ORIGINAL COMMUNICATIONS

Osteoarthritis of the trapeziometacarpal joint: The pathophysiology of articular cartilage degeneration. I. Anatomy and pathology of the aging joint

An anatomic study of the trapeziometacarpal joint was conducted on 47 cadaver thumb specimens. The superficial capsule restrained only metacarpal rotation about its long axis. Intracapsular anatomy was notable for a large anterior subthenar recess limited dorsally by the abductor pollicis longus insertion and palmarly by the deep palmar or "beak" ligament. This beak ligament was essential for translational stability of the metacarpal on the trapezium with flexion of the thumb ray. There was a direct correlation between the status of the articular surfaces and the integrity of the beak ligament. Normal surfaces were associated with an intact ligament confluent with the hyaline cartilage of the palmar lip of the metacarpal; degeneration of the palmar lip cartilage was always associated with attritional detachment of the beak ligament. Advanced articular disease occurred only in the palmar contact areas and was predicted by degeneration of the adjacent beak ligament; only nonprogressive chondromalacia was found on the dorsal portions of the articular surfaces. (J HAND SURG 1991;16A:967-74.)

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Despite the prevalence of osteoarthritis in the trapeziometacarpal joint and the profound impact of osteoarthritis on hand function, little is known concerning the cause of the disease in this location.4,14 Although many different operative procedures have been developed, the pathologic anatomy of trapeziometacarpal osteoarthritis remains undescribed and poorly understood.4,9 Empirical evidence supports a hypothesis of pathologic ligamentous laxity resulting in degeneration of articular cartilage10-13; soft tissue reconstruction for stabilization of symptomatic hypermobile joints has retarded the apparent progression of osteoarthritis in these hands.7,8 Furthermore, the effects of the normal aging process and its relationship to pathologic articular degeneration of the basal joint are currently unknown. Accordingly, this study was undertaken to investigate the effects of physiologic aging on the trapeziometacar-
Fig. 1. Cadaver specimen of right thumb showing capsular anatomy and disease. A, Anterior oblique ligament (AOL), superficial. Orientation does not effectively stabilize dorsal metacarpal translation on the trapezium. MC, Metacarpal; TR, trapezium; APL, abductor pollicis longus. B, Anterior thenar capsular recess (single arrows), intact ligament. The boundaries of the recess are sharply defined by the beak ligament at the apex of the metacarpal articular surface (triple arrow) and the dorsal expansion of the abductor pollicis longus insertion (double arrow). C, Pathologic extension of anterior thenar capsular recess (single arrows) caused by detachment of palmar beak ligament (triple arrows) from metacarpal. Abductor pollicis longus expansion (double arrows) remains intact. Compare with B.

carpal joint and to provide insight into the mechanisms of articular damage operational at the base of the thumb.

Materials and methods

Forty-seven thumb specimens from human cadavers were harvested to include the entire thumb ray and trapezium. Twelve specimens were obtained fresh and 35 had been embalmed. There were 29 female and 18 male specimens, with an overall average age of 79 years. There was no significant age difference between any of the specimen subgroups. Male specimens, with an average age of 79 years, consisted of 16 embalmed with an average age of 78 years and 2 obtained fresh at an average of 85 years; female specimens, with an average age of 80 years, consisted of 19 embalmed with an average age of 80 years and 10 obtained fresh at an average of 78 years. Overall, the embalmed group averaged 79 1/2 years of age, whereas the fresh group averaged 79 years. The cause of death and the previous medical history were known for each subject from which the specimens were harvested; none had a history of previous injury or surgery on the basal joint of the thumb, and none had rheumatoid arthritis or other connective tissue disease.

Dissection was begun by elevation of the thenar musculature from the underlying joint capsule; orientation of the superficial capsular fibers and their points of attachment were noted. Dorsal capsulotomy preserving a palmar capsuloligamentous hinge allowed observation of the intracapsular structures. Three fourths of the specimens were dissected through such a dorsal approach. The remainder were opened through a palmar approach, thereby allowing study of the intact dorsal capsular structures. Particular attention was directed to the status of the articular cartilage (normal, chondromalacia, or eburnation), the topographic distribution of articular wear (dorsal or palmar, radial or ulnar), the points of attachment of the intracapsular soft tissue restraints relative to the articular margin, and any evidence of degenerative attritional change. The relative contribution of various capsular components to trapeziometacarpal stability was assessed during serial ligament division by observation of joint surface translation under manual loading.

Initially, all articular surfaces were stained (Diff-Quik; American Scientific Products, McGaw Park, Ill.) to delineate areas of cartilage wear and zones of eburnation. However, as familiarity with the specimens al-
Fig. 2. Cadaver specimen of right thumb showing intracapsular anatomy and disease. A, Graphic representation of right trapeziometacarpal joint hinged open on the palmar beak ligament with denotation of pertinent anatomic structures. This will serve as a key for subsequent specimens also portrayed as right thumbs. B, Intact palmar beak ligament, anterior thenar recess. Palmar beak ligament attachment (single arrows) at the apex of the metacarpal articual surface delimits the palmar extent of the thenar recess (double arrows). C, Palmar beak ligament flush with articular surface. Ligament fibers are confluent with the normal articular cartilage of the palmar compartment (single arrows). Thenar recess is adjacent (double arrows). D, Profile of metacarpal beak (double arrows) in specimen with advanced osteoarthritic disease and beak ligament detachment (single arrows). Compare with C.

allowed easier recognition of eburnated and chondromalacic zones, the staining process was discontinued to permit subsequent biochemical analysis of the articular surfaces. The surface topography of each joint was photographed and, for ease of presentation, is portrayed as a right thumb hinged open on the palmar beak ligament. Orientation of the trapeziometacarpal joint is described with reference to the plane of the thumbnail defining the dorsal position.

Results
Superficial capsular fibers, including the anterior oblique ligament, were consistently oriented from proximal dorsal to distal palmar along both anterior and posterior surfaces of the joint capsule, as viewed from the palm (Fig. 1, A). This anatomic arrangement was not conducive to stabilization of the thumb metacarpal in flexion and did not discourage dorsal metacarpal translation. Rather, these fibers became taut with axial rotation; the posterior fibers limited supination, and the palmar fibers checked pronation of the thumb ray. The insertional expansion of the long abductor broadly reinforced both dorsal and radial components of the superficial joint capsule. Intracapsular dissection demonstrated that the anterior, radial, or "subthenar" capsule was attached several millimeters from both the
trapezial and metacarpal joint surfaces, creating a constant voluminous pouch accommodating metacarpal translation during palmar adduction and abduction. In specimens without articular disease the limits of this pouch were defined by the ligament attachment and the abductor pollicis longus (APL) insertion (Fig. 1, B). Complete excision of this redundant capsular segment, anatomically clothed by the thenar muscles, had no effect on trapeziometacarpal joint stability.

Inspection of the joint through a dorsal arthroscopy demonstrated that the palmar “beak” ligament arose from the apex of the thumb metacarpal and formed an abrupt limit to the anterior thenar capsular recess (Fig. 2, A and B). This attachment was confluent with the joint surface in specimens without articular disease (Fig. 2, C). Attaching at the apex of the metacarpal beak and extending ulnarily along the articular margin of the metacarpal, the beak ligament became taut in pronation to effectively limit dorsal translation of the thumb metacarpal. At the dorsal ulnar corner the capsular attachment receded 2 to 3 mm from the metacarpal joint surface, creating a minor capsular recess. From the mid-dorsum to slightly beyond the dorsal radial corner of the metacarpal, the abductor pollicis longus expansion provided a stout attachment directly at the articular margin of the metacarpal. This expansion contributed significantly to, but was not essential for, control of dorsal metacarpal translation. The thenar capsular recess began at the anterior or radial margin of the abductor pollicis longus insertion as previously described.

Thus, around the pentagonal base of the thumb metacarpal, there were major and minor intracapsular ligaments and recesses diagonally oriented from
LIGAMENT INTEGRITY AND ARTICULAR DISEASE

A

![Graph showing ligament disease distribution.]

B

**PALMAR LIGAMENT STATUS**

Fig. 4. Relationship of palmar ligament integrity and severity of articular disease. A, More severe ligament detachment accompanied increasing frequency of end-stage cartilage disease. B, Increasing ligament degeneration predicts increasing severity of articular cartilage disease. C/M, Chondromalacia.

...one another (Fig. 2, A). The major ligamentous restraint, or peak ligament, extended along the ulnar side of the palmar metacarpal peak opposite the abductor insertion expansion; the large anterior or thenar capsular recess was located opposite a lesser recess at the dorsal ulnar limit of the abductor pollicis longus expansion. In this manner, starting beneath the thenar muscles and moving in clockwise fashion around the perimeter of the right trapeziometacarpal joint (or counterclockwise from the thenar region of the left thumb), an alternating pattern of major thenar recess, palmar peak ligament, minor dorsal recess, and abductor pollicis longus capsular expansion was observed. This "normal" pattern of intracapsular ligamentous architecture was most frequently accompanied by grossly normal articular surfaces as found in one fourth of all joints, comprising 21% of the female and 33% of the male specimens.

Of the remaining specimens, two degrees of articular damage were apparent—chondromalacia and eburation—and were found to correspond to specific patterns of attritional change in the palmar peak ligament.

Softening and fissuring of the articular cartilage (chondromalacia) occurred in two topographic patterns and was found in 28% of all specimens (24% of females and 33% of males). More than two thirds of all specimens with chondromalacia had changes limited to the dorsal region of the joint. There was an adjusted male prevalence of 2 to 1 in this subgroup; indeed, 83% of all male specimens demonstrated dorsal chondromalacia. Attritional changes in the palmar ligament were seen in fewer than one half of these specimens and were of only minor degree, with no loss of continuity of ligamentous attachment to the articular margin. In no joint did an apparent progression of this dorsal chondromalacia result in eburation of the dorsal compartment. However, half of all male specimens with eburation in the palmar compartment demonstrated concomitant dorsal chondromalacia. Coexistent dorsal and palmar changes of this nature were not found in any of the female specimens.

Chondromalacia in the palmar joint compartment was consistently located adjacent to the palmar "peak" lig-
Fig. 5. Mechanism of palmar compartment wear secondary to beak ligament detachment and resulting articular surface shear. Note increasing shear during lateral pinch with ligament detachment (single arrows) from metacarpal beak. Cadaver specimen demonstrates palmar contact and translation (double arrows) of articular surfaces during lateral pinch.

ament attachment on the metacarpal. (Fig. 3, A). In contrast to the dorsal compartment, the location of palmar chondromalacia corresponded exactly to that of eburnation in all specimens with more advanced disease. The adjusted female prevalence of 1.9 to 1 for specimens with palmar compartment chondromalacia paralleled that seen in specimens with palmar eburnation. Furthermore, all specimens with palmar chondromalacia demonstrated significant palmar beak ligament degeneration of the attachment to the articular margin (Fig. 3, B); this was of sufficient severity in 50% of the specimens to extend the anterior capsular recess beyond the apex of the metacarpal beak by virtue of complete detachment of the beak ligament (Figs. 1, C, 2, D, and 3, C and D).

Eburnation was present in 22 joints, nearly half of the total series, comprising 55% of the female and 33% of the male specimens, with an adjusted female prevalence of 1.7 to 1. Eburnation was found exclusively in the palmar compartment and was always adjacent to the beak ligament, which in every case had become detached from its metacarpal insertion, occasionally with bony fragments (Fig. 3, C and D). This ligament degeneration was severe enough in 86% of the specimens to create a pathologic extension of the anterior capsular recess around to the ulnar side of the metacarpal beak (Fig. 1, C). When both surfaces were involved, the area of eburnation on the trapeziun consistently exceeded that found on the metacarpal. End-stage involvement was noted in 94% of the female specimens in contrast with only 34% of the male specimens. Conversely, 66% of the male specimens demonstrated isolated eburnation of the metacarpal, while only 6% of the eburnated female specimens had disease limited to the metacarpal. In no specimen was eburnation seen in isolation on the trapeziun.

Focused analysis of the status of the capsuloligamentous restraints demonstrated degeneration of the palmar beak ligament in 64% of the specimens, with a close correlation to the extent of articular surface disease (Fig. 4, A and B). As in the groups with palmar chondromalacia or eburnation, female specimens predominated in this subgroup by 1.5 to 1. Of those with palmar ligament degeneration, 73% demonstrated eburnation, with similar prevalence in both sexes, while the remaining 27% demonstrated chondromalacia. Conversely, ligament degeneration was found in 100% of the specimens with eburnation and in only 62% of those with chondromalacia. Of the chondromalacia subset, ligament degeneration was present in all joints with palmar disease and in only 44% of those with dorsal disease.

More severe ligament degeneration, resulting in actual detachment and pathologic extension of the anterior capsular recess, was noted in 45% of the study group, with a female prevalence of nearly 3 to 1. Of this group, 90% demonstrated eburnation, with similar involvement of both sexes; the remaining 10%, all female specimens, demonstrated palmar chondromalacia. In no joint with primarily dorsal compartment disease was there pathologic extension of the anterior capsular recess secondary to palmar ligament degeneration.

Discussion

This study provides an anatomic basis for several observations regarding the functional importance of the capsuloligamentous complex of the trapeziometacarpal joint. The superficial capsular fibers—the subject of
nearly all previous anatomic investigations of this joint complex—are best positioned to restrain rotation about the long axis of the metacarpal shaft. However, the orientation of these fibers, including the anterior oblique ligament, renders them ineffective in controlling palmar to dorsal translation of the metacarpal on the trapezium during physiologic flexion—adduction of the thumb in lateral pinch. In contrast, two deep intracapsular structures are the primary stabilizers of the trapeziometacarpal joint. The palmar beak ligament is tightened by pronation of the thumb, as naturally occurs during forceful lateral pinch, and is the primary stabilizer in this position. The dorsal expansion of the abductor pollicis longus assumes the major stabilizing role in the functionally less important position of supination. The anterior capsular recess deep to the thenar musculature provides a surgical window for access to the joint between these two primary ligamentous structures. The relative functional significance of these two structures is implied in their vastly different correlation with the appearance of degenerative articular disease. Complete integrity of the capsuloligamentous structures about the joint closely correlated with the presence of normal articular surfaces. The dorsal capsular expansion reinforced by the long abductor insertion maintained its strong articular attachment, irrespective of the status of the articular surfaces. In contrast, degeneration of the palmar beak ligament attachment predicted the existence of significant articular disease of the palmar compartment.

Equally valuable observations can be made in primarily analyzing the occurrence of degenerative articular disease. Normal articular surfaces were associated with an intact deep capsuloligamentous complex; in particular, there was no evidence of degeneration of the palmar beak ligament. Chondromalacia occurred in two distinct patterns of involvement. Most frequently it was found in the dorsal compartment of the joint corresponding to the noncontact area during lateral pinch; usually this was not associated with any degenerative change in the palmar beak ligament. This was the only group in the study in which there was male predominance. It is notable that in no specimen was there eburnation in the dorsal compartment, where this most common form of chondromalacia appeared. Less common, chondromalacia was seen in the palmar compartment, where eburnation appeared exclusively in the more diseased specimens. In all cases of palmar chondromalacia there were associated degenerative changes in the beak ligament, and females predominated in this group. Eburnation was seen in the most severely degenerated joints and occurred only in the palmar compartment adjacent to the beak ligament attachment. This region corresponds to the contact area of metacarpal and trapezium during lateral pinch and would appear to be the focus for concentration of shear forces produced by functional trapeziometacarpal translation. In all eburnated cases there was coexistent degeneration of the beak ligament, frequently of sufficient degree to result in frank detachment from the metacarpal and pathologic extension of the adjacent thenar capsular recess around the metacarpal beak. Again there was clear female predominance in this group.

Female specimens demonstrated more frequent and more advanced joint destruction and ligament degeneration with a predilection for palmar compartment articular disease, which seemed to be progressive from chondromalacia to end-stage eburnation. In contrast, male specimens had less eburnation, less degeneration of the beak ligament, and a predilection for involvement of the dorsal compartment of the joint by a nonprogressive form of chondromalacia, perhaps representing a manifestation of physiologic aging. Indeed, palmar beak ligament degeneration paralleled, preceded, and even predicted severe palmar compartment articular disease (Fig. 4). The sexual variation in prevalence of palmar ligament degeneration accounted for the discrepant incidence of severe trapeziometacarpal osteoarthritis between the sexes; once palmar ligament detachment was present, severe palmar compartment articular disease was noted regardless of sex. In sharp contrast, there was no relation between the status of the dorsal abductor pollicis longus expansion reinforcing the dorsal capsule and the degree of joint degeneration.

This study of postmortem material has demonstrated the existence of eburnated lesions in the palmar compartment in association with degenerative disruption of the adjacent intracapsular palmar beak ligament. Palmar chondromalacia appears to be a progressive pathologic precursor lesion, culminating in eventual eburnation and marked by a strong female prevalence. In contrast, no dorsal compartment eburnation was noted in any specimen. Dorsal chondromalacia probably results from poor cartilage nutrition in zones of less predictable surface contact; it is nonprogressive, exhibits a male prevalence, and would appear to represent a manifestation of physiologic aging. Such a phenomenon of nonprogressive chondromalacia in areas of poor surface contact has been previously demonstrated in other joints by analysis of osteoarthritis wear pattern. This pattern of wear is in contrast to previous observations by Eaton and Littler, who suggested that the radiodorsal facet...
of the trapezium was the fulcrum of the cantilever system controlling the trapeziometacarpal joint and the first region to exhibit cartilage deterioration in osteoarthritis.

The status of the palmar beak ligament accurately and reliably predicts the condition of the articular surface in the adjacent palmar compartment of the joint, suggesting an etiologic relationship. Our data support a pathologic sequence of palmar beak ligament degeneration resulting in increased joint laxity, dorsal translation of the metacarpal on trapezium during flexion—adduction of the thumb ray in lateral pinch, and generation of abnormal shear forces in the palmar contact areas of the joint, with eventual articular cartilage wear. Dorsal zones of less frequent contact are characterized by a nonprogressive form of chondromalacia. Degeneration of the palmar beak ligament attachment from the metacarpal articular margin moves the ligamentous pivot point for metacarpal flexion distally along the shaft away from the joint surface (Fig. 5). This effectively increases the translation of metacarpal on trapezium with thumb flexion and amplifies detrimental shear forces between the articular surfaces in the palmar contact areas. The central role of loss of integrity of the intracapsular palmar beak ligament causing trapeziometacarpal osteoarthritis is supported by this study.

REFERENCES