Force transmission via myofascial pathways between EDL muscle and other muscles of the rat anterior compartment

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Introduction

Anatomical studies have revealed intermuscular connections in human (Vleeming *et al.*, 1995) and rat (Van der Wal, 1988). Indications for mechanical interactions between muscles have also been found (Gregor *et al.*, 1988; Riewald & Delp, 1997). It has been suggested that force is transmitted out of muscle onto structures in its direct environment or to neighboring muscles without passing its tendons (Huijing, 1999a). This was named extra- and intermuscular myofascial force transmission. Unequal forces between proximally and distally measured EDL force, which is direct evidence for the proposed hypothesis, have been reported (Huijing, 1999b; Huijing, 2000).

The aim of the present study was to investigate mechanical interactions between muscles in the anterior crural compartment of rat, containing tibialis anterior (TA), extensor hallucis longus (EHL) and extensor digitorum longus (EDL) muscles. Specifically, length effects of the TA+EHL complex on proximal and distal EDL forces are studied.

Methods

The tendons of the muscles of the anterior crural compartment were exposed but connective tissue at the muscle bellies of TA, EHL and EDL was left intact. Isometric force was measured simultaneously at proximal and distal tendons of EDL muscle as well as at the tied distal tendons of TA and EHL (the TA+EHL complex). Effects of TA+EHL complex length and force on proximally and distally measured forces of EDL muscle kept at constant muscle–tendon complex length were assessed. Supramaximal stimulation of the peroneal nerve excited all muscles maximally and simultaneously.

Results & Discussion

Isometric

Changes of TA+EHL active force, obtained by lengthening the distal tendons, affected proximal as well as distal EDL active force, despite the fact that EDL muscle–tendon complex length was left unchanged (Fig. 1). Distal EDL forces were significantly higher than proximal EDL forces at low TA+EHL forces. Distal TA+EHL lengthening decreased the proximo–distal difference in EDL active force (from ≈ –18% to 0% of proximally determined optimum active EDL force). This is brought about by differential effects of increasing TA+EHL length on proximally and distally measured EDL force: diminishing distal force but increasing proximal force significantly.

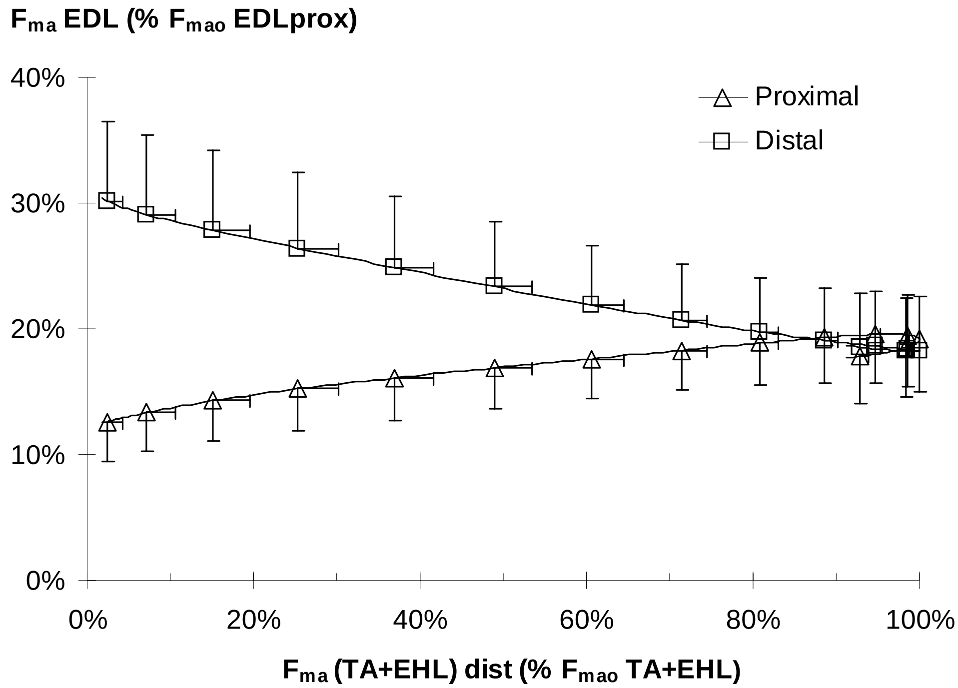

Fig. 1 Proximally and distally measured active force (F_{ma}) of EDL kept at constant muscle-tendon complex length as a function of TA+EHL active force. Forces are normalized with respect to optimal active force (F_{mao}) of proximal EDL (2.60 ± 0.40 N, mean ± SD) or the TA+EHL complex (8.55 ± 1.01 N, mean ± SD). Values are shown as mean either + or – SD (n=7).

Dynamic

During one experimental trial, the connection of the TA+EHL complex to the force transducer was severed (Fig. 2). First, TA+EHL force decreased from approximately 9 N to just below 6 N. Simultaneously, proximal EDL force declined and distal EDL force increased. Temporary, the force bearing capacity of the connection between TA+EHL and its force transducer was restored. The definite release of the TA+EHL complex, the rapid drop from about 6 N to zero, resulted in more pronounced changes of proximal as well as distal EDL force. It should be noted that the signal of the force transducer did no longer represent TA+EHL force after release. Vibration of the force signal of the TA+EHL complex, and likely also of proximally measured EDL, is brought about by vibration of the force transducer. These results are compatible with the results shown in Fig. 1: a small or no difference between proximal and distal EDL active force at high TA+EHL forces, and an increasing difference at low TA+EHL forces.

The interaction between properties of the TA+EHL complex and EDL muscle, in isometric (Fig. 1) as well as dynamic (Fig. 2) conditions, indicates intermuscular myofascial force transmission. Such transmission must be mediated by the intra-, inter and extramuscular connective tissues. The TA+EHL complex length effects can be understood on the basis of changes in the configuration, and consequently the stiffness, of the compartmental connective tissue network. The anterior tibial compartment should therefore be viewed as one functional unit consisting of a connective tissue tunnel–like network and muscle fibers that are able to shorten. It is concluded that the concept of morphologically defined muscles acting as independent components is not appropriate to describe force transmission from muscle to bone. These phenomena may play an important role under *in vivo* muscle functioning and, therefore, should be incorporated into models of human movement, which up to now have predominantly been based on properties of "isolated" *in situ* muscle.

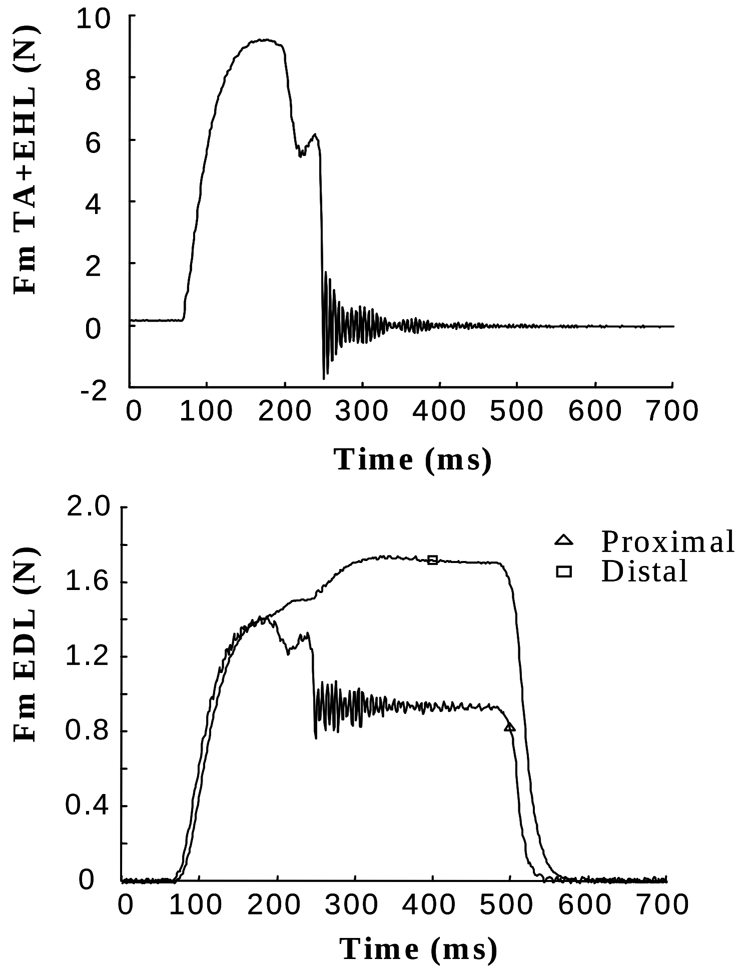

Fig. 2 Distally force time signals of the TA+EHL complex (upper panel) as well as proximally and distally force time signals of EDL muscle (lower panel). During isometric contraction, the connection between the TA+EHL complex and the force transducer was severed. TA+EHL force dropped to zero, proximal EDL force decreased and distal EDL force increased at the same time. The TA+EHL force recovery indicates that the force bearing capacity of the fixation was restored temporary before the TA+EHL complex was definitely disconnected from its force transducer.

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