

A BIOMECHANICAL MODEL OF THE ELBOW, FOREARM AND WRIST

Rahman Davoodi, David Kleiman, Tomo Murakata and Gerald E. Loeb

A.E. Mann Institute for Biomedical Engineering and Department of Biomedical Engineering
University of Southern California, Los Angeles, CA 90089 USA; [Http://ami.usc.edu](http://ami.usc.edu); Davoodi@usc.edu

INTRODUCTION

Biomechanical models of the human arm provide a convenient and safe environment for studying the control of natural reaching movement and its restoration after paralysis. The model developed here simulates the movement of the elbow, forearm and wrist joints under arbitrary muscle excitations and external forces. It incorporates the most recent experimental data available regarding the moment arms and musculotendinous architecture of the muscles. It has been developed in a popular modeling environment for ease of sharing and future upgrades.

METHODS

The model has four segments (humerus, ulna, radius and hand), three joints (elbow, forearm and wrist), and fifteen muscles (Fig. 1). The skeleton was constructed by averaging the sizes of ten cadaver specimens reported by Murray (1997). Inertial parameters of the segments were estimated by the use of Hanavan's geometric models and experimentally measured segment densities.

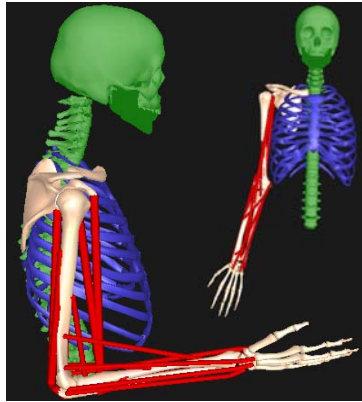
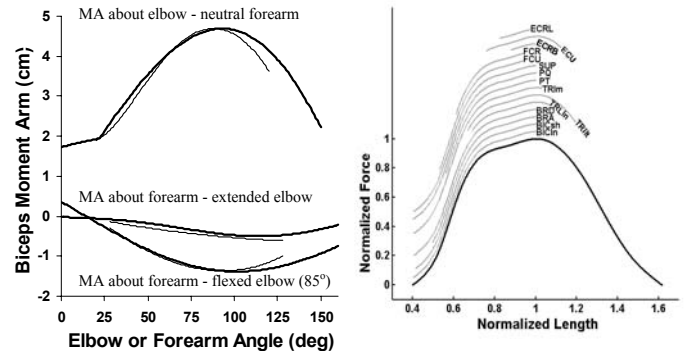


Figure 1. Anatomical model of the arm implemented in SIMM® from Musculographics, Inc.

To complete the anatomical model, the muscles were attached to the bony landmarks. Adjustments to cylindrical wrapping surfaces and muscle attachment points were used to reproduce the average experimental moment arms (Murray, 1997; Horii *et al.*, 1993; Lemay and Crago, 1996; Loren *et al.*, 1996) as a function of joint angle. The moment arms about the primary joint, where the muscle is a prime mover, were matched first. Then, additional parameters were modified to match the moment arms about the remaining joints as well as possible. The muscles' architectural parameters were selected from literature (Murray, 1997; Lieber *et al.*, 1990; Lieber *et al.*, 1992). Because the musculotendon lengths were slightly different from that of the model, the lengths of the tendons were adjusted to match the modeled and experimental operating ranges of the muscle fascicles.

Model parameters were fed to Virtual Muscle™ (Cheng *et al.*, 2000), SIMM (Delp and Loan, 2000), and MMS (Davoodi and Loeb, 2001) to build the forward dynamic model of arm



that runs in the Simulink® simulation environment of MATLAB.

Figure 2. Biceps Brachii's modeled (thick) and experimental (thin) moment arms (left) and muscle fibers operating ranges superimposed on a normalized force-length curve (right).

RESULTS AND DISCUSSION

As an example of realistic moment arms for multijoint muscles, the modeled and experimental moment arms of the biceps muscle are shown in figure 2. Also shown are the operating ranges of the muscle fibers that are similar to those reported in the literature (Murray, 1997; Loren *et al.*, 1996).

The moment arms about multiple joints and operation of the muscle fibers in the correct region of the force length curve are key features of a realistic arm model. Further validation of the model requires moment arm data about all the joints crossed by each muscle and in different arm configuration. The data from single cadaver specimens should also be as complete as possible because there is no validated methodology for scaling the biomechanical data among specimens.

The model is being used to design neural prostheses for reach and grasp. The MATLAB software environment is slow and simulation of one second of movement requires minutes of computation time on a PC. This modeling environment is suitable for developing and testing highly accurate models that can then be simplified and converted to fully compiled versions for specific requirements.

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