MUSCULOSKELETAL MODEL OF ARM POSITION FOR CASTING OR SPLINTING AND MUSCLE SELECTION FOR BOTULINUM TOXIN IN INDIVIDUALS WITH CEREBRAL PALSY

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INTRODUCTION
Children with spastic cerebral palsy experience difficulties in activities of daily living because of hypertonia and limited range of motion (ROM). Casting, splinting and botulinum toxin (BT) injection of spastic muscles can reduce spasticity in spite of muscle weakness from BT [1,2]. Given that spasticity is a movement disorder, producing optimal force at the endpoint of the limb is crucial. Our objectives were 1) to find the optimal arm posture for maximal capacity to generate force at the end-point during immobilization and 2) to develop a BT model, using feasible force sets (FFS) which comprises all possible forces that muscles can generate at the end-point.

METHODS
To build a model of 3-linkage system with 6 degrees of freedom, we selected 12 upper arm postures of shoulder, elbow (30, 60, 90, 120°), and wrist (45, 0, -15°) for reaching (figure 1) and a total 9 muscles: biceps, triceps, brachial (Br), brachioradialis (BBr), flexor carpi ulnaris (FCU), flexor carpi radialis (FCR), extensor carpi ulnaris (ECU), extensor carpi radialis longus (ECRL), and extensor carpi radialis brevis (ECRB). The model maps from 9 muscles coordination to the 2-dimensional limb endpoint force, and we applied linear programming in MATLAB to determine the maximal force for each postures, using a cost function equation, F_{max} = J R F_0 a, J: jacobian matrix from geometric model of the limb end-point R: moment arm matrix of 9 muscles for 12 postures F: the maximal muscle force from muscle fiber a: muscle activation from the neural input [3,4].

Figure 1. The 12 postures of upper extremity for reaching.

Monte Carlo analysis was performed to measure robustness of the model at the optimal posture, manipulating two parameters, PCSA and the optimal muscle length with +/- 50% and +/- 20% of upper and lower bounds of the original values respectively.

FFS at the optimal posture was found multiplying F_{max} by all possible muscle coordination patterns and presented in 2-dimension. 4 muscles (biceps, BBr, FCU, FCR) were chosen for BT simulations based on its clinical applications. Muscle activation was modified to 30% of the maximal neural input for BT simulations.

RESULTS
The maximal optimized muscle force was generated at the posture 11, which was 60° shoulder flexion, 60° elbow flexion, and 15° wrist extension (figure 2). The greater forces were produced at 60° of elbow flexion (P3, 7, 11). Monte Carlo analysis showed the model was robust.

FFS decreased by BT simulation, and the amount of decrease was different between two elbow flexors and between two wrist flexors. We found a significant decrease in FFS when simulating application of BT in multiple muscles (figure 3).

DISCUSSIONS & CONCLUSIONS
The greater forces were generated at 60° of elbow flexion and neutral to 15° of wrist extension. This suggests that the maximal reaching force is generated in the middle range of the elbow joint. Individuals with CP exhibit muscle weakness, and additional BT injections cause further muscle weakness. Therefore, instead of administering BT in multiple muscles at one visit, BT could be administered as a series of treatments, combining with strengthening exercise and physical therapy, to maximize ROM and minimize loss of muscle strength.

REFERENCES