THE ROLE OF THE ACHILLES AND PATELLAR TENDON IN GIBBON LOCOMOTION

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SUMMARY
Tendon properties have an important effect on the mechanical behavior of muscles, with compliant tendons allowing near isometric contraction and hence more economical force production of the muscle fibres. Stiff tendons, on the other hand, have important dissipative properties and facilitate rapid force transfer.

In this study, we have investigated the material properties of Achilles and patellar tendons in gibbons (stiffness, Young’s modulus and hysteresis) and linked this with available anatomical, kinematic and kinetic data to evaluate their role in leaping and bipedalism.

We found a functional difference between the Achilles and patellar tendon, with the Achilles tendon being rather compliant and suitable for energy storage and release during both bipedalism and leaping. The patellar tendon is three times as stiff, has a low Young’s modulus and high hysteresis, making energy recovery during bipedalism unlikely. During leaping, the high muscle forces occurring in the quadriceps will allow some stretching of the patellar tendon. Its high stiffness will favour fast force transfer upon recoil, and possibly power generation at take-off.

INTRODUCTION
In vitro and in vivo animal and human experiments have demonstrated that long, compliant tendons – such as the human Achilles tendon – have an important effect on the mechanical behavior of the muscle-tendon unit [1,2,3]. Their spring-like features facilitate energy-recovery during locomotion and reduce the amount of shortening of the muscle fibres, resulting in higher and more economical force production.

Anatomical studies have indicated that gibbons (fam. Hylobatidae) also possess relatively long Achilles and patellar tendons, coupled to short-fibred, pinnate triceps surae and quadriceps femoris muscle groups [4], and it has been suggested that these may play a role in storage and release of elastic energy during hind limb powered locomotion such as leaping and bipedalism [5].

By assessing the material properties of the Achilles and patellar tendon in gibbons, we want to investigate their role in leaping and bipedal locomotion.

METHODS
Material properties of the Achilles and patellar tendon were obtained using a materials testing machine (Instron E3000). Tendon samples (patellar tendon: n=7, Achilles tendon: n = 14) were taken from the left or right hind limb of fresh-frozen gibbon cadavers, which were obtained via collaboration with the National Museums of Scotland and the Royal Zoological Society of Antwerp. All animals included in this study died under natural circumstances.

The samples were thawed and clamped in the materials tester and load versus displacement curves were obtained using a sinusoidal wave test. Stiffness, hysteresis and Young’s modulus were determined for each tendon sample. These material properties were combined with anatomical measurements of the triceps and quadriceps muscles and with available kinematic and kinetic data from previous studies [4,5,6,7,8] to investigate the energy storing capacity of the Achilles and patellar tendon during leaping and bipedalism.

RESULTS AND DISCUSSION
The stiffness of the patellar tendon (S = 303 N/mm) is almost triple that of the Achilles tendon (110 N/mm; Figure 1). This marked difference in stiffness can be linked to the morphological appearance of the patellar tendon, being a thick tendon attached to a voluminous quadriceps femoris. The Achilles tendon, on the other hand, is relatively long and thin and is connected to the less sizeable triceps surae. The hysteresis (H) of the Achilles tendon is much lower, and the Young’s Modulus (E) markedly higher, than that of the patellar tendon (H = 14% and 24% resp.; E = 853 MPa and 307 MPa resp.; Figure 1), indicating that the Achilles tendon is more appropriate for elastic energy storage and release, whereas the patellar tendon seems more geared towards energy dissipation and force transfer.

During bipedalism, gibbons adopt spring-mass mechanics, with knee and ankle flexion preceding extension of both joints at push-off, which facilitates elastic energy storage and release in the Achilles and patellar tendon [8]. However, the high stiffness and hysteresis of the patellar tendon make energy recovery less favorable. In leaping, the knee and ankle joint are also flexed before extending at take-off, stretching the Achilles and patellar tendon and allowing elastic energy storage. The higher forces occurring during leaping will also stretch the stiffer patellar tendon. The low Young’s modulus...
of the patellar tendon indicates that to attain a same amount of tendon strain (approx. 4% during locomotion), much lower tendon stresses are needed for the patellar tendon, leading to a faster reaction time and rapid force transfer. The high stiffness of the patellar tendon is likely needed to resist the high force of the bulky quadriceps, yet also entails a higher shortening velocity in the quadriceps. This corresponds with the architecture of the quadriceps, which has short, pinnate fibres, a large physiological cross-sectional area, and small moment arm [4,5], important for fast knee and powerful knee extension in leaping.

**CONCLUSIONS**

Assessment of the material properties of Achilles and patellar tendons of gibbons point to a functional differences between both tendons. The Achilles tendon is relatively long and compliant, with a moderate Young’s modulus and hysteresis, making it suitable for elastic energy recovery during bipedalism and leaping. The patellar tendon, on the other hand, is relatively thick and stiff, and has a high hysteresis. This suggests that energy recovery via the patellar tendon during bipedalism is unlikely. However, during strenuous activities such as leaping, it might have an important role in energy recovery (as indicated by the low Young’s modulus) and rapid force transfer (due to its high stiffness).

**REFERENCES**


![Figure 1: Stiffness and hysteresis of the patellar and Achilles tendon of gibbons (average and standard error).](image)