The Teleology of the Thumb: On Purpose and Design

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The Andrew J. Weiland Medal is presented by the American Society for Surgery of the Hand to a midcareer researcher dedicated to advancing patient care in the field of hand surgery. The Weiland Medal for 2017 was presented to the author at the annual meeting of the American Society for Surgery of the Hand. The purpose of this article is to present current evidence on how biomechanics and morphology influence the pathophysiology of thumb carpometacarpal joint osteoarthritis. *(J Hand Surg Am. 2018;43(3):248−259. Copyright © 2018 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Thumb osteoarthritis, carpometacarpal, trapeziometacarpal, kinematics, functional tasks.

Evolutionary development of the brain has afforded the accomplishment and possibility of the human hand.[1−6] In turn, the hand and thumb serve the human brain—the actuator and receiver to perform simple activities of daily living and, to the artist or athlete, highly coordinated movement. The teleology of the trapeziometacarpal joint—the thumb carpometacarpal (CMC) joint—represents the inextricable relationship of function to form. The CMC's unique saddle shape represents a complex design that accommodates similarly complex demands: mobility, to produce precision pinch and firm grasp, and stability to manipulate or position an object.[7,8] The paradox of motion arguably drives the design.

The conventional wisdom regarding the etiology of CMC joint osteoarthritis (OA) implicates ligamentous laxity, postmenopausal hormonal imbalance, and the wear and tear of daily life. Despite being the most common site for surgical treatment in the hand,[9] controversy exists regarding the varying roles of these factors as primary, secondary, or interrelated contributors.[3,6,10,11] Compelling research on systemic OA suggests a more intricate balance of joint homeostasis, with pathomechanics considered the driving force to upregulate inflammatory markers and injure the surrounding soft tissue structures of the joint itself.[12−14] With the premise of OA as an organ system gone awry, we review current evidence that thumb CMC joint OA reflects its teleology—its purpose and design.

AS TO PURPOSE—BIOMECHANICS

The thumb ray, in the neutral state, is out of plane to the rest of the hand but opposes the fingers, ever ready for digital communication. Three tasks representing the breadth of thumb CMC stability, mobility, and demands in opposition include lateral key pinch, grasp, and torsional grip such as a jar twist.[6,10] In pinch, the thumb pad engages another finger and, in grasp, acts in concert with the fingers to close around an object. Fine motor intrinsic muscles stabilize the joint for key pinch. Grasp—prehension—typically requires forceful isometric load to accommodate a larger spherical or cylindrical shape, actively engaging intrinsic and extrinsic muscles. Opening a jar adds a torsional or shear load to the grasp position. The CMC joint carries extraordinary load in these routine tasks, and cadaveric biomechanical studies indicate that grasp

From *The Robert A. Chase Hand Center, Stanford, CA.

Received for publication November 26, 2017; accepted in revised form January 3, 2018.

No benefits in any form have been received or will be received related directly or indirectly to the subject of this article.

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0363-5023/18/4303-0008$36.00/0
https://doi.org/10.1016/j.jhsa.2018.01.002

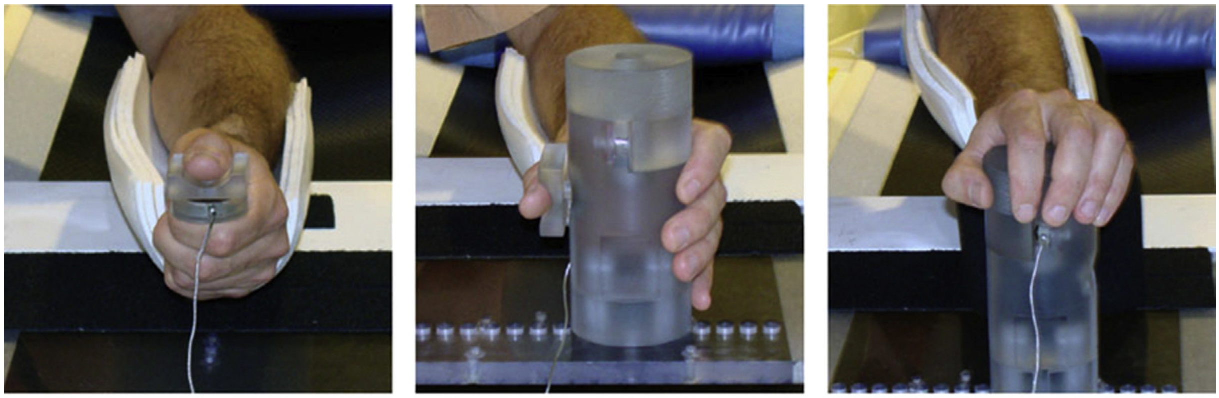

FIGURE 1: The 3 positions (left to right) of lateral key pinch, cylindrical grasp, and jar twist for functional and kinematic assessment, measured with infrared motion capture markers and CT markerless registration. The load cell measuring force is embedded in the positioning jigs. (Image reproduced from Luker KR, Aguinaldo A, Kenney D, Cahill-Rowley K, Ladd AL. Functional task kinematics of the thumb carpometacarpal joint. *Clin Orthop Relat Res*. 2014;472[4]:1123−1129.[18])

produces a 10-fold increase in stress at the CMC joint compared with pinch.[15]

What is the *in vivo* evidence of force generation and motion, supporting laboratory studies? The answer lies in analyzing the interdependent joint motion of the trunk and extremities as well as discrete motion at the CMC joint. The hand is the terminus of coordinated, integrated movement of the upper extremity. Like the early hominins, good trunk and leg support, freeing a mobile shoulder, permits 3-dimensional, spherical opportunity for the hand. This linkage creates powerful mechanical coupling for hand manipulation.

Examining abnormal motion best elucidates normal coordinated function. We have examined the hand, upper limb, and trunk in purposeful motion of reach and grasp of an object as well as pinch, grasp, and jar opening with marker-based kinematic analysis.[16−18] Like with abnormal gait, an errant golf swing,[19] or the contracted space of a spastic upper limb,[16,17] compensatory motion that is phasic in nature can be quantified. In each study, subjects with abnormal motion took longer to complete a task, used substitutions, and had compromised efficiency. For hand tasks, typical substitutions include shoulder abduction with elbow flexion to improve mechanical advantage. The adducted, arthritic thumb dynamically compensates with increased metacarpophalangeal abduction and extension.[18] Our quantification of complex interactive hand and thumb motion in both normal and abnormal states provides target zones for emulating functional activity. We propose that this serves as a basis for creating training tools for rehabilitation, in both the nonsurgical and the perisurgical setting.

We have analyzed the functional tasks of key pinch, cylindrical grasp, and jar twist (Fig. 1) in asymptomatic, healthy subjects without radiographic disease, compared with those with early symptomatic arthritis (modified Eaton 0/1[20]). The cylindrical grasp demonstrated weakness in the early OA population when adjusting for age, sex, and handedness. Standard gross grasp dynamometer measurements in these subjects showed no difference in comparison with asymptomatic controls.[21] In addition, key, tripod, and tip pinch diminished in the early OA population compared with controls, with key pinch the most robust predictor of OA.[22] This suggests sensitive measurements exist for early, symptomatic disease, which may complement and refine nonsurgical joint protection and strengthening protocols.

The discrete and complex nature of the CMC joint poses a challenge to define during purposeful, coordinated motion. Micromotion at a discrete joint may be analyzed with computed tomography (CT), with markerless motion analysis protocols adopted from large joint (hip and knee) kinematic analysis, as well as the wrist dart-thrower's motion.[23,24] Our 10-year longitudinal, multi-institutional investigation of the thumb CMC joint examines age, sex, and radiographic disease and CT kinematics of the 3 functional tasks performed at 80% effort as measured by positioning jigs with an embedded load cell (Fig. 1). Defining neutral with a thumb orthosis adjusted for the subject's hand size, we have measured position based on segmented joint morphology for neutral, extension, flexion, abduction, and adduction as well as loaded and unloaded pinch, jar twist, and grasp.[25]