SCIENTIFIC ARTICLE

In Vivo Kinematics of the Trapeziometacarpal Joint During Thumb Extension-Flexion and Abduction-Adduction

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Purpose The primary aim of this study was to determine whether the *in vivo* kinematics of the trapeziometacarpal (TMC) joint differ as a function of age and sex during thumb extension-flexion (Ex-Fl) and abduction-adduction (Ab-Ad) motions.

Methods The hands and wrists of 44 subjects (10 men and 11 women with ages 18–35 y and 10 men and 13 women with ages 40–75 y) with no symptoms or signs of TMC joint pathology were imaged with computed tomography during thumb extension, flexion, abduction, and adduction. The kinematics of the TMC joint were computed and compared across direction, age, and sex.

Results We found no significant effects of age or sex, after normalizing for size, in any of the kinematic parameters. The Ex-Fl and Ab-Ad rotation axes did not intersect, and both were oriented obliquely to the saddle-shaped anatomy of the TMC articulation. The Ex-Fl axis was located in the trapezium and the Ab-Ad axis was located in the metacarpal. Metacarpal translation and internal rotation occurred primarily during Ex-Fl.

Conclusions Our findings indicate that normal TMC joint kinematics are similar in males and females, regardless of age, and that the primary rotation axes are nonorthogonal and nonintersecting. In contrast to previous studies, we found Ex-Fl and Ab-Ad to be coupled with internal-external rotation and translation. Specifically, internal rotation and ulnar translation were coupled with flexion, indicating a potential stabilizing screw-home mechanism.

Clinical relevance The treatment of TMC pathology and arthroplasty design require a detailed and accurate understanding of TMC function. This study confirms the complexity of TMC kinematics and describes metacarpal translation coupled with internal rotation during Ex-Fl, which may explain some of the limitations of current treatment strategies and should help improve implant designs. *(J Hand Surg Am. 2015;40(2):289–296.* *Copyright © 2015 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Thumb, TMC, *in vivo*, ROM, kinematics.

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THE UNIQUE[1] AND IMPORTANT[2] functions of the thumb are achieved largely through motion at the thumb trapeziometacarpal (TMC) joint. In their healthy state, the articular surfaces of the TMC joint are saddle-shaped. Based on this morphology, the TMC joint historically has been described to function as a universal joint[3–5] with 2 orthogonal axes of rotation centered within and aligned with the convex articular surfaces of the trapezium and first metacarpal (MC1). However, the limitation of this idealized model was revealed in an elegant cadaver experiment by Hollister et al.[6] Using a mechanical axis finder, they demonstrated clearly that the extension-flexion (Ex-Fl) and abduction-adduction (Ab-Ad) axes are nonorthogonal and nonintersecting.

Edmunds[7,8] proposed that the soft tissues surrounding the TMC joint generate a stabilizing screw-home motion at the end of thumb opposition, similar to the previously described screw-home mechanism that occurs at the end of knee extension.[9] Essential to such screw-home mechanisms are the stabilizing translations and/or rotations that are coupled with the primary rotation. However, to date, experimental studies have not described translation or rotational coupling of the TMC joint.[6,10–14] There have been several studies of thumb motion based on data acquired using skin marker–based motion-tracking systems.[15–17] These marker-based studies are limited because they were capable only of approximating true skeletal kinematics due to skin-motion artifact. Moreover, they could not differentiate TMC, scaphotrapezial, or scaphoradial joint motion from total thumb motion. One study directly tracked skeletal motion at the TMC joint of a single subject using a magnetic resonance imaging–based tracking methodology.[18] Consistent with the results from previous cadaver studies, it described skewed and nonintersecting Ex-Fl and Ab-Ad rotation axes, but no metacarpal translation or coupled rotation.

Our incomplete understanding of TMC mechanics is exemplified by a biomechanical modeling study in which simplified kinematic descriptors resulted in nonrealistic predictions of forces at the TMC joint.[19] Advancing our understanding of TMC joint mechanics should improve the understanding and treatment of TMC pathology and provide new insight into the etiology of TMC joint osteoarthritis. The higher prevalence of TMC osteoarthritis in women compared with men[20] has not been fully explained, but differences in thumb use that result in abnormal joint mechanics is a leading theory.[21] Implant failure may also reflect the fact that current devices do not accurately replicate *in vivo* kinematics.[22–24]

Accordingly, the purpose of this study was to determine whether *in vivo* TMC joint kinematics differ as a function of age and/or sex. Our secondary aim was to confirm with *in vivo* data the predictions of previous *in vitro* studies that the Ex-Fl and Ab-Ad rotation axes of the TMC joint are nonorthogonal and nonintersecting.

MATERIALS AND METHODS

Subjects

After approval from our institutional review board, 44 asymptomatic subjects with no history of thumb injury were recruited as part of a larger cohort in a study on biomechanics and TMC joint osteoarthritis.[25–27] Recruiting was designed to yield 4 subcohorts stratified by age and sex: younger participants, aged 18 to 35 years (10 young men, age = 23 ± 3 y; 11 young women, age = 24 ± 1 y), and older participants, aged 40 to 75 years (10 older men, age = 57 ± 9 y; 13 older women, age = 55 ± 8 y). In the larger cohort, we previously analyzed articular shape [25,26] and the subtle motion of the TMC joint that occurred during 3 isometric functional tasks.[27]

Imaging and image processing

Computed tomography (CT) volume images of the dominant wrists of all subjects were acquired at maximum positions of active thumb extension, flexion, abduction, and adduction. Custom-designed polycarbonate fixtures were used to standardize the directions of thumb motion (Fig. 1). A vertical polycarbonate plate, angled 30° to the dorsum of the hand, facilitated positioning during thumb Ex-Fl, and a horizontal polycarbonate plate abutting the radial surface of the index digit facilitated positioning during thumb Ab-Ad. Image volumes were generated with a 16-slice clinical CT scanner (GE LightSpeed 16; General Electric, Milwaukee, WI) at tube settings of 80 kVp and 80 or 40 mA, slice thickness of 0.625 mm, and an in-plane resolution of at least 0.4 × 0.4 mm. The average effective radiation dose for the imaging involved in this study was 0.25 mSv per participant (maximum, 0.53 mSv).

The complete outer cortical bone surfaces of the trapezium and MC1 were segmented, or digitally extracted, from the neutral CT volumes using a commercially available software package (Mimics v.13.1, Materialise, Leuven, Belgium). The bone surfaces were exported as meshed objects and the principal directions of curvature for the articular surfaces of each trapezium were used to construct bone-fixed coordinate systems.[28] The coordinate systems were

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