ANALYSIS AND MODELING OF GAIT DISABILITY DUE TO STROKE

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INTRODUCTION

Modeling can be used to improve the effectiveness of clinical gait analysis (Cooper, Quatrano et al. 1999). We use a spectrum of models, ranging from fundamental conceptual models, e.g., the determinants of gait, to complex computer-based forward-dynamic musculoskeletal models. This presentation illustrates how we have used various models our quest to better understand and treat gait disability due to stroke.

METHODS

The "determinants of gait," originally described by Saunders et al. (Saunders, Inman et al. 1953) as a **conceptual model,** has value because it addresses two fundamental issues: 1) how local impairments affect global disability, and 2) how movement patterns affect and are affected by patient strength and endurance. A rigid link-segment **kinematic model** facilitated refining and quantifying the determinants of gait.

Impairments are frequently described in imprecise language, and are thus, immeasurable. The use of kinematic and **inverse dynamic models** in modern motion analysis laboratories permit, indeed force, the development of precise, quantitative definitions of gait impairments.

Using these precise measurements of impairment as a starting point, **dynamic models** can then be used to determine how impairment contributes to disability. These models allow us, in the cyber world, to isolate the effects of individual impairments that, in the real-world, only occur in the presence of other impairments or compensations. They also allow us to estimate physical and physiological parameters that are currently immeasurable. These computer models will be the basis for **model-based design** of the next generation of prosthetics and orthotics, and of rehabilitation technology.

RESULTS

Determinants of Gait: We first conducted a series of studies to quantify center of mass (CoM) excursion (Kerrigan, Viramontes et al. 1995; Kerrigan, Thirunarayan et al. 1996; Thirunarayan, Kerrigan et al. 1996),\ and assess its significance. (Duff-Raffaele, Kerrigan et al. 1996; Kerrigan, Thirunarayan et al. 1996) We then used rigid link-segment kinematic models to refine and quantify the determinants of gait. (Kerrigan, Della Croce et al. 2000; Della Croce, Riley et al. 2001; Kerrigan, Riley et al. 2001) The kinematic model was used to perform induced displacement analyses that quantified the relative contributions of pelvic kinematics, knee flexion, and heel rise (ankle kinematics) to CoM vertical displacement.

Precise Characterization of Stroke Related Gait Pathology: The effect of stroke on the determinant of gait parameters was also precisely measured and data characterizing their interactions were obtained. We quantified hip hiking and circumduction in this population. (Kerrigan, Frates et al. 2000) Stiff-legged gait, the most characteristic knee impairment in stroke was analyzed in detail. (Kerrigan, Gronley et al. 1991; Kerrigan, Frates et al. 1999; Kerrigan, Karvosky et al. 2001) Similarly, we investigated toe-walking in detail, (Kerrigan, Riley et al. 2000) elucidating a possible link between toe-walking and stiff-legged gait. (Kerrigan, Burke et al. 2001)

Dynamic Models: These clinical studies highlighted the importance of kinetic parameters in characterizing the various impairments, motivating analyses based on dynamic biomechanical and musculoskeletal models. Starting with a relatively simple 2-D model of stiff-legged gait (Kerrigan, Roth et al. 1998) we progressed to 3-D forward dynamic musculoskeletal (Riley and Kerrigan 1998) and biomechanical (Riley and Kerrigan 1999) models. The latter analysis used a technique called induced acceleration analysis, which promised to be an extremely useful tool for investigating the linkage between specific impairments and disabilities. We used this technique to investigate the dynamics of CoM displacement, the kinetic determinants of gait. (Riley, Della Croce et al. 2001; Riley, Della Croce et al. 2001; Riley, DellaCroce et al. 2001; Riley and Kerrigan 2001)

Model-based Design: We are now engaged in the development of a dynamically controlled body-weight support system to be used in the rehabilitation of stroke survivors and others. The underlying assumption of this effort is the determinants of gait in reverse, that inducing appropriate CoM excursion will facilitate treating specific impairments. The model-based controller for this system builds on our analytical models, (Lee, Allaire et al. 2004; Lee, Allaire et al. 2004) and biomechanical models are being used to guide protocol development.

SUMMARY

Our modeling approach applied to gait disability due to stroke has been multi-modal, subject specific, data driven, and data verifiable. Our approach has been hypothesis driven and most importantly, it has been clinically focused.

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