INTRAOPERATIVE MEASUREMENT OF HUMAN SPASTIC GRACILIS MUSCLE ISOMETRIC FORCES AS A FUNCTION OF KNEE ANGLE

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SUMMARY
The goal was to measure previously unstudied isometric forces of activated human spastic Gracilis (G) muscle as a function of knee joint angle during muscle lengthening surgery. Peak spastic G muscle forces (81.73 ± 41.25 N) show a sizable variability with no significant correlations to typical patient anthropometrics. Remarkably, 80% of the entire set of data points collected represents muscle forces exerted at muscle lengths corresponding to optimum knee angle or lower. Therefore, spastic G muscle operates within a fairly wide length range of active force exertion such that higher muscle forces are exerted only at higher muscle lengths corresponding to a more extended knee. Explanations for this “normal” muscular mechanics shown in present experimental conditions are discussed based on epimuscular myofascial force transmission.

INTRODUCTION
Improved understanding of human muscle functioning in health and disease necessitates collection of data that relates isometric muscle force to joint angle, directly. However, access to human muscle for experimental purposes is limited and therefore studies reporting direct measurements of human muscle forces [e.g., 1-2] are rare. The goal of the present study was to measure previously unstudied isometric forces of activated human spastic G muscle as a function of knee joint angle, intraoperatively.

METHODS
Surgical and experimental procedures [for full details see 3], in strict agreement with the guidelines of Helsinki declaration were approved by a Committee on Ethics of Human Experimentation at Istanbul University, Istanbul. Seven subjects (four male and three female: mean age 8 ± 4.6) diagnosed with spastic diplegic cerebral palsy however, with no prior history of remedial surgery participated. Knee angle-G muscle force data (n=10) were collected intraoperatively from these patients (three of which were operated bilaterally) during muscle lengthening surgery. Subjects were under general anesthesia and no muscle relaxants or tourniquet was used. Intraoperative experiments were performed after routine incisions to reach the distal G tendon before any other surgical procedures of muscle lengthening surgery. A buckle force transducer (S shape, width, length and height equaling respectively 12, 20 and 9 mm, TEKNOFIL, Turkey) was mounted over the tendon. Note that prior to each experiment, the force transducer was (i) calibrated using bovine tendon strips and (ii) sterilized (using dry gas at maximally 50⁰ C).

Isometric spastic G muscle force was measured at various muscle lengths imposed by manipulating the knee joint angle 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. Using a custom designed apparatus, the knee angle as well as the hip angle (to 0° both in the sagittal and frontal planes) was fixed. A pair of gel-filled skin electrodes (EL501, BIOPAC Systems, CA, USA) were placed on the skin, over G muscle belly. Using a custom made constant current high voltage source (cccVBioS, TEKNOFIL, Istanbul, Turkey) the muscle was stimulated supramaximally (transcutaneous electrical stimulation with a bipolar rectangular signal, 160 mA, 50Hz). After each contraction, the muscle was allowed to recover for 2 minutes at flexed knee posture.

Figure 1: Isometric muscle knee angle-force characteristics.
RESULTS AND DISCUSSION

Peak spastic G muscle forces show a sizable variability: mean peak force = 81.73 ± 41.25 N. No significant correlations were found between peak spastic G muscle force and thigh length (27.5 ± 5.4 cm) or mid-thigh perimeter (32.3 ± 8.8 cm): Spearman’s rank correlation coefficient equals -0.09 and -0.06, respectively. These results indicate that due to existence of inter-subject variability, patient specific planning of remedial surgery may be necessary and that typical anthropometric parameters cannot be used safely as predictors of the contribution of spastic human muscles to joint moments.

Our results showed interesting findings indicating that spastic G muscle is not operating within a narrow length range (Figure 1) as one would expect looking at the limited joint range of motion: (1) For none of the knee angles studied, spastic G muscle was at active slack length (i.e., the shortest muscle length at which the muscle can still exert non-zero force) indicating that this length corresponds to a knee flexion over 120°. Remarkably, (2) 80% of the entire set of data points collected represents muscle forces exerted at muscle lengths corresponding to optimum knee angle or lower: (i) for four of the limbs experimented (IV, VII, VIII, and X), spastic G muscle was active entirely in the ascending limb of its knee joint angle-muscle force characteristics. (ii) For the remainder six, operational range of this curve consisted of parts of both ascending and descending limbs nevertheless, with the exception of V, majority of data points were still in the ascending limb.

The activity of spastic G muscle predominantly in the ascending limb indicates that the greatest resistance of this muscle to knee extension is available only at higher muscle lengths (optimal knee angle equals 30.0° ± 31.6°), attainable closer to full knee extension. This contradicts with an expectation that spastic muscle is a source of high forces causing movement limitation at the joint: muscle under spastic control is typically one at low length and our results show that knee angles corresponding to lower lengths of spastic G muscle are not the lengths favorable for high force exertion. Nevertheless, it is clear that the knee joint is forcefully kept in a characteristic flexed position. Recently, Huijing [4] addressed this point by posing the question “what could be the origin of high forces within the spastic paretic limb?”. According to him, the mechanism should involve epimuscular myofascial force transmission [for a review of key concepts see 5] such that a plausible source could be the synergistic muscles. However, the possibility of a strong contribution of this seemed not feasible as, although these muscles may be not as short as the spastic one, they are also at low lengths due to the imposed joint angle and therefore, they should not be capable of exerting very high forces. Based on these arguments and also on recent evidence showing the occurrence of epimuscular myofascial force transmission among the antagonistic muscles [e.g., 6] Huijing developed an hypothesis that high forces within the spastic paretic limb may originate from the antagonistic muscles which are at higher length (favorable for higher force exertion): forces generated within sarcomeres of antagonistic muscles can be exerted at the distal tendons of a target muscle due to epimuscular myofascial force transmission. A conceivable requirement for this to happen is higher stiffness of myofascial structures in patients with spastic paresis.

Our present results show that in the experimental conditions studied, knee angle-muscle force characteristics measured from human spastic G muscle are not truly representative of the pathological condition occurring at the joint and are comparable qualitatively to those measured intra-operatively from healthy subjects in our previous study [3]. Among others, an important difference of the present experimental conditions to those in vivo (which does feature a movement limitation at the joint), is that experimentally the target G muscle was activated solely. Therefore, our present data suggests that if activated alone, spastic muscle may function normally. This is in agreement with Huijing’s hypothesis and generates a new, specific hypothesis that if epimuscular myofascial force transmission plays such a role, simultaneous simulation of antagonistic knee extensor muscle may cause enhanced G muscle force at lower muscle lengths and even a narrower joint range of active force exertion (i.e., a shift of optimum knee angle towards knee flexion). This needs to be tested in new studies.

CONCLUSIONS

Our intraoperative experimental techniques allowed us to quantify for the first time forces of spastic human G muscle as a function of knee joint angle. A major finding is that isometric knee angle-force characteristics of spastic G muscle stimulated alone appears “normal”: G muscle operates within a fairly wide length range of active force exertion and more importantly higher muscle forces are exerted only at higher muscle lengths corresponding to a more extended knee. We suggest that Huijing’s recent hypothesis may explain such normal mechanics of spastic G muscle shown as present lack of activation of antagonistic muscles may have inhibited transmission via epimuscular myofascial pathways of their active force onto this muscle.

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