CAN NEUROMUSCULAR REFLEXES STABILIZE THE KNEE DURING VALGUS LOADING?

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INTRODUCTION

We have previously shown that reflex activity mediated by periarticular tissue afferents can be elicited consistently in knee muscles by applying valgus angular perturbations to the human knee joint (Dhaher et al., 2003). Although a stabilizing role for these reflexes is widely proposed, there are as of yet no quantitative studies describing the contribution of such a system to joint stiffness in humans.

In the present study we estimated the mechanical contribution of muscle contractions mediated by periarticular tissue afferents to joint stiffness. We hypothesize that these reflex muscle contractions will significantly increase knee joint stiffness in the varus/valgus direction and enhance the over-all stability of the joint.

METHODS

Ten normal subjects (mean age 26 +/- 2 yrs; height 179 +/- 5 cm; weight 82 +/- 4.5 kgs), were tested. After securing the subject's limb in a single-degree of freedom servomotor system, the knee joint was pre-loaded (4° of valgus) to insure initial stretch of passive joint tissues (see Dhaher et al., 2003 for details). The subject was asked to maintain different knee muscle co-contraction levels as a percent of the valgus passive torque (VPT) measured at the joint's pre-loaded position with acquiescent knee muscles (η_o). The five different contraction levels were $\eta_1 \equiv$ 5-10, $\eta_2 \equiv$ 10-20, $\eta_3 \equiv$ 20-30, $\eta_4 \equiv$ 30-40, and $\eta_5 \equiv$ 40-50% of VPT measured with a six-degree of freedom load-cell (Figure 1).

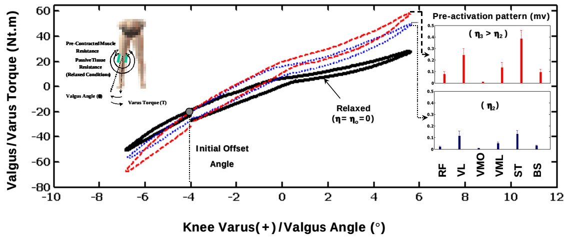

Figure 1: Torque-Angle relation in the varus /valgus direction on a representative subject.

Valgus positional perturbations were applied at the knee at 60°/s ramp speed with an amplitude of 7° (Figure 2).

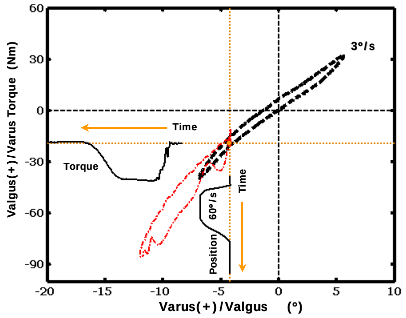

Figure 2: Torque-Angle relation with the mechanical perturbation superimposed. Note that the superimposed time-torque and time-position signals were scaled down by a factor of three. The cross plot, however, reflects the accurate amplitudes.

Surface EMG electrodes were used to record the muscle activity of knee flexor and extensors (see Figure 1). For each subject, only trials/conditions that exhibited consistent reflex response in all six muscles were used in the stiffness estimation procedure. This is to insure that stiffness estimates are due to reflexes and are not corrupted by non-reflex components.

A second order system describing the knee and lower limb musculoskeletal model was used and takes the following form:

$$I \cdot \ddot{\theta} + (B(\eta) + B_r(t \geq t_d; \eta)) \cdot \dot{\theta} + (K(\eta) + K_r(t \geq t_d; \eta)) \cdot \theta = \mathrm{T} \quad (1)$$

where η defines the varus/valgus torque level at the joint as a percent of VPT; t_d is the average periarticular reflex delay, estimated as the minimum reflex delay observed across all muscles for each subject (t_d ~ 70 ms, Dhaher et al., 2003) ; T is the joint's measured varus/valgus torque (output), and θ is the knee varus/valgus angle (input). In this model, the intrinsic and reflex based joint's musculoskeletal varus/valgus dynamic properties are separated and are assumed to be a function of the background varus/valgus torque. The inertia, I, stiffness, $K(\eta)$, and damping, $B(\eta)$ represent the intrinsic mechanics, including the pre-perturbation muscle contractions, contribution to the knee joint dynamics. $K_r(\eta)$ and $B_r(\eta)$ are the stiffness and damping reflex contributions, respectively. A nonlinear least squares optimization technique (Gill et al., 1981) was used to estimate a total of 5 parameters. The model was cross-validated with simulations based on fresh data not used in the estimation procedure. The linear association between K_r and $\hat{\eta} = 100 \cdot ([\eta_i - \eta_o]/\eta_o)$ was estimated using repeated measures linear regression to account for the multiple measurements taken from each subject (SAS version 8.02, Cary, NC). The method used to fit the data was restricted maximum likelihood (REML) with an unstructured covariance structure.

RESULTS AND DISCUSSION

Estimates of varus/valgus knee stiffnesses in ten subjects are shown for up to six joint valgus/varus torque levels in Figure (3-top). Reflex stiffness (K_r) was significantly greater than zero (mean=82.2 N.m/rad; 95% confidence interval: 67.7, 96.8) at relaxed condition ($\eta = \eta_o$), and increased on an average of 5.3 N.m/rad for every 10% increase in background varus torque (p = 0.015). When compared to the intrinsic joint stiffness, reflex mediated stiffness accounted for as much as 20% (mean across all subjects) of the over all joint varsus/valgus stiffness (Figure 3-bottom).

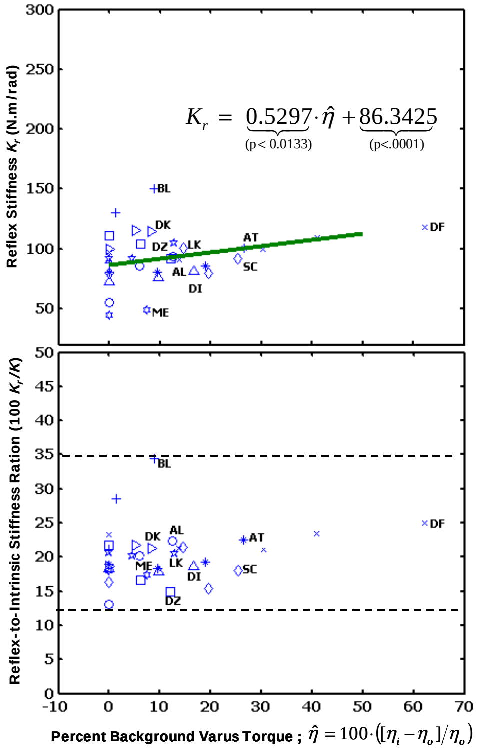

Figure 3: Reflex stiffness estimates (top) and Reflex-to-intrinsic stiffness ratio (bottom) as a function of the percent background varus torque in ten subjects.

SUMMARY

Based on our preliminary data, reflex activation of knee muscles is sufficient for active neuromuscular stabilization in the varus/valgus direction, where knee medial-lateral loading arises frequently in the course of normal locomotion (Andriacchi and Strickland, 1985).

REFERENCES

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