Morphological Evaluation of the Baboon Hind Limb Muscles Based on Relative Weight

By

Junji ITO, Naoki SHIRAISHI, Makoto UMINO, Tadanao KIMURA* and
Hiroshi AKITA

Department of Anatomy, Showa University School of Medicine, Shinagawa-ku, Tokyo 142-8555, Japan

*Department of Biomedical Anatomy and Physiology, University of Shizuoka School of Nursing, Shizuoka 422-5826, Japan

– Received for Publication, August 18, 2000 –

Key Words: Baboon, Hind limb muscle, Relative weight, Muscular morphology

Summary: Morphological features of the hind limb muscles reflect the muscular function correlating with the locomotion. In this study, the muscles of the baboon hind limb were weighed and the relative muscle weights were compared with those of the human lower extremity. In the baboon, the biceps femoris was the largest (11.60%) and the vastus lateralis (10.67%) was placed second. The gluteus medius (8.55%) among the hip muscles and the gastrocnemius (4.38%) among the leg muscles were predominant in each segment. The relative weights of the gluteus medius and the biceps femoris were especially larger in the baboon than in the human, while the gluteus maximus and the soleus were larger in the human. The baboon gluteus medius and biceps femoris chiefly generate the propulsive power during quadrupedal locomotion and the human soleus is essential for the erect bipedalism.

Morphological features (configuration, weight and muscle fiber composition) of the skeletal muscles reflect the muscular function correlated with various modes of locomotion. Within the muscular morphology, it has been considered that the larger muscle controls the more important action at that joint and that a greater mass of the muscle should generate a more powerful muscle force. The muscles of the lower extremity (hind limb) generate the propulsive power in locomotion. Fleagle (1977) described the differences in the relative muscle masses of the limb and trunk between leaf monkeys, which differed in their locomotion activities. Haxton (1947) and Ishida (1972) reported that the large muscles in quadrupeds were two or more joint muscles and those in humans were one-joint muscles. Comparative anatomy based on the relative muscle weight is very useful method for discussing the relationship between the morphological features and the locomotion patterns. One of the authors previously weighed the muscles of the human lower extremity and clarified that the largest muscles were the gluteus maximus, the quadriceps femoris and the soleus in the hip, the thigh and the leg, respectively (Ito, 1996). The purpose of this

study was to clarify the morphological characteristics of the hind (lower) limb muscles in relation to the locomotion mode (the baboon terrestrial quadrupedalism and the human erect bipedalism) based on the relative muscle weight.

Material and Method

Two male hamadryas baboons *Papio hamadryas* (body weights, 6.5 kg and 24.0 kg) and two male anubis baboons *Papio anubis* (body weights, 8.2 kg and 16.5 kg) were examined. All specimens were fixed and stored in 10% formalin solution at the Department of Anatomy, Showa University School of Medicine. Dissections were made on the left side of the hind limb in each specimen and the wet weight of each muscle was weighed in same way as in the previous report (Ito, 1996). Muscle classification was due to the description by Howell and Straus (1961). From the measured values (absolute muscle weight), the relative weight to the total mass was calculated and compared with those of human muscle (Ito, 1996).

Results

The absolute weight of each muscle was proportional to the body weight, while the variation of the relative weight was narrow among all specimens. The mean value and standard deviation (SD) of the

relative muscle weight in the baboon hind limb are summarized in Table 1 together with the mean values of humans. Of the baboon hind limb muscles, the hip, the thigh, the leg and the foot muscles occupied about 25%, 58%, 16% and 2%, respectively. The thigh muscle was larger in the baboon than in

Table 1. Individual muscle percentages in lower extremity

	Muscle	Baboon		Man*
		Mean	SD	Mean
Hip	Iliopsoas	6.42	0.51	5.89
	Gluteus maximus	4.12	0.59	12.83
	Gluteus medius	8.55	0.52	5.87
	Gluteus minor	1.00	0.12	2.06
	Tensor fasciae latae	1.59	0.25	0.94
	Piriformis	0.61	0.11	0.64
	Obturator internus	1.36	0.10	1.28
	Gemelli	0.27	0.01	0.29
	Quadratus femoris	0.83	0.12	0.70
	Hip total	24.72		30.50
Thigh	Sartorius	0.81	0.14	1.73
	Rectus femoris	3.81	0.42	3.30
	Vastus lateralis	10.67	0.86	8.40
	Vastus intermedius	2.10	0.44	3.84
	Vastus medialis	3.05	0.40	5.65
	Pectineus	0.33	0.07	0.76
	Adductor longus	0.52	0.11	2.24
	Adductor brevis	0.78	0.05	1.59
	Adductor magnus	9.45	0.24	7.75
	Gracilis	3.74	0.46	1.02
	Obturator externus	1.32	0.15	1.00
	Biceps femoris	11.60	0.41	3.91
	Semitendinosus	3.31	0.63	2.15
	Semimembranosus	6.20	0.30	3.53
	Thigh total	57.68		46.87
Leg	Tibialis anterior	2.12	0.18	2.34
	Extensor digitorum longus	0.65	0.02	1.15
	Extensor hallucis longus	0.24	0.03	0.49
	Peroneus longus	0.97	0.10	1.17
	Peroneus brevis	0.55	0.02	0.51
	Peroneus digiti quinti	0.05	0.01	**
	Gastrocnemius	4.38	0.67	4.26
	Soleus	2.15	0.21	6.78
	Plantaris	0.85	0.12	0.11
	Popliteus	0.68	0.15	0.41
	Perotibialis	0.05	0.01	**
	Tibialis posterior	0.56	0.07	1.70
	Flexor digitorum tibialis	0.81	0.04	0.47
	Flexor digitorum fibularis	1.68	0.12	1.11
	Leg total	15.72		20.50
Foot	Muscles of big toe	0.40	0.08	0.93
	Muscles of little toe	0.21	0.04	0.37
	Muscles of central part of foot	0.96	0.15	0.91
	Muscles of dorsal part of foot	0.31	0.05	0.12
	Foot total	1.88		2.33

* Ito (1996).

** Muscle lacking in man.

the human. Of the individual muscles, the biceps femoris was the largest (11.60%) and the vastus lateralis (10.67%) was placed second. The gluteus medius (8.55%) in the hip and the gastrocnemius (4.38%) in the leg were predominant in each segment. Figure 1 shows the differences of the relative

weights between the baboon and human. A positive value shows the predominant muscle in the baboon, while a negative value shows the predominant muscle in the human. The muscles larger in the baboon than in the human were the gluteus medius, the vastus lateralis, the biceps femoris, the gracilis,

Fig. 1. The differences of the relative weights between the baboon and human. A positive value shows the predominant muscle in the baboon, while a negative value shows the predominant muscle in the human.

the semimembranosus, plantaris and the flexor digitorum fibularis, while the muscles larger in the human were the gluteus maximus, the vastus medialis, the soleus and the tibialis posterior.

Discussion

Based on the relative muscle weight of the baboon hind limb, it was proved that the predominant muscles were the gluteus medius and the iliopsoas in the hip muscles, the biceps femoris and the vastus lateralis in the thigh muscles and the gastrocnemius in the leg muscles. These morphological traits of the hind limb muscles are similar among baboons, Japanese macaques (Ishida, 1972) and crab-eating macaques (Kimura and Takai, 1970), whose locomotion patterns are terrestrial and/or arboreal quadrupedalism. On the other hand, the gluteus maximus and the soleus are remarkably predominant in the human lower extremity muscles. These muscles have been investigated to elucidate the evolution of human bipedalism by comparative anatomical studies or electromyographical examinations (Ishida, 1985; Kumakura, 1989).

There is a conception of Haxton (1947) that the hind limb of the quadrupeds is used as "propulsive lever" and that the lower extremity of man is used for "propulsive strut". For the hind limb as a propulsive lever, strong extensor muscles at the hip joint and preventive extensor muscles at the knee joint are required. The muscular movements of the hind limb during quadrupedal walking/running consist of a propulsive and a recovery phase. In the propulsive phase, the thigh is retracted while the knee is not extended, but remains in a semi flexed position for most of the stride, and in the recovery phase the thigh is flexed while the knee remains partly flexed. The locomotion pattern in the baboon is typical terrestrial quadrupedalism. Therefore, at the hip joint, the gluteus medius, which is the largest muscle in the hip muscle, and the biceps femoris, which is the largest in the thigh, surely contribute to the strong extensor during the propulsive phase. On the other hand, the iliopsoas acts chiefly as a thigh flexor during the recovery phase. At the knee joint, the biceps femoris and the gastrocnemius maintain the flexed position, which is antagonistic to the extension by the quadriceps femoris. At the ankle joint, the plantarflexion is principally performed by the gastrocnemius, which simultaneously acts as the knee stabilizer.

The action of the gluteal muscles in non-human primates takes part in strong retraction of the thigh in the quadrupedal posture. In general, the gluteus medius has the largest mass among the gluteal

muscles in non-human primates, while the gluteus maximus is largest in humans (Stern, 1972). Regarding the muscle fiber composition in the gluteal muscles of the crab-eating monkey, the gluteus maximus has more white (fast twitch) muscle fibers, while the gluteus medius has more red (slow twitch) muscle fibers and thicker muscle fibers (Tsurukiri, 1984). These compositions reveal that the gluteus maximus is suitable for fast contraction while the gluteus medius is suitable for continuous and strong contraction.

The baboon iliopsoas contains more white muscle fibers, while the human's contains more red muscle fibers (Kimura, 1999). The larger mass with the fast fibers in the baboon iliopsoas is suited for the rapid protraction of the thigh during the recovery phase. The human iliopsoas, which contains the slower anti-fatigue fibers, is suitable for the sustenance of the human erect bipedal posture (Kimura, 1991).

The biceps femoris in most monkeys originates from the ischial tuberosity by only one head and inserts into the lateral fascia of the thigh and crus (Hamada, 1985). This muscle can be divided into two functional parts: the femoral part is situated to retract the thigh and the crural part is situated to flex the knee and to retract the thigh. The former is a one-joint muscle at the hip joint and the latter is a two-joint muscle at the knee and ankle joints. The relative mass of the crural part of the biceps femoris is significantly greater in the more quadrupedal Dusky leaf monkey and that of the femoral part is larger in the leaping Banded leaf monkey (Fleagle, 1977). According to anatomical and electromyographical analyses (Kumakura, 1989), the crural part is not considered to relate to the regulation of propulsive force, but acts for the postural adjustment of the crural segment during locomotion in Japanese macaques. Furthermore, the proportion of the white muscle fibers was higher in the proximal part than in the distal region and the red fibers was more in the distal than in the proximal region (Uetake, 1989). On the supposition that the proximal region corresponds to the femoral part and the distal one corresponds to the crural part, the femoral part has greater speed and powerful contractile capacity while the crural part has the slower and more continuous contractile capacity. These reports on the biceps femoris show the functional differentiation between the femoral and the crural part. In this study, we weighed the whole mass of the biceps femoris. However, we observed during the dissection that the femoral part composed the main part of the biceps femoris.

For the quadriceps femoris, the relative weight of the vastus lateralis was larger in the baboon than

in the human, while those of the vastus medialis and intermedius were larger in the human. These differences show that the actions of extension at the knee joint differ among the three vasti muscles. The vastus lateralis in the baboon is active during the stance phase, while the human vastus lateralis is only active at the heel strike (Ishida, 1985). The muscle fiber size in the vastus lateralis is largest among the vasti muscles in the rhesus macaque, which has the same locomotion pattern as the baboon (Kimura, 1978). The difference in muscle fiber size is small among the human vasti muscles (Kobayashi, 1991). Among the baboon vasti muscles, the vastus lateralis act as the chief extensor at the knee joint.

Of the triceps surae muscles, the gastrocnemius is twice as heavy as the soleus in the baboon, while the soleus is heavier than the gastrocnemius in the human. The human soleus is considered unique among the anti-gravity muscles. In quadrupeds, the gravity center lies between the fore and hind limb and the load to the hind limb is less in the quadrupedal monkeys than in human. Therefore, the quadrupeds do not require the large mass of the soleus. From the histological studies of the triceps surae, the gastrocnemius has more fast-twitch/glycolytic myofibers, and the soleus has more slow-twitch/oxidative fibers than the other myofiber types in the Japanese macaque (Suzuki, 1994). The muscle fiber size is larger in the gastrocnemius than in the soleus in the crab-eating macaque (Kataoka, 1987). From morphological studies, the contraction of the gastrocnemius contributes to fast movement, while the soleus contributes to powerful movement during the ankle plantarflexion (Kumakura, 1991, 1995). The gastrocnemius, which performs the fast and powerful contraction, is more profitable than the soleus for the quadrupedalism. The large mass of the human soleus is essential for the bipedal standing/walking as a propulsive strut, which requires powerful plantarflexion at the ankle joint.

As morphological traits, it is true that the one-joint muscles (the gluteus maximus and the soleus) develop remarkably in the human lower extremity muscles. On the other hand, the developing muscles in the quadruped are not only two-joint muscles (the crural part of the biceps femoris and the gastrocnemius), but also one-joint muscles (the gluteus medius and the femoral part of the biceps femoris).

Acknowledgment

We wish to thank Prof. Noboru GOTO (Department of Anatomy, Showa University School of Medicine) for his supports and suggestions

and Dr. Hiroo KUMAKURA and Dr. Yoshihiko NAKANO (Department of Biological Anthropology, Faculty of Human Sciences, Osaka University) for supplying the materials.

References

- 1) Fleagle JG. Locomotor behavior and muscular anatomy of sympatric Malaysian leaf-monkeys (*Presbytis obscura* and *Presbytis melalophos*). *Am J Phys Anthropol* 1977; **46**:297–308.
- 2) Hamada Y. Primate hip and thigh muscles: Comparative anatomy and dry weights. In Kondo S (ed.): *Primate morphology, locomotor analyses and human bipedalism*, pp 131–152, University of Tokyo Press, Tokyo, 1985.
- 3) Haxton HA. Muscles of the pelvic limb. *Anat Rec* 1947; **98**:337–346.
- 4) Howell AB and Straus WL. The muscular system. In Hattoman CG and Straus WL (ed): *The anatomy of the rhesus monkey*. New York, Hafner, 1961; pp 89–175.
- 5) Ishida H. On the muscular composition of lower extremities of apes based on the relative weight. *J Anthropol Soc Nippon* 1972; **80**:125–145. (in Japanese with English summary)
- 6) Ishida H, Kumakura H and Kondo S. Primate bipedalism and quadrupedalism: Comparative electromyography. In Kondo S (ed): *Primate morphology, locomotor analyses and human bipedalism*. Tokyo, University of Tokyo Press, 1985; pp 59–79.
- 7) Ito J. Morphological analysis of the human lower extremity based on the relative muscle weight. *Okajimas Folia Anat Jpn* 1996; **73**:247–252.
- 8) Kataoka J. Comparative studies on muscle structure of the m. triceps surae and m. plantaris in man and monkey. *J Showa Med Assoc* 1987; **47**:851–861. (in Japanese with English summary)
- 9) Kimura K and Takai S. Comparative anatomical studies of the extremities of the crab-eating monkey based on the relative muscle weight. *Acta Anat Nippon* 1970; **45**:80–90. (in Japanese with English summary)
- 10) Kimura T. Myofibrous development of the lower extremity muscles of rhesus monkey (*Macaca mulatta*). *J Showa Med Assoc* 1978; **38**:593–603. (in Japanese with English summary)
- 11) Kimura T. Comparison of muscle fiber composition of the greater psoas muscle among humans, orangutans, and monkeys. In: *Arboreal locomotion adaptation in primates and its relevance to human evolution*. 1999; 77–80. (Abstract)
- 12) Kimura T, Kouda M, Ishida M and Fukado S. Myofibrous organization in human psoas major muscle. *J Showa Med Assoc* 1991; **51**:509–513. (in Japanese with English summary)
- 13) Kobayashi K. Myofibrous organization in human quadriceps femoris muscles. *J Showa Med Assoc* 1991; **51**:186–196. (in Japanese with English summary)
- 14) Kumakura H. Functional analysis of the biceps femoris muscle during locomotor behavior in some primates. *Am J Phys Anthropol* 1989; **79**:379–391.
- 15) Kumakura H. The functional morphology of the primate triceps surae muscles based on the static evaluation. *Anthropol reports* 1995; **52**:27–41. (in Japanese with English summary)
- 16) Kumakura H and Inokuchi S. Lay-out of the human triceps

- surae muscle: with special concern for the origin of the human bipedal posture. *Showa Univ J Med Sci* 1991; **3**:79–89.
- 17) Stern JT. Anatomical and functional specializations of the human gluteus maximus. *Am J Phys Anthropol* 1972; **36**:315–340.
- 18) Suzuki A and Hayama S. Individual variation in myofiber type composition in the triceps surae and flexor digitorum superficialis muscle of Japanese macaque. *Anthropol Sci* 1994; **102**:127–138.
- 19) Tsurukiri K. On the myofibrous organization of gluteal muscle groups in crab-eating monkeys. *J Showa Med Assoc* 1984; **44**:185–194. (in Japanese with English summary)
- 20) Uetake T. Diversity of myofibrous constitution within a muscle. *J Showa Med Assoc* 1989; **49**:444–453. (in Japanese with English summary)