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An improved multi-joint EMG-assisted optimization approach to estimate joint and muscle forces in a musculoskeletal model of the lumbar spine

Denis Gagnon [a,*], Navid Arjmand [b,d], André Plamondon [b], Aboulfazl Shirazi-Adl [c], Christian Larivière [b]

[a] Faculté d'éducation physique et sportive, Université de Sherbrooke, Sherbrooke, Québec, Canada
[b] Institut de recherche Robert Sauvé en santé et en sécurité du travail, Montréal, Québec, Canada
[c] Division of Applied Mechanics, Department of Mechanical Engineering, école Polytechnique, Montréal, Québec, Canada
[d] Department of Mechanical Engineering, Sharif University of Technology, Tehran, Iran

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ABSTRACT

Muscle force partitioning methods and musculoskeletal system simplifications are key modeling issues that can alter outcomes, and thus change conclusions and recommendations addressed to health and safety professionals. A critical modeling concern is the use of single-joint equilibrium to estimate muscle forces and joint loads in a multi-joint system, an unjustified simplification made by most lumbar spine biomechanical models. In the context of common occupational tasks, an EMG-assisted optimization method (EMGAO) is modified in this study to simultaneously account for the equilibrium at all lumbar joints (M-EMGAO). The results of this improved approach were compared to those of its conventional single-joint equivalent (S-EMGAO) counterpart, the latter method being applied to the same lumbar joints but one at a time. Despite identical geometrical configurations and passive contributions used in both models, computed outcomes clearly differed between single- and multi-joint methods, especially at larger trunk flexed postures and during asymmetric lifting. Moreover, muscle forces predicted by L5-S1 single-joint analyses do not maintain mechanical equilibrium at other spine joints crossed by the same muscles. Assuming that the central nervous system does not attempt to balance the external moments one joint at a time and that a given muscle cannot exert different forces at different joints, the proposed multi-joint method represents a substantial improvement over its single-joint counterpart. This improved approach, hence, resolves trunk muscle forces with biological integrity but without compromising mechanical equilibrium at the lumbar joints.

1. Introduction

Lumbar spine musculoskeletal models are essential tools to assess physical exposure as well as document lumbar function and injury mechanisms through reliable prediction of muscle forces and spinal loads. As such, they play a crucial role in prevention of occupational injuries as well as design of rehabilitation interventions. However, to deal with the complexity of human trunk in terms of anatomy, tissue properties, and musculoskeletal system redundancy, assumptions with different degrees of accuracy are often required to predict muscle forces and joint loads. Selection of muscle force prediction method and musculoskeletal system simplifications are the key issues that influence model outcomes, and thus recommendations addressed to health and safety professionals.

In a musculoskeletal model, the choice of the method to deal with the existing redundancy is crucial to predict reliable muscle and joint forces (Reeves and Cholewicki, 2003). Typical single-joint lumbar spine models partition muscle forces either mathematically (optimization-based; Bean et al., 1988; Hughes et al., 1994; Schultz et al., 1982), biologically (EMG-driven; McGill and Norman, 1986; Granata and Marras, 1995), or using a hybrid formulation combining these two approaches (EMG-assisted optimization; Cholewicki et al., 1995; Gagnon et al., 2001). EMG-based approaches are sensitive to individual muscle activation strategies (Cholewicki et al., 1995; Gagnon et al., 2001) but do not balance the net joint moments. The opposite is however true with the optimization-based methods (Reeves and Cholewicki, 2003), which have led to combined approaches to simultaneously respect the mechanical and biological requirements of the musculoskeletal system (Cholewicki et al., 1995; Gagnon et al., 2001).

A critical modeling concern (Arjmand et al., 2007, 2009, 2010) is the use of single-joint equilibrium (usually a transverse cut across the L4-L5 or L5-S1) to estimate muscle forces and internal loads, a simplification commonly made by most lumbar spine

* Correspondence to: Département de kinanthropologie, Faculté d'éducation physique et sportive, Université de Sherbrooke, Sherbrooke, Québec, Canada J1K 2R1. Tel.: +1 819 821 8000x62734; fax: +1 819 821 7970.
E-mail address: Denis.Gagnon@USherbrooke.ca (D. Gagnon).

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