The gibbon's Achilles tendon revisited: consequences for the evolution of the great apes?

Peter Aerts, Kristiaan D'Août, Susannah Thorpe, Gilles Berillon and Evie Vereecke

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SUPPLEMENTARY MATERIAL

1) Achilles tendon anatomy of gibbons

Gibbon cadavers were obtained from animals that had died in captivity via collaboration with different zoos and institutes in Europe. Fourteen fresh-frozen cadavers were dissected to study the properties of the Achilles tendon (see further; Material properties). The sample consisted of different genera and species: *Hylobates lar* (n=6), *Hylobates moloch* (n=2), *Hylobates pileatus* (n=2) and *Symphalangus syndactylus* (n=4). A well-developed Achilles tendon was observed in each dissected specimen (unilateral sampling, see Fig. 1).

In the context of other projects, we also dissected several ape specimens (Vereecke et al. 2005a: 3 gibbons and 2 bonobos) but without full quantification of the Achilles tendon anatomy or material properties.

We always observed a well-developed Achilles tendon in the gibbon sample, amounting to on average 76% of the total muscle-tendon unit length (Table 1). In contrast, we only found a short Achilles tendon in the bonobo specimens, amounting to 4-8% of the muscle-tendon unit length and without externally visible tendon. During our dissections, we also noted that both the (short) bonobo and (long) gibbon Achilles tendon invariably inserts onto the tuber calcanei and is not continuous with the plantar aponeurosis.

Figure 1 : Triceps surae of a gibbon

Table 1. Measurements of the triceps surae complex in Hylobatidae.

N=14 (Vereecke & Channon 2013)	**Average**	**Standard deviation**
Triceps surae FL (mm)	31	7
Triceps surae MTU (mm)	183	21
Achilles tendon CSA (mm2)	10	4
Achilles tendon TL (mm)	139	23
Achilles tendon ETL (mm)	74	12
TL/MTUL	0.76	

Legend: MTU, muscle-tendon unit length; CSA, cross-sectional area; TL, tendon length; ETL, external tendon length.

2) The Achilles tendon in cercopithecoids

The Achilles tendon of eight cercopithecoids, covering phylogeny and including both terrestrial as well as arboreal species, were investigated (ranked from more terrestrial to more arboreal): *Theropithecus gelada* (gelada baboon), *Papio anubis* (olive baboon), *Macaca maura* (Moor macaque), *Macaca mulatta* (rhesus monkey), *Semnopithecus entellus* (Hanuman langur), *Colobus guereza kikuyensis* (mantled guerza), *Colobus* spec., *Trachypithecus francoisi* (François' leaf monkey).

Three *Papio anubis* and one *Macaca mulatta* cadavers were obtained from animals that died in captivity at the CNRS Primatology Station (Rousset, FR) and had been preserved on site in a freezer at -18°C. One *Colobus* #1927-496 was obtained from an animal that died in captivity at the Museum National d'Histoire Naturelle (Paris), preserved in formaline solution (10%) in the collection in fluid of Comparative Anatomy, MNHN (Paris). Specimens were all adult. We dissected the specimens on site and took linear measurements of the hind limb musculature using a digital calliper (according to Vereecke & Channon, 2013). A well-developed Achilles tendon was observed in each specimen within this cercopithecoid sample, amounting to 38% to 52% of the total muscle-tendon unit length (Table 2). In all specimens, the Achilles tendon firmly inserted on the posterior side of the tuber calcanei.

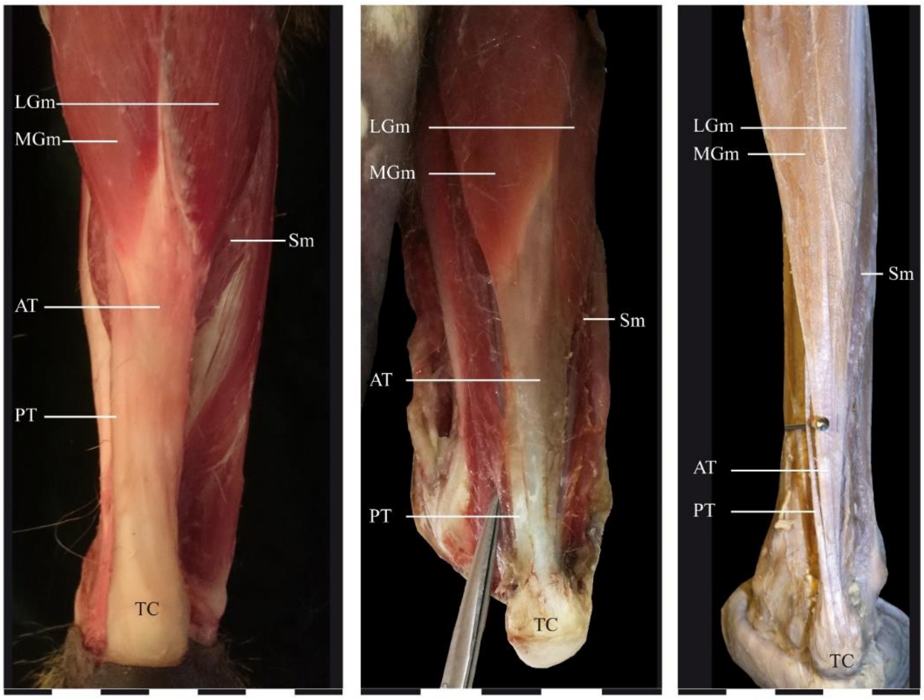

Figure 2*. Triceps surae and its distal attachments in the right lower leg of (from left to right) olive baboon, rhesus monkey and Colobus sp. in posterior view. Legend: LGm, Lateral gastrocnemius muscle; MGm, Medial gastrocnemius muscle; Sm, Soleus muscle; AT, Achilles tendon; PT, Plantaris tendon; TC, Tuber calcanei. Scales in cm.*

Table 2. *Measurements of the triceps surae complex.*

	Papio anubis			*Macaca mulatta*	*Colobus* sp.
	sp. 1	sp. 2	sp. 3	sp. 4	sp. 5
Triceps surae MTU (mm)	227	383	201	186	143
Achilles tendon TL (mm)	111	167	105	72	54
Achilles tendon ETL (mm)	84	111	75	49	45
TL/MTU	0.49	0.44	0.52	0.39	0.38

Legend: MTU, muscle-tendon unit length; TL, tendon length; ETL, external tendon length.

Visual inspection of the Achilles tendon was done for *Theropithecus gelada, Macaca maura, Semnopithecus entellus*, *Colobus guereza kikuyensis,* and *Trachypithecus francoisi,* obtained from the zoo of Besançon (FR). The skin was opened along the dorsal side of the lower leg and dorsal view photographs were taken for us by dr. Mélanie Berthet. Unfortunately, linear measures were not taken on the cadavers, but a well-developed Achilles tendon, firmly attached to the heel bone, is also clearly seen in these species. Estimated from the photographs, in each specimen about 50% of the total muscle-tendon unit length is taken by the Achilles tendon.

Figure 3: Triceps surae and its distal attachments in the lower leg of several cercopithecoids :(*A) Gelada baboon; (B) Moor macaque; (C) Hanuman langur; (D) mantled guerza; (E) François' leaf monkey.*

3) Information on the source data

Inverse dynamics

Inverse dynamics was used to determine the ankle joint moment throughout the stance phase which, in turn, was then used to calculate the loading of the Achilles tendon. The kinematical data (high speed video recordings, 250Hz) and the dynamics data (ground reaction forces and plantar pressure distribution, 250hz) were collected for a group of *Hylobates lar* specimens at the Animal Park of Planckendael (BE). The data specifically used for this study are the average profiles of 8 representative strides of one male *H. lar* (6.3 kg; see also '*Moment arms*') selected on the basis of steadiness, speed, and position regarding the camera (perfect sagittal view) from a much larger data set. The representativeness of this sample (intra- and interindividual) is argued in Vereecke and Aerts (2008). The ground reaction force data and the position of the centre of pressure are the averages of the profiles of 32 cycles extracted for the same individual and for the same speed range of the large data set collected for and analysed in Vereecke et al. (2005b). The full details concerning the data used for the inverse dynamics calculations are published in Vereecke et al. (2005b) and Vereecke and Aerts (2008).

Moment arms

In order to calculate the loading of the Achilles tendon throughout stance, moment arms of the ground reaction force and the balancing force from the triceps surae with respect to the ankle joint are needed. Combining the kinematical and plantar pressure data provided accurate moment arm profiles for the ground reaction force. The moment arm profile for the Achilles tendon was determined for the ankle range of motion observed during stance by means of the tendon travel method. For the full details of the procedure we refer to Channon et al. (2010). Several species were used in this study. For the present integration and re-analysis we used, however, the results for the *H. lar* individual used for the kinematical and dynamical experiments. This animal died of natural causes shortly after the experimental data collection.

Material properties

An Instron material testing machine was used to impose dynamic loading-cycles on the Achilles tendon of 14 gibbons (10 *Hylobates* spec., 4 *Symphalangus*, spec., 8 male, 6 female, age ranging from 9 to 35 years, 5 specimens were labelled only as 'adult') obtained from zoos and animal parks (n= 9) and museums (n = 5). Load-controlled sine wave-cycles at the frequency mimicking that of the loading-defomation cycles occurring during stance were used. Tendon stiffness is obtained from the slope of linear loading part of the load-deformation cycles. Given the diversity of the sample, average stiffness is used for the present study. Hysteresis is determined as the percentage difference in the area under respectively the loading and unloading parts of the load-deformation cycles. As for the stiffness, average hysteresis is used. The full details of the calculation of the material properties of the Achilles tendon are given in Vereecke & Channon (2013).

References

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