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Full Length Article

# Effects of antagonistic and synergistic muscles' co-activation on mechanics of activated spastic semitendinosus in children with cerebral palsy

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ABSTRACT

*Objectives:* Most activities involve co-activation of several muscles and epimuscular myofascial force transmission (EMFT) can affect their mechanics. This can be relevant for spastic muscles of cerebral palsy (CP) patients. Isometric spastic semitendinosus (ST) forces vs. knee angle (KA-$F_{ST}$) data were collected intra-operatively to test the following hypotheses: (i) Inter-antagonistic EMFT elevates $F_{ST}$, (ii) changes the shape of KA-$F_{ST}$ characteristics, (iii) reduces the muscle's joint range of force exertion (Range-$F_{ST}$) and (iv) combined inter-antagonistic and synergistic EMFT further changes those effects.
*Methods:* 11 limbs of 6 patients with CP (mean (SD) = 7.7 (4.7) years; GMFCS levels = II–IV) were tested in 3 conditions from 120° to full extension: ST activated (I) exclusively, (II) simultaneously with an antagonist, and (III) with added activation of synergists.
*Results:* Condition II increased $F_{ST}$ (e.g., peak force = 87.6 N (30.5 N)) significantly (by 33.6%), but condition III caused no further change. No condition changed the muscle's wide Range-$F_{ST}$ (100.7° (15.9°)) significantly. Therefore, only the first hypothesis was confirmed.
*Conclusions:* Co-activating its antagonist elevates forces of activated spastic ST substantially, but does not change its joint range of force exertion. Added activation of its synergists causes no further effects. Therefore, EMFT effects in CP can be relevant and need to be tested in other knee flexors.

## 1. Introduction

Spasticity is one of the common features of cerebral palsy (CP) characterized by repetitive muscle contractions related with exaggerated stretch reflexes (Botte, Nickel, & Akeson, 1988; Sheean, 2002). In intermediate to long term, muscles kept at short length develop contractures due to spastic hypertonia (Farmer & James, 2001). Although soft tissue adaptation mechanisms in CP are not well known, the major outcome of spastic contractures causing loss of mobility is increased joint stiffness (Botte et al., 1988) and limited joint range of motion (Dietz, Quintern, & Berger, 1981; Gracies, 2005). This indicates a narrow joint range of force exertion for the muscles affected (Gracies et al., 2010). However, recent studies aiming at revealing the mechanical characteristics of activated gracilis (GRA) (Ates, Temelli, & Yucesoy, 2013) and semitendinosus (ST) (Ates, Temelli, & Yucesoy, 2016) muscles of spastic CP showed non-zero force production from high knee flexion to full extension with the peak force encountered only in extended joint positions. This unexpected lack of narrow joint range of force exertion of the spastic muscle was ascribed to the lack of co-activation

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of synergistic and/or antagonistic muscles during those experiments (Ates et al., 2013). However, co-activity of muscles is a typical feature of daily activities as shown by using EMG for e.g., children at different age groups and for various walking speeds (Frost, Dowling, Dyson, & Bar-Or, 1997). Stabilizing the joint affected from spasticity by co-activating the antagonistic muscles is considered essential for CP patients due to their motor coordination problems (Damiano, Martellotta, Sullivan, Granata, & Abel, 2000; Unnithan, Dowling, Frost, & Bar-Or, 1996). Accordingly, such co-activation is more pronounced in children with CP compared to healthy children (Ikeda, Abel, Granata, & Damiano, 1998).

Direct collagenous connections exist between the epimysia of adjacent muscles, and also indirect connections are present between distant muscles via neurovascular tracts continuous with compartmental boundaries (Yucesoy & Huijing, 2007). This network causes mechanical interactions and hence epimuscular myofascial force transmission (EMFT) between synergistic and antagonistic muscles (Huijing, 2009; Yucesoy, 2010). EMFT is evident in human muscles *in vivo* (Carvalhais et al., 2013; Pamuk & Yucesoy, 2015; Yaman, Ozturk, Huijing, & Yucesoy, 2013) and alters local strain distributions along muscle fibers (Karakuzu, Pamuk, Ozturk, Acar, & Yucesoy, 2017; Pamuk, Karakuzu, Ozturk, Acar, & Yucesoy, 2016). Animal experiments and modeling have shown that EMFT changes the muscle's force production and length range of force exertion, as well as the shape of force–length characteristics (Ates, Ozdeslik, Huijing, & Yucesoy, 2013; Yucesoy, Baan, Koopman, Grootenboer, & Huijing, 2005; Yucesoy & Huijing, 2007). Therefore, EMFT caused by co-activation of synergistic and/or antagonistic muscles could affect mechanics of spastic muscles. However, this has not been tested. In the present study, we aimed at measuring forces of spastic ST ($F_{ST}$) as a function of knee angle (KA) after co-activating its antagonist vastus lateralis (VL) and after added activation of its synergists GRA and semimembranosus (SM) muscles. Consequently, our goal was to test the following hypotheses: (i) Inter-antagonistic EMFT elevates $F_{ST}$, (ii) changes the shape of KA-$F_{ST}$ characteristics, (iii) reduces the muscle's joint range of force exertion and (iv) combined inter-antagonistic and synergistic EMFT further changes those effects.

## 2. Methods

### 2.1. Patients

Six male patients (at the time of muscle lengthening surgery mean age (SD) = 7 years 7 months (4.7 years)) diagnosed with spastic diplegic CP, however with no prior remedial surgery participated. Their GMFCS scores were at least level II (Table 1) indicating severity of their limited mobility. The popliteal angle (PA) of the limbs tested (mean (SD) = 76.4° (13.1°)) indicated abnormal knee flexor tightness compared to the conventions for abnormality (PA > 50°) (Katz, Rosenthal, & Yosipovitch, 1992). Additional to knee flexion deformity, five participants (limbs 2–11) showed positive Duncan Ely's Tests indicating rectus femoris (RF) tightness. Pre-operative clinical examinations led to a decision that all patients required remedial surgery including release of hamstrings, but no intervention on knee extensor muscles.

### 2.2. Experimental design

Surgical and experimental procedures, in strict agreement with the guidelines of the Helsinki declaration, were approved by a Committee on Ethics of Human Experimentation at Istanbul University, Istanbul. The patients and/or their parents gave informed consent to the work.

The patients received general anesthesia and no muscle relaxants were used. Data collection succeeded routine incisions to reach the distal ST tendon and before any other surgical procedures of muscle lengthening surgery. Using a scalpel blade (number 18), a longitudinal skin incision was made immediately above the popliteal fossa. After cutting the adipose tissue, the distal ST tendon was exposed. Subsequently, an S-shape buckle force transducer (dimensions 12 × 20 × 9 mm; maximal force range = 400 N; for test range 0–200 N: accuracy < 3% (< 0.19% below 100 N); resolution = 0.62 N and high linearity: $R^2 = 0.99963$ (peak non-linearity = 1.31%), TEKNOFIL, Istanbul, Turkey) (Fig. 1) was mounted and secured over the tendon. Prior to measurements, the force

**Table 1**
Patient parameters.

| # | Participant | Age (years) | $L_{thigh}$ (cm) | $C_{mid\text{-}thigh}$ (cm) | GMFCS | PA (°) |
|---|---|---|---|---|---|---|
| 1 | 1-L | 17 | 39.0 | 39.0 | II | 90 |
| 2 | 2-L | 5 | 23.0 | 26.5 | IV | 70 |
| 3 | 2-R | 5 | 23.0 | 26.0 | IV | 65 |
| 4 | 3-L | 5 | 23.0 | 29.0 | IV | 70 |
| 5 | 3-R | 5 | 23.0 | 28.5 | IV | 50 |
| 6 | 4-L | 6 | 27.0 | 30.5 | II | 75 |
| 7 | 4-R | 6 | 27.0 | 29.0 | II | 70 |
| 8 | 5-L | 8 | 27.0 | 28.0 | IV | 90 |
| 9 | 5-R | 8 | 26.0 | 27.0 | IV | 90 |
| 10 | 6-L | 5 | 22.5 | 24.0 | IV | 90 |
| 11 | 6-R | 5 | 22.0 | 23.0 | IV | 80 |

#: Limb number, L: Left limb, R: Right limb, $L_{thigh}$ (cm): Thigh length, $C_{mid\text{-}thigh}$ (cm): Mid-thigh circumference, PA (°): Popliteal angle, GMFCS: Gross Motor Function Classification System scores.