ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

WRIST ANGLE–FLEXION MOMENT CHARACTERISTICS FOLLOWING AGONIST-TO-ANTAGONIST TENDON TRANSFER IN THE RAT

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SUMMARY
The aim of this study was to investigate the contribution of transferred m. flexor carpi ulnaris (FCU) to the joint moment exerted by its previously synergistic muscles. Five weeks after FCU tendon transfer, effects of FCU distal tenotomy and dissection on wrist angle-moment characteristics of all wrist flexion muscles were assessed. FCU disruption resulted in a significant increase in wrist moment, which indicates that transferred FCU exerts an extension moment at the wrist. However, the estimated extension moment of transferred FCU was substantially higher than the FCU moment measured during excitation of FCU muscle fibers exclusively. This indicates that during excitation of all wrist flexion muscles, some force is transmitted from the excited, non-transferred flexor muscles via transferred FCU to the extensor side of the wrist.

INTRODUCTION
Agonist-to-antagonist tendon transfers are performed to improve gait or upper extremity function in individuals with severe disabilities. Ideally, transferred muscles convert completely from their previous mechanical effect (e.g., flexion) to yielding a moment according to its new path and relocated insertion (e.g., extension). We recently demonstrated using a rat model that the mechanical effect of a transferred muscle can be quite different, being dependent on joint angle [1]. This is likely caused by scar tissue formed at muscle-tendon boundaries, which was shown to transmit some muscle fiber force to neighboring structures instead of the new insertion [2].

To further understand the functional outcome of tendon transfers, changes in the joint angle - moment characteristics of the donating muscle group need to be assessed. Therefore, the aim of this study was investigate the contribution of transferred muscle to the joint moment exerted by its previously synergistic muscles.

METHODS
In deeply anesthetized rats (n=6), FCU muscle was partially dissected free and transferred to the distal tendons of m. extensor carpi radialis brevis and longus (ECR), see [2] for details of surgical procedures.

Five weeks after the surgery, the right forelimb was shaved and the skin was resected from the shoulder to the wrist, while the rats were deeply anesthetized. Within the brachial compartment, the ulnar and median nerves were identified and placed in a bipolar cuff electrode. The ulnar and median nerves innervate all palmar muscles of the antebrachium ('wrist and digit flexors'), including FCU. The right forelimb was secured rigidly to the experimental setup (Fig. 1).

Wrist joint moments exerted upon supramaximal and simultaneous stimulation of the ulnar and median nerves (100 Hz, 500 ms) were measured for different positions of the wrist joint (from 32° flexion to 22° extension). In each experiment, three sets of wrist angle-moment data were collected: 1) with minimally disrupted connective tissues of the antebrachial compartment; 2) after distal tenotomy of FCU; and 3) after maximal dissection of FCU distal tendon and muscle belly. Active moments were calculated by subtracting passive moment from total moment at equal wrist angles.

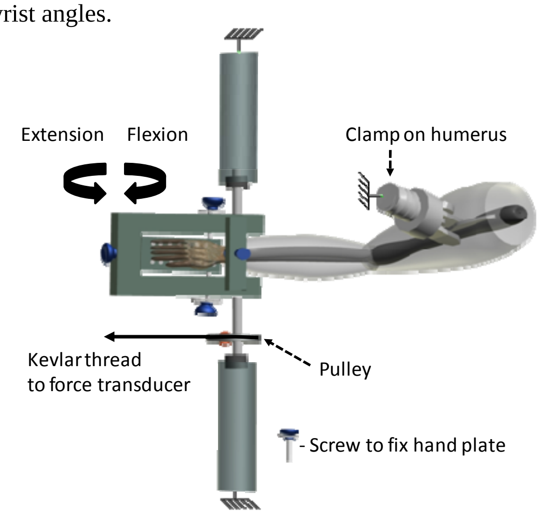
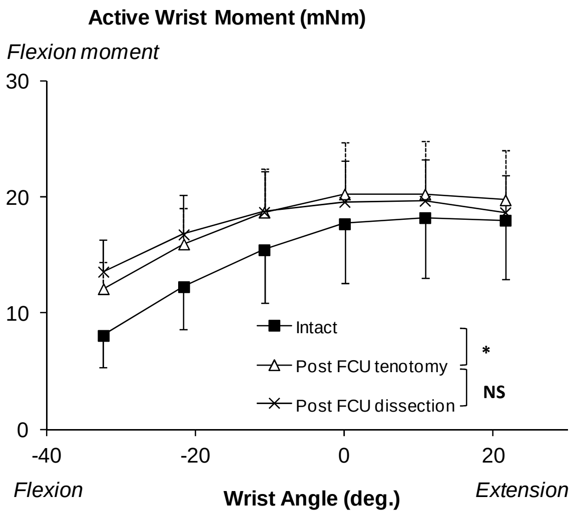


Figure 1: Schematic drawing of experimental setup. See [1] for a detailed description.

RESULTS AND DISCUSSION
Distal FCU tenotomy resulted in a significant increase in wrist flexion moment, particularly at flexed wrist positions (between -32° and -11°). Maximal FCU dissection, however, did not yield any additional significant change of active moment (ANOVA and Bonferroni post hoc analysis).

Peak flexion moment in the initial condition was 18.2 ± 5.2 mNm (Fig. 2, top). Distal tenotomy increased the peak moment to 20.3 ± 4.4 mNm, equivalent to 111% of that of the intact condition. Peak flexion moment after maximal FCU dissection was 19.7 ± 3.6 mNm or 108% of the intact moment.

The fact that wrist flexion moment upon stimulation of the ulnar and median nerves increased and not decreased following FCU disruption indicates that in accordance with its new moment arm, transferred FCU exerts an extension moment at the wrist.



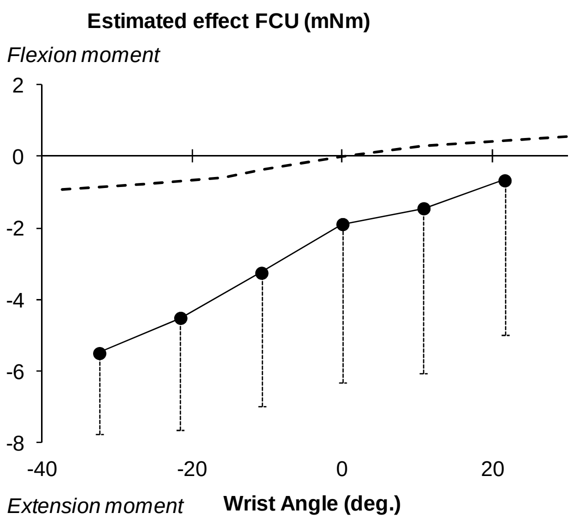


Figure 2: Wrist angle-moment characteristics and estimated effect of transferred FCU muscle. * Significant difference ($p<0.05$). NS, not significant. Values are shown as mean + or – SD (n = 6). Dashed line indicates the previously reported [1] mean wrist angle-moment characteristics of selectively activated transferred FCU muscle in the same rats.

The estimated mechanical effect of transferred FCU to wrist moment was calculated by subtracting the moment exerted after maximal dissection from the moment in the initial condition. For this calculation mechanical independence of FCU was assumed. At all wrist angles tested, the estimated effect of FCU was an extension moment (Fig. 2, bottom), which was maximal in the most flexed wrist position (5.5 ± 2.6 mNm) and near zero in the most extended position (0.7 ± 2.1 mNm). These results are substantially different, both in magnitude and direction, from those obtained if muscle fibers of FCU exclusively were excited (dashed line in Fig. 2). Measured active FCU wrist moment was much smaller and bidirectional: extension moments in flexed wrist positions and flexion moments in extended wrist positions (see [1]).

These results indicate that coactivation of wrist flexor muscles alters the mechanical effects of transferred FCU muscle. The higher wrist extension effect suggests that some force is transmitted from the excited, non-transferred flexor muscles via transferred FCU to the extensor side of the wrist.

In a previous study, we have shown mechanical interactions between transferred FCU muscle and non-transferred palmaris longus muscle in the rat, despite the fact that a substantial part of FCU muscle belly was rerouted to the extensor side of the forearm [3]. Such mechanical interactions between adjacent muscles are most likely mediated by connective tissues (i.e., scar tissue) at the FCU muscle-tendon boundaries.

CONCLUSIONS

To the best of our knowledge, this is the first study in which the mechanical effects of transferred muscle during coactivation of its formerly synergistic muscles have been investigated. An adequate neural response to an agonist-to-antagonist tendon transfer requires that the activity pattern of the transferred muscle is adjusted to its altered mechanical function. Several studies in human patients and various animal models have shown that such neural adjustments occur only partially or do not occur at all [4,5]. In such cases, the transferred muscle is excited simultaneously with its formerly synergistic muscles comparable to the experimental conditions in the present study.

We conclude that following FCU-to-ECR tendon transfer, the wrist flexion moment generated by all wrist flexors is decreased not only due to the change in the mechanical effect of FCU, but also due to force transmission from wrist flexion muscles to the extensor side of the wrist.

ACKNOWLEDGEMENTS

Supported by the European Community's Seventh Framework Programme Grant MIRG-CT-2007-203846 by the Division for Earth and Life Sciences, Netherlands Organization for Scientific Research Grant 864–10-011.

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