MUSCLE WEAKNESS AND FORCE SHARING IN THE CAT HINDLIMB

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INTRODUCTION
One of the most basic problems in biomechanics is the so-called distribution (Crowninshield and Brand, 1981) or force sharing problem. Due to the redundant nature of musculoskeletal systems, the force sharing problem is concerned with determining the force contributions and the coordination of muscles to voluntary movement, stability, and control of joints. However, the properties of muscle can change over time due to use, injury, or illness, leading to the weakening of the muscle; which in turn affects the ability of the muscle to produce force and to control movements in an appropriate way.

It is desired to determine if the weakening of the force production capacity in one muscle of a functional group will alter the normal force sharing patterns observed between synergistic muscles. Misiaszek and Pearson (2002) conducted an initial study into this problem using a botulinum toxin type-A injection into the ankle extensor muscles of cats. Botulinum toxin type-A (BTX-A) is a neuromuscular blocking agent, which inhibits the fusion of acetylcholine with the motor nerve ending (Brin, 1997). Without the release of acetylcholine, the muscle fibres cannot be physiologically activated.

To examine the implications of muscle weakness on force sharing, this study investigated two synergistic muscles in the cat hindlimb: soleus and medial gastrocnemius. It was hypothesized that when the force production capability if soleus is reduced via an injection of BTX-A, a corresponding increase in the force production of the other synergistic muscles, represented by the medial gastrocnemius, would be seen.

METHODS
A skeletally mature, male cat (5.75 kg) was anesthetised using halothane. The soleus (SOL) and medial gastrocnemius (MG) muscles in the left hindlimb were surgically implanted with buckle-type muscle force transducers (Walmsley et al., 1978) and indwelling bipolar fine wire electrodes (Herzog et al., 1993) for the measurement of muscle forces and muscle activations, respectively.

At 6 days following the implantation surgery, kinematics, ground reaction forces, muscle forces and EMG recordings were taken. Kinematics and three-dimensional ground reaction forces of the cat during locomotion on a walkway were recorded using a high-speed video system and a set of walkway-embedded, animal size force platforms (AMTI). Four reflective, circular skin markers (diameter: 8mm) were placed over the hip, knee, ankle, and metatarsophalangeal joint of both hindlimbs to allow joint position identification in the subsequent digitization of the video.

Seven days following the implant surgery, the SOL muscle in the left hindlimb was surgically exposed and BTX-A was injected into the muscle belly of SOL to weaken it. A 100-unit vial of vacuum-dried Clostridium botulinum type-A (BOTOX, Allergan, Inc., Toronto, Ontario, Canada)
was rehydrated with 0.9% preservative free saline to a concentration of 50 units/ml. The muscle belly was injected at multiple sites with a total dose of 40 units of BTX-A to increase toxin diffusion. The exposed muscle was irrigated with sterile saline solution prior to closing the incision site to remove any BTX-A, which may have seeped from the injection site. Following a 24-hour recovery period, data recordings of cat locomotion on the walkway were made over the next 13 days.

RESULTS AND DISCUSSION
The muscle force recordings from SOL show that the injection of botulinum toxin type-A into the muscle belly resulted in a loss of force production during locomotion (Fig. 1). Within 24 hours following the injection, the force had decreased by approximately 52%, and after 48 hours the loss of force was near complete (97%). Over the course of the remaining 12 days following the injection, the muscle force in SOL began gradually increasing from 3% of the pre-injection force level to 8%.

![Figure 1: Soleus muscle forces as a percentage of pre-injection level (day 0).](image)

However, a corresponding rise in the MG muscle force was not detected. The overall trend of the MG force, following the BTX-A injection of SOL, was observed to decrease slowly over the testing period. Therefore the original stated hypothesis of this study was not supported. In addition, throughout the post injection test period, the ground reaction forces exerted by the left hindlimb remained approximately constant, indicating that the left hindlimb was not being unloaded to a large extent.

One possibility for the lack of increase in the MG force production is simply that some diffusion of the botulinum toxin occurred from SOL into the neighbouring muscles. At the conclusion of testing, when the implantation site was surgically exposed, the buckle transducer was encapsulated in new tissue growth. This may have created an alternate force transmission route in the tendon, decreasing the MG force sensed by the transducer. Finally, it is possible that when the SOL muscle is weakened, the corresponding increase in force is occurring in synergist muscles other than MG, such as lateral gastrocnemius or plantaris, or that the ankle moments are reduced by small changes in walking kinematics despite similar ground reaction forces. Further research into the force sharing of the ankle extensor muscle of the cat hindlimb must be performed before more definitive conclusions can be made.

REFERENCES

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