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SIMULTANEOUS ANTAGONISTIC-AGONISTIC STIMULATION CAUSES PARALLELISM BETWEEN MECHANICS OF SPASTIC GRACILIS MUSCLE AND THE PATIENTS' MOVEMENT LIMITATION

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SUMMARY

Recently we showed that if activated alone, spastic gracilis (GRA) muscle shows no abnormal mechanics. The goal was to test the following hypothesis: if activated simultaneously with an antagonistic muscle (vastus medialis), knee angle-GRA muscle force (KA-F_{GRA}) curves measured intraoperatively are representative of joint movement disorder. For four of the experimented limbs (n=10), testing of a whole KA range from flexion to full extension was not feasible. In one of these limbs and in three of the remainder six, KA-F_{GRA} curves include a local minimum at intermediate knee extension positions, which is followed by an increase of F_{GRA}. This is a remarkable indicator of a narrow joint range of force exertion: with knee extension, the muscle appears to be stretched to a length unfavorable for active force exertion and that F_{GRA} increase shown is ascribable to increasing passive force. For three of the limbs, the force exerted at knee flexion was quite a high percentage of the peak force (up to 84.8%). The proximity of KA for peak F_{GRA} to flexed knee positions suggests that active resistance capacity of the GRA muscle to stretch is substantial for most limbs. These results confirm our hypothesis and indicate the importance of inter-antagonistic muscular interaction in determining spastic muscle's mechanical characteristics.

INTRODUCTION

Implementing a novel intra-operative method developed [1] our recent study [2] reported spastic GRA muscle's isometric forces as a function of knee joint angle. The results showed no abnormal mechanics: the muscle has no narrow operational joint range of force exertion and no supreme active resistance capacity to stretch at low length. Among other explanations, a tenable one was that the GRA muscle was activated alone. Such condition limits epimuscular myofascial force transmission (EMFT) [3, 4], which has been shown to change the magnitude of muscle force and how it is related to muscle length [5]. We hypothesized that the knee joint angle-muscle force curves of spastic GRA muscle activated simultaneously with its antagonist VM show abnormal mechanics representative of joint movement disorder. The goal was to test this hypothesis.

METHODS

Surgical and experimental procedures in strict agreement with the guidelines of Helsinki declaration were approved by a Committee on Ethics of Human Experimentation at Istanbul University, Istanbul. Six patients (four male and two female, age 10.7 ± 3.6 years, mean ± SD) diagnosed with spastic diplegic cerebral palsy; however, with no prior remedial surgery participated. The Gross Motor Functional Classification System (GMFCS) was used to classify the mobility of the patients who attained scores of level II to IV, indicating the severity of their limited mobility. Popliteal angle (PA = 85.5° ± 8.0°) and hip abduction angle (HAA= 31.0° ± 6.6°) values were well beyond pathological limits (>50° for PA and <40° for HAA, see [2] for appropriate references). Clinical tests led to a decision that all patients required remedial surgery including release of hamstrings and hip adductors.

KA-F_{GRA} data (n=10) were collected intraoperatively (four patients were operated bilaterally) during muscle lengthening surgery. Subjects were under general anesthesia and no muscle relaxants or tourniquet was used. After routine incisions to reach the distal GRA tendon, a buckle force transducer (S shape, dimensions equaling w=12, l=20 and h=9mm, TEKNOFIL, Turkey) was mounted over the tendon. Prior to each experiment, the force transducer was (i) calibrated using bovine tendon strips and (ii) sterilized (using dry gas at maximally 50ºC).

Muscles were stimulated supramaximally (transcutaneous electrical stimulation with a bipolar rectangular signal, 160 mA, 50Hz generated by custom made constant current high voltage source cccVBioS, TEKNOFIL, Istanbul, Turkey) by placing a pair of gel-filled skin electrodes (EL501, BIOPAC Systems, CA, USA) on the skin, over GRA and VM muscle bellies. After each contraction, the muscles were allowed to recover for 2 minutes. All experimental preparations and data collection were completed within 30 min, the maximal study duration allowed by the ethics committee. F_{GRA} was measured isometrically at various muscle lengths imposed by manipulating the KA from 120° (knee joint at maximal experimentally attainable flexion, as limited by the surgery table) to 0° (full knee extension) by extending the knee with 30° increments. However, such full extension was not possible for some limbs. Using a least squares criterion, KA-F_{GRA} data were fitted with a polynomial function [2].

RESULTS AND DISCUSSION

Figure 1 shows KA-F_{GRA} curves obtained for the limbs tested. Peak force ($F_{GRApeak}$) equaled 47.9N ± 22.1N.

<u>(I) Joint range of muscle force exertion</u>

Limbs with full KA range feasible: For six of the limbs (limbs 1-4, 7, and 9) non-zero muscle forces were measured for all KA studied. This suggests that GRA muscle's operational joint range of muscle force exertion includes the entire joint range studied. However, although for limbs 1, 7 and 9 this seems to hold true, the remainder of the limbs deserves further attention. Limbs 2-4 show a very notable property that the KA-F_{GRA} curves include a local minimum (KA_{Fmin} at KA= 74°, 22°, and 55° for limbs 2, 3 and 4, respectively), which is followed by an increase of GRA total force. For limbs 3 and 4, the KA-F_{GRA} curves include an ascending and a subsequent descending portion, and KA_{Fmin} is attained after the descending portion. A tenable explanation for this is that with knee extension, the muscle is stretched to a length unfavorable for active force exertion and that the total muscle force increase shown is ascribable to increasing passive force. For limb 2, KA_{Fmin} appears to succeed only the descending portion of the KA-F_{GRA} curve.

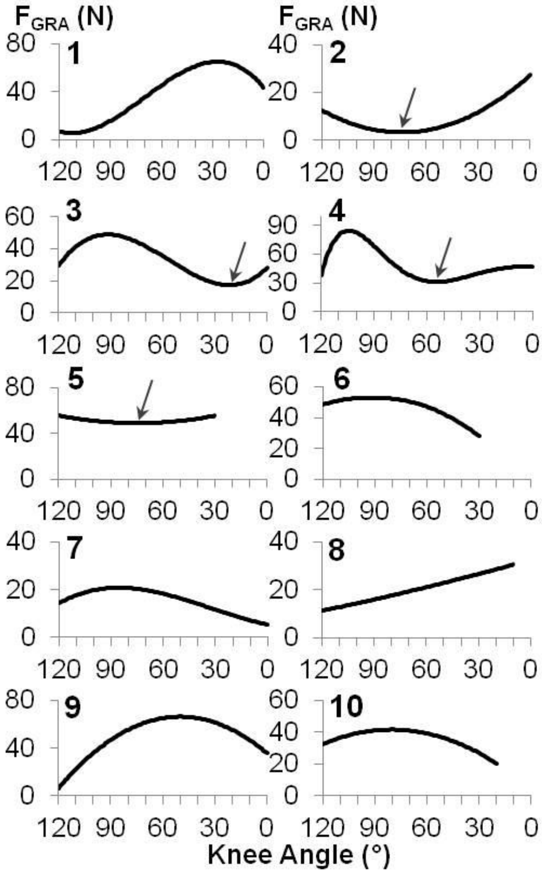

Figure 1: The isometric KA-F_{GRA} curves of human spastic GRA muscle activated simultaneously with its antagonistic VM. Arrows indicate existence of a local minimum point within the curve for some limbs as a remarkable finding.

Limbs with full KA range <u>not</u> feasible: For four of the limbs, muscle force measurements had to be ceased at certain knee extension position (for limbs 5-6 at KA= 30°, for 8, and 10 at 10° and 20°, respectively) as full knee extension could not be achieved. For limb 5, also KA_{Fmin} was attained (KA= 75°). KA-F_{GRA} curves of limbs 6 and 10 include both ascending and descending portions whereas, that of limb 8 appears to have only the former.

<u>(II) Availability of high muscle force at knee flexion</u>

For two of the limbs (2 and 5), were the highest muscle forces available at the maximal knee flexion angle studied. For limbs 6, 7 and 10, the percentage of $F_{GRA\ peak}$ exerted at KA=120° ($\%F_{GRA\ peak|120°}$) was quite high: 84.8%, 69.0%, and 78.3%, respectively. For limbs 3-4, $\%F_{GRA\ peak|120°}$ was lower (60.1% and 44.5%, respectively). However, the proximity of the KA at which $F_{GRA\ peak}$ was measured to 120° (92° and 104°, respectively for limbs 3 and 4) suggests that active resistance capacity of the GRA muscle to stretch is still substantial at flexed joint angles. In contrast, for the remainder of the limbs (1 and 8-9) availability of force at flexed knee positions is not appreciable.

Our results show that apart from limbs 1 and 9, spastic GRA muscle activated simultaneously with its antagonist VM muscle does show an abnormal mechanics: (I) regarding joint range of force exertion due to (i) existence of KA_{Fmin} within the KA-F_{GRA} curves and/or (ii) a lack of feasibility of attaining of full KA range, and (II) regarding availability of high force at flexed knee positions. Therefore, our hypothesis is confirmed for a majority of the limbs tested.

Because the time allowed for our intraoperative experiments was limited, it was not possible to test the condition of exclusive GRA stimulation prior to the present experiments for a direct comparison. This is a limitation of our study. We hope our results will convince the authorities to allow for a longer intraoperative experimentation in the future.

Our previous experimental and model studies [for a review see 5] showed that EMFT can manipulate considerably the force-length characteristics of muscles via (i) changes in lengths of sarcomeres arranged in series within muscle fibers, and (ii) transmission of a portion of the active force of a muscle to the joint through the tendon of another muscle. Moreover, it was shown that inter-antagonistic EMFT plays an important role affecting the forces of muscles within an entire limb [3]. We don't know how such effects are in spastic muscles. On the other hand, due to its long fibered structure, the GRA muscle may be relatively spared in cerebral palsy from adapting to the flexed joint position. This may be responsible in part for the previously shown "normal" mechanics [2] for this muscle. However, our present results do show that if inter-antagonistic EMFT is promoted for active muscles of a CP patient, the KA-F_{GRA} curves obtained represent much more the pathology clearly present at the joint even for a muscle like the GRA which may be argued to be less prone to be affected from spasticity. This supports an earlier proposal for the role of EMFT in spastic paresis [4].

CONCLUSIONS

The present data indicate that inter-antagonistic mechanical interaction between activated muscles may play an important role in producing movement disorders spastic paresis patients suffer.

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