Vibration Analysis of Finger Using Non-linear FEM to Understand HAV Syndrome

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What is HAVS

Hand–Arm Vibration Syndrome

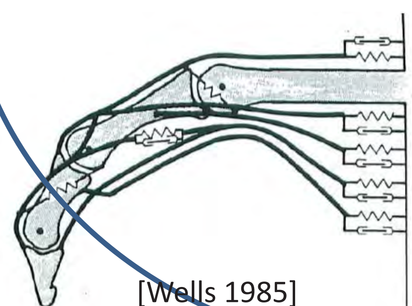
- Excessive vibration from Hand Tool causes MSD
- Muscoskeletal
- Sensorineural
- Vasospastic

Raynaud’s disease
(blanching, numbness, pain)
affects motor function

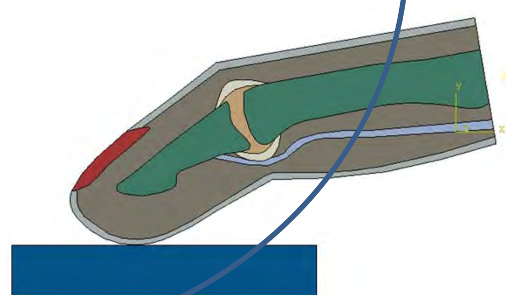
Modeling Techniques

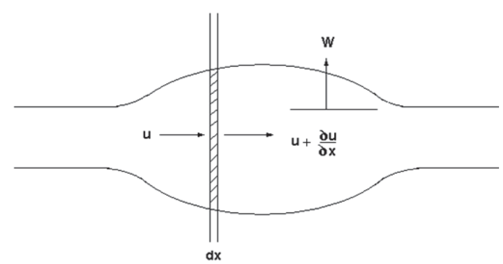
Frequency

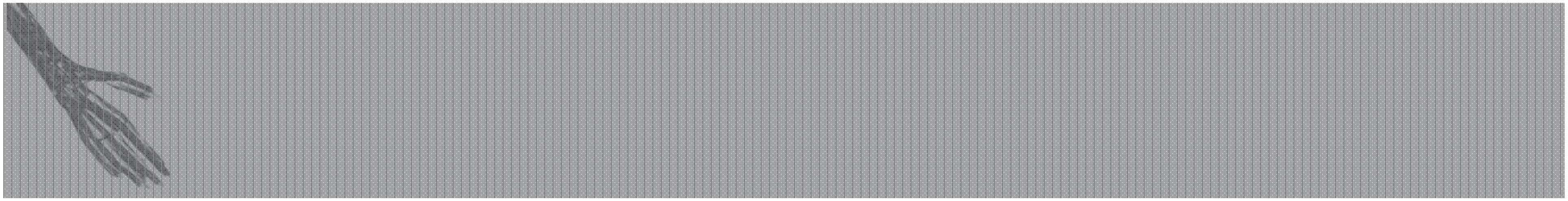
- Low (0-50Hz)
  - Lumped parameter model
  - Vibration Transmission
  - Joint & Muscle Pain
- Mid (50-250Hz)
  - Flexible Body Model, FEA
  - Strain Energy Absorption
  - Tissue Damage
- High (250-)
  - Wave Propagation
  - Interference
  - Blood flow disruption



[Wells 1985]





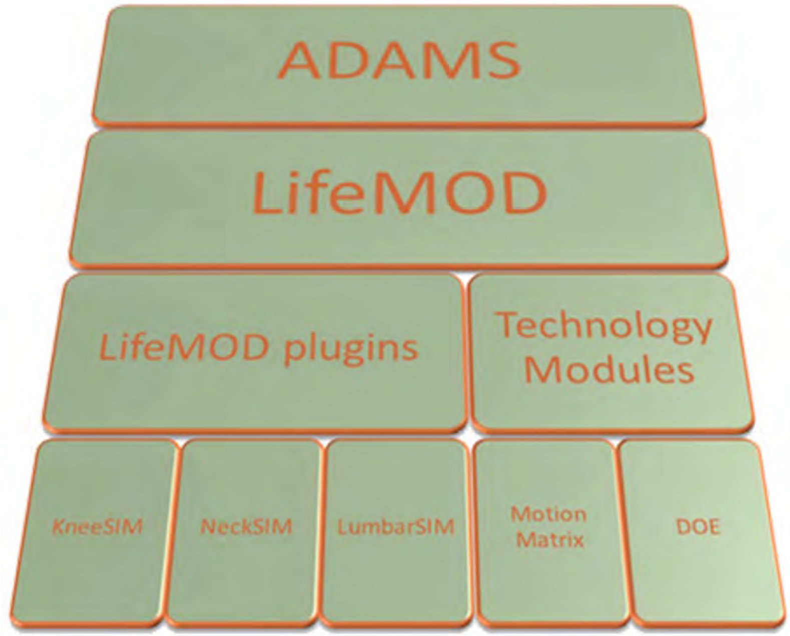


Modeling | Lumped Parameter

Kinematic Model

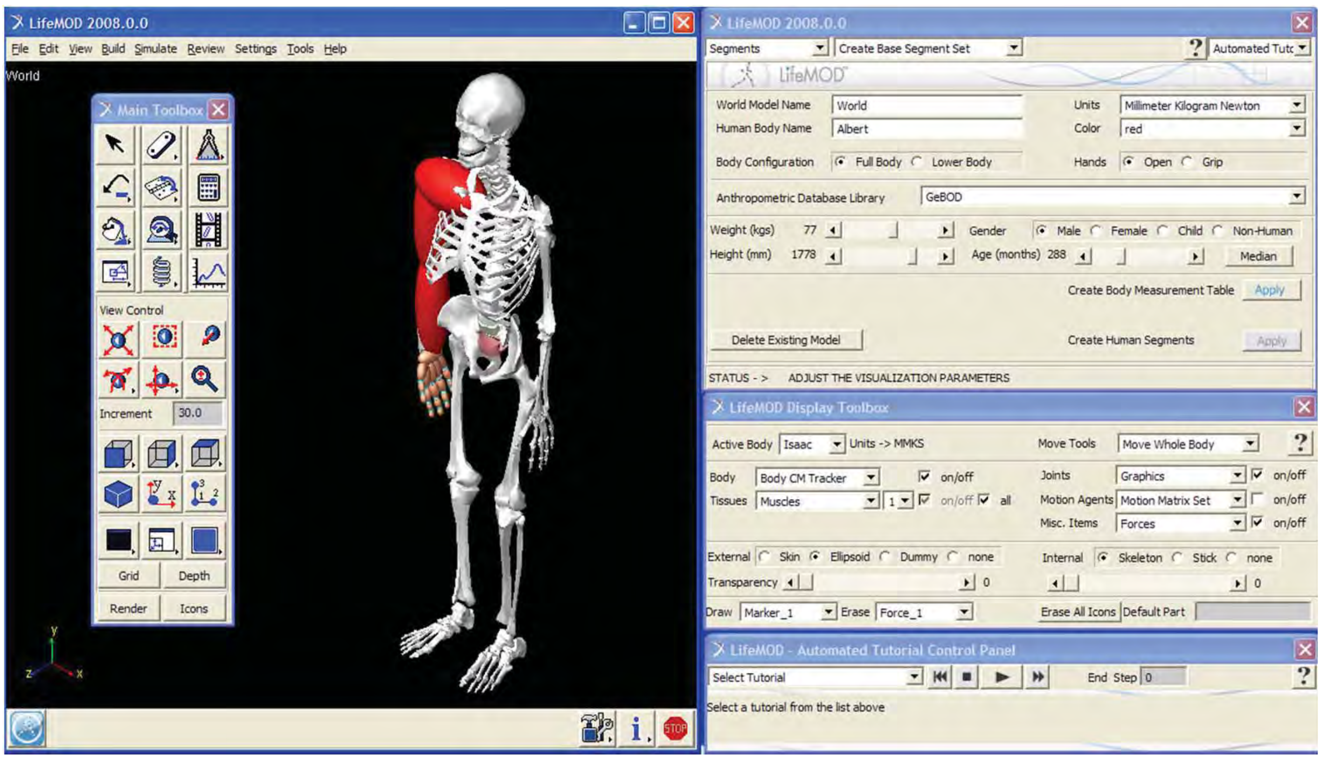
LifeMOD A plug-in of ADAMS

- plug-in module to the ADAMS physics engine.
- Human models can be combined with any ADAMS model for full dynamic interaction.
- Additional plug-ins – e.g. KneeSIM, NeckSIM - are available through LifeMOD.

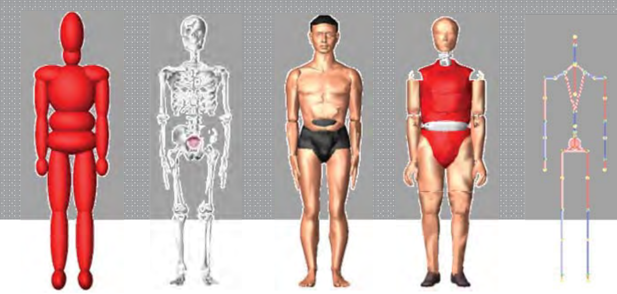


* http://www.lifemodeler.com/ LM_Manual

HandSIM A plug-in of LifeMOD

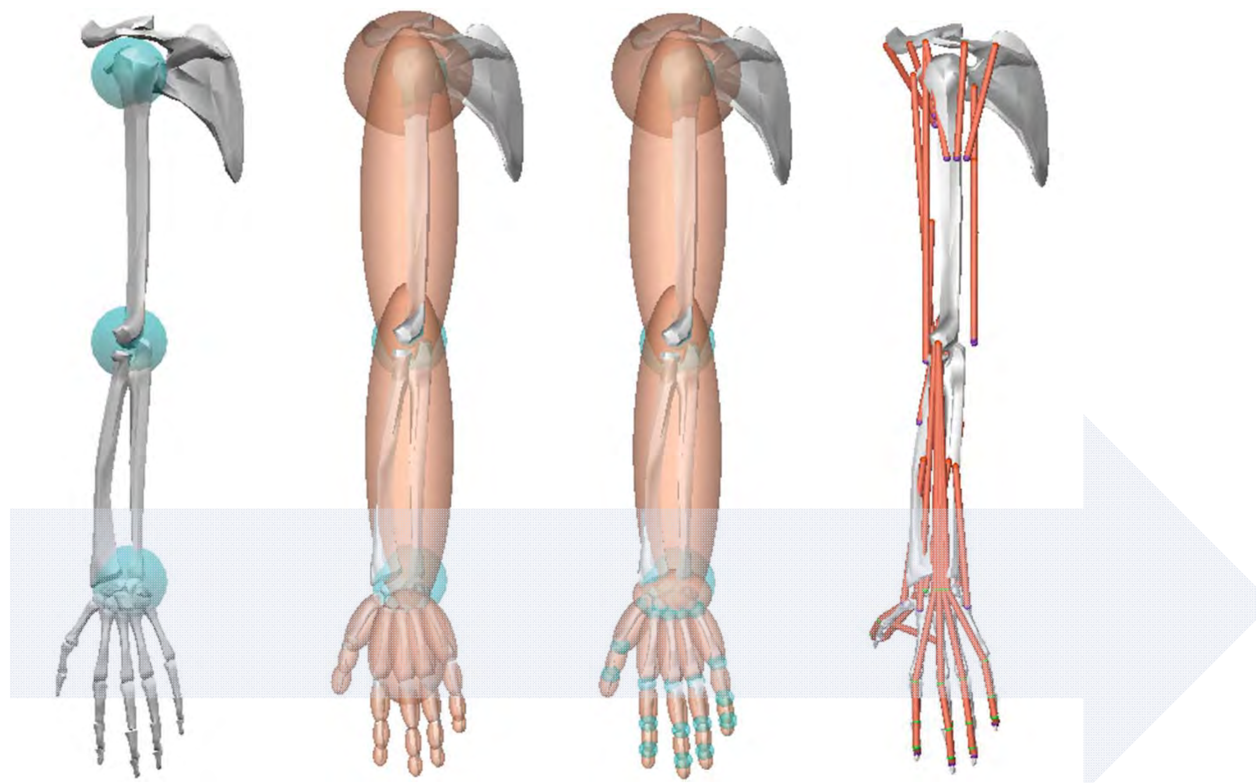


Building Model



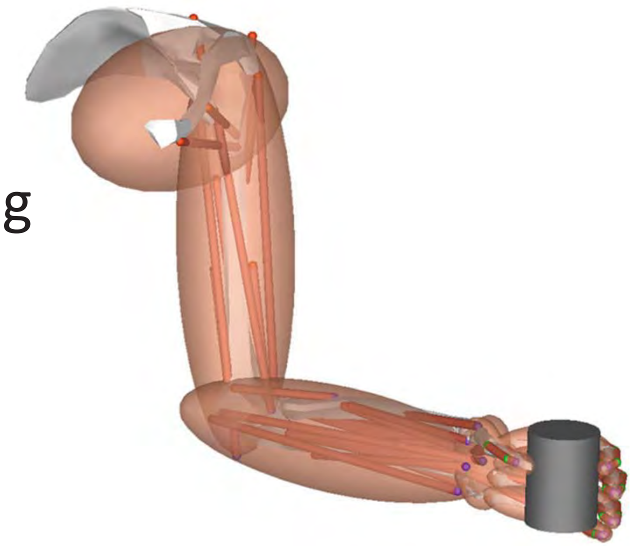
- Building a Model
  - Segments
  - Joints
  - Soft Tissues

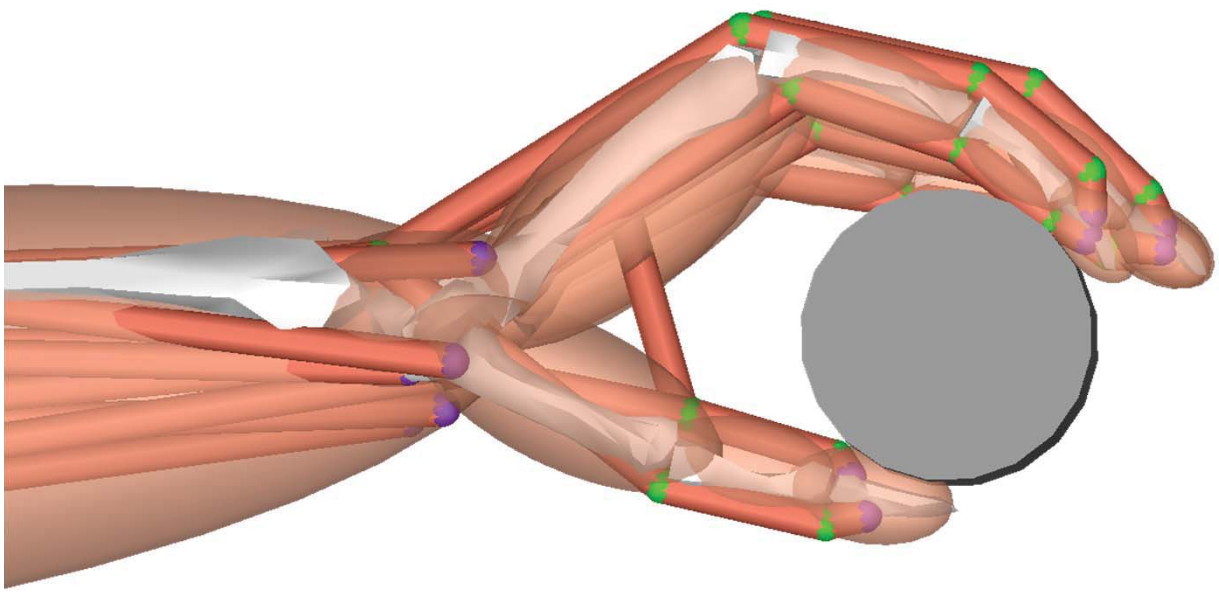
Muscle Model
  - Passive Modeling
  - Active Modeling



Kinematic Modeling

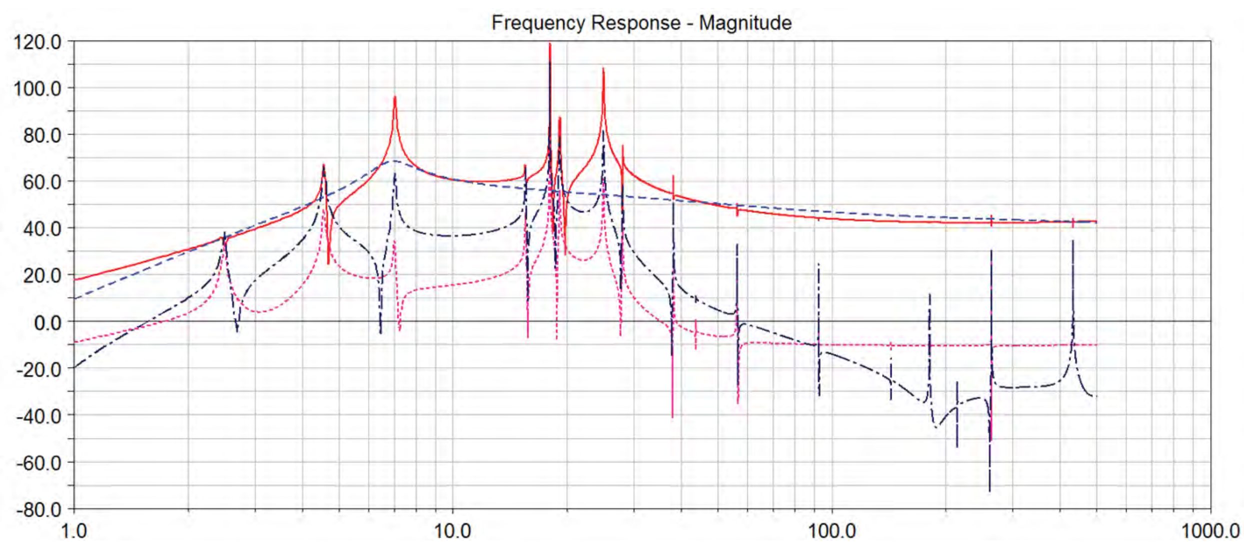
- Accurate geometry/mass properties
- 50^{th} percentile human male attributes
- Tri-axial stiff joints, muscle with tissue wrapping
- Tension only muscle and “tone” defined





- Posture prediction
- Pre-load estimation

Results: Frequency Response



Joint 12 (red) vs. elbow joint (magenta) vs. wrist (blue)
z- accelerations upon input acceleration of $1m/s^2$ at tip of cm of index finger.

Assumptions/Issues of Lumped Model

Assumptions – Lumped Parameter based Model:

- Predefined degrees of freedom
- Linearity, non-viscous parameters
- Hand-tool rigid body based (only force and displacement)
- Assuming small displacements at the handle location, the dynamic response of the hand-arm system is considered to be uncoupled along its three orthogonal directions. ISO 8727

Issues:

- High static deflections
- Lower natural frequencies with less mass and stiffness values in the parameters
- Dissipative property and other nonlinear behavior cannot be seen.

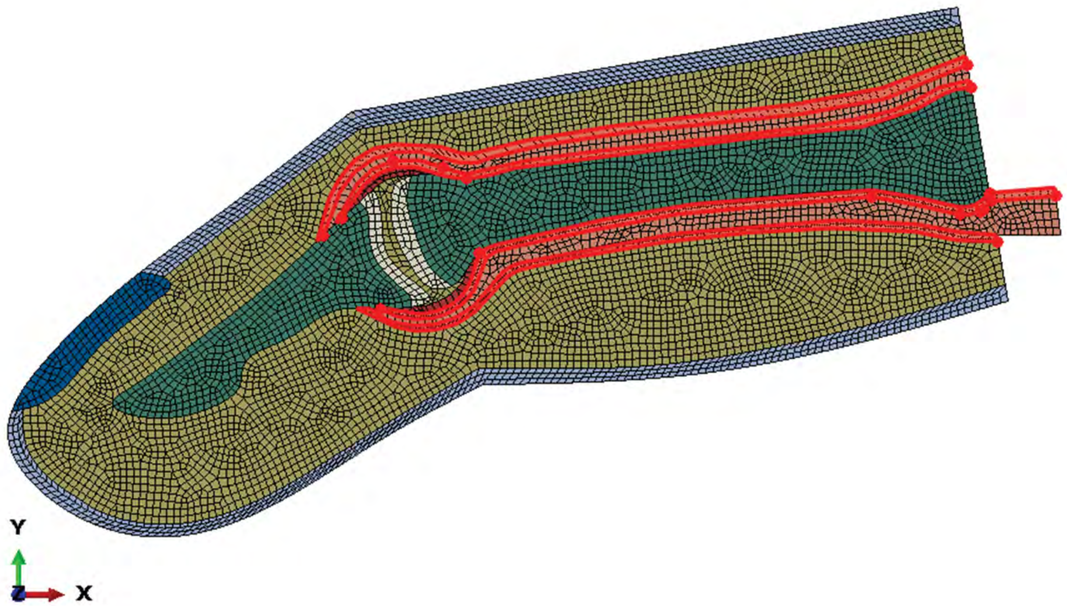
Modeling | Flexible Body

(Finite Element)

SIMULIA

ABAQUS

Finite Element Model



Bone

Soft Tissue

Skin

Nail

Tendon

Synovial Fluid

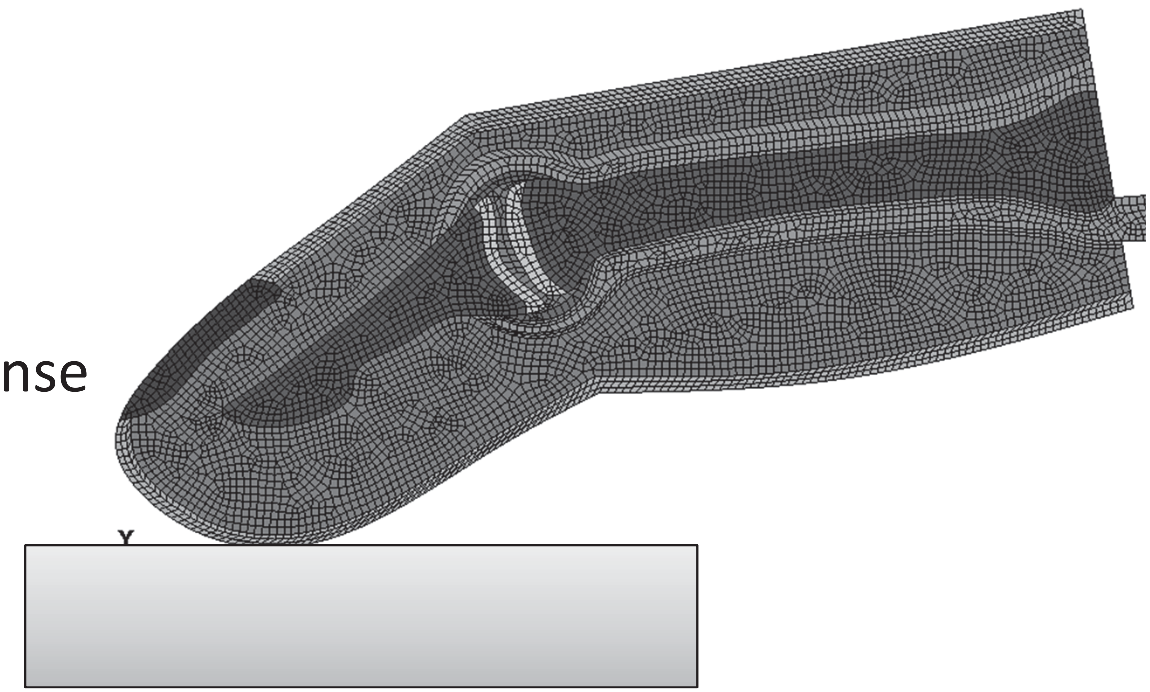
Cartilage

Ligament

Sheath

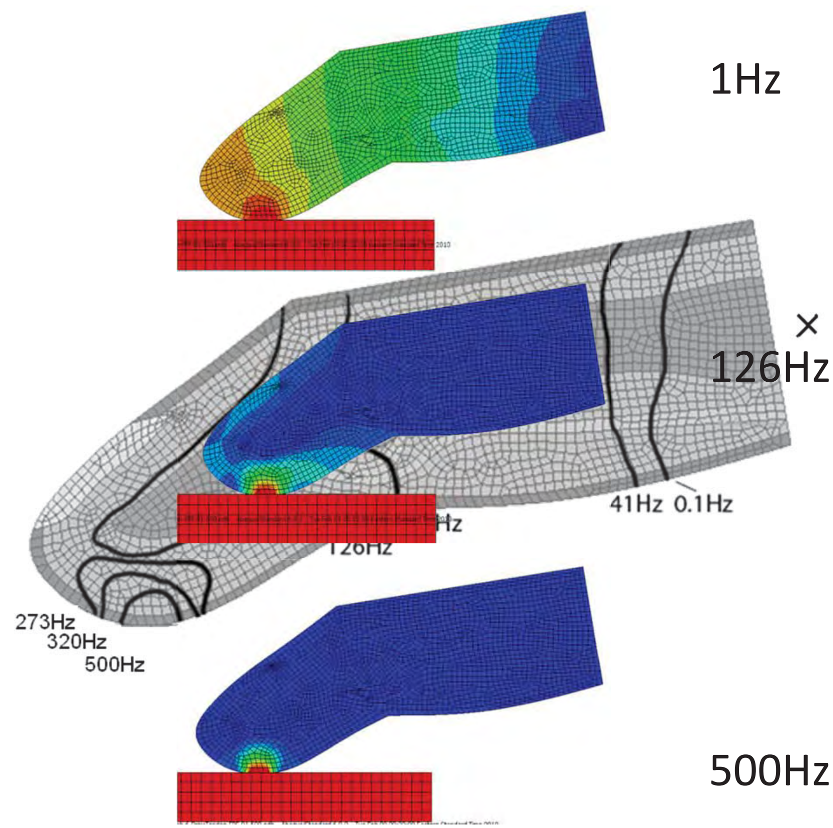
Finite Element Model

- Pre-loaded tendon
- Static deflection
- Dynamic simulation
- Modal Extraction
- High frequency response



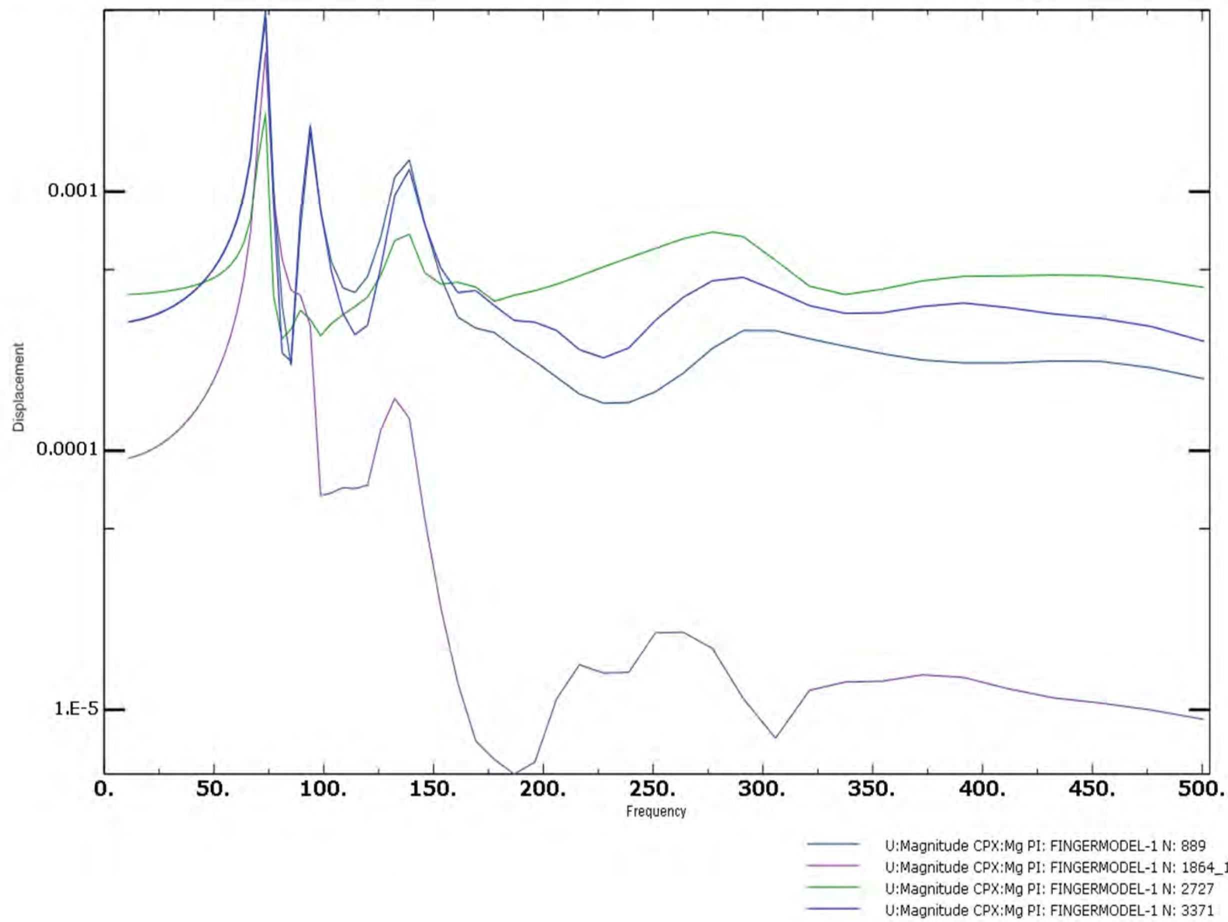
Results: Dynamic response

- Frequency response
- Stress/Strain evaluation
- Localized behavior with higher frequency



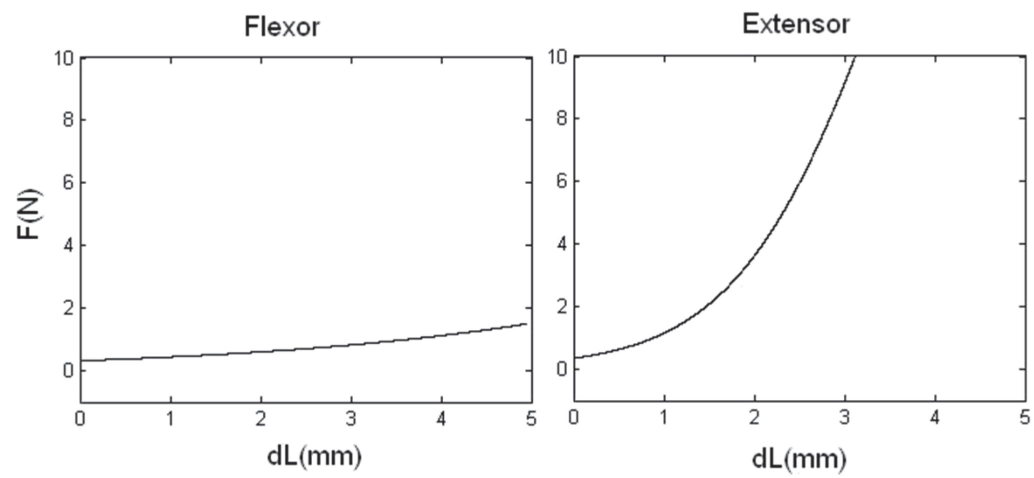
Results: Frequency Response

Mode	Freq(Hz)	Mode	Freq(Hz)
1	62.86	11	192.26
2	73.69	12	196.72
3	92.04	13	206.72
4	107.43	14	214.26
5	128.86	15	220.78
6	134.83	16	226.78
7	142.45	17	230.38
8	159.85	18	235.70
9	168.29	19	241.83
10	179.34	20	243.39

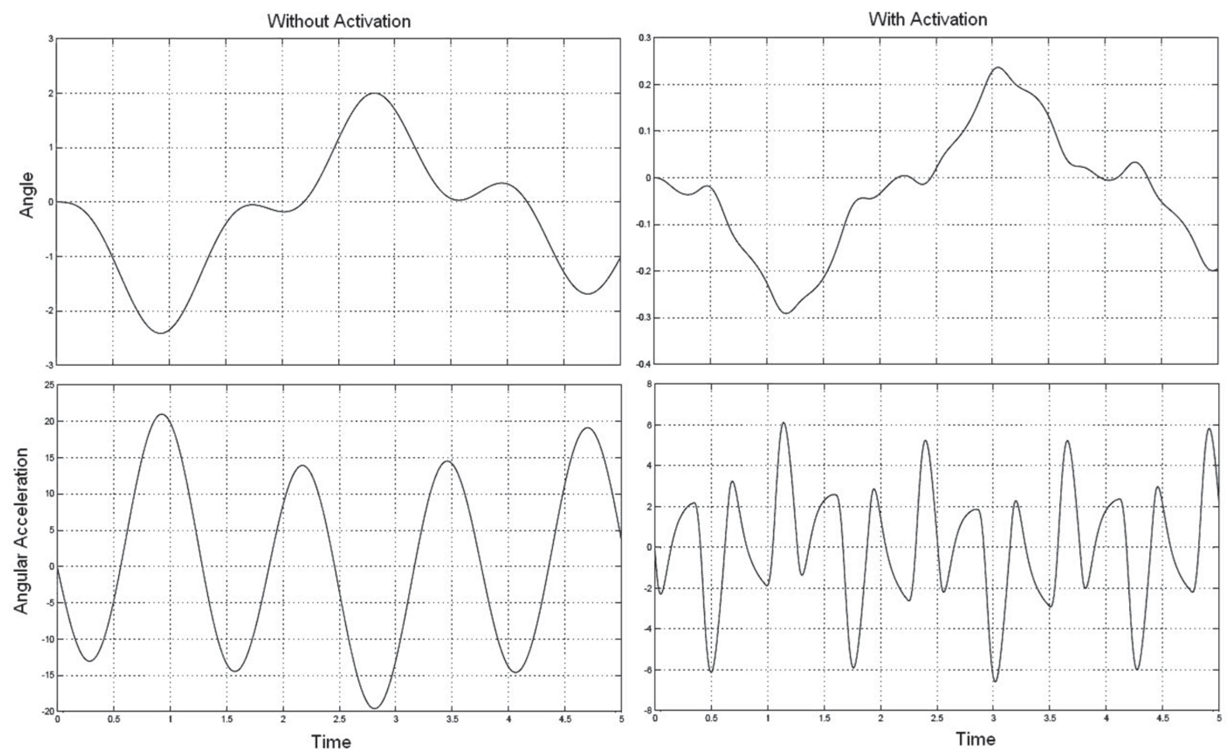


Observation 1/2: Relative Muscle Contribution

- Nonlinear response
- Flexor four times size of Extensor
- Short and long range force output
- Static vs. Dynamic counterbalance



Observation 2/2: Activated Response

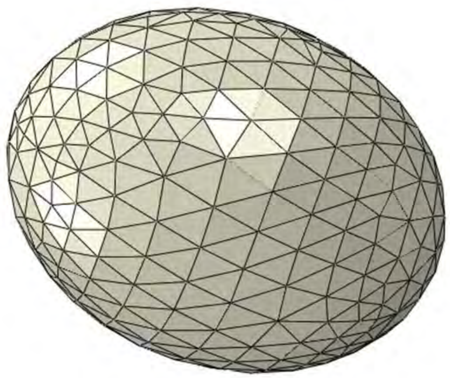


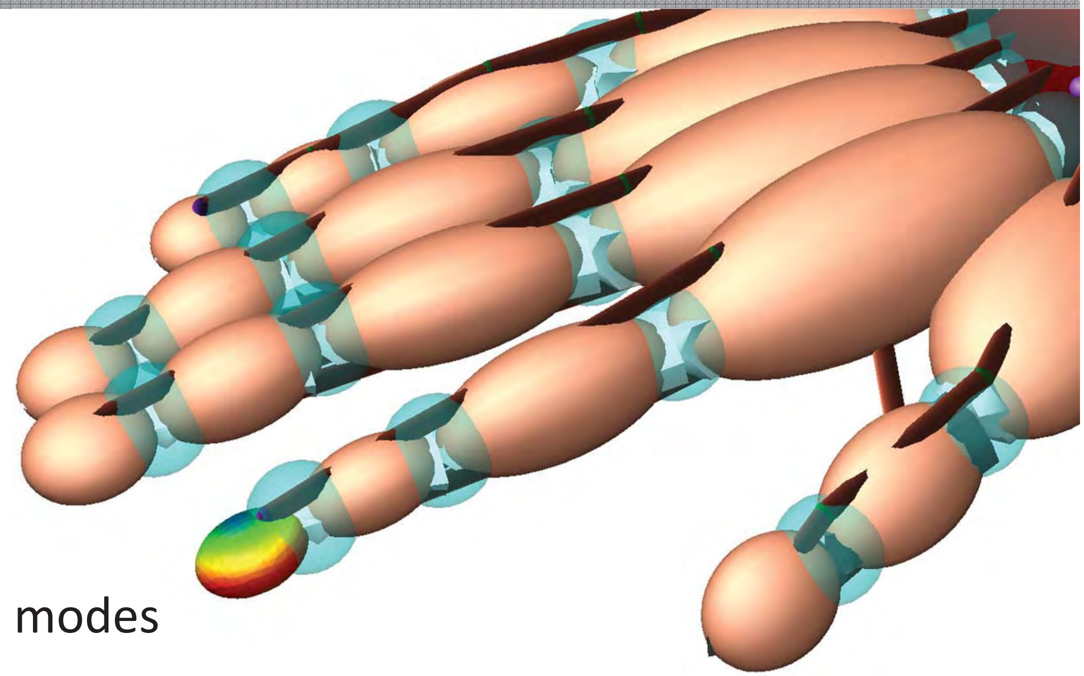
Distal Interphalangeal (DIP) Joint

Coupled Modeling | Rigid + Flexible

Kinematic + Finite Element

Rigid-Flexible Coupled Approach





Steps

- LifeMOD – export IGES
- ABAQUS – substructure – extract modes
- Run Macro - Mode Neutral File
- Import LifeMOD replace rigid with Flex

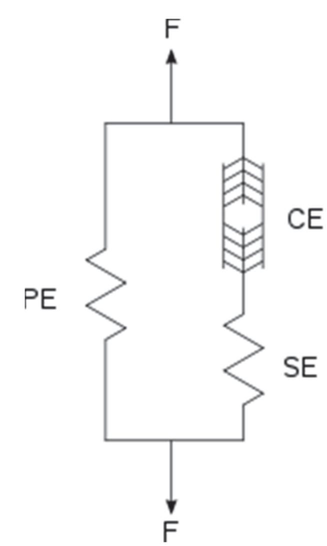
Stress/Strain Contour on a Flexible part

Discussion 1/3

- Damping can occur by three mechanisms:
  - passive damping properties of elastic tissue and tool surface
  - force-velocity properties of active muscle
  - well-timed activation pulses that occur when a muscle is in the lengthening phase of the vibration.

  (Low freq)
- High freq – passive spring series element

(Hill's model)



Discussion 2/3

- Extrinsic (Flexor) creates static grip force.
- dynamic load –Extensor & Intrinsic
- Interphalangeal joint stabilized with co-activation
- Transmission of vibration increases with co-contraction.
- Higher grip force -> higher impedance and higher resonance (muscles stiffened)
- Higher muscle force higher stiffness lesser is the deformation needed to absorb same energy

Discussion 3/3

- Under dynamic loading friction coefficient of articular cartilage reduces
- Fast Dynamic load – elastic behavior (approx.)
- Tougher the component and the greater the volume more strain energy it is likely to absorb.
- Capacity of absorbing strain energy
  - Highest - Tendon 65 times of muscle
  - Bone 55 times of muscle
  - Lowest - Muscle

Conclusion/Future Work

- Improve Combined approach (Kinematic and FE)
- High frequency -> faster Type II (vs. Slower Type I)
- Rest of the segments of hand
- Contact stress evaluation
- Fatigue model

Thank You

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PRPS
pilot research project symposium

University of Cincinnati
11th Annual
Pilot Research Project Symposium
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Produced by Kurt Roberts Department of Environmental Health