Assessing Assumptions in Kinematic Hand Models: A Review

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I. Introduction

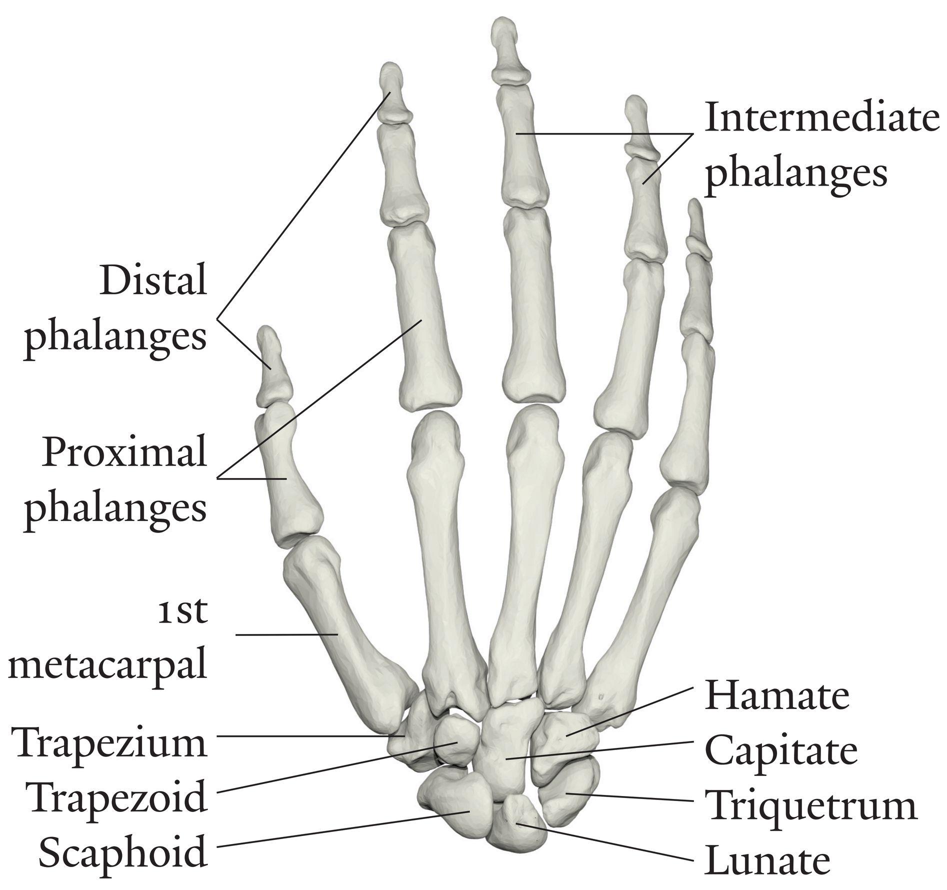
Because of the incredible complexity of the human hand, simplifications are generally made during kinematic modeling. However, these simplifications have important implications for the final model accuracy. This work provides a brief overview of human hand biomechanics, followed by a review of kinematic hand modeling. Assumptions made by these models are then discussed, along with the effects on overall model accuracy. General suggestions are then provided for future modeling applications.

II. Related Work

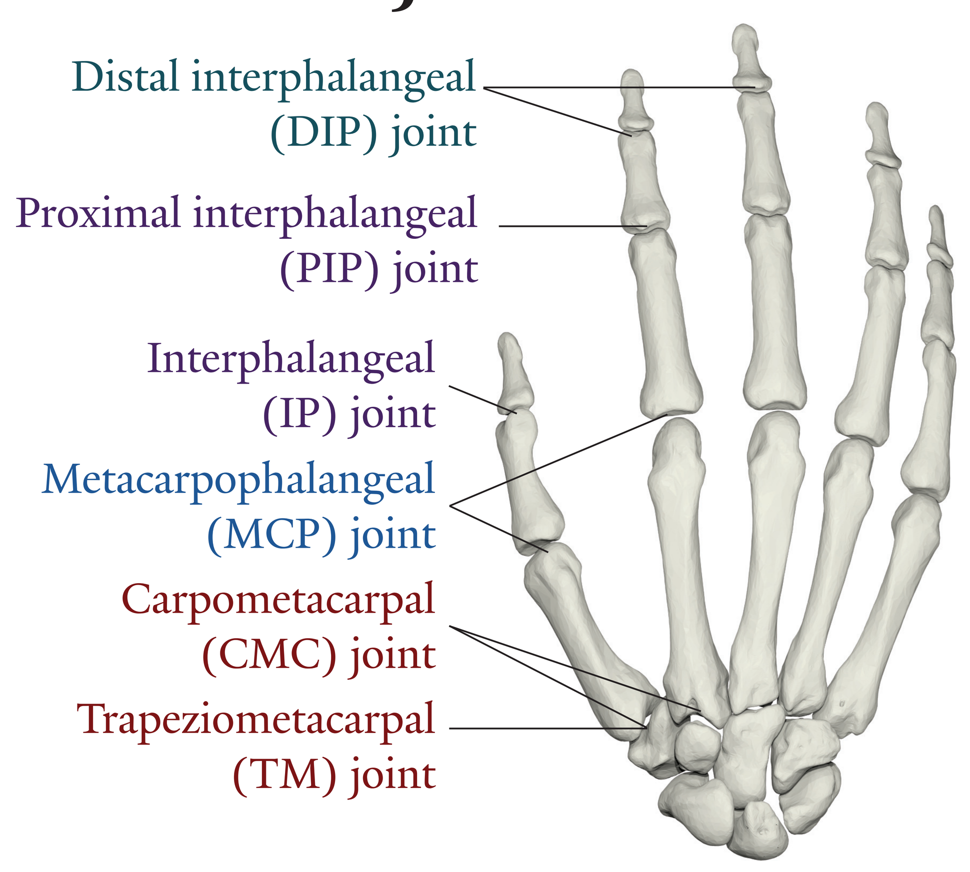
- [Brand and Hollister 1999] and [Kapandji 1982] describe hand biomechanics
- [Valero-Cuevas 2005] discusses using hand models to study neuromuscular control
- [Pavlovic et al. 1997] and [Erol et al. 2007] review gesture and pose recognition techniques
- [Sancho-bru et al. 2011] gives short summaries of a wide variety of topics in hand modeling

III. Hand Anatomy Overview

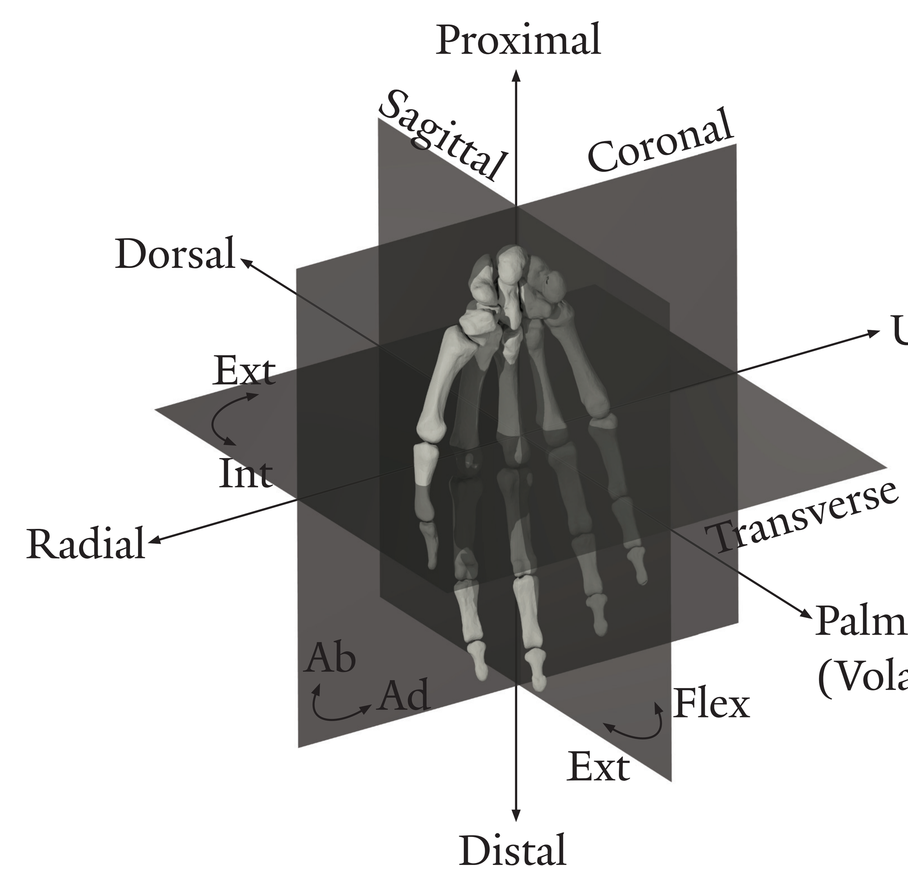
Bones



Joints

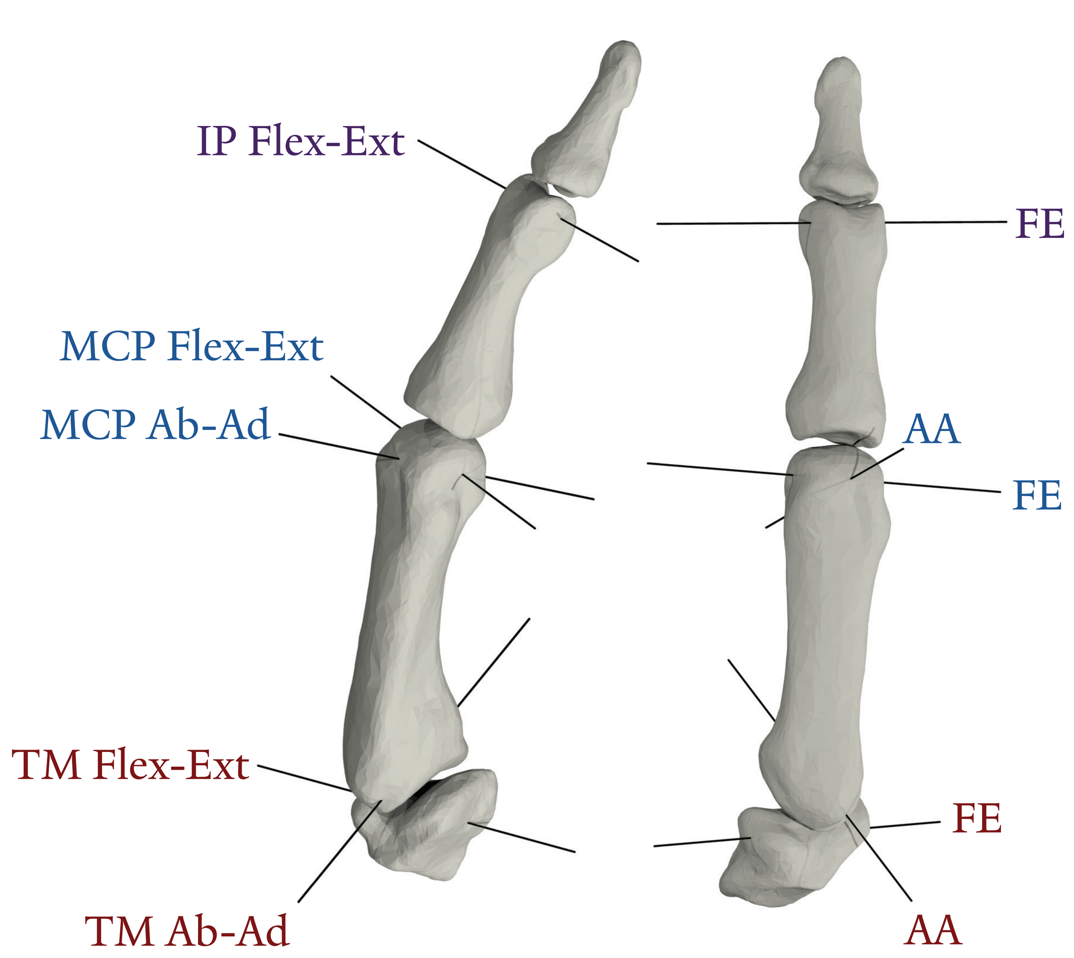


Anatomical Conventions



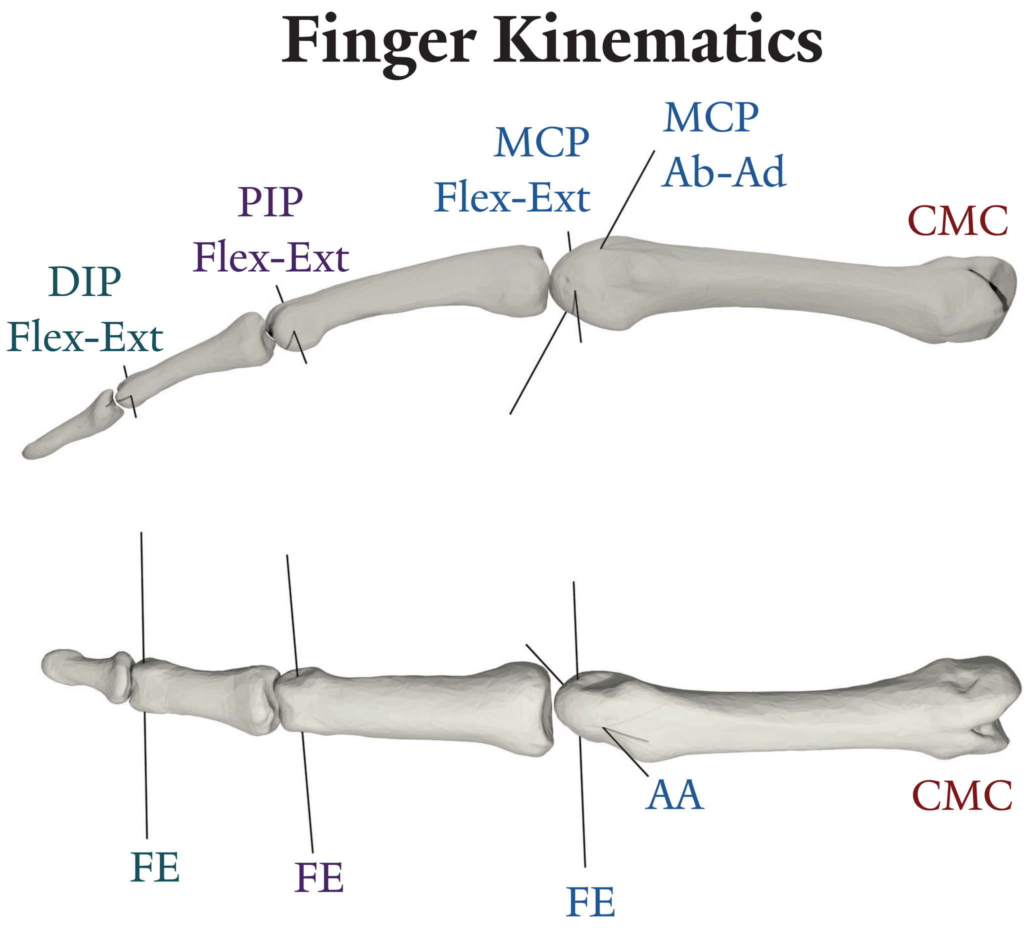
IV. Kinematic Modeling and Assumptions

Thumb Kinematics



Thumb Joint		DOF	Description
IP	Interphalangeal	FE	• 1 DOF (e.g. [Hollister et al. 1995]) • Axis is at 83 ± 4° relative to the midline of the bone, and 5 ± 2° relative to the bone palmar surface [Hollister et al. 1995], so assuming that the axis is perfectly perpendicular will introduce error
MCP	Metacarpophalangeal	FE AA	• 2 DOF, non-orthogonal, non-intersecting axes [Hollister et al. 1995] • MCP moves in coordination with the TM, so it may be possible to model a healthy thumb using less than 4 DOF for MCP and TM motion [Brand and Hollister 1999] • Angle between Ab-Ad and F-E axes is 85 ± 12° [Hollister et al. 1995] • Anatomical variability in kinematic ordering of MCP axes [Santos and Valero-Cuevas 2006] may help explain a bimodal distribution for MCP range of motion
TM	Trapeziometacarpal	FE AA	• 2 DOF, non-orthogonal, non-intersecting axes [Hollister et al. 1992] • Often modeled with orthogonal, intersecting axes. [Cerveri et al. 2008] found 4 mm RMS error for this model vs. 2 mm RMS error for a non-orthogonal, non-intersecting version • The trapezium is generally assumed fixed, but may actually translate by about 2 mm [Pearlman et al. 2004]

Finger Kinematics



Finger Joint		DOF	Description
DIP, PIP	Distal Interphalangeal, Proximal Interphalangeal	FE FE	• 1 DOF • PIP and DIP joint become progressively oblique during flexion [Kapandji 1982] and vary by up to 14° [Miyata et al. 2005] • However, often modeled with fixed axes perpendicular to the bone axis (planar finger model)
MCP	Metacarpophalangeal	FE AA	• Orthogonal, intersecting axes, Ab-Ad at 60° of flexion [Brand and Hollister 1999] • Axis position may vary by as much as 2 mm [Weiss et al. 2004] • Passive 3rd DOF may exist
CMC	Carpometacarpal	1	• Finger CMC joints allow about 20° of motion, if modeled by revolute hinges between the joints [Stillfried and Smagt 2010] • Little finger CMC joint is a saddle joint and helps to produce cupped palm shape [Kapandji 1982]

V. Conclusion

- Metacarpal motion should not be omitted in most models
- For high precision finger models, non-perpendicular PIP/DIP axes or even MCP axis motion should be used
- The five link thumb model [Giurintano et al. 1995] with non-orthogonal, non-intersecting axes is an accurate representation of overall thumb motion
- Modeling trapezium motion could enhance thumb model accuracy

VI. Open Questions

- The relative accuracy of universal joint models and non-orthogonal, non-intersecting axis models for the thumb metacarpophalangeal (MCP) joint is unclear
- Trapezium motion has not been characterized in detail
- Little data is available describing unactuated, compliant degrees of freedom in the hand (e.g. passive axial finger rotation)