



# Musculoskeletal modelling

Let's talk about muscles



UNIVERSITATEA  
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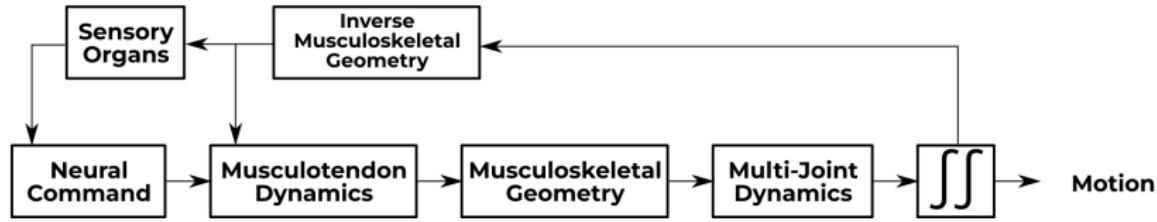
# Agenda

- Where do muscles fit
- Neural activation
- Muscle contraction
- Muscle models
- Activation dynamics
- Measuring muscle activation



# Musculoskeletal modelling

## Movement production



# Musculoskeletal modelling

## Muscles

There are three types of muscles:



# Musculoskeletal modelling

## Muscles

There are three types of muscles:

- Skeletal



# Musculoskeletal modelling

## Muscles

There are three types of muscles:

- Skeletal
- Smooth



# Musculoskeletal modelling

## Muscles

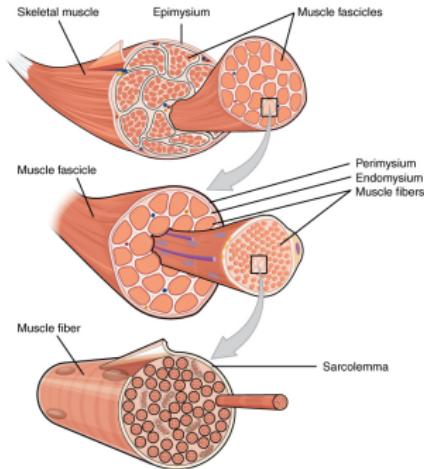
There are three types of muscles:

- Skeletal
- Smooth
- Cardiac



# Musculoskeletal modelling

## Muscles



There are three types of muscles:

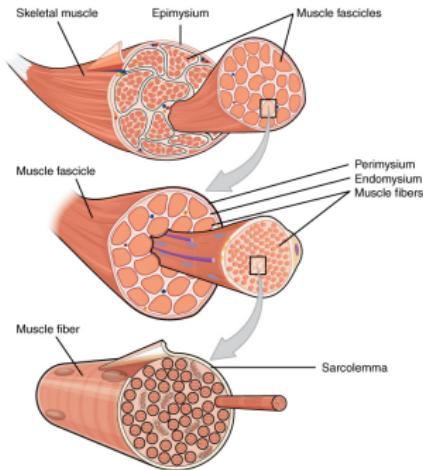
- Skeletal
- Smooth
- Cardiac

Very complex structure of fibers bundled together



# Musculoskeletal modelling

## Muscles



There are three types of muscles:

- Skeletal
- Smooth
- Cardiac

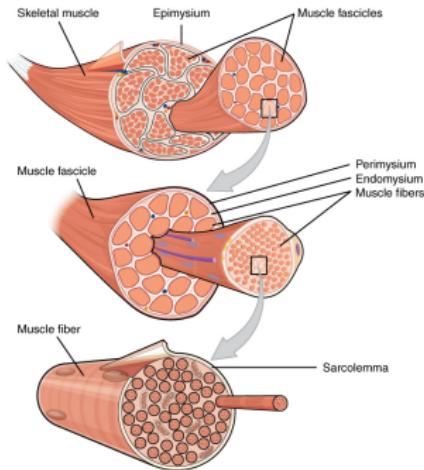
Very complex structure of fibers bundled together

They generate force by contracting and relaxing.



# Musculoskeletal modelling

## Muscles



There are three types of muscles:

- **Skeletal**
- Smooth
- Cardiac

Very complex structure of fibers bundled together

They generate force by contracting and relaxing.



# Musculoskeletal modelling

## Motor units

### Motor units

Motor neuron + skeletal muscle.

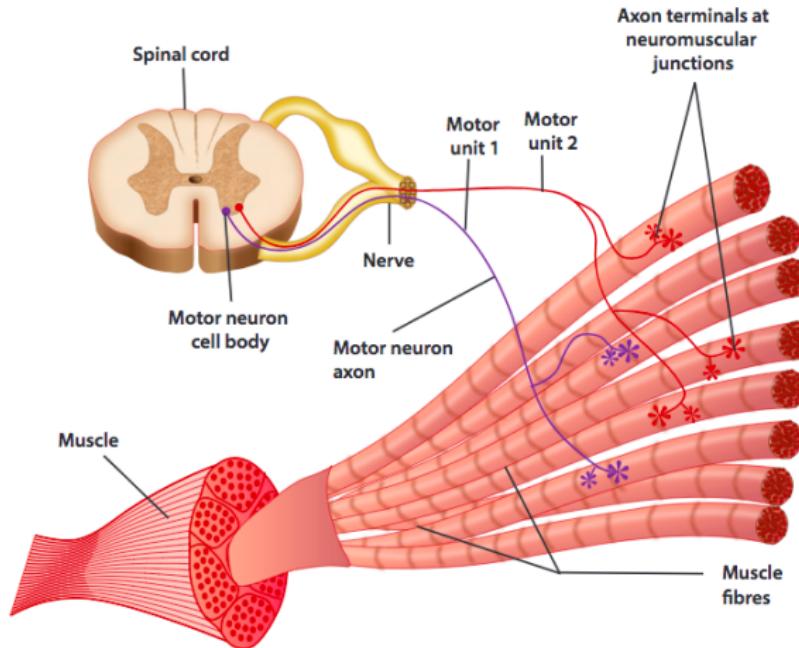


# Musculoskeletal modelling

## Motor units

### Motor units

Motor neuron + skeletal muscle.

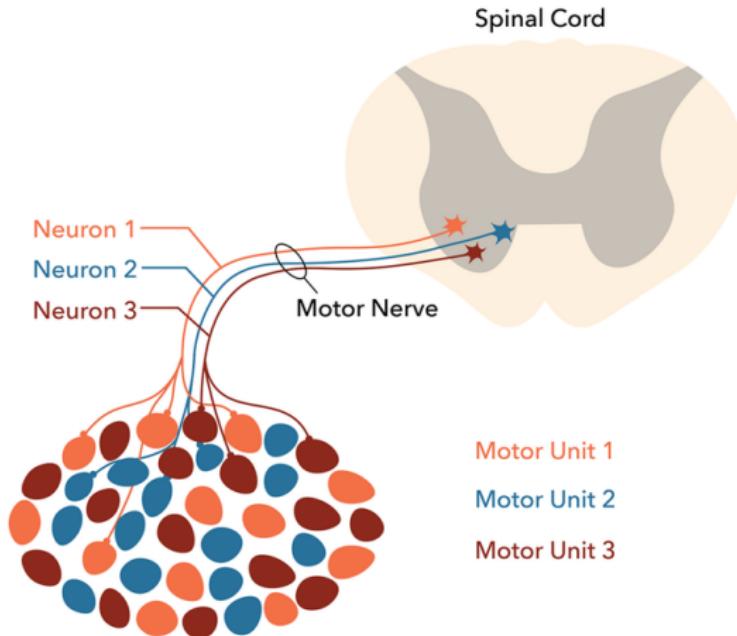


# Musculoskeletal modelling

## Motor units

### Motor units

Motor neuron + skeletal muscle.



# Musculoskeletal modelling

## Motor units

Big muscles -> Many units bundled together -> Less fine control

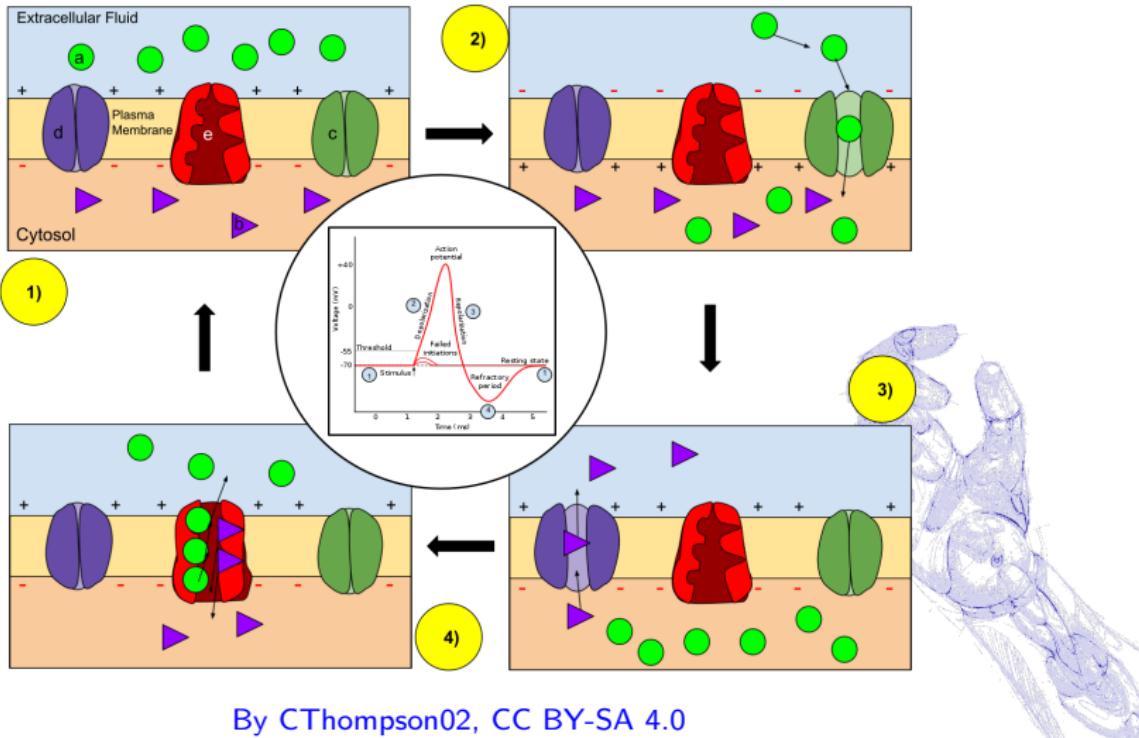
Small muscles -> One unit per fiber -> Finer control

Human arm -> 30-ish muscles -> 35K axons



# Muscle contraction

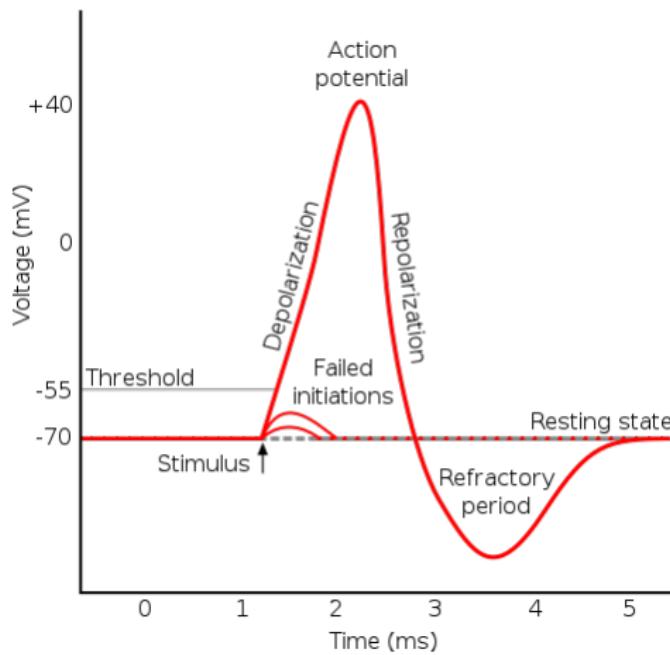
## Action potential



By CThompson02, CC BY-SA 4.0

# Muscle contraction

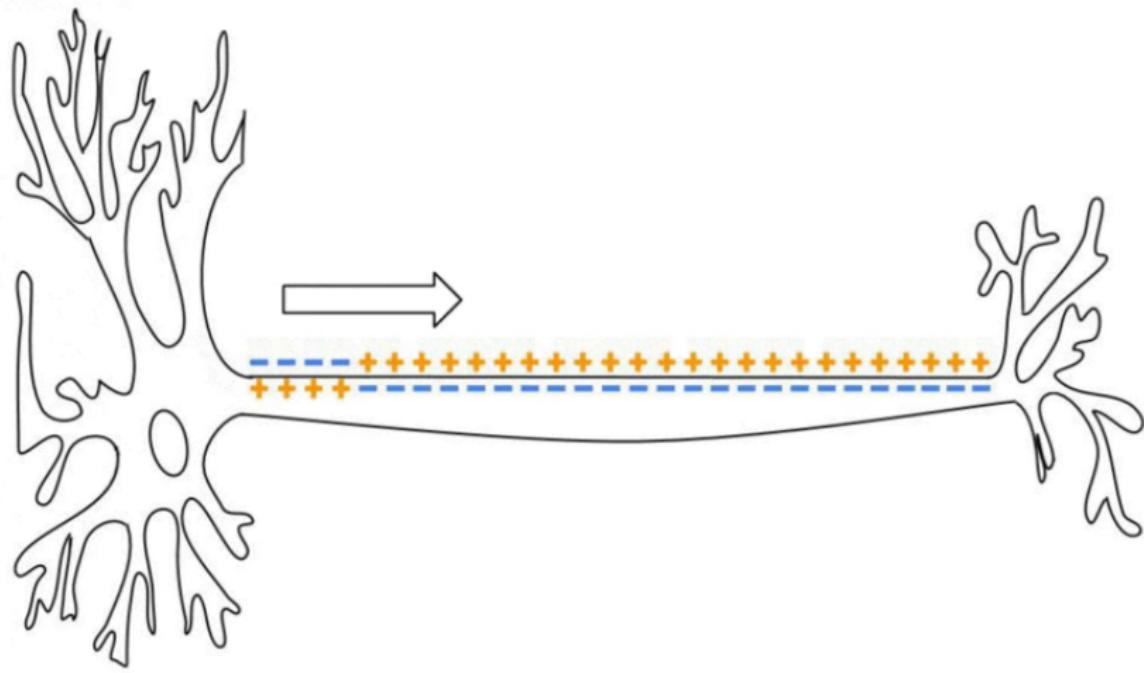
## Action potential



By Chandres, CC BY-SA 3.0

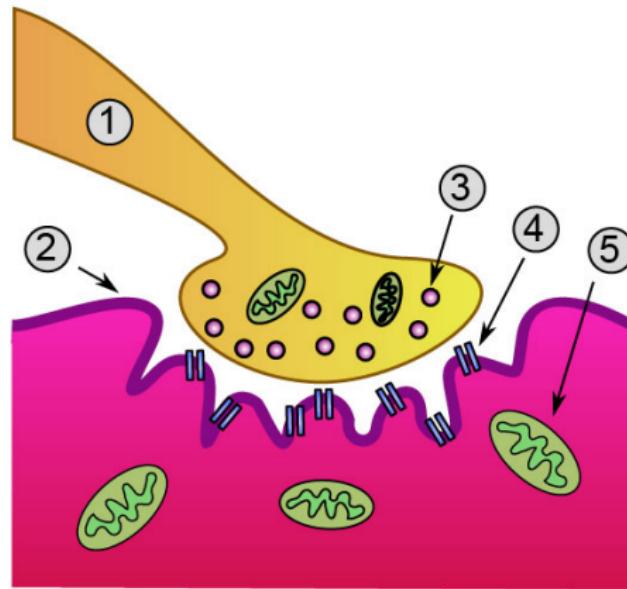
# Muscle contraction

Animation



# Muscle contraction

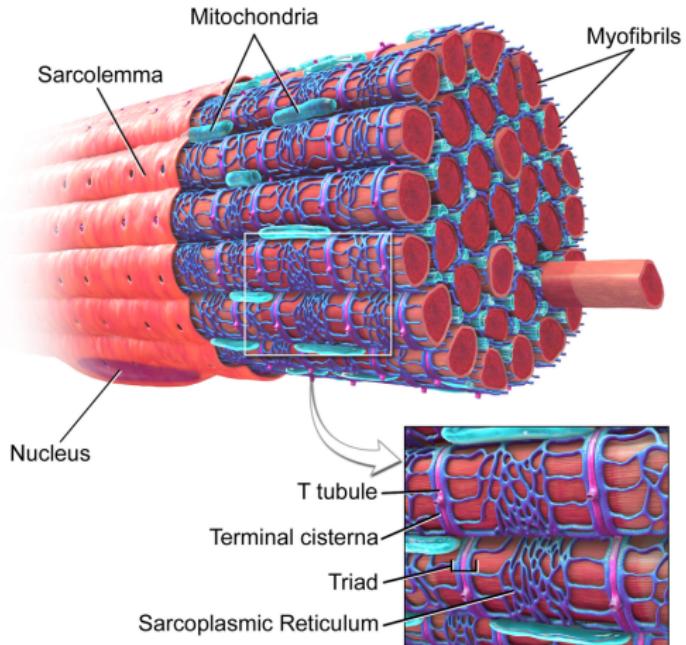
## Neuromuscular junction



CC BY-SA 3.0

# Muscle contraction

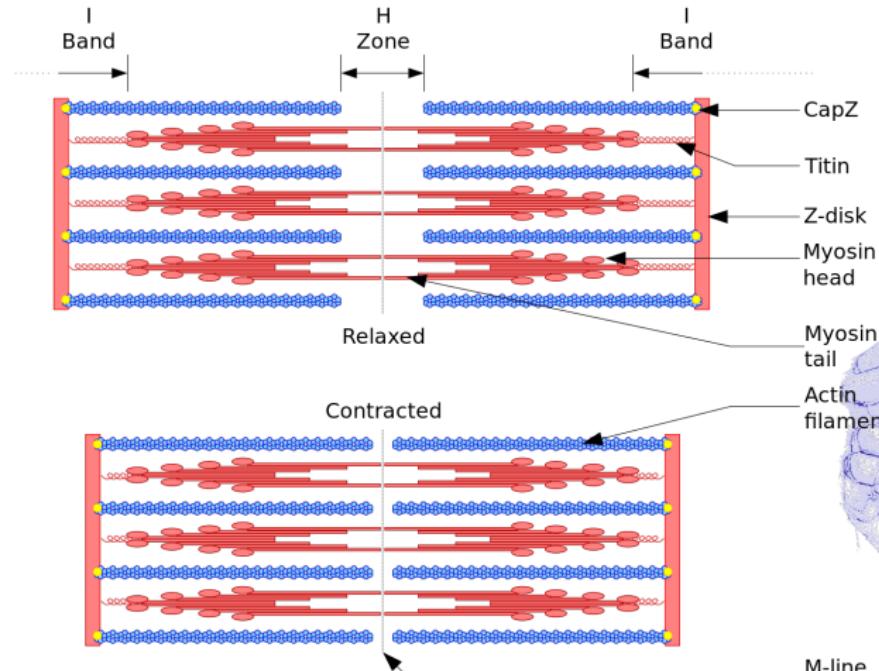
## Muscle fibers



Blausen.com staff (2014)

# Muscle contraction

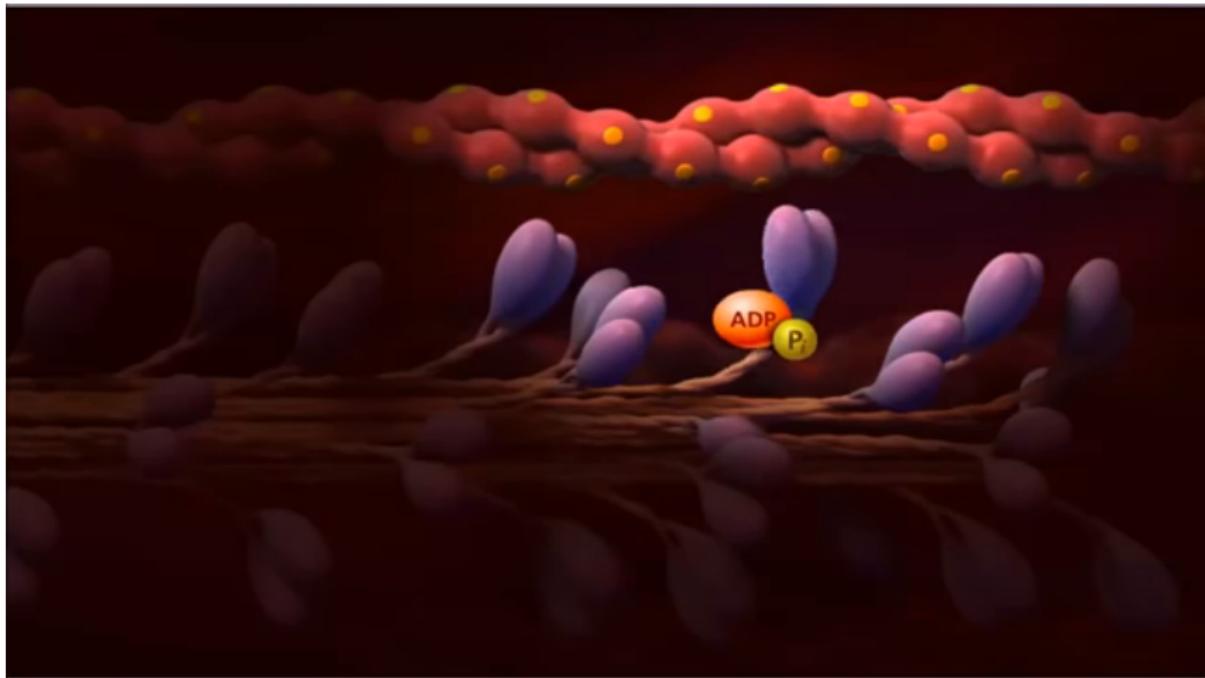
## Sarcomere



Richfield, David (2014)

# Muscle contraction

Animation



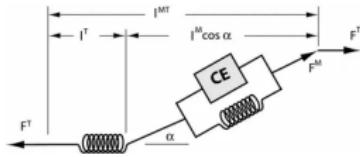
# Musculoskeletal modelling

## Muscle models



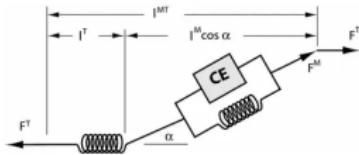
# Musculoskeletal modelling

## Muscle models



# Musculoskeletal modelling

## Muscle models

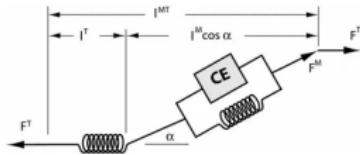


$$(v + b)(F + a) = b(F_0 + a)$$



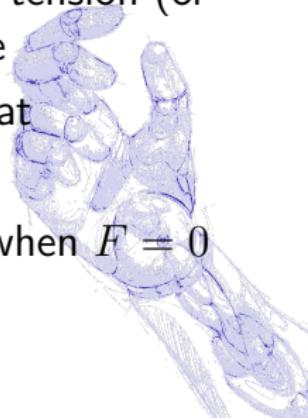
# Musculoskeletal modelling

## Muscle models



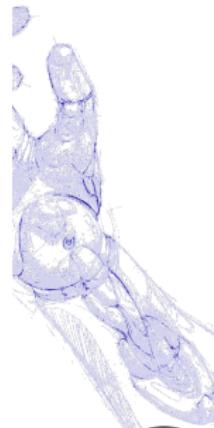
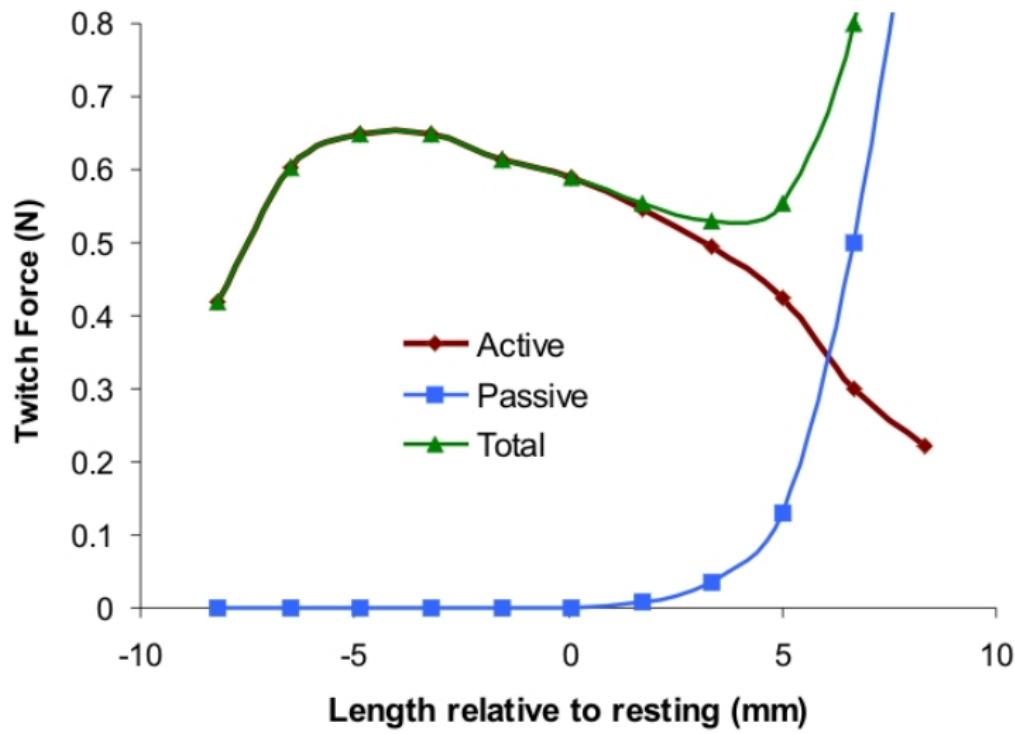
$$(v + b)(F + a) = b(F_0 + a)$$

- $F$  is the tension (or load) in the muscle
- $v$  is the velocity of contraction
- $F_0$  is the maximum isometric tension (or load) generated in the muscle
- $a$  coefficient of shortening heat
- $b = a \cdot v_0 / F_0$
- $v_0$  is the maximum velocity, when  $F = 0$



# Musculoskeletal modelling

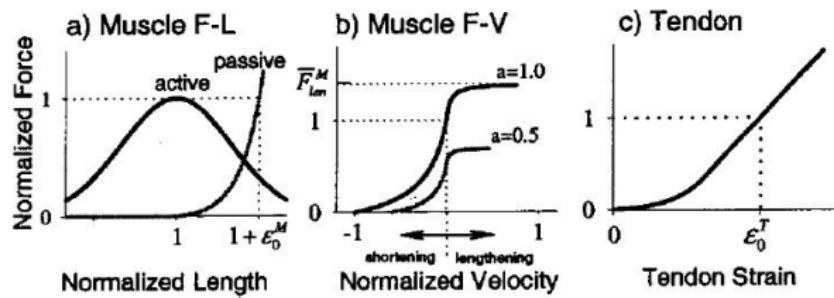
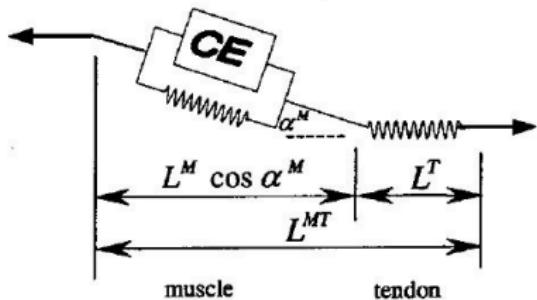
## Muscle models



# Musculoskeletal modelling

## Muscle models

- Maximum isometric force

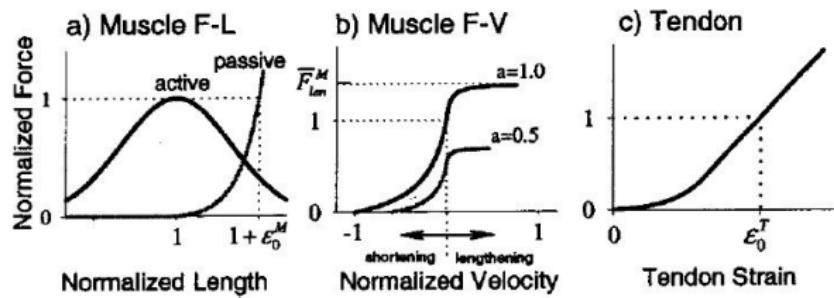
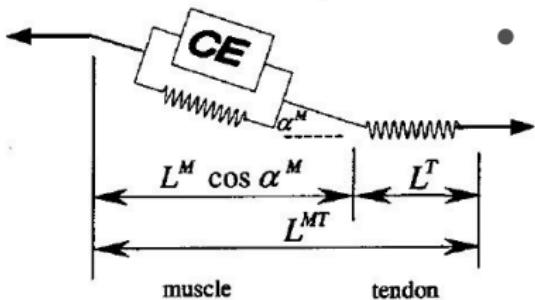


From Thelen (2003)

# Musculoskeletal modelling

## Muscle models

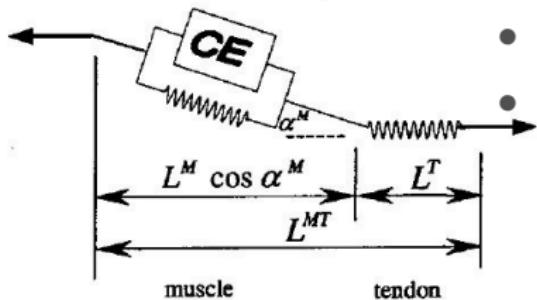
- Maximum isometric force
- Optimal muscle fiber length



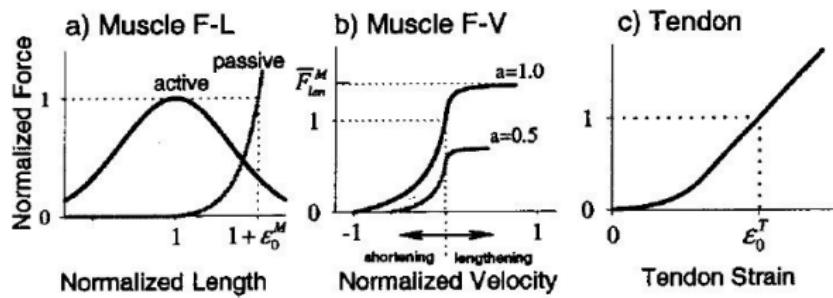
From Thelen (2003)

# Musculoskeletal modelling

## Muscle models



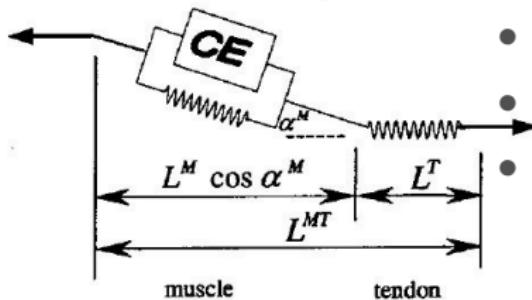
- Maximum isometric force
- Optimal muscle fiber length
- Tendon slack length



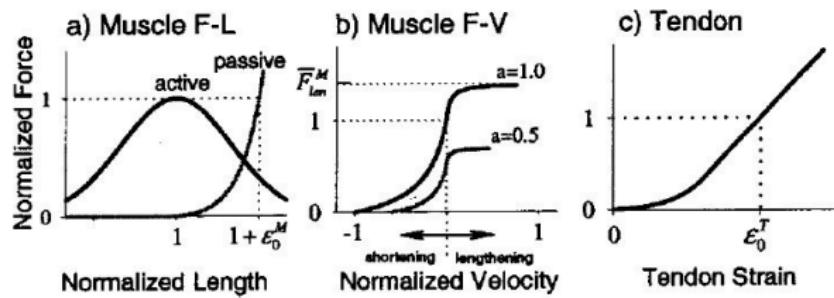
From Thelen (2003)

# Musculoskeletal modelling

## Muscle models



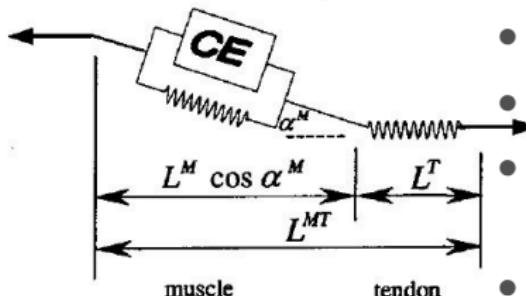
- Maximum isometric force
- Optimal muscle fiber length
- Tendon slack length
- Maximum contraction velocity



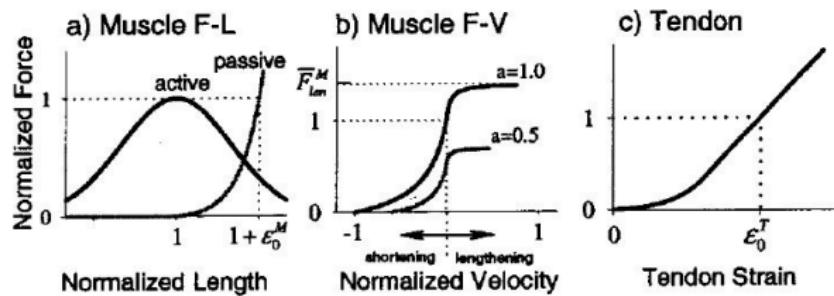
From Thelen (2003)

# Musculoskeletal modelling

## Muscle models



- Maximum isometric force
- Optimal muscle fiber length
- Tendon slack length
- Maximum contraction velocity
- Pennation angle



From Thelen (2003)

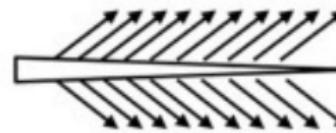
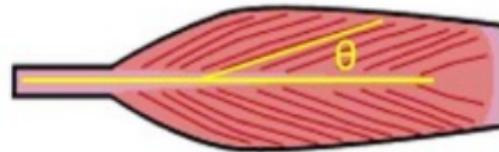
# Musculoskeletal modelling

## Muscle models

A

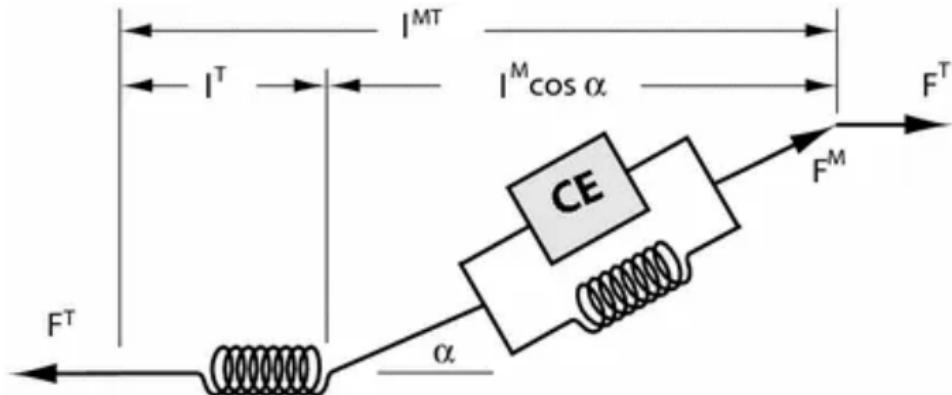


B



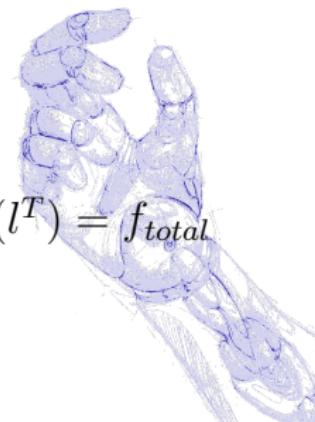
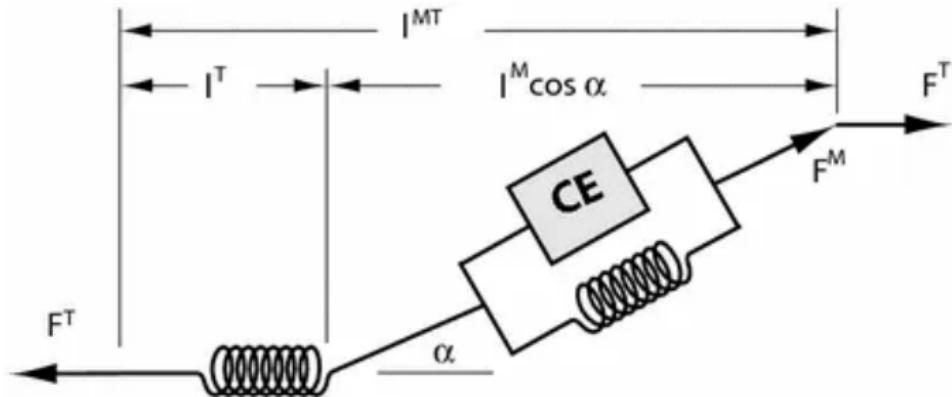
# Musculoskeletal modelling

## Muscle models



# Musculoskeletal modelling

## Muscle models



$$f_{iso}(\alpha(t)f_{AL}(l^M)f_v(i^M) + f_{PL}(l^M))\cos a - f_{iso}f_{SE}(l^T) = f_{total}$$

# Musculoskeletal modelling

## Muscle activation dynamics

Delays in the activation/deactivation of muscles



# Musculoskeletal modelling

## Muscle activation dynamics

Delays in the activation/deactivation of muscles

$$\frac{d\alpha}{dt} = \frac{u - \alpha}{\tau(\alpha, u)}$$



# Musculoskeletal modelling

## Muscle activation dynamics

Delays in the activation/deactivation of muscles

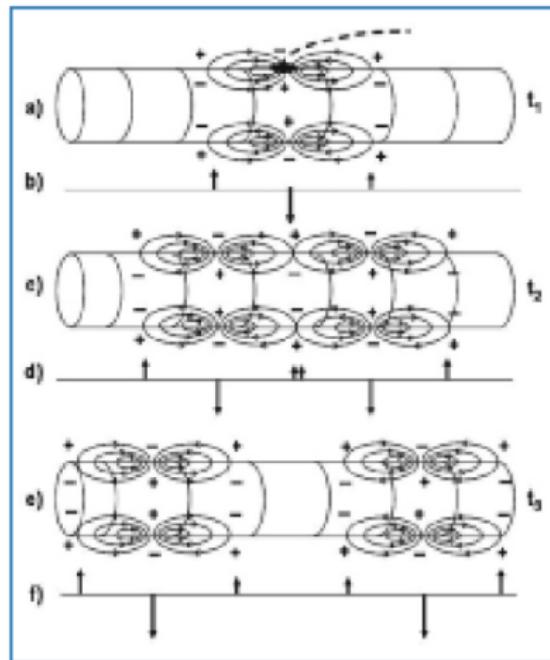
$$\frac{d\alpha}{dt} = \frac{u - \alpha}{\tau(\alpha, u)}$$

$$\tau(\alpha, u) = \begin{cases} t_{act}(0.5 + 1.5\alpha) & : u > \alpha \\ t_{deact}/(0.5 + 1.5\alpha) & : u < \alpha \end{cases}$$



# Musculoskeletal modelling

## Measuring muscle activation

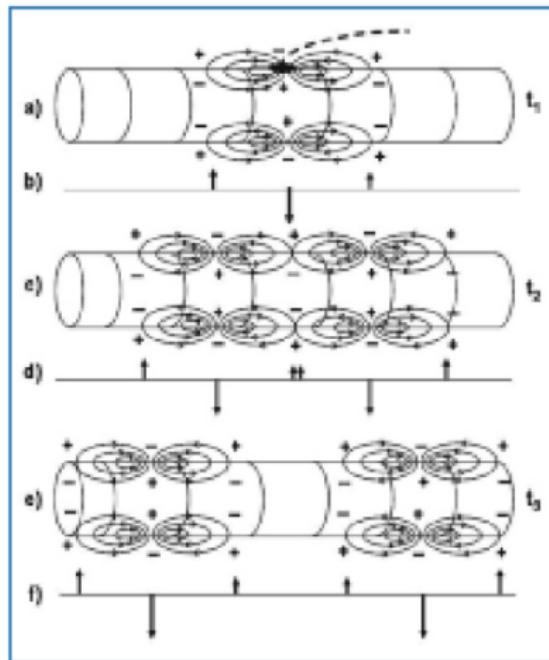


From Atlas of Muscle Innervation Zones, Springer 2012



# Musculoskeletal modelling

## Measuring muscle activation

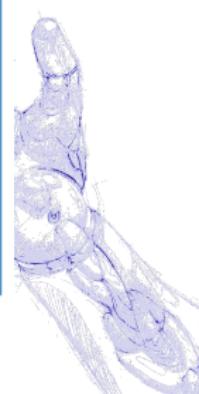
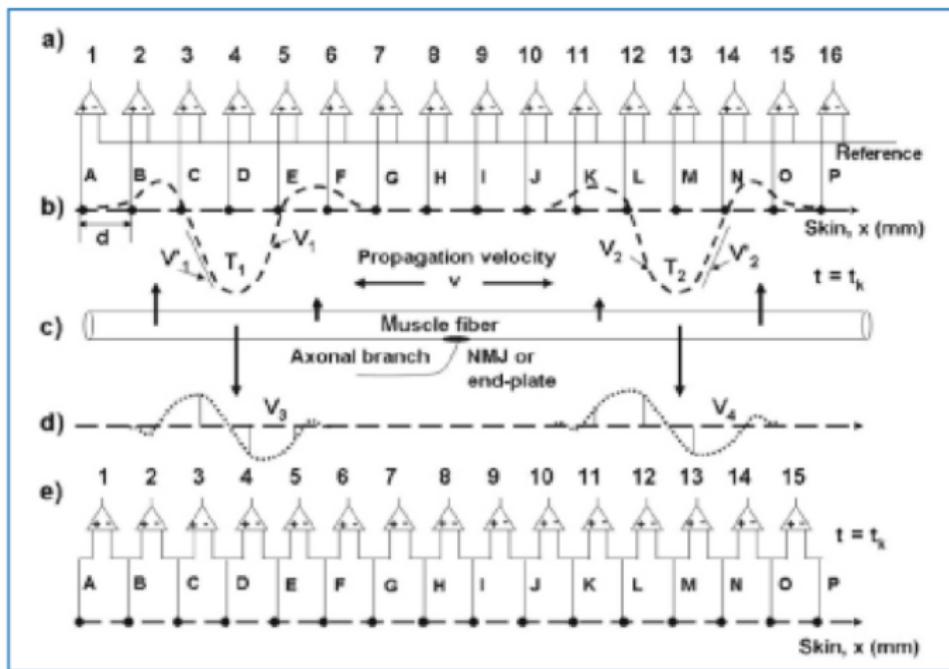


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Another action potential propagating

# Musculoskeletal modelling

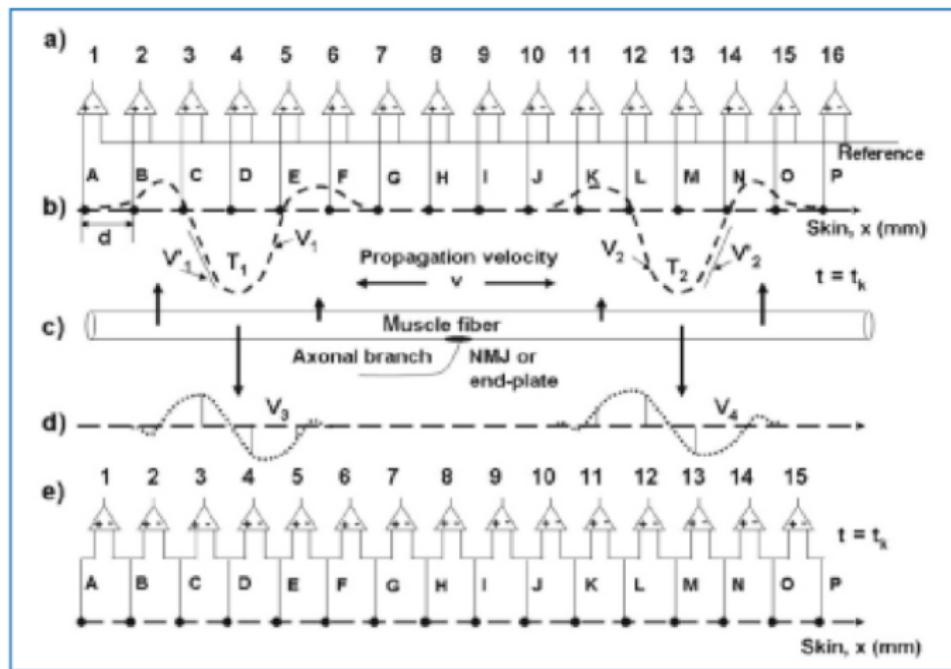
## Measuring muscle activation



From Atlas of Muscle Innervation Zones, Springer 2012

# Musculoskeletal modelling

## Measuring muscle activation

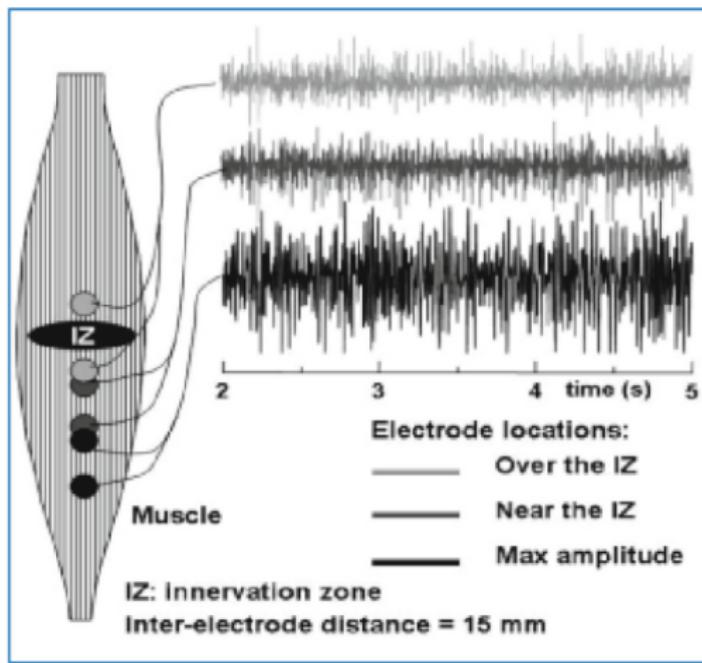


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## Differential voltage measurements

# Musculoskeletal modelling

## Measuring muscle activation

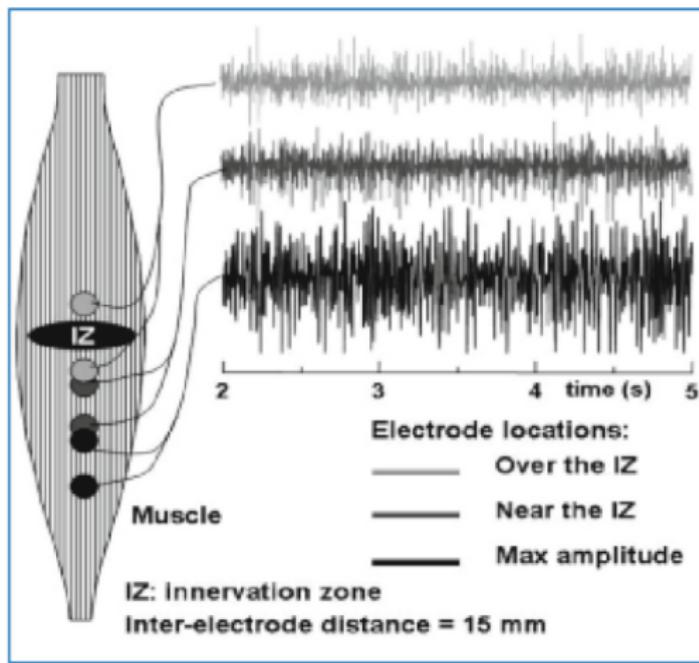


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# Musculoskeletal modelling

## Measuring muscle activation



From Atlas of Muscle Innervation Zones, Springer 2012

Location makes a difference!

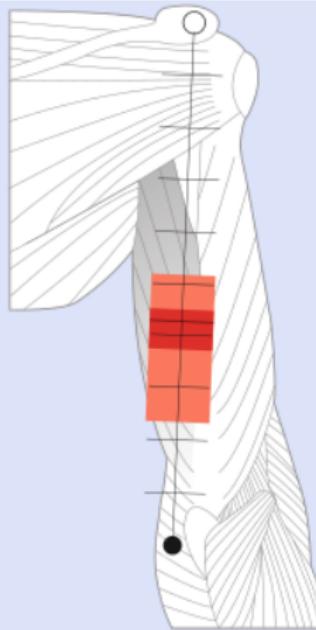
# Musculoskeletal modelling

## Measuring muscle activation

Subjects investigated	Izs detected
20 Males	20
20 Females	13

Results	
Min	48%
1st quartile	56%
Median	58%
3rd quartile	63%
Max	76%

Quality analysis		
Items	Values	Score
1 Signal quality	0 or 2	2
2 Area without IZ	0 or 2	2
3 Physiological signal propagation	0 or 1	1
4 Motor units identification	0 or 1	1
Total		6



From Atlas of Muscle Innervation Zones, Springer 2012

# Further reading

[https://nmbi.stanford.edu/publications/pdf/  
Millard2013.pdf](https://nmbi.stanford.edu/publications/pdf/Millard2013.pdf)

<https://uwnmbi.engr.wisc.edu/pubs/jbme03.pdf>



# Coming up next

Forward kinematics of musculoskeletal models





# Questions?