Mechanical Properties of Tendon and Aponeurosis of Human Gastrocnemius Muscle in Vivo

T. Fukunaga¹, T. Muramatsu², T. Muraoka¹, D. Takeshita¹, Y. Kawakami¹

¹Tokyo University (Tokyo, Japan)
²Keio University (Yokohama, Japan)

Introduction
Knowledge of the strain distribution along the tendon and aponeurosis is necessary to understand structure and function of the tendinous tissues and to make more accurate models of the muscle-tendon unit. Although recent studies reported mechanical properties of the human tendinous tissues in vivo by using ultrasonography (Ito et al. 1998; Maganaris and Paul, 2000; Narici et al. 1996), few of those estimated strain of the tendon and aponeurosis separately (Maganaris and Paul, 2000). In addition, no study to date has estimated strain distribution along human medial gastrocnemius (MG) muscle that has functional importance during locomotion. The purposes of this study were 1) to measure and compare the strain of the human tendon and aponeurosis in vivo and 2) to examine the strain distribution along the aponeurosis.

Methods
Seven male subjects exerted isometric plantar flexion torque from relaxation to 90% MVC (maximum voluntary contraction) while the elongation of tendinous tissues of MG was determined from the tendinous movements using ultrasonography. The ankle joint angle was set at 90deg (the sole of the foot was at 90deg to the tibia) and the knee joint was kept extended. The probe (7.5 MHz) of the ultrasonic apparatus was put at three different places on MG (Fig.1): muscle-tendon junction (MTJ), central (APC) and proximal (APP) intersection made by the fascicles and aponeurosis of MG. The Achilles tendon length at rest was defined as the distance between MTJ and the osteo-tendinous junction (OTJ) detected by ultrasonography. The aponeurosis length of MG was defined as the distance between MTJ and APP. The proximal and distal aponeurosis length was defined as the distance between APC-APP and MTJ-APC, respectively. The elongation of each segment was given by subtracting the distal point’s displacement from the proximal one. The strain of each segment was obtained by dividing the elongation by the length of the segment at rest.

Results & Discussion
Figure 2 shows the displacement of each point (MTJ, APC, APP) at nine torque levels. The maximal strain, derived from the displacement data, of the Achilles tendon and aponeurosis, estimated separately from the elongation data, was 5.1 ± 1.1 and 5.9 ± 1.6%, respectively. As for maximal strain of aponeurosis, the result of the present study was in the range of previous studies on animals [2% for frog gastrocnemius (Trestik and Lieber, 1993), 3.5% for rat gastrocnemius (Huijing and Ettema, 1988/89), 8% for frog semitendinosus (Lieber et al. 2000), and 14.3% for rat MG (Zuurbier et al. 1994)]. Some studies have shown that the strain of the aponeurosis was larger than that of the tendon (Ettema and Huijing, 1989; Lieber, et al. 1991; Maganaris and Paul, 2000), whereas other studies have shown that the difference in strain between tendon and aponeurosis did not exist (Rack and Westbury, 1984; Scott and Loeb, 1995; Trestik and Lieber, 1993). The present study supports the latter studies. No significant difference in strain was observed between the distal (MTJ-APC) and proximal (APC-APP) regions of the aponeurosis. The tendinous tissues of the gastrocnemius muscles have been shown, from animal experiments, to be the site of elastic energy storage (Alexander, 1984) that enhances the efficiency of locomotion and mechanical buffer (Griffiths 1991) to protect the muscle fibers during eccentric contractions. Significant strain of both Achilles tendon and aponeurosis of human, as observed in this study, would reflect the contribution of the whole tendinous tissues as an elastic component that could favor movement performance.

These findings are particularly important for understanding the mechanical functions of the human gastrocnemius muscle-tendon unit in vivo, and for more accurate muscle modeling in future studies.
References

Fig. 1. Schematic illustration of the human medial gastrocnemius muscle (MG). The measurement sites (OTJ – APP) are also shown.
Fig. 2
Displacement of each point (APP: 2-A; APC: 2-B; MTJ: 2-C) at nine torque levels of all subjects (n=7)