MYOFASCIAL FORCE TRANSMISSION IS NOT ONLY IMPORTANT FOR SYNERGISTIC MUSCLES BUT ALSO FOR ANTAGONIST MUSCLES

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INTRODUCTION

Generally muscles are considered as independent force generators. However, recently it has been shown that force is also transmitted between muscles and other tissues (e.g. Huijing & Baan, 2001). Such transmission is thought to be of particular importance for mechanical interaction between synergists. Preliminary work supports the idea that it may also be active for antagonist muscles. The main aim of the present work is to test the hypothesis that force is also transmitted between antagonist muscles.

METHODS

Surgical and experimental procedures were in strict agreement with the guidelines and regulations concerning animal welfare and experimentation set forth by Dutch law, and were approved by a Committee on Ethics of Animal Experimentation at the Vrije Universiteit, Amsterdam.

Male Wistar rats (n=6, mean ± SD of body mass 301 ± 16.25 g) were anaesthetized by intraperitoneally injecting a urethane solution (initial dose 150 mg /100 g body mass). Supplementary doses of the anaesthetic agent (0.62 mg) were injected intraperitoneally (maximally 3 times), if necessary to maintain deep aesthesia. The animals were placed on a heated water pad (37°C) during surgery and experimentation.

Forces were measured at the tied distal tendons of all muscles (PER) within the peroneal compartment of the hind leg, and of the tied tendons of m. tibialis anterior and m. extensor hallucis longus (TA+ EHL), as well as at proximal and distal tendons of m. extensor digitorum longus muscle (EDL). The latter two are located within the anterior crural compartment, and are antagonists of PER. The two compartments are separated by an intermuscular septum, which prevents direct intermuscular myofascial force transmission. All muscles mentioned were activated maximally for isometric contractions. Moving proximal or distal EDL tendons changed only EDL muscle-tendon complex length. This was done in such a way, as to reach identical EDL lengths.

TA+EHL and PER complexes were kept at a constant muscle tendon-complex length. The length selected yielded a initial mean force Fma = 2.6N and Fma = 4.25 N, for TA+EHL and PER respectively. Note that, if synergistic as well as antagonist muscle groups would act independently, changing EDL length should not affect TA+EHL or PER forces at all.

RESULTS

EDL

At most lengths, EDL forces exerted at proximal and distal tendons differed substantially, indicating myofascial force transmission. Both magnitude and direction of this difference were quite dependent on length as well as location of lengthening. EDL force exerted at the location of lengthening was always higher. Figure 1 shows results for active EDL force after proximal and distal lengthening.
For the present experimental conditions, proximal and distal forces are equal at a length very close to EDL reference length (mean lref ± SE = 41.2± 0.49), as no significant differences could be shown for proximal and distal active force at reference length. For both active and passive EDL forces, ANOVA indicates significant effects for factor length and factor proximal or distal location of force measurement, as well as interaction between these factors. After lengthening EDL from the respective active slack lengths, isometric active force measured at the location of lengthening rises much faster with length changes than active force measured at the other (fixed) tendon. This is true for both distal and proximal EDL active forces. Note, however, that optimum lengths for length-force characteristics measured at the tendon at the lengthened side of EDL or at its non-lengthened side are similar.

**TA+EHL**

![Graph](image1)

**Figure 2:** Effects of proximal and distal lengthening of EDL to equal lengths on absolute force of TA+EHL kept at constant length. EDL length is expressed as deviation from its reference length. Note the effects of distal, but not of proximal lengthening in the active condition. Effects on passive force were not significant. Mean values and SE are shown in both (a) and (b).

Note that, if synergistic muscles would act independently, changing EDL length should not affect TA+EHL. However, despite the fact that TA+EHL was always kept at constant length, after EDL length was changed, active force of synergistic TA+EHL was altered, (ANOVA). This was particularly true for distal EDL lengthening (Figure 2a) after distal lengthening (post-hoc test). Effects of EDL length change on TA+EHL force (Figure 2b) could not be shown to be significant for the passive condition.

Distal EDL lengthening affected TA+EHL active force significantly ($\Delta F_{ma}$ ≈ -0.3 N, i.e. by approximately -10% of initial force). It is concluded that particularly for distal lengthening there is evidence of intermuscular myofascial force transmission between the active synergists.

**Peroneal Muscles**

As EDL was changed in length, PER was always kept at constant length. Despite such constant length, isometric active force exerted distally by antagonists PER was altered, after EDL length was changed (ANOVA). This was particularly true (Figure 3a) for distal lengthening (post-hoc test): As EDL length and distal force were increased, PER force decreased by approximately 10%.

![Graph](image2)

**Figure 3:** Effects of proximal and distal lengthening of EDL to equal lengths on force of PER muscles kept at constant length. PER force is expressed as deviation from its initial value. EDL length is expressed as deviation from its reference length. Note the effects of distal, but not of proximal lengthening in the active condition. Effects on passive force were not significant. Mean values and SE are shown in both (a) and (b).
This indicates that myofascial force transmission between antagonist EDL and PER does occur. It is concluded that even antagonist muscles are not to be considered independent force actuators, but show substantial mechanical interaction through myofascial force transmission. As the intermuscular septum separates the two compartments, such intermuscular effects cannot be considered intermuscular myofascial force transmission, defined as direct transmission of force between continuous adjacent muscular connective tissue matrices.

DISCUSSION

Effects of muscle relative position
In combination with length effects, the factor relative muscular position is shown to be a major co-determinant of muscle force: For comparisons at equal length obtained by either proximal or distal lengthening, force actually exerted at proximal or distal EDL tendons may be quite different (e.g. Figure 2). Note that any length change of the muscle is accompanied by changes of relative position of the muscle with respect to its surroundings. For a more detailed analysis see (Huijing et al., 2003a and Maas et al., 2003).

It is concluded that imposing a length change on the muscle with extra and inter-muscular connections inseparably involves some changes of relative position and that such position effects will affect force exerted by a muscle.

Effects of EDL lengthening on synergists
The lack of effects of proximal length change and thus relative position of EDL on force exerted by neighbouring muscle groups is not fully surprising. Such a lack of effect proximal EDL lengthening specifically on TA+EHL in the present study confirms previous observations (Huijing and Baan, 2001). On the other hand the magnitude of this effect is it is expected to be very much dependent on the experimental conditions, such as muscle lengths (Maas et al, 2001) and muscular relative positions. The effect of distal EDL lengthening on both synergists (within the same compartment) that are maintained at constant muscle-tendon complex length is much clearer for the experimental conditions of the present study. Such interaction between EDL and TA+EHL is compatible with earlier conclusions regarding intermuscular myofascial force transmission (Maas et al, 2001).

Effects of EDL lengthening on antagonists
According to our definitions, that interaction cannot simply be ascribed to intermuscular myofascial force transmission. In contrast to EDL and TA+EHL, those two muscle groups are not immediately adjacent, so that the intramuscular connective tissue networks cannot be continuous. The first two possibilities involve connections via extramuscular connective tissues:

(1a) Connections between both muscles via the neurovascular tract. Innervation of EDL is arranged via nerve branches (from the n. peroneus profundus) and circulation via branches of blood vessels (e.g. art. tibialis). These structures enter into the anterior crural compartment from the peroneal compartment, through a fenestration within the anterior intermuscular septum. Rather stiff connective tissues protect these delicate structures. We refer to the complex of all these elements to as neurovascular tract. As superficial branches from the common peroneal nerve and tibial artery and their associated connective tissue make connections also to the intramuscular connective tissues of the peroneal group, this pathway is one of the prime candidates for explaining interaction between the muscle groups by extramuscular myofascial force transmission.

(1b) Connections of the intramuscular connective tissues of both muscles’ belly to the septum. Such connections are not hard to imagine for the peroneal group, as part of the peroneus longus as well as brevis muscle fibres originate from the septum, presumably with a myotendinous type of junction. As with origins onto a regular intramuscular aponeurosis, parallel to such a junction the endomysium is expected to connect to or even be continuous with the septum as well. In contrast, EDL muscle fibres have no origin or insertion of muscle fibres onto that structure. However, a sheet of connective tissue (which is a kind of extension of the neurovascular tract) connects the belly of EDL to the septum (Huijing et al., 2003b). Morphological analysis of the content of the peroneal compartment shows that a similar sheet as extension from the neurovascular tract of the superficial peroneal nerve connects the bellies of peroneus longus and brevis muscles to the septum. Such a connection, in principle, does allow mechanical interaction between the two compartments by means of extramuscular force transmission.

Are myofascial effects to be expected in vivo?
Even though the purpose of the present work was to identify in principle the effects of muscular relative position related to muscular length changes, the question should be asked if it is reasonable to expect such effects in vivo. It is evident that some of the conditions imposed in the present work are not usually encountered in vivo (e.g. synchronized maximal activity of all muscles studied). Nevertheless, co-activation of synergists and antagonists is a common feature of in vivo movement (e.g. Baratta et al., Solomonow et al., 1988 ). If synergists would undergo similar length changes, the effects could be minimized. However, differences in moment arm for different muscles with respect a joint are quite common and sometimes substantial (e.g. McClean, 1985; Lieber and Boakes, 1988; Visser et al., 1990; Helm et al. 1992, Fukunaga et al, 1996; Ettema, 1997; Eijden, 1997). For example for the mouse, the moment arm of TA at the ankle is reported to be 17% higher than for EDL (Lieber, 1997). Therefore, differences in moment arm may contribute to considerable changes in vivo muscular relative positions. Another important consideration is the mono-, bi- or polynartic character of a muscle. If a monoarticular muscle is not changed in length and position, its neighbouring polynartic muscle may change length and position because of movement in a more distant joint.

It is concluded that substantial changes of in vivo muscle position with respect to neighbouring muscles and extramuscular structures are likely. Nevertheless,
quantification of such effects awaits application of in vivo imaging techniques to this problem.

SUMMARY

A proximo-distal force difference for EDL force indicates myofascial force transmission from or to EDL. Differential effects of location of EDL lengthening, while obtaining identical EDL lengths, indicate that muscle relative position is an important co-determinant of force exerted. Effects of length changes of EDL on synergists, as well as antagonists kept at constant length, also indicate myofascial force transmission from these muscles.

The hypothesis that such transmission will also occur even between antagonists is confirmed.

REFERENCES