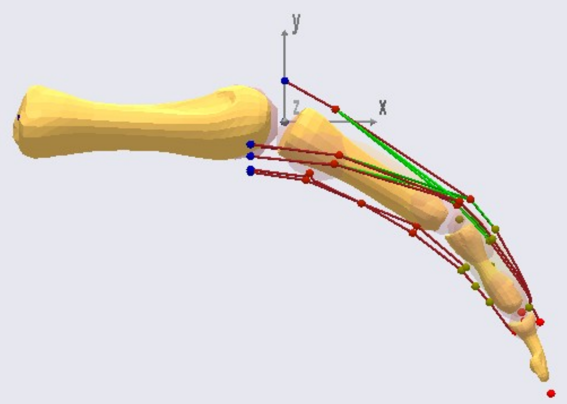
Simulating the Dynamic Muscle Force in an Index Finger During Tapping

Presenter: John Z. Wu



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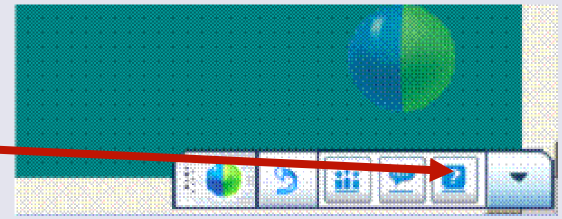

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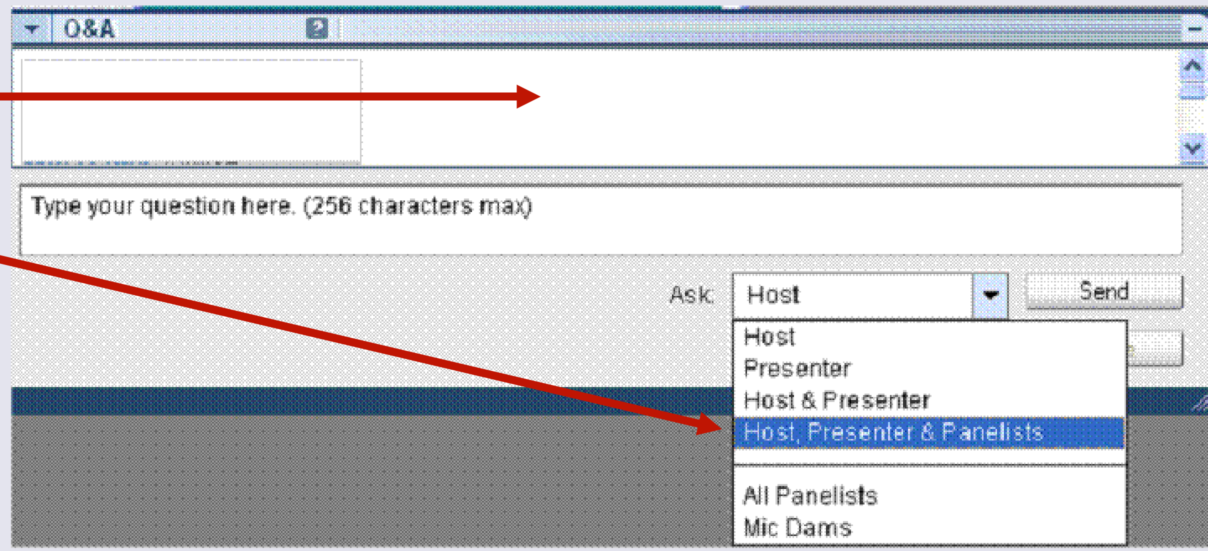

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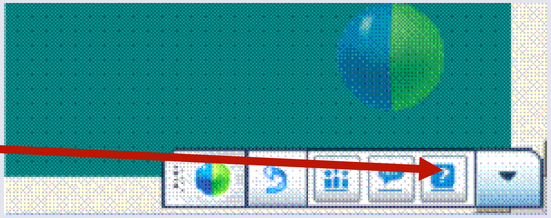
Questions, it is ok to ask



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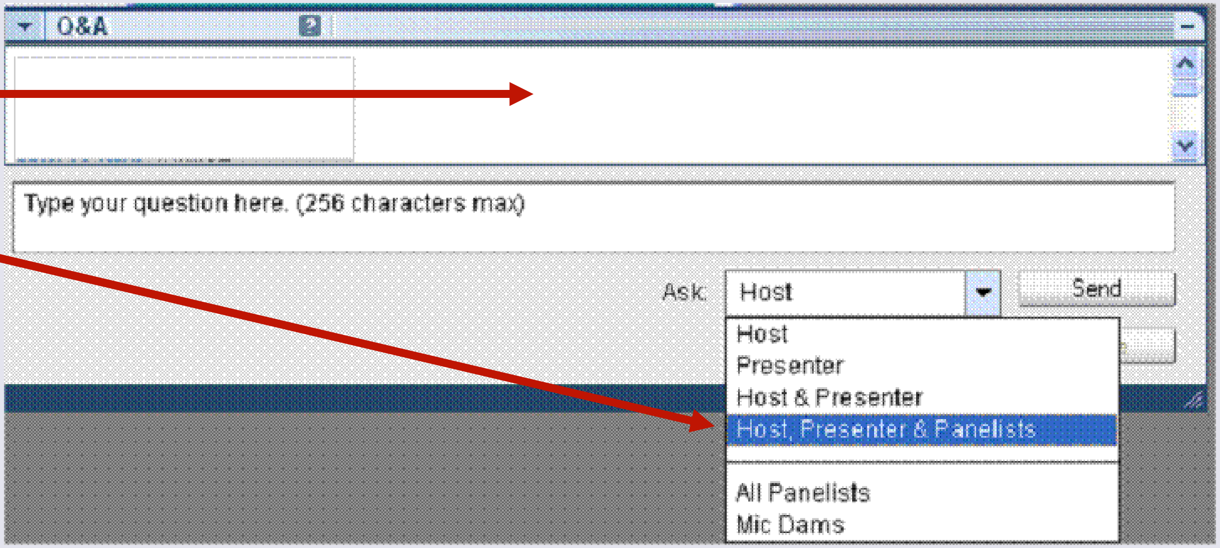

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Q&A Panel

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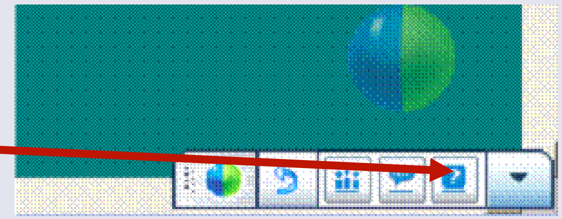

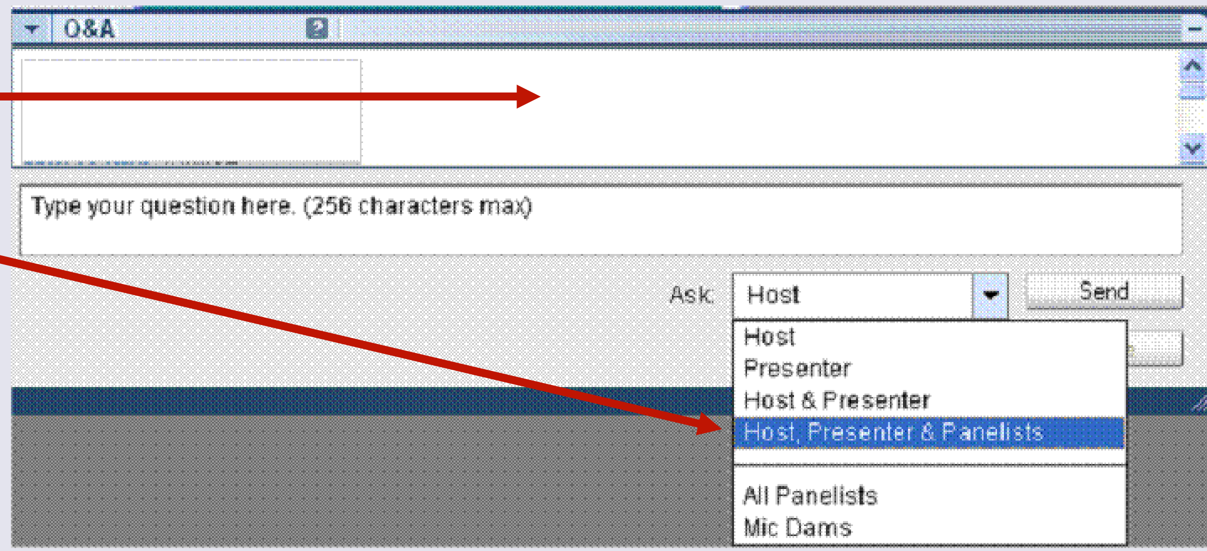

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Simulating the Dynamic Muscle Force in an Index Finger During Tapping

John Z. Wu[1], Kai-Nan An[2], Robert G. Cutlip[1], Kristine Krajnak[1] Ren G. Dong[1]

[1]National Institute for Occupational Safety & Health Morgantown, WV, USA

[2]Mayo Clinic College of Medicine, Rochester, MN, USA

Background

- Epidemiological studies demonstrated that excessive computer use results in an increased risk of developing musculoskeletal disorders (MSDs) of the upper extremities

(e.g., Cail and Aptel, 2003; Gerr et al., 2006)

- Electromyography (EMG) studies evaluating muscle activity during typing suggest that MSDs in the upper extremities are induced by excessive repetitive musculoskeletal loading.

(e.g., Woods and Babski-Reeves, 2005; Gerard et al., 1999)

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Background

- **Because the experimental evaluation of the dynamic loading in individual muscles of the hand during typing is technically difficult, multi-body finger models have been developed to study the dynamic contact force between the fingertip and keypad, joint moments, and joint angle motions:**

  (e.g., *Gerard et al., 1999; Jindrich et al, 2004; Dennerlein et al., 1998; Kuo et al., 2006*)

Background

One of the most promising theoretical approaches for exploring the muscle forces in fingers during typing is a biomechanical model containing muscle and tendon structures:

- Sancho-Bru et al. (2003) – static gripping and free movements
- Brook et al. (1995) – muscle forces in pinch grip and disc rotation
- Biggs and Horch (1999) – tendon/muscle excursions
- Valero-Cuevas et al. (1998) – anatomically realistic tendon/muscle connections and musculoskeletal parameters

Objective

- **To analyze the dynamic muscle forces in an index finger during tapping using a universal finger model developed on a platform of the commercial software package AnyBody** *(AnyBody Technology Inc., Aalborg, Denmark)***.**

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Method: Index finger model

- The index finger is modeled as a linkage system.
- The index finger model consists of distal, middle, proximal, and metacarpal phalanges.
- DIP (distal interphalangeal) and PIP (proximal interphalangeal) joints are modeled as hinges; The MCP (metacarpo-phalangeal) joint is modeled as a universal joint.

Method: Index finger model

- Attachment locations and finger section dimensional scales are defined according to the normative model (An et al., 1979).
- Seven muscles were included in the proposed model: flexor profundus (FP), flexor sublimis (FS), extensor indicis (EI), extensor digitorum communis (EC), radial interosseous (RI), ulnar interosseous (UI), and lumbrical (LU).

Method: Index finger model

- Bony section meshes were obtained via micro-CT scanning of a cadaver right hand and included in the model.

- The model was developed on the platform of AnyBody and written in *Anyscript* code, a AnyBody program language.

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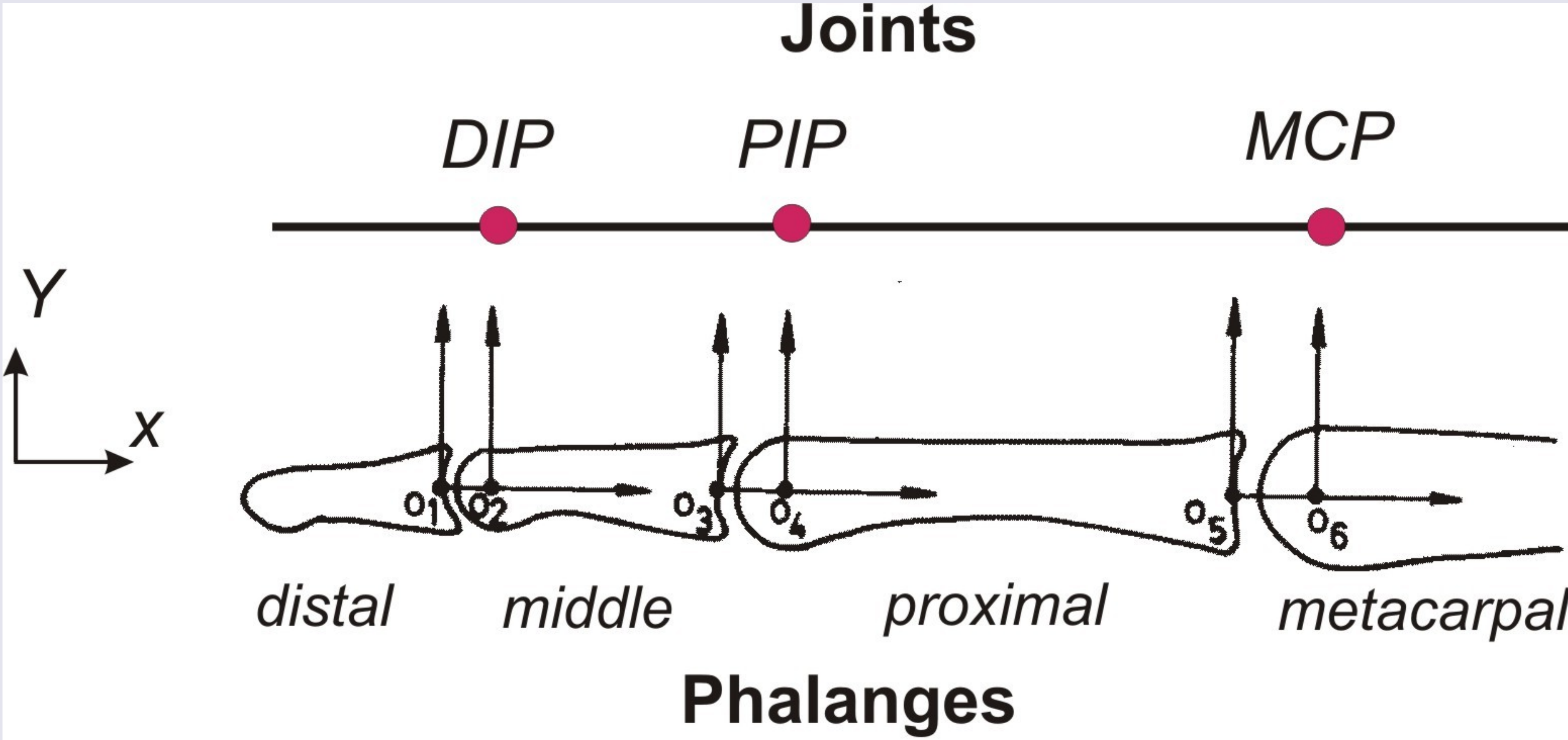
Method: Index finger model

- Hill-type three-element muscle model: a contractile element and an elastic element in parallel, and a series elastic element.
- The recruitment of the muscle forces is calculated by using a min/max optimization procedure in AnyBody, in which the maximal normalized muscle force is minimized.
- Muscle parameters: Physiologic Cross-Section Area (PCSA), the optimal fiber length, and the pennation angle are taken from the literature.

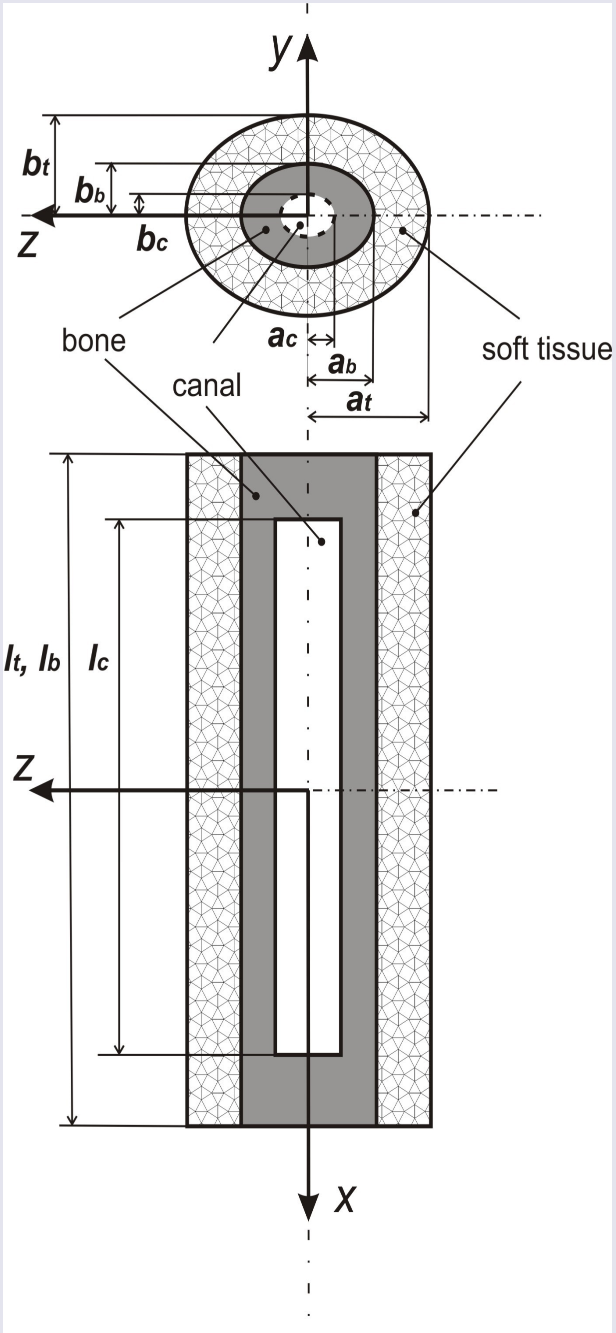
Coordinate of the Normative Finger Model (An et al., 1983)



O1 O2	O2 O3	O3 O4	O4 O5	O5 O6
0.228	1.000	0.288	1.919	0.432

Tendon attachment locations of the Index Model
The values in

		Distal Point				Proximal Point			
Joint	**Tendon**	X	Y	Z	ΔR	X	Y	Z	ΔR
DIP	TE	0.026 (0.004)	0.169 (0.199)	-0.010 (-0.010)	0.037	0.050 (0.000)	0.100 (0.196)	-0.009 (-0.009)	0.108
	FP	0.010 (0.004)	-0.184 (-0.184)	0.026 (0.026)	0.006	0.150 (0.300)	-0.200 (-0.245)	0.054 (0.054)	0.157
PIP	FP	-0.212 (-0.212)	-0.308 (-0.308)	0.009 (0.009)	0.000	0.450 (0.400)	-0.209 (-0.409)	0.027 (0.027)	0.206
	RB	-0.112 (-0.112)	0.186 (0.186)	0.223 (0.223)	0.000	0.100 (0.100)	0.200 (0.181)	0.268 (0.268)	0.019
	UB	-0.112 (-0.112)	0.151 (0.151)	-0.290 (-0.290)	0.000	0.100 (0.100)	0.191 (0.131)	-0.312 (-0.312)	0.060
	FS	-0.212 (-0.212)	-0.249 (-0.249)	0.015 (0.015)	0.000	0.400 (0.400)	-0.211 (-0.311)	0.028 (0.028)	0.100
	ES	-0.038 (-0.038)	0.278 (0.278)	-0.027 (-0.027)	0.000	0.050 (0.000)	0.200 (0.266)	-0.026 (-0.026)	0.083
MCP	FP	-0.218 (-0.118)	-0.386 (-0.386)	0.031 (0.031)	0.100	0.450 (0.300)	-0.459 (-0.619)	-0.150 (0.004)	0.266
	FS	-0.218 (-0.118)	-0.477 (-0.477)	-0.074 (-0.074)	0.100	0.550 (0.300)	-0.489 (-0.689)	-0.114 (-0.114)	0.320
	RI	-0.318 (-0.318)	-0.033 (-0.033)	0.443 (0.443)	0.000	0.300 (0.400)	-0.362 (-0.362)	0.529 (0.629)	0.141
	LU	-0.318 (-0.318)	-0.148 (-0.148)	0.370 (0.370)	0.000	0.400 (0.400)	-0.650 (-0.704)	0.200 (0.541)	0.345
	UI	-0.318 (-0.318)	-0.039 (-0.039)	-0.461 (-0.461)	0.000	0.400 (0.400)	-0.279 (-0.379)	-0.242 (-0.442)	0.224
	LE	-0.018 (-0.018)	0.421 (0.421)	-0.033 (-0.033)	0.000	0.000 (0.000)	0.483 (0.483)	-0.026 (-0.026)	0.000



$$I_{xx}(tissue) = \frac{\pi\rho_t}{4}\left[(a_t b_t l_t)(a_t^2 + b_t^2) - (a_b b_b l_b)(a_b^2 + b_b^2)\right],$$
$$I_{yy}(tissue) = \frac{\pi\rho_t}{12}\left[(a_t b_t l_t)(3a_t^2 + l_t^2) - (a_b b_b l_b)(3a_b^2 + l_b^2)\right],$$
$$I_{zz}(tissue) = \frac{\pi\rho_t}{12}\left[(a_t b_t l_t)(3b_t^2 + l_t^2) - (a_b b_b l_b)(3b_b^2 + l_b^2)\right]$$

$$I_{xx}(bone) = \frac{\pi\rho_b}{4}\left[(a_b b_b l_b)(a_b^2 + b_b^2) - (a_c b_c l_c)(a_c^2 + b_c^2)\right],$$
$$I_{yy}(bone) = \frac{\pi\rho_b}{12}\left[(a_b b_b l_b)(3a_b^2 + l_b^2) - (a_c b_c l_c)(3a_c^2 + l_c^2)\right],$$
$$I_{zz}(bone) = \frac{\pi\rho_b}{12}\left[(a_b b_b l_b)(3b_b^2 + l_b^2) - (a_c b_c l_c)(3b_c^2 + l_c^2)\right]$$

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Dimensions, mass, and mass moment of inertia of finger sections used in the model

	Bone external			Bone canal			Tissue external		
(mm)	*a*	*b*	*l*	*a*	*b*	*l*	*a*	*b*	*l*
(a)									
Distal	3.92	2.42	19.67	1.96	0.80	14.75	8.29	6.86	19.67
Middle	5.56	3.48	24.67	2.78	1.15	18.50	9.21	8.11	24.67
Proximal	6.57	4.65	43.57	3.29	1.53	32.68	9.75	9.52	43.57

Finger section	*M* (kg)	I_{xx} (kg m^2)	I_{yy} (kg m^2)	I_{zz} (kg m^2)
(b)				
Distal	3.91E − 03	1.04E − 07	1.90E − 07	1.70E − 07
Middle	6.79E − 03	2.32E − 07	4.84E − 07	4.51E − 07
Proximal	1.55E − 02	6.48E − 07	2.86E − 06	2.83E − 06

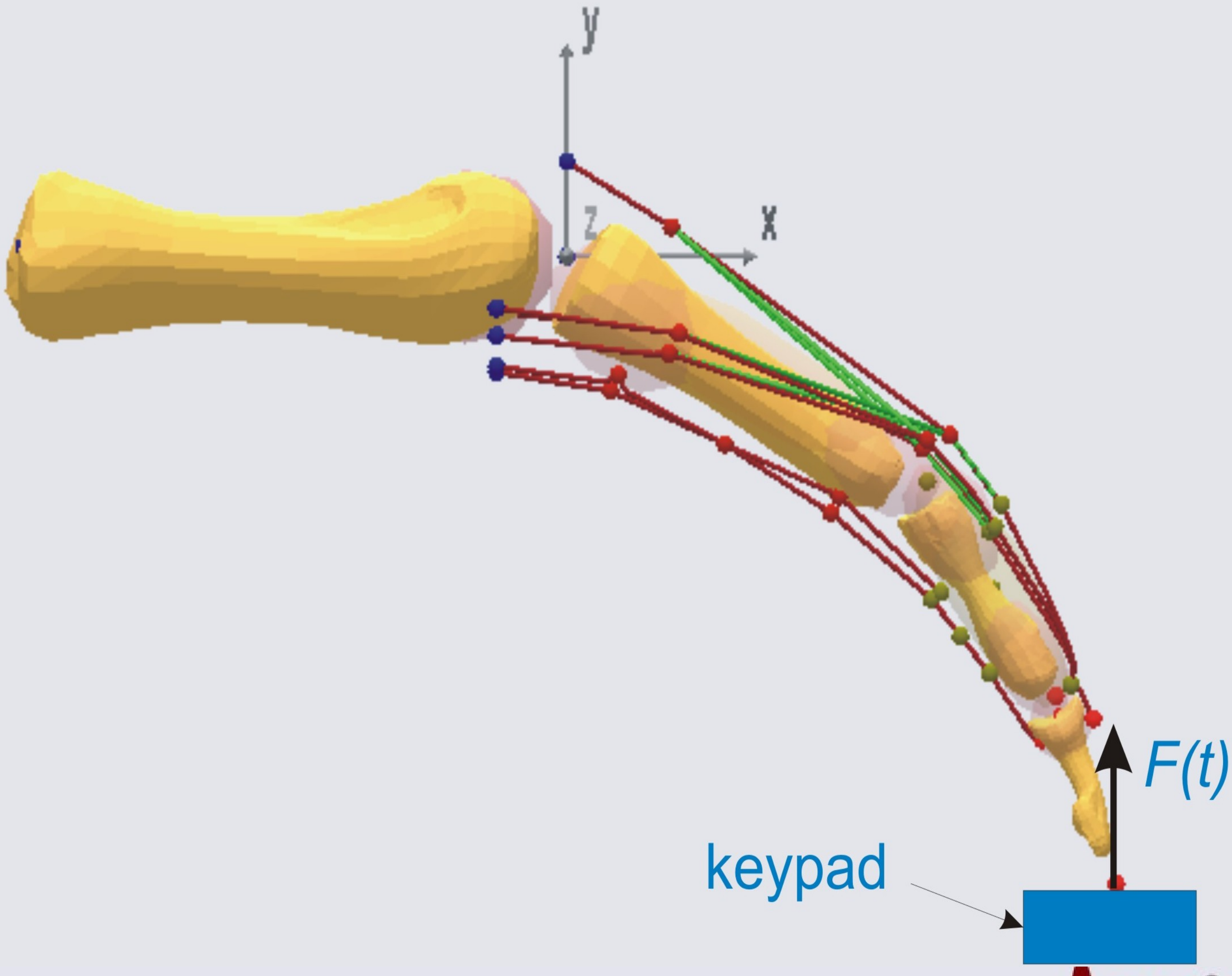
Soft tissue relative density = 1.0

Bone relative density =1.9

Parameters of the Three-Element Muscle Model

Muscle	PCSA (cm^2)	Fiber length (mm)	Pennation angle (deg)
FP	4.79	66	12.1
FS	4.79	70	3.1
RI	3.53	14	9.2
UI	2.80	15	9.2
LU	0.28	66	1.2
EI	1.12	60	3.5
EC	1.39	60	3.5

Index Finger Model



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Model Predictions

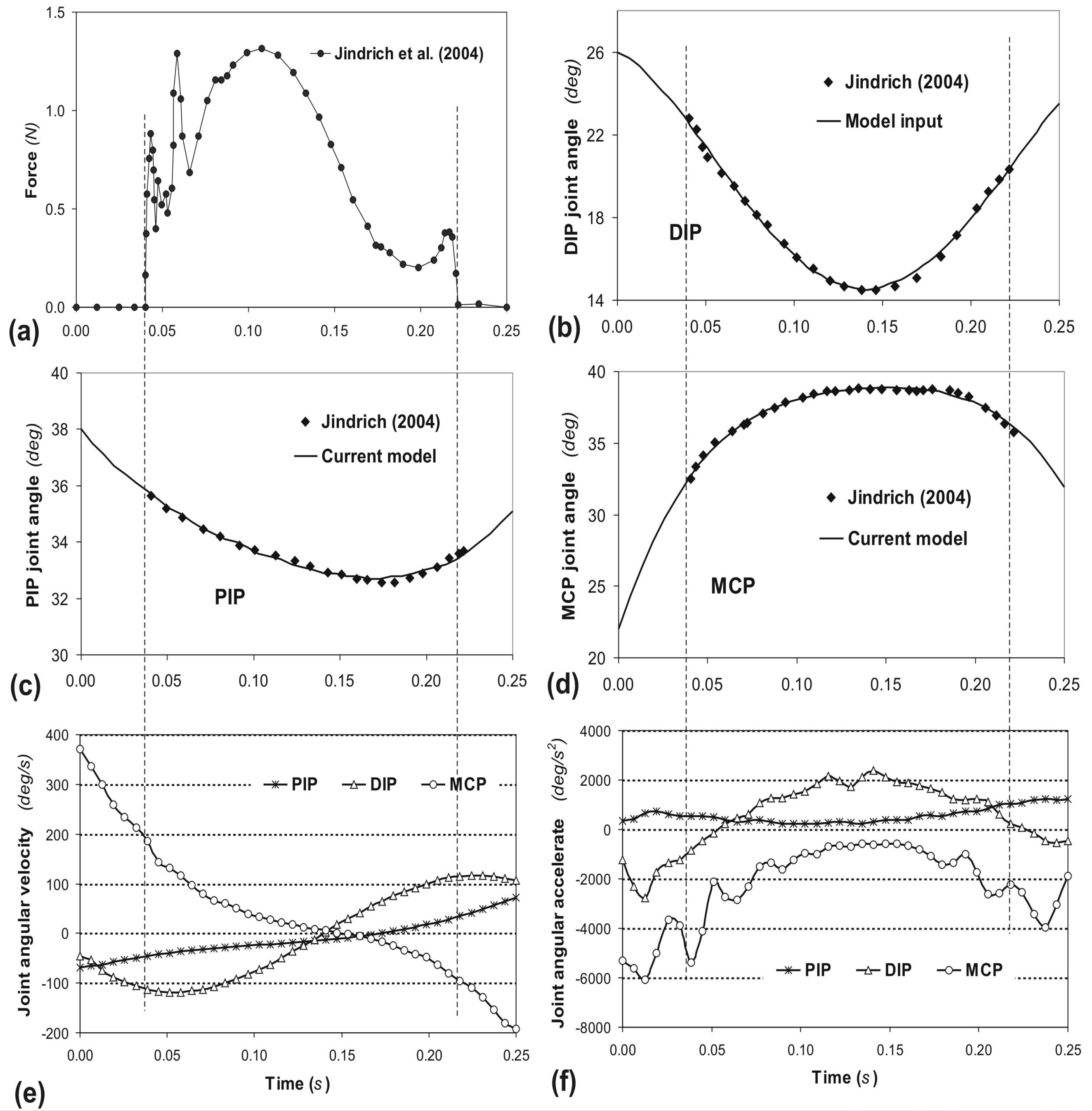
Model inputs: Time-histories of the typical impact force at the fingertip; time-histories of DIP, PIP, and MCP joint angles during tapping. (Jindrich et al., 2004);

Model outputs: Time-histories of the joint torques and muscle forces.

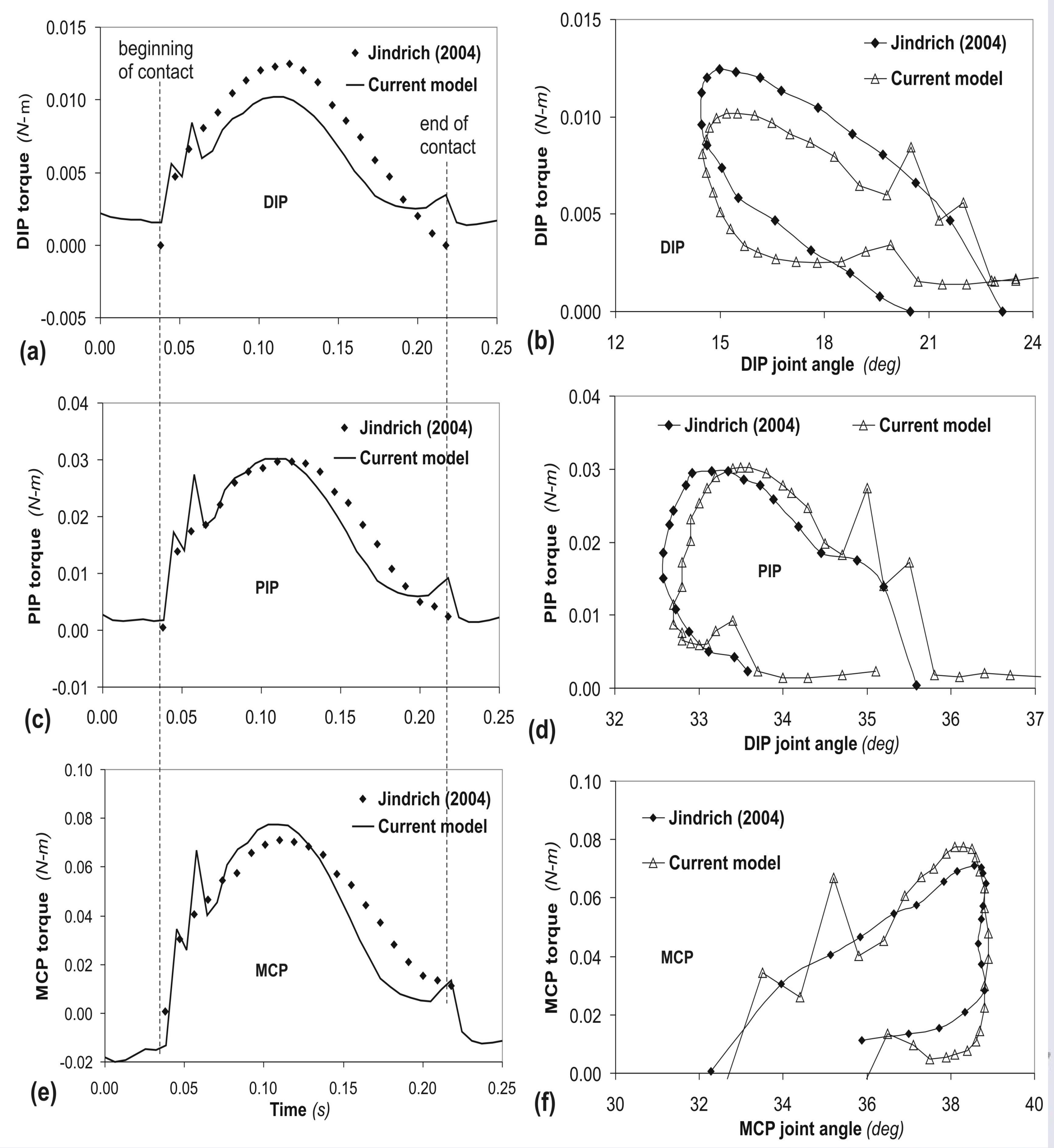
Simulation procedure:

6. Calculating the joint torques. “Joint muscle models” are applied. All three joints are constrained and the generalized joint reactions are considered as the joint torques.
7. Calculating the individual muscle loading. “Three-Element muscle models” are applied. The constraints in the joints are removed, and the joint torques are carried by the muscles.

Contact Force
Joint Angle
Angular Velocity
& Acceleration



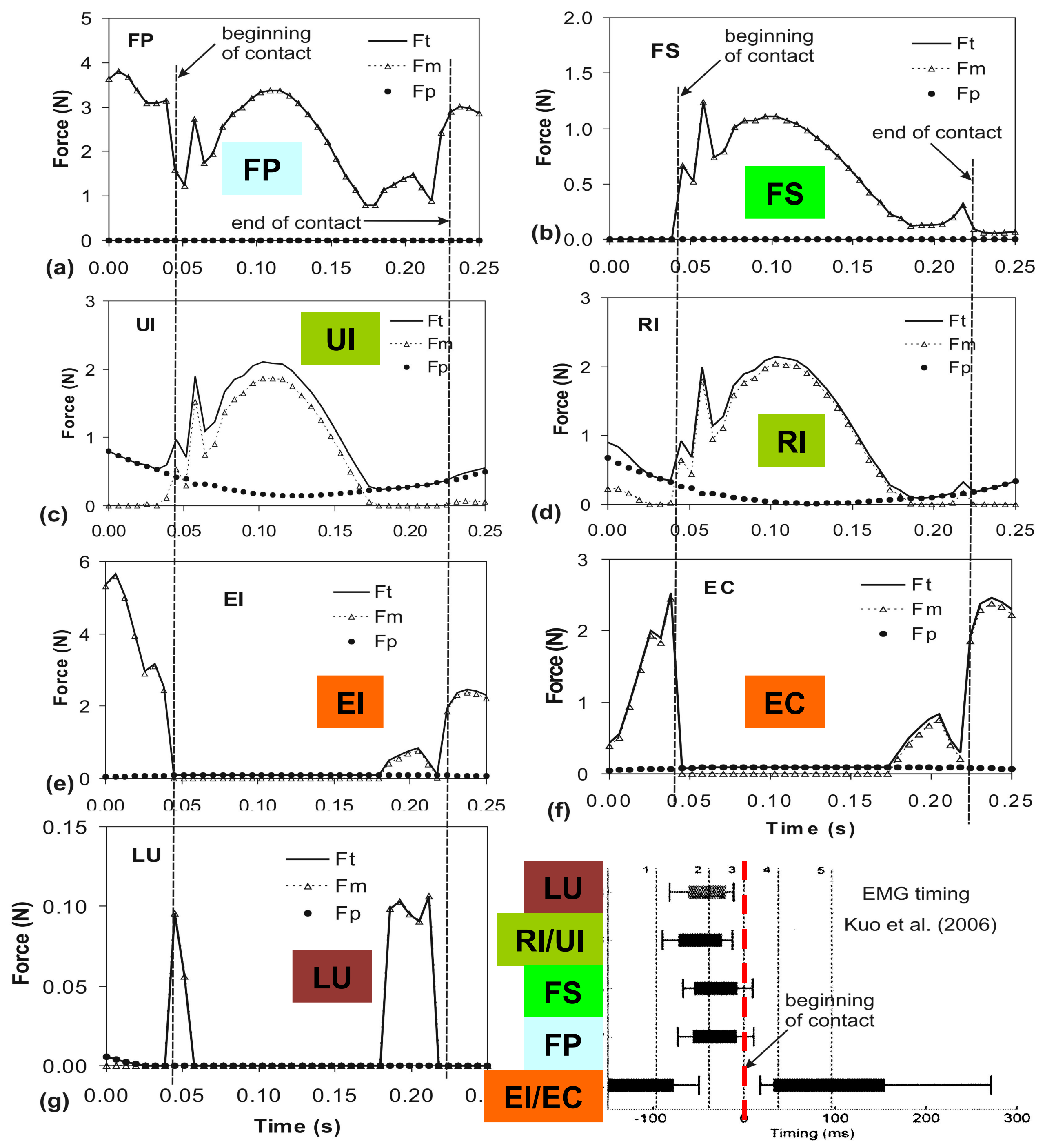
Joint Torques



Muscle Forces

F_{FS}/F_{tip} = 0.95

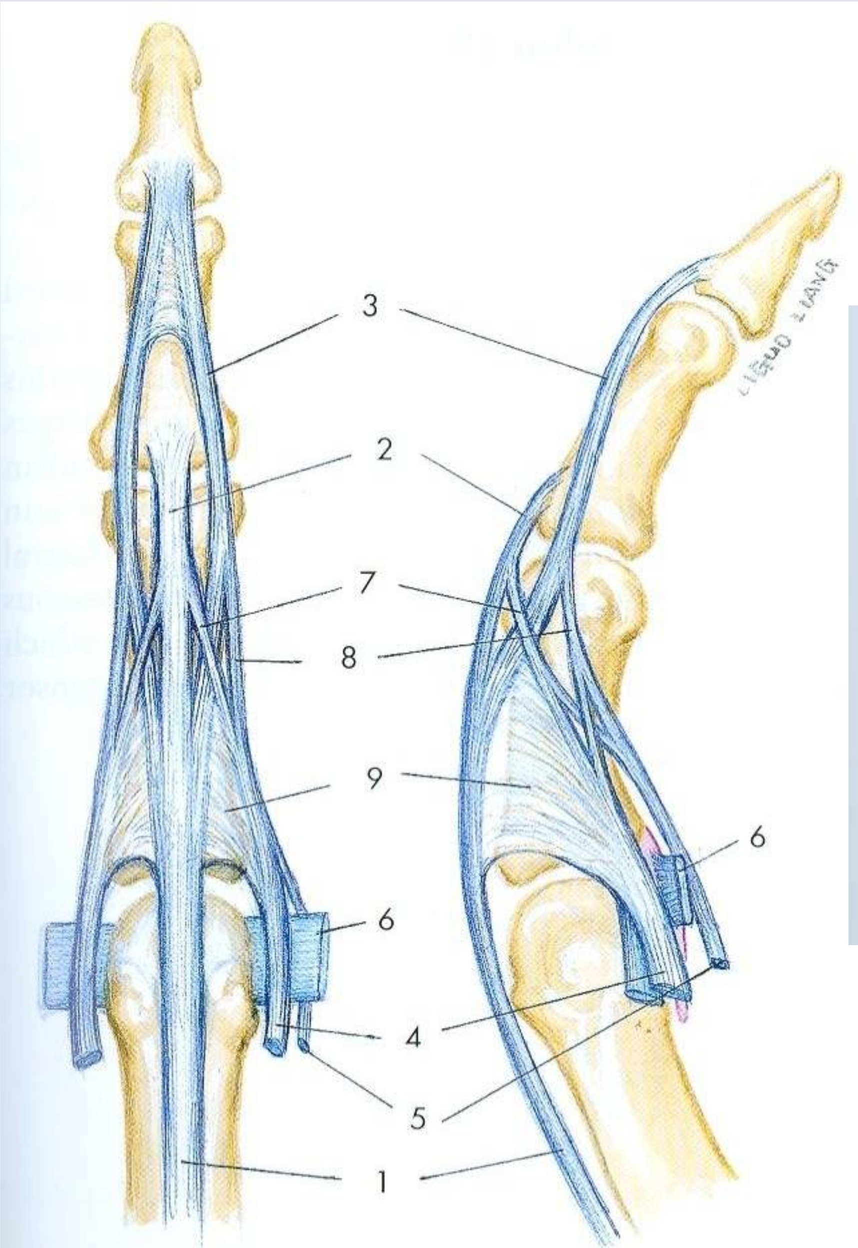
F_{FP}/F_{tip} = 2.90



Discussions

- The predicted maximal peak forces in the FS and FP tendons are consistent with the recent experimental data reported by Kursa et al. (2005), but much smaller than the early experimental data by Schuind et al. (1992) and Dennerlein et al. (1999).
- Predicted time sequence of the muscle loading is consistent with the EMG measurements by Kuo et al. (2006).
- Simulation results suggested that the muscle forces in the finger during tapping are mainly induced by the impact force at the fingertip.

Discussion: tendon network



1. Extensor tendon
2. Central band of the extensor tendon
3. Collateral band of the extensor tendon
4. Interosseous tendon
5. Lumbrical tendon
6. Deep transverse metacarpal ligament
7. Medial band of the intrinsic tendons
8. Lateral band of the intrinsic tendons
9. Arciform fibers

(Yu, Chase, and Strauch, 2004)

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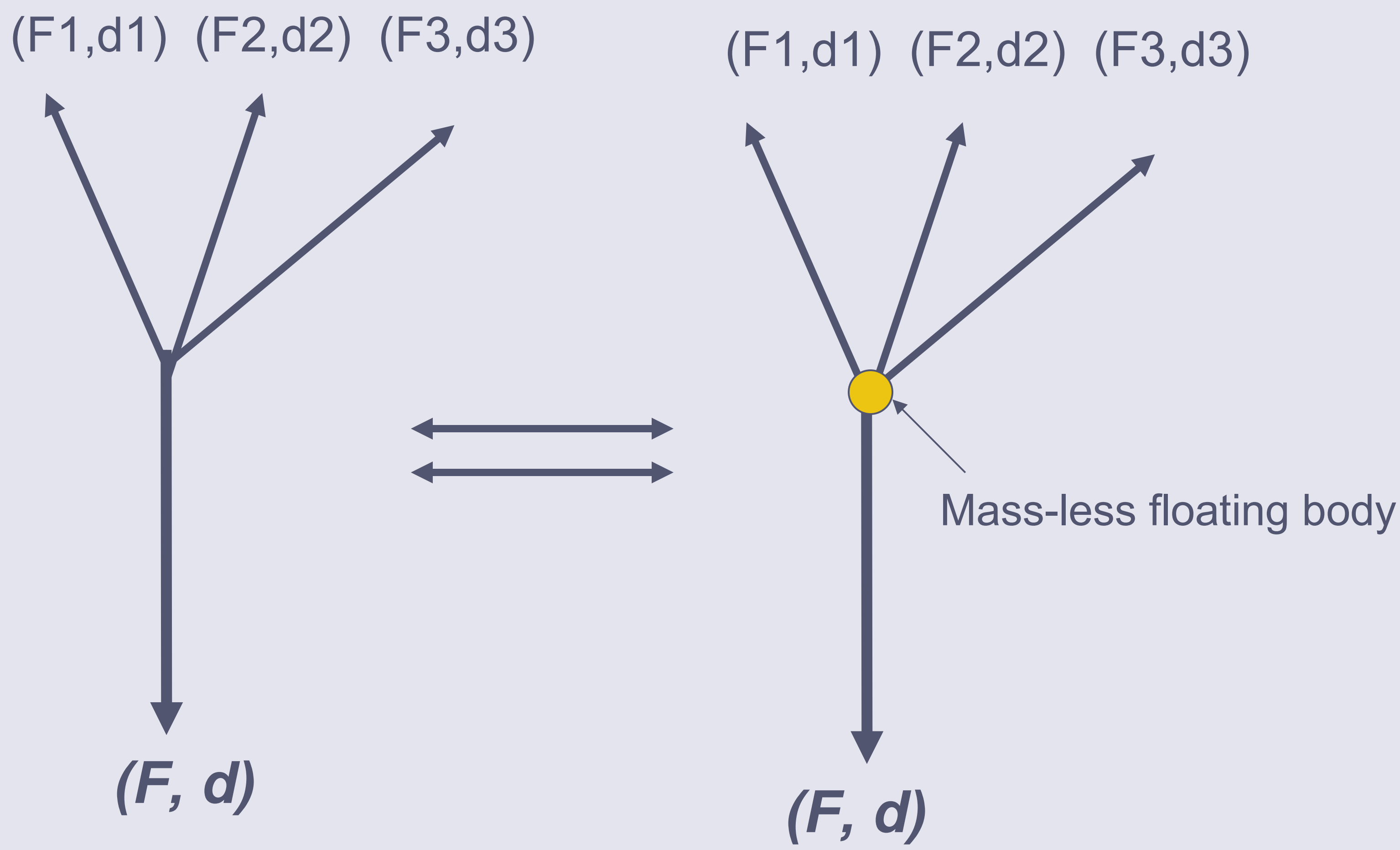
Discussion: tendon network
Ideal model: need forward dynamics



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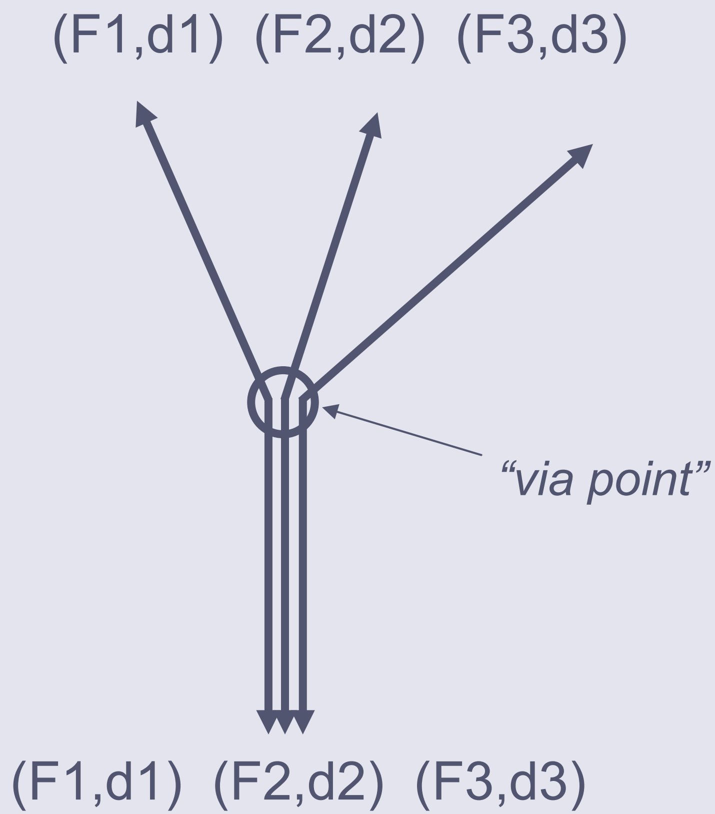
Discussion: tendon network
-- Approximation in inverse dynamics



$$F = F1 + F2 + F3$$

$$d = (d1 + d2 + d3)/3$$

Publication:

Wu JZ, An KN, Cutlip RG, Krajnak K, Welcome D, Dong RG. Analysis of musculoskeletal loading in an index finger during tapping. J Biomech. 2008, 41(3):668-76.

Thank You !

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