ASSESSMENT OF ELBOW FLEXORS ACTIVITY LEVELS DURING INCREMENTAL ISOMETRIC CONTRACTIONS USING SUPERSONIC SHEAR IMAGING

1 Antoine Nordez, 1 Killian Bouillard and 1 François Hug
1 EA 4334 “Motricité, Interactions, Performance” UFR STAPS, Université de Nantes

SUMMARY
Our previous study has shown that supersonic shear imaging (SSI) can be accurately used to estimate muscle activity level. The present study was designed to assess the muscle activity level of the main elbow flexors using this technique during linear torque ramps of 30 s from 0 to 40% of the previously determined maximal voluntary contraction (MVC). The echographic probe was randomly placed on the short head of the biceps brachii (BB), the long head of the biceps brachii (BB), the brachialis (BA), the brachioradialis (BR) and the long head of the triceps brachii (TB). A good repeatability of the shape of the shear elastic modulus changes was observed. The shear elastic modulus patterns highlighted changes in load sharing between the elbow flexors. The torque was mainly produced by BR and BA at low torque levels, and the increase in torque after ~10% of MVC was mainly due to the BB. This phenomenon has not been identified earlier due to lack of information regarding the BA muscle (deep muscle). This study provides a step towards confirming the viability of SSI as a tool to estimate muscle stress or force, but the accuracy of such estimation will have to be assessed.

INTRODUCTION
Several studies have reported a non-linear relationship between the electromyographic (EMG) activity and torque for the biceps brachii (BB) muscle [e.g., 1,2,3]. In the literature, it is explained by the motor unit recruitment strategy for muscle force gradation, which is mainly due to the recruitment of additional motor units (i.e., spatial recruitment) for the BB muscle [1]. Surprisingly, no study has explored the putative influence of changes in the load sharing on the non-linear EMG-torque relationships among the synergist muscles (i.e., long head of the BB, short head of the BB; brachialis and brachioradialis). This is probably because of the inability to record EMG activity from deep muscles using surface electrodes and the inherent selectivity of intramuscular EMG that compromises the representativeness of recordings.

Recently, Nordez and Hug [2] showed that the shear elastic modulus, measured using an innovative elastographic technique known as Supersonic Shear Imaging (SSI) [4], is highly correlated to muscle activity level recorded by EMG (R²=0.94±0.05 for linear isometric torque ramps from 0 to 40% of maximal voluntary contraction). Consequently, SSI could be used as an alternative noninvasive technique to indirectly assess muscle activity level, and would be particularly useful for deep muscles [2,3]. Another advantage of this technique is that it prevents some limitations of surface EMG recording, such as crosstalk or signal cancellation, and allows averaging over a wide region to be more representative of muscle activity than surface or intramuscular EMG [2].

Therefore, the aim of the present study was to determine the relationships between muscle activity level and torque among the elbow flexors, and identify potential changes in the sharing load with increases in external torque.

METHODS
Ten healthy subjects volunteered to participate in this study (3 women, 7 men; aged 24.9 ± 3.6 years; height 175.8 ± 9.9 cm; weight 70.4 ± 10.6 kg). A Biodex system 3 research (Biodex medical, Shirley, NY) isokinetic dynamometer was used to measure elbow angle and torque in the previously described position [2,4]. Briefly, subjects sat on the dynamometer with their right upper arm and forearm placed in a 90° flexion position, and wrist in supinated position.

An aixplorer ultrasonic scanner (Supersonic Imagine, Aix en Provence, France) was used in the SSI mode [4]. Measurements were made on the short head of the biceps brachii (BB), the long head of the biceps brachii (BB), the brachialis (BA), the brachioradialis (BR) and the long head of the triceps brachii (TB). Maps of the shear elastic modulus were obtained at 1 Hz with a spatial resolution of 1x1 mm.

Subjects performed ten smooth linear torque ramps of 30 s from 0 to 40% of the previously determined maximal voluntary contraction (MVC) using direct visual feedback of the torque signal. The shear elastic modulus of each of the five studied muscles was measured twice in random order.

The software of the ultrasound scanner permitted the measurement of an averaged shear elasticity value per map obtained in a circular region (from 0.5 to 1.5 cm in diameter, depending on muscle thickness) (Figure 1).

Figure 1: Typical example of shear elastic modulus measurement of the brachialis muscle. The region of interest (colored region) was chosen using the echographic image. The shear elastic modulus was averaged over the circular region shown.
The repeatability of the shape of the shear elastic modulus/torque relationship between the two trials was assessed by calculating the Pearson’s correlation coefficient (r). For each muscle, the changes in shear elastic modulus over time were assessed using an analysis of variance for repeated measures (“subjects” as the random factor; “torque” as the inter-subject factor).

RESULTS AND DISCUSSION

Due to a technical limitation of the ultrasonic scanner, the measurements saturated at 100 kPa, limiting the range of analysis for some muscles, for most of the subjects.

Excluding the data for TB, individual r-values ranged from 0.85 to 0.99 demonstrating a good repeatability of the shape of the shear elastic modulus changes, in accordance with our previous results for the BB muscle [2].

For each muscle, the mean shear elastic modulus/torque relationship is depicted in Figure 2. The ANOVA demonstrated a main effect of torque for the shear elastic modulus, indicating a significant increase with torque for each elbow flexor muscle. However, the results show that the muscle shear elastic modulus increased slowly, and then more rapidly for both heads of the BB. In contrast, the BA shear elastic modulus increased rapidly, but after 7% of the MVC, the modulus reached plateau. The BR shear elastic modulus increased significantly (P<0.05) and linearly. The TB shear elastic modulus was not significantly changed during the isometric ramps, suggesting no influence of the antagonist co-activation on the relationship between activity level and torque.

In agreement with several previous studies using EMG as an index of BB activity [1,2,3], the present work showed a non-linear muscle activity level/torque relationship for both BBsh and BBsl. However, there are few data-driven studies in the literature concerning BA and BR. The shear elastic modulus patterns reported herein highlight the putative load-dependent changes in load sharing between the elbow flexors (Figure 2). These results suggest that the torque is mainly produced by BR and BA at low torque levels, and the increase in torque after ~10% of MVC is mainly due to the BB. This provides evidence of changes in the load sharing between the synergist muscles as external torque increased.

Because of the non-linearity of the mechanical properties of biological tissues, the muscle stress is linked to its elastic modulus. Thus, one would expect that the shear elastic modulus measured by SSI reflects the muscle stress more accurately than the EMG activity [2]. In this case, the shear elastic modulus would be less sensitive to the activation pattern of the motor units than EMG, and more sensitive to the force production. In this way, Nordez and Hug [2] reported a non-linear EMG/torque relationship in the BB, but they also reported the same shape of shear elastic modulus/torque relationship. These results suggest that the non-linear relationship cannot be explained solely by the activation pattern of the motor units as classically reported in the literature [e.g., 1,5].

Because BB has a moment arm that is approximately two times higher than BA at 90° of elbow flexion [6], the changes in the load sharing might be explained by different functions of these muscles. A shorter moment arm (i.e., BA) would provide an advantage for the force graduation (i.e., exertion of a low force level with precision), while a longer

![Figure 2: Mean shear elastic modulus/torque relationship depicted for each muscle. BBsh: Biceps Brachii Short Head; BBsl: Biceps Brachii Long Head; BR: Brachioradialis, BA; Brachialis, TB: Triceps Brachii.](image)

CONCLUSIONS

By measuring the shear elastic modulus of each elbow flexor muscle during an isometric ramp contraction from 0 to 40% of MVC, the present study provides evidence of changes in the load sharing depending on the torque production. This has not been identified earlier due to the lack of information regarding some synergy involved in the task (i.e., deep muscles). This study provides a step towards confirming the viability of SSI as a tool to estimate muscle stress and then, using estimations of both moment arm and physiological cross-section area, to estimate muscle force. Some ex vivo experiments on isolated muscles and experiments with muscles that are the sole muscle that contributes to joint torque (e.g., first dorsal interosseous or abductor digiti minimi) will be performed to assess the accuracy of muscle force estimation using SSI.

REFERENCES