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A baseline of dynamic muscle function during gait

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Abstract

An existing induced acceleration (IA) model was used to create a comprehensive baseline of dynamic muscle function. In this study, 20 control subjects were modelled as three-dimensional linkage systems. Muscle architecture was taken from an existing muscle model. Each subject-specific model was configured with gait data and 36 unit muscle forces were then applied one at a time to each linkage model. After muscle force application, all joint, segment, and centre of mass (COM) accelerations were derived. The results showed that most uni-articular muscles function as expected while some bi-articular muscles function in a paradoxical manner. This indicates that both the local and remote effects of muscles should be considered when assessing dynamic muscle function during gait. The results also agree with previous IA studies, lending support to the validity of IA analysis as a means for understanding dynamic muscle function.

Keywords: Induced acceleration; Dynamic muscle function; Bi-articular muscle function

1. Introduction

If the goal of clinical gait analysis is to optimize the outcomes of clinical interventions, then a causal link must be established between observed dynamics and the underlying pathology that creates movement anomalies. A clinician must have a clear notion of how treatments that alter muscle function might affect a particular subject's gait. Determining which gait variables to measure, as well as how to interpret these variables, is difficult. Muscles are force-generating entities and because of this, kinetic data has been generally considered the appropriate variable to measure to gain insight into dynamic muscle function. To date, however, there is no consensus, or even widely accepted guidelines, on how to use kinetic data in gait assessment.

Joint moments are defined as the sum of local muscle moments but in this paradigm only muscles spanning a joint are considered contributors to the total joint moment. The problem with this concept is that it does not consider the complexity of the musculoskeletal dynamics, particularly bi-articular muscles, which allows for a moment applied at one joint to act remotely, causing accelerations in other joints in the system. Thus, joint moments have remote effects in addition to local effects. A well-known example is the plantar flexion/knee extension couple in which a muscle directly contributing to the ankle joint moment (local effect), indirectly contributes to the knee joint moment (remote effect).

Some studies have shown bi-articular muscles acting in a paradoxical or counterintuitive manner which opposed their anatomical classification [1]. An example is the rectus femoris, which may cause hip extension instead of hip flexion [Fig. 1]. These paradoxical results are a consequence of only considering the local effects of a joint moment. Bi-articular muscles have traditionally been considered two separate muscles acting in isolation at two separate joints. But if joint moments have remote effects, then the interaction of a bi-articular muscle's two joint moments must be considered.

Induced accelerations (IA) analysis is an interpretive framework for kinetics that may serve as an enhancement to conventional approach. IA provides an analytical method for quantifying the dynamic effect of a muscle contraction on every joint and segment in the body. In IA studies, subjects are modelled as three-dimensional linkages. Applying forces or moments to the linkages causes reactive forces, linear segment accelerations, angular segment accelerations,

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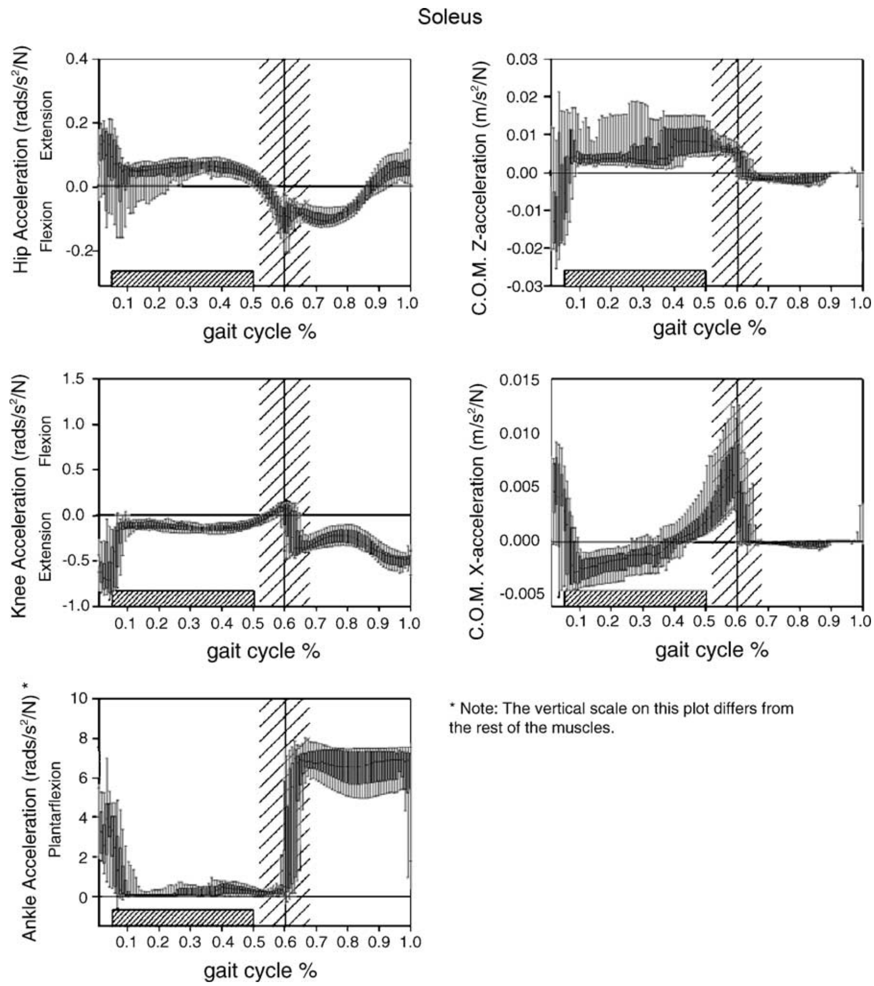

Fig. 11. Soleus abridged IA profile.

practical. Fourthly, there are also limitations in using unit muscle forces. The advantages of using unit muscle forces includes simplicity, ease of implementation and computational efficiency. It also eliminates the ambiguity associated with predicted muscle forces, and emphasizes the importance of the overall configuration of the musculoskeletal system in determining a muscle's dynamic function. One drawback is that inter-muscle comparisons have limited meaning and because all of the muscles apply 1N, it is difficult to determine which muscle plays a larger role during specific phases of the gait cycle.

5. Conclusions

This study has lent support for the validity of IA analysis to understand dynamic muscle function. It also provides a framework for viewing the dynamic function of bi-articular muscles. For a long time, bi-articular muscles were more-or-less thought of as two different muscles acting at two different joints. Viewing the muscles in this manner is not incorrect, but rather, incomplete, failing to consider both the local and remote actions of the muscles. This study shows that an IA model can be used to create a comprehensive baseline of dynamic muscle function during gait, an important first step in the application of IA in the clinical gait laboratory.

References

[1] Neptune RR, Zajac FE, Kautz SA. Muscle force redistributes segmental power for body progression during walking. Gait Posture 2004;19:194–205.

[2] Kepple TM, Siegel KL, Stanhope SJ. Relative contributions of the lower extremity joint moments to forward progression and support during gait. Gait Posture 1997;6:1–8.

[3] Schwartz M, Lakin G. The effect of tibial torsion on the dynamic function of the soleus during gait. Gait Posture 2002;17:113–8.

[4] Anderson FC, Pandy MG. Individual muscle contributions to support in normal walking. Gait Posture 2003;17:159–69.

[5] Neptune RR, Kautz SA, Zajac FE. Contributions of the individual ankle plantar flexors to support, forward progression and swing initiation during walking. J Biomech 2001;34:1387–98.

[6] Zajac FE, Gordon M. Determining muscle's force and action in multi-articular movement. Exercise Sport Sci Rev 1989;17:187–230.

[7] Delp SL, Loan JP, Hoy MG, Zajac FE, Topp EL, Rosen JM. An interactive graphics-based model of the lower extremity to study orthopaedic surgical procedures. IEEE Trans Biomed Eng 1990;37:757–67.

[8] Dempster WT, Gaughran GRL. Properties of body segments based on size and weight. Am J Anat 1967;120:33–54.

[9] Hinrichs RN. Adjustments to the segment centre of mass proportions of Clauser. J Biomech 1990;23(9):949–51.

[10] Brand RA, Crowninshield RD, Wittstock CE, Pedersen DR, Clark CR. A model of lower extremity muscular anatomy. Trans ASME 1982;104:304–10.

[11] Kepple TM, Siegel KL, Stanhope SJ. Relative contributions of the lower extremity joint moments to forward progression and support during gait. Gait Posture 1997;6:1–8.

[12] Perry J. Gait analysis: normal and pathological function. New Jersey: SLACK Incorporated, 1992. p. 160.