDu (%)	VBDl (%)	VBHa (%)	VBHp (%)	VBWu	VBWl	VBDu	VBDl	VBHa	VBHp
Sheep	61–85	81–59	111.4–56.7	103–58.8	1.32–1.71 times	139–190	Similar	Similar	Opposite	Opposite	Similar	Similar
Deer	98–133 (from T1 to T6), 71–91 (from T7 to T12)	122.6–72.5	144.8–67.9	148.7–72.1	127–219	146–230	Opposite in T1–T3, similar in T4–T12	Opposite in T1–T3, similar in T4–T12	Opposite	Opposite	Opposite	Similar
Porcine	54.8–77.1	52.7–71.2	Nearly half	Nearly half	90.3–121.3	Nearly the same	Similar	Similar	Similar	Similar	Similar	Similar

pedicles are larger than human, indicating a human pedicle screw can be used in animal models. Animals seem to be small for human cage sizes due to lower VBW and VBD. Only if we know how the parameters of interest differ between animal and human spine, experimental studies involving interbody cages, and screw–rod systems could be sized appropriately to provide meaningful results.

Although each porcine, calf, deer or sheep could be a choice of experimental animal for in vivo and in vitro experimental studies according to anatomical studies, several factors such as biomechanical property, availability, costs, breeding and growth also should be considered. The animals selected for spine in vivo research must be of an appropriate size both at the beginning and at the end of the experiment. Therefore, mature sheep model could be chosen for in vitro experimental use. Pig and calf generally are not to be considered for in vivo experimentation is that they grow too rapidly, high cost and not easy to handle. Calf model (age 6–8 weeks) in the present review study include open growth plates, and may lead to oversize vertebrae. Mature porcine (age 18–24 months) may avoid these limitations. Therefore, in stability

Table 5 Comparisons of vertebral body of lumbar spine

	The average percent of those in the human						The change trend compared with human (from L1 to L5)					
	VBWu (%)	VBWl (%)	VBDu (%)	VBDl (%)	VBHa (%)	VBHp (%)	VBWu	VBWl	VBDu	VBDl	VBHa	VBHp
Sheep	60.60	60.7–64.7	57.1–58.9	56.6–59.4	147–173	155–181	Similar	Similar	Similar	Similar	Similar	Similar
Deer	74–77	66.0–76.9	71.5–64.7	68.7–75.6	1.60–1.98 times	Nearly two times	Similar	Similar	Similar	Similar	The highest is at L2	Similar
Porcine	78.4–83.5	78.1–85.7	65.7–71.3	Nearly half	142–157	146.6–158.5	Similar	Similar	Similar	Nearly the same	Similar	Similar
Calf	88.1 in T6, 65.6 in T12, 70.7 in L3	81.9 in T6, 60.8 in T12, 65 in L3	87.3 at T6, 68.9 at T12, 70.4 at L3	71.2 at T6, 67.6 at T12, 84.3 at L3	135 at T6, 103 at T12, 110 at L3	135 at T6, 103 at T12, 110 at L3						

Table 6 Comparisons of spinal canal

	The average percent of those in the human		The change trend compared with human (from C2-L5)	
	SCW (%)	SCD (%)	SCW	SCW
Cervical spine				
Baboon	51–61	71–88	Similar	Opposite
Sheep	57–61	62–74	Similar	The sheep SCD/human SCD increases from C3 to C7
Thoracic spine				
Sheep	52.2–78.8	45–73	Similar	Opposite
Deer	71.3–106	77–101	Similar	Opposite
Porcine	59.9–67.6	56.7–82.9	Similar	Opposite
Lumbar spine				
Sheep	Nearly 50	44–48	Similar	Similar in L3–L5
Deer	63.7–85.9	72–84	Similar	Similar in L3–L5
Porcine	67.4–76.4	60.9–66.9	Similar	Similar in L3–L5
Calf	94.2 at T6, 86.4 at T12, 80.6 at L3	81.2 at T6, 75.6 at T12, 86.2 at L3		

biomechanical testing, both calf and porcine models could be selected for thoracic and lumbar spine research. However, when used as a traumatic model, the presence of open growth plates in immature calf spine specimens, which may affect the results of biomechanical experiment, have to be considered. The deer spine specimens could be an alternative to calf and porcine for human thoracic and lumbar spine, but it has the disadvantage of difficult availability and higher cost.

In all included papers, fresh specimens were evaluated anatomically, and parameters were measured using digitized caliper or hand-held micrometer. However, some limitations of the current study have to be noted. First, this study has not included bone mineralization and biomechanical properties of the specimens that may influence the choice of experimental specimens. Theoretical considerations show that the spine of the quadruped animal is mainly loaded along its long axis, just like the human spine [19]. However the animals have higher vertebral bone densities, thus, indicating that axial compression stress is higher than in humans [19]. Moreover, significant differences have been identified in flexibility testing between animal and human cadaveric specimens [16]. All differences of these biomechanical properties may affect the animal models as a substitute for human spine. Secondly, the present study was aimed solely at identifying published peer-reviewed English literature, so that publication bias cannot be entirely ruled out. Thirdly, the present study excluded the paper on the morphometry of a single vertebra from large animal models [5, 10], which may lost some information. However, we believe data from more than a single vertebra is necessary, because spinal instrumentation and implant testing are commonly at least three

Table 7 Comparisons of pedicle

	The average percent of those in the human		The change trend compared with human (from C2-L5)	
	PW (%)	PH (%)	PW	PH
Cervical spine				
Baboon	31.6–54.9	Nearly the same	Similar	Similar
Sheep	Two times	Four to five times	Similar	Opposite
Thoracic spine				
Sheep	98–198	146–164	Similar in T1–T4, opposite in T4–12	Similar
Deer	72–158	1.5–2 times	Similar	Opposite in T1–T9, similar in T10–T12
Porcine	78.3–125	93–128	Similar	Similar
Lumbar spine				
Sheep	57–110	Nearly 2 to 2.5 times	Similar	Opposite
Deer	55–123	153–238	Similar	Opposite
Porcine	157–66.1	110–156	Opposite	Similar
Calf	121 at T6, 87.5 at T12, 83.3 at L3			

vertebral levels, and more important is to show the anatomical trend of the vertebrae. Finally, the present study did not make an anatomical comparison of all the segments of the animal spines to that of the humans, because of the different measurement conditions. Therefore, the anatomy of the goat and canine spines and the porcine and calf cervical spines need to be studied in the near future.

This study gives us a clear view of similarities and differences of vertebrae geometries between common experimental animal and human spines. This will be useful to choose animal model in vivo and in vitro spine research; also, when a certain animal is selected for spine research, the structural similarities and differences found in the animal model studies must be kept in mind.

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