Comparative Morphometry of Coxal Joint Angles

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Abstract: The angles related to the coxal joints were comparatively studied in four-limbed walking animals and two-limbed ones including man and birds. Between animals with both types of walking, no significant difference was observed in the neck-shaft angles (NSA), which was equivalent to the acetabulum angles (ACA) at the connection of the femoral head with the acetabulum. The anteversion angles (AVA) were equivalent to the horizontal ACA. Canine species showed two different forms of the femoral neck with or without modification by the femoral AVA, probably being breed-specific and nutrition-dependent. In the narrow-striped wallaby as well as avian species, the femoral head showed a postversion with a minus-version angle for lifting the body axis in the frontal and upward direction to hold the whole body weight on the hind-limbs, in particular at the anterior part of the acetabulum. In man, the connection between the femur and acetabulum greatly varied among individuals, possibly according to differences in the life style.

Key words: acetabulum, coxal joint, femoral head, morphometry

Introduction

In four-limb walking animals sixty and forty per cent of their body weight is charged to the fore- and hind limbs, respectively [1, 13], and the resulting curved body is effective for rapid driving, hunting and fighting. In the two-limb walking animals, however, the function of the hind limbs is to support most of the body weight. On the other hand, obese older animals and man therefore suffer from disorders in the over-loaded knees and coxal joints [10, 14, 17].

The proximal head of the round-shaped femur has ligaments at the head pit, while the femur makes a sweep to the landing site at the distal end, showing a

constricted neck and forming a neck-shaft angle (NSA) [3, 16] against the bone trunk. The femoral neck bends either forward or backward forming an anteversion angle (AVA) [3, 8, 9, 16], determining the direction of the femoral head, and the size of the angle is closely related to the walking manner of the animals.

In this study the angles related to the coxal and knee joints were comparatively studied in four-limbed animals and two-limbed ones, including birds and man.

Materials and Methods

Animals: The bones were measured mostly in adult Thoroughbred horses, adult mongrel dogs, and puppies

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Fig. 1. Measurement of AVA (Left) and NSA (Right).

Fig. 2. Measurement of horizontal ACA (Right) and vertical ACA (Left).

reared at this school, and Holstein-Friesian cows were from a slaughterhouse. Measurements in some wild animals was made at the museum or laboratory of veterinary anatomy of this school. The bones of Japanese adult men were measured at Showa University Medical School. The data for fowls and pheasants were provided by Yamashina Bird Institute, Tokyo, and those of dinosaurs by the National Museum of Nature, Tokyo, as well as Seibu Dinosaur Museum, Saitama. The approximate ages were known only in dogs.

Measurement: All test animals were subjected to measurement of the NSA and AVA. The NSA was an angle formed between a straight line connecting the femoral head center with the neck center and another line connecting the proximal femoral trunk with the distal end (Fig. 1). The AVA was formed between a straight line connecting the femoral head center with the femoral axis and another line connecting the medial condyle with the lateral one. To simplify the data, the NSA

values were replaced by NSA' ($= \text{NSA} - 90^\circ$). In dogs and some other animals, the acetabular angles (ACA) were also measured horizontally or vertically (Fig. 2). The horizontal ACA was formed by the frontal and caudal edges of the acetabulum against the femoral axis, while the vertical ACA was formed by a line connecting the upper and lower edges of the acetabulum with the vertical line. In man and fowls the measurement was done on the photographs, as there was much difficulty in direct measuring.

Results

As shown in Table 1, the AVA and NSA' of the femur were 20° to 30° and 30° to 40° in cows, and 25° to 35° and 30° to 45° in horses, respectively. The horizontal and vertical ACA varied in size corresponding to the AVA and NSA', respectively, and differences were less than 5° .

Table 1. Femoral AVA, NSA' and ACA in cattle and horses

Case		AVA	NSA'	ACA	
				Vertical	Horizontal
Cattle	A	20°	35°	35°	10°
	B	30	40	35	25
	C (calf)	25	30	30	15
	Mean $\pm$ SD	27.5 ± 3.55	35 ± 7.07	32.5 ± 3.54	20 ± 7.07
Horse	A	25	30	30	25
	B (colt)	30	35	30	25
	C	35	45	40	30
	D	30	45	40	30
	E	35	45	40	35
	Mean $\pm$ SD	31 ± 4.18	40 ± 7.07	36 ± 5.48	29 ± 4.18

In a bovine case, of which the AVA and vertical ACA were 20° and 10°, respectively, the femoral head was introduced into the articulation with a forward-incline of 10°, indicating that the leg axis was always oblique on landing. In an equine case, the femoral head was vertically combined with the acetabulum and the axis was located at the center of the acetabulum, since the NSA' and AVA were equivalent to the vertical and horizontal ACA, respectively (Fig. 3).

In mongrel dogs, the AVA and NSA' ranged from 10.0° to 14.5° and from 24.4° to 30.9°, respectively, as shown in Table 2. As presented in Table 3, the canine ACA increased with age, and the horizontal ACA were

longer at the anterior edge than the posterior one in adults. It was slightly greater in males than females. The vertical ACAs were also greater with age. The anterior edge also was more developed than the posterior one in males than females. No difference in the NSA' was seen between puppies and adults, or between males and females.

In dogs, the size of the horizontal ACA seemed to be correlated with that of the AVA. By regression analysis the multiple correlation coefficient was found to be smaller in males than in females (Fig. 4). Except for one case with a much smaller AVA, the horizontal ACA seemed to be proportional to the AVA in one group of animals, while remaining unchanged in the others (Fig. 5). Except for some cases with widely different values (Fig. 6), the multiple correlation was also reliably high between the vertical ACA and NSA' (Fig. 7). All the angles measured became greater with age, but multiple correlation was high with values for all the canine cases (Figs. 8 and 9).

As shown in Table 4, the AVA as well as NSA' greatly varied in man. In one human skeletal sample, both AVA and horizontal ACA were 20°, and both NSA' and vertical ACA were 35°. In a Japanese monkey, both AVA and NSA' were 10°, and the corresponding horizontal and vertical ACAs were also 10°, representing the curvature of the femur (Table 5).

The fowl had a less-curved femur with an NSA' of 50° and an AVA of -13° on average from 9 birds (Table 6). Although the fowl values varied greatly among breeds, the NSA' and AVA values were 17° to 20° and 4° to 5°, respectively, being less than those of the pheasant and *Bamboo partridge*.

Fig. 3. Connection of the acetabulum with the femoral head of cattle (Upper) and horses (Lower).

Table 2. Femoral NSA' and AVA in adult mongrel dogs (I)

B.W. (kg)	Number of cases	Male		B.W. (kg)	Number of cases	Female	
		AVA	NSA'			AVA	NSA'
6.7 ± 1.2 (5-8)	4	13.5° ± 1.7° (11°-15°)*	25.0° ± 1.0° (24°-26°)	7.6 ± 0.9 (6-9)	8	10.0° ± 2.3° (6°-14°)	24.4° ± 3.9° (20°-30°)
11.7 ± 1.5 (10-14)	15	13.9° ± 2.1° (11°-18°)	29.6° ± 3.1° (21°-34°)	11.2 ± 1.0 (10-12.3)	11	11.4° ± 3.3° (6°-17°)	26.3° ± 4.4° (20°-33°)
25.2 ± 9.2 (15-37)	6	14.5° ± 4.0° (8°-19°)	30.8° ± 3.4° (26°-36°)	28.3 ± 6.3 (16-34)	6	14.3° ± 5.9° (8°-25°)	26.2° ± 3.2° (21°-30°)

*Mean and range in parenthesis.

Table 3. Femoral AVA, NSA' and ACA in mongrel dogs (II)

	Number of cases	B.W. (kg)	AVA	NSA'	ACA	
					Vertical	Horizontal
Puppy*	11	3.4** (1.5–5)	8.3° (5°–15°)	22.8° (21°–25°)	21.6° (17°–25°)	5.9° (3°–8°)
Female	9	10.3 (6–16)	11.3° (7°–15°)	26.7° (23°–30°)	26.2° (20°–34°)	10.0° (8°–13°)
Male	18	12 (8–20)	11.3° (6°–16°)	26.6° (20°–33°)	27.6° (21°–32°)	11.0° (5°–19°)

* 3- to 6-month-old, ** Average and range in parenthesis

Fig. 4. Regression analysis of horizontal ACA and AVA in mongrel dogs (I). —●— Adult male, --■-- Adult female, ---▲--- Puppy.

The coxial articulations of man, non-human primates and fowls are shown in Fig. 10. The AVA and NSA' were equivalent to the horizontal and vertical ACA, respectively. These two-limb walking animals had the vertically standing limbs with the femur directly facing in the anterior direction, but for the femoral head the AVA values were as seen in four limb-walking animals such as dogs, cows and horses. In contrast, the avian femoral head had a postversion with a minus-version angle.

The data for other animal species are shown in Table 7. The narrow-striped wallaby, a marsupial, had an NSA' of 45° and an AVA of -16°, being similar to the values for birds. The NSA' and AVA for *Tarbosaurus* of *Saurischia* walking on two strong hind-limbs [6], were 50° and 0°, respectively. On the other hand, in those of the *Edmontosaurus* of amphibian *Omithischia*, with a different shaped femur, the NSA' and AVA were 50° and 14°, respectively.

Fig. 5. Regression analysis of vertical ACA and NSA' in mongrel dogs (I). —●— Adult male, —■— Adult female, —▲— Puppy.

Fig. 6. Regression analysis of horizontal ACA and AVA in mongrel dogs (II). —●— Adult male, —■— Adult female, —▲— Puppy.

Fig. 7. Regression analysis of vertical ACA and NSA' in mongrel dogs (II). —●— Adult male, —■— Adult female, ---▲--- Puppy.

Fig. 8. Regression analysis of horizontal ACA and AVA in mongrel dogs.

Fig. 9. Regression analysis of vertical ACA and NSA' in mongrel dogs.

Table 4. Femoral AVA and NSA' in adult man

Number of cases	AVA	NSA'
29	21.8° ± 5.2° (0°–32°)*	37.7° ± 5.2° (29°–49°)

* Mean ± SD (range) from 29 cases

Discussion

The four limb-walking animals, horses, cows and dogs still have the extremities vertically standing on the land, taking a broad-based position. Such a standing posture is possibly by the acetabulum accepting the femoral head, protruding forward and forming an AVA of 5° to 30° to determine the direction of the limbs. The greater and smaller ACAs produce the inner- and outer directing postures, respectively [7]. There might be, however, modification of the limb direction to take an ACA posture corresponding to the AVA.

The canine femur is variable in shape [2], having an AVA of 21.2° and NSA' of 41.0° in small breeds and an AVA of 24.4° and NSA' of 44.0° in large breeds

Table 5. Femoral AVA, NSA' and ACA in man and non-human primates

	AVA	NSA'	ACA	
			Vertical	Horizontal
Man	20°	35°	35°	20°
Japanese monkey A	10°	10°	10°	10°
Japanese monkey B	34°	33°	32°	–
Rhesus monkey	24°	31°	–	–
Gorilla	37°	55°	–	–
Orangutan	27°	58°	–	–

[15]. Canine species had two forms of femoral neck with or without the modification by the femoral AVA, possibly being either breed-specific or nutrition-dependent. In the case of canine hip displasia, the femoral head is deformed corresponding to the shallow acetabulum [14, 16]. In addition to the genetic factors involved, the excess intake of calcium might influence bone growth including deformation [3].

Four limb-walking monkeys are known to have sufficiently extended moments of muscles attached to the hucklebone nodes, when they are walking on their two hind-limbs [12]. The large human femoral muscles,

Table 6. Femoral AVA and NSA' in birds

	Number of cases	Male		Number of cases	Female	
		AVA	NSA'		AVA	NSA'
Fowl (12-week-old)	9	$-13.4^\circ \pm 1.5^\circ$ (-16° – -11°)*	$49.7^\circ \pm 5.9^\circ$ (36° – 55°)			
Pheasant	13	$-18.8^\circ \pm 1.3^\circ$ (-21° – -17°)	$33.3^\circ \pm 3.1^\circ$ (31° – 40°)	7	$-18.3^\circ \pm 1.3^\circ$ (-20° – -17°)	$32.4^\circ \pm 2.9^\circ$ (29° – 36°)
Bamboo partridge	8	$-16.9^\circ \pm 1.6^\circ$ (-19° – -15°)	$29.0^\circ \pm 3.4^\circ$ (25° – 34°)	1	-18°	28°

* Mean and range in parenthesis

Fig. 10. Connection of the acetabulum and the femoral head in man (Upper), two-limb walking non-human primate (Middle) and fowl (Lower).

being able to widely move the long legs with minor contractions, rather resemble those of the four limb-walking ungulates with fast and persistent balanced movement [11]. In NSA' there was no difference between man and the four-limbed walking animals, but

Table 7. Femoral AVA and NSA' in wild and petrol animals

	AVA	NSA'
Brown bear	19°	50°
Common raccoon	38°	38°
Hippopotamus	44°	45°
Indian elephant	14°	56°
Japanese deer	10°	62°
Japanese serow	50°	53°
Lesser panda	14°	50°
Lion	21°	30°
Narrow-striped wallaby	-16°	45°
One-humped camel	11°	44°
Edmontosaurus/Cretaceous	14°	50°
Tarbosaurus/Cretaceous	0°	50°

the connection between the femur and acetabulum in man greatly varied between individuals. The human NSA was reported to be 126° ($\text{NSA}'=36^\circ$) in adults and to decrease with aging, while the AVA varied greatly between individuals, ranging from -25° to 37° [3, 18], and the present study gave similar results. The human AVA may be dependent upon age and life style.

Dogs seem to have an ideal combination of the femur and acetabulum, showing that the femoral head was introduced perpendicularly into the acetabulum with NSA's of 25° to 30° and AVAs of 10° to 15° . This results in equal distribution of the body weight to the axial centers of the four limbs. In this study the inclinations of the upper and lower acetabular lips were measured as vertical ACA, and were equivalent to the NSA with a perpendicular combination of the femoral head and acetabulum. In the horizontal position the

AVA should be equivalent to the horizontal ACA when the femoral head combines perpendicularly with the acetabulum.

Although the human femoral head is introduced into the acetabulum from either the lateral or posterior side, the pheasant and *B. thoracica* had NSA's of 25° to 38°, and AVAs of -11° to -22°, being equivalent to those of the four-limb walking animals. Birds have come to have wings differentiated from fore-limbs and to lift the body axis in the frontal and upward direction to support the whole body weight on the hind limbs with the radially extended digital bones, the first of which is directed backward [5]. In this case, all the body weight can be supported by the anterior part of the acetabulum. Similarly, the narrow-striped wallaby was shown to have a minus AVA and to always walk on the land limbs. It is of interest that the two-limb walking *Tarbosaurus* had an AVA similar to that of man, but the AVA of the amphibian *Edmontosaurus* was equal to that of the lesser panda.

References

1. Brookhart, J.M., Parmeggiani, P.L., Petersen, W.A., and Stone, S.A. 1965. Postural stability in dog. *Am. J. Physiol.* 208: 1047-1057.
2. Daigo, M. 1962. Comparative anatomy of canine skeletal bones. V. *Femur. J. Vet. Med.* 332: 852-855.
3. Dunlap C.K., Shands A.R. Jr., Hollister M.C. Jr., Gaul J.S. Jr., and Streit H.A. 1953. A new method for determination of torsion of the femur. *J. Bone and Joint Surg.* 35-A: 289-311.
4. Hazewinkel, H.A.W., Goedegebuure, S.A., Poulos, P.W., and Wolvekamp, W.Th.C. 1985. Influences of chronic calcium excess on the skeletal development of growing Great Danes. *JAAHA* 21: 377-391.
5. Kato, Y. 1980. pp. 33-43. *In: Kachiku-no Kaibou to Seiri*, Yokendo, Tokyo.
6. Kohata, I. (Glut, D.F.) 1981. pp. 1-212. *In: Kyoryu Zukai Jiten*, 1st ed., Tsukiji Shokan, Tokyo.
7. Koike, T. and Nakamura, Y. 1989. pp. 4-7. *In: Rinsho Kachiku-Geka Kougi* (Koike, T. and Sakai, T. eds), Yokendo, Tokyo.
8. Magilligan, D.J. 1956. Calculation of the angle of anteversion by means of horizontal lateral roentgenography. *J. Bone and Joint Surg.* 38-A: 1231-1246.
9. Montavon, P.M., Hohn, R.B., Olmstead, M.L., and Rudy, R.L. 1985. Inclination and anteversion angles of the femoral head and neck in the dog. Evaluation of a standard method of measurement. *Vet. Surg.* 14: 277-282.
10. Ohkida, M. 1992. Obesity and deformative knee arthrosis. *Yokohama Med. J.* 43: 347-354.
11. Okada, M. 1979. To the two-limb walking from the four-limb one. *Taiiku-no-Kagaku* 29: 5-11.
12. Robinson, J.T., Freeman, L., and Sigmon, B.A. 1972. Some aspects of pongid and hominid bipedality. *J. Hum. Evol.* 1: 361-369.
13. Roy, W.E. 1971. Diagnosis of disorders in the canine bone and muscles. *Vet. Clin. North. Am.* 1: 59-74.
14. Sasaki, N. 1993. Corpulence and joint disease. *J. Vet. Med.* 46: 495-498 (in Japanese).
15. Sato, K., Hayashi, K., Ohtani, H., Yoshinaga, N., Sugawa, Y., Tsukise, A., Tanaka, N., and Saito S. 1974. Studies on the patellar luxation in dogs. II. Morphological observations on the femur. *J. Vet. Med.* 623: 983-987.
16. Weigel, J.P. and Wasserman, J.F. 1992. Biomechanics of the normal and abnormal hip joint. *Vet. Clin. North. Am.* 22: 9-21.
17. Whitehair, J.G., Vasseur, P. B., and Willits, N.H. 1993. Epidemiology of cranial cruciate ligament rupture in dogs. *J. Am. Vet. Med. Assoc.* 203: 1016-1019.
18. Yamamuro, T. 1976. Kokansetsu-no Keitai-no Hatsuiuku. pp. 19-37. *In: Kokansetsu-Gekagaku* (Ito, T. ed.), Kinpodo, Tokyo.