# INPUT PARAMETERS FOR MODELS II

## Lecture Overview

- Required model parameters
- Estimation of muscle forces
- Muscle model parameters
  - Maximum muscle force
  - Force-length curve
  - Force-velocity curve
  - Force-length properties tendon
  - Activation dynamics
- Parameter determination
- Out et al.

# REQUIRED MODEL PARAMETERS

To run a direct dynamics muscle model driven simulation model of human movement requires

- Body Segment Inertial Parameters
- Kinematics (complete for inverse dynamics)
- Segment Kinematics (partial for direct dynamics)
- Muscle Moment Arms
- Muscle-Tendon Lengths
- ***Maximum Muscle Force***√
- ***Parameters for Force-Length Curve***√
- ***Parameters for Force-Velocity Curve***√
- ***Parameters which describe Activation Dynamics***√

# ESTIMATION OF MUSCLE FORCES

The force produced by the muscle model ($F_m$) can be described using the following function

$$F_m = a_f . F_{max} . F_1(L_f) . F_2(V_f)$$

Where

$a_f$ - normalized degree of activation of muscle fibers.

$F_{max}$ - maximum isometric force muscle can produce

$F_1(L_f)$ - normalized force length relationship of muscle,

$F_2(V_f)$ normalized force-velocity relationship of muscle.

Generally the muscle model takes care of the estimation of muscle state during simulation, but the model still requires parameters.

# ESTIMATION OF MUSCLE FORCES

$$F_m = a_f . F_{max} . F_1(L_f) . F_2(V_f)$$

## Solution Requires

- Relationship to estimate Muscle-Tendon Lengths
- Maximum Muscle Force
- Parameters for Force-Length Curve
- Parameters for Force-Velocity Curve
- Parameters which describe Activation Dynamics

As $\boldsymbol{L_{mt} = L_f + L_t}$ and $\boldsymbol{V_{mt} = V_f + V_t}$

need to know

There are two principle sources of these data

- Morphological (cadaver and isolated specimens)

- Experimental (measurements made in vivo)

# MUSCLE MODEL PARAMETERS

## MAXIMUM MUSCLE FORCE

- The force a muscle can produce is a direct function of the amount of contractile machinery.

- For a parallel fibered muscle the following is true

$$F_T = F_M \propto CSA$$

Where $CSA$ is the cross-sectional area of the muscle.

- For a pennated muscle the following relationship can be stated

$$F_T = F_M . cos(a) \propto cos(a) . CSA$$

- To allow for the pennation angle the concept of physiological cross-sectional area ($PCSA$) has been introduced.

- For a parallel fibered muscle the following is true

$$PCSA = CSA$$

- Whilst for a pennated muscle

$$PCSA = CSA . cos(a)$$

# MUSCLE MODEL PARAMETERS
## MAXIMUM MUSCLE FORCE

- The specific tension of muscle is constant across individuals and species (Close, 1972), therefore the force a muscle can produce is directly proportional to its physiological cross-sectional area.

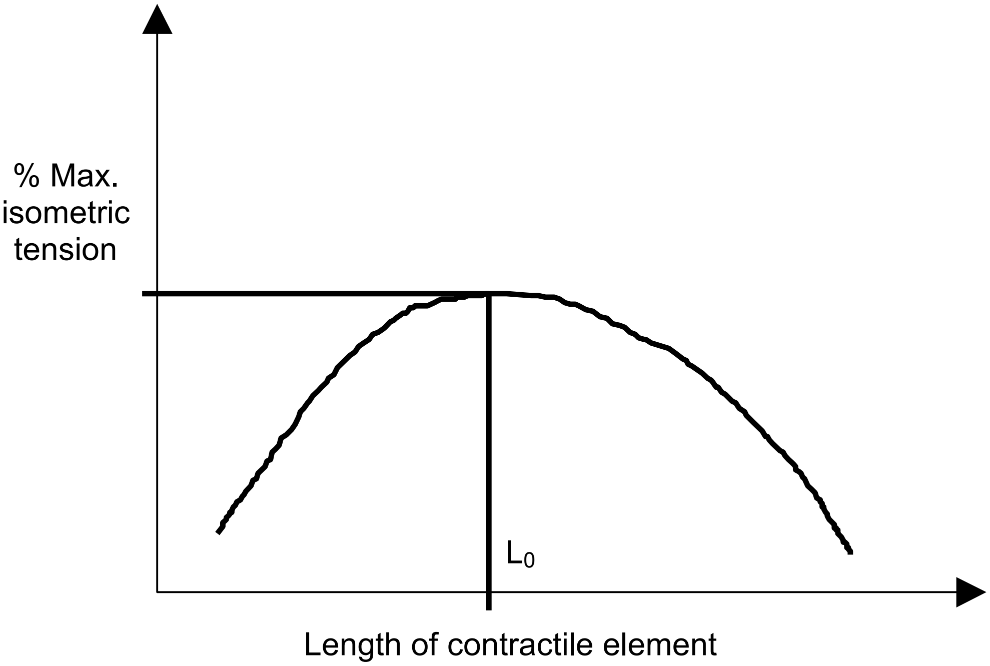
## Determination of PCSA

- Assume it is the same as data in the literature
- Measure in vivo using an imaging technique
- Other experimental means

## Reference

Narci et al. (1992) Assessment of human knee extensor muscles stress from in vivo physiological cross-sectional area and strength measurements. ***European Journal of Applied Physiology*** 65, 438-444.

# MUSCLE MODEL PARAMETERS
## FORCE-LENGTH CURVE



$$F_I = exp\left[-\left(\frac{\frac{L_F}{L_{FO}}-1}{SK}\right)^2\right]$$

## Parameters Required

- Optimum Length
- Spread of force-length curve

# MUSCLE MODEL PARAMETERS

## FORCE-LENGTH CURVE

## Determination of Optimum length

- Assume it is the same as in the literature
- Estimate from sarcomere data
- Other experimental means

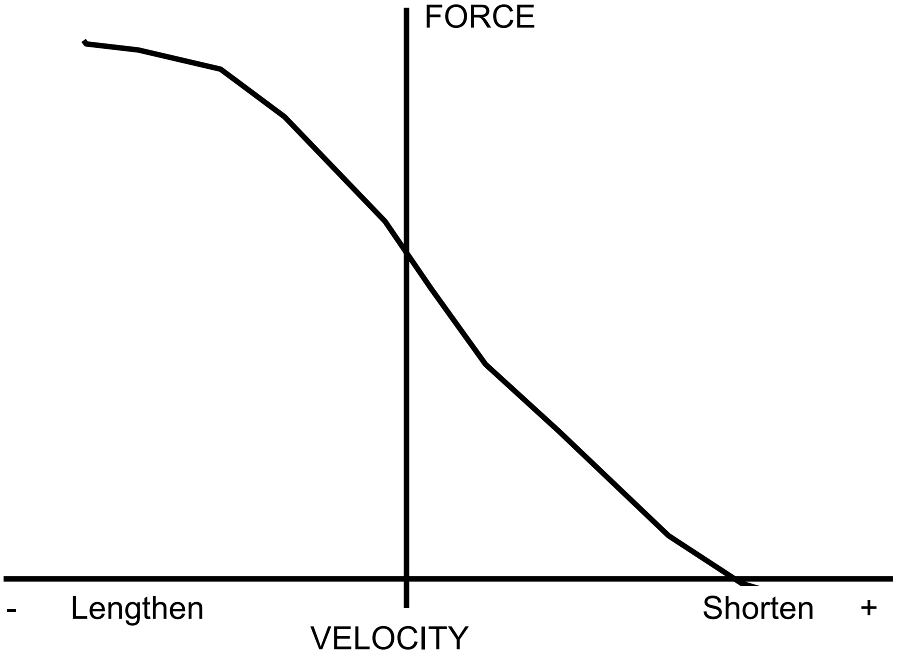
## For example

- Vastus lateralis has a mean number of sarcomeres per fiber of 40,716.
- The optimum length of a sarcomere is 2.73 μm (Walker and Schrodt,, 1974), which gives an optimum length of 11.1 cm.

## Determination of force-length curve

- If the standard deviation of the number of sarcomeres per fiber is 4,806, the width of the force-length curve can also be determined.

# MUSCLE MODEL PARAMETERS
## FORCE-VELOCITY CURVE



$$F_V = \frac{b.(F_I + a)}{b + V_F} - a$$

## Parameters Required

- Coefficients ***a*** and ***b***
- Maximum shortening velocity

**Note** - $a.V_{MAX} = b.F_I$

So as long as you know ***a*** or ***b*** you can compute the other.

# MUSCLE MODEL PARAMETERS

## FORCE-VELOCITY CURVE

### Determination of Coefficient

- Assume it is the same as in the literature
- Estimate from sarcomere data
- Other experimental means

### For example

Faulkner, Clafin, and McCully (1986) computed the ratio of $\frac{a}{F_I}$ by fitting the data for human muscle at body temperature to Hill's equation.

- Type I fibers the value was 0.15.
- Type II fibers the value was 0.25.

# MUSCLE MODEL PARAMETERS
## FORCE-VELOCITY CURVE

## Determination of Max. Shortening Velocity

- Assume it is the same as in the literature
- Estimate from fiber length data
- Other experimental means

## Example

Faulkner et al. (1986) examining bundles of human muscle fibers found that

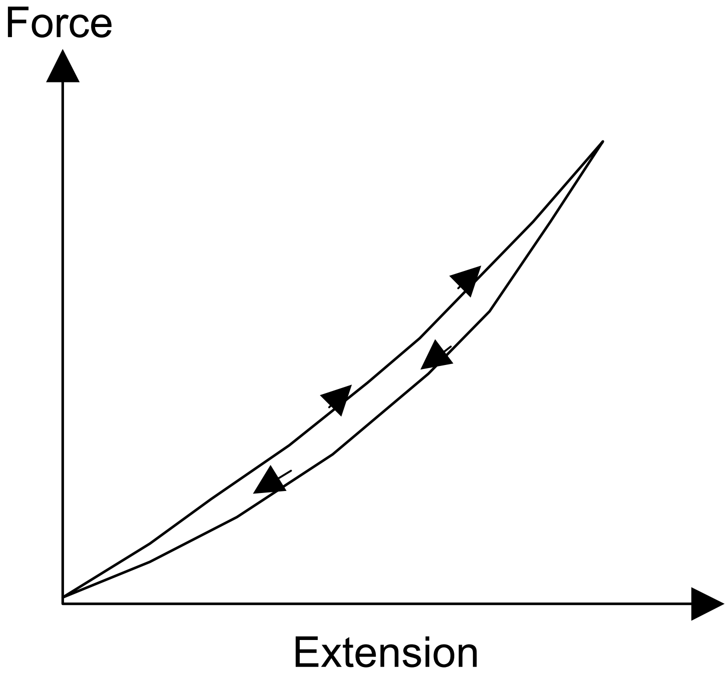
- Type I fibers – max. velocity of shortening of 2 fl.s$^{-1}$.
- Type II fibers – max. velocity of shortening of 6 fl.s$^{-1}$.

So if you know the optimum length of your fibers you can compute maximum velocity of shortening.

## Problem

Both of these determinations rely on know muscle fiber type distributions.

# MUSCLE MODEL PARAMETERS
## FORCE-LENGTH PROPERTIES TENDON



$$L_T = L_{T\,Rest} + K.F_V$$

OR $$L_T = L_{TR}.\left[1.0 + \frac{F_M}{A_T.E}\right]$$

## Parameters Required

- Resting length of the tendon
- Stretch in tendon under maximum isometric force

# MUSCLE MODEL PARAMETERS

## FORCE-LENGTH PROPERTIES TENDON

## Determination of Tendon Rest Length

- Assume it is the same as in the literature
- Estimate from in vivo imaging

## Determination of Tendon Stretch

- Assume it is the same as in the literature
- Estimate via experimental means

## Example I

Bobbert et al. (1990) Force-length properties of a muscle-tendon complex: Experimental results and model calculations. ***European Journal of Experimental Physiology*** 297, 1-7.
Estimated that stretch in tendon under maximum isometric force is 4%. Commonly used number.

# MUSCLE MODEL PARAMETERS
## FORCE-LENGTH PROPERTIES TENDON

## Determination of Tendon Stretch

- Estimate via experimental means

## Example II

Hof, A. L., and van den Berg, J. W. (1981) EMG to force processing, Parts I-IV. ***Journal of Biomechanics***, 14, 747-792.

If a muscle is exerting a force, and then the resistance is removed the whole muscle tendon complex recoils. The initial phase is due to the initial reaction of the tendon. From the analysis of such “quick release mechanisms” it is possible to estimate tendon elasticity.

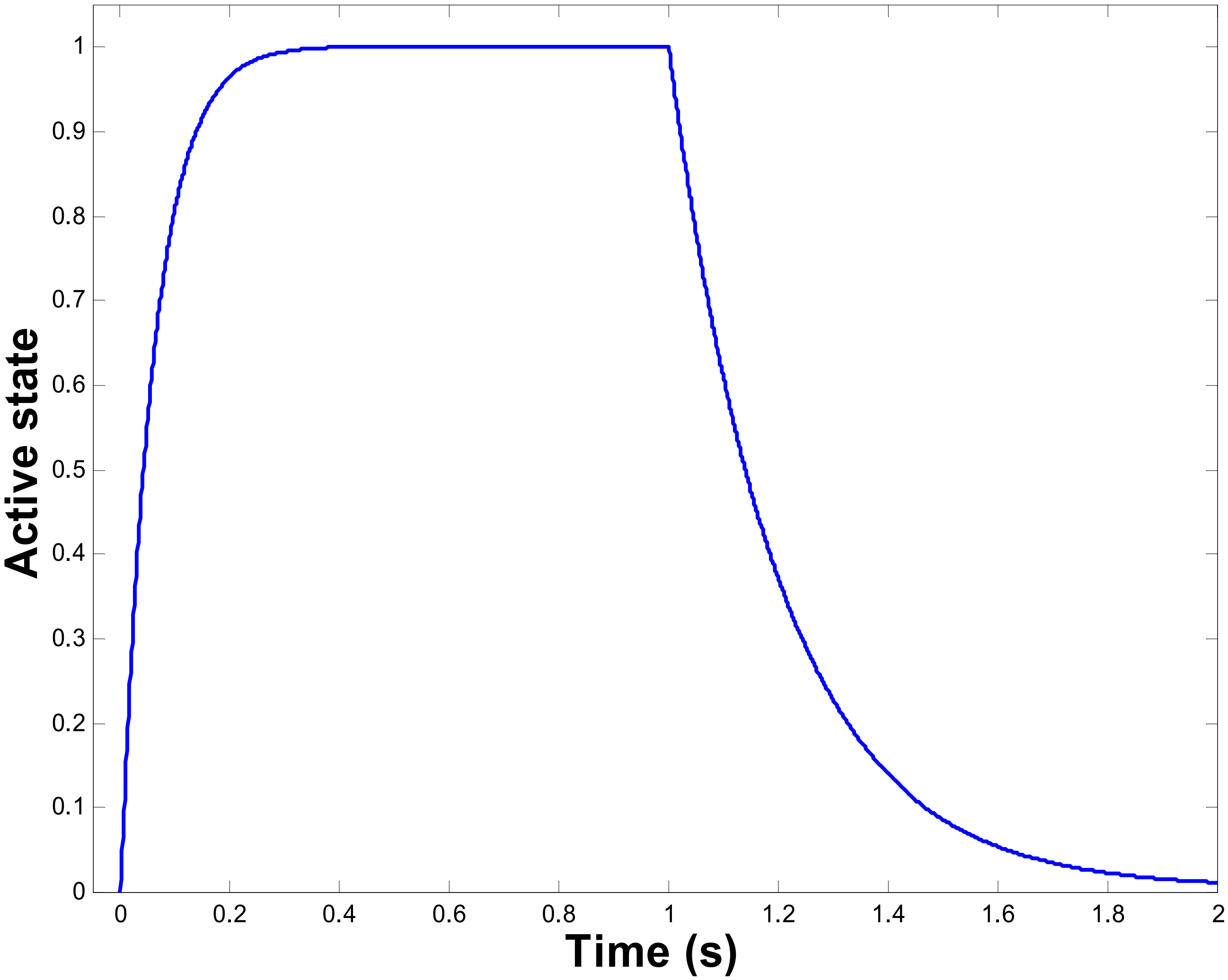
# MUSCLE MODEL PARAMETERS
## ACTIVATION DYNAMICS

$$\frac{dq}{dt} = (u - q) + (K_1.u + K_2)$$

Where

$u$ - neural excitation $(0 \le u \le 1)$

and $K_1, K_2$ are time constants



# MUSCLE MODEL PARAMETERS
## ACTIVATION DYNAMICS

## Parameters Required

- Time constants $K_1, K_2$

(Reflect time to activation and time for deactivation.)

## Determination of Constants

- Assume it is the same as in the literature

## Problem

Require knowledge of muscle fiber type.

# PARAMETER DETERMINATION

Have the subject perform some action involving muscle forces normally maximal. measure the subjects net output (e.g. joint moment). Then compare model output with reality and determine model parameters so they minimize the following objective function.

$$U = \sum_{j=1}^{NT} \left( T_{real_j} - T_{model_j} \right)^2$$

- The optimization algorithm can be made to search for the muscle model parameters which minimize this objective function.
- Seed with different start values to confirm global minimum.
- Sensitivity analyses.

## References

Hatze, H. (1981). Estimation of myodynamic parameter values from observations on isometrically contracting muscle groups. ***European Journal of Applied Physiology***, 46, 325-338.

Challis, J. H., & Kerwin, D. G. (1994). Determining individual muscle forces during maximal activity: Model development, parameter determination, and validation. ***Human Movement Science***, 13, 29-61.

# PARAMETER DETERMINATION

**Reference:** Pierrynowski, M. R. (1995) Analytic representation of muscle line of action and geometry. In P. Allard, I. A. F. Stokes, & J. P. Blanchi (Eds.), ***Three-Dimensional Analysis of Human Movement*** (pp. 215-256). Champaign, Illinois: Human Kinetics Publishers.