The concept of altering the length of one of the forearm bones to achieve a therapeutic result for a clinical problem at either the elbow or the wrist is scarcely new. Excision of the distal ulna for pain at the distal radioulnar joint and excision of the radial head for post-traumatic changes or arthritic problems proximally are well known. The orthopedic literature suggests that these procedures are in fact efficacious in the great majority of instances.

Such destructive procedures do, however, lead to marked alterations in a complex mechanical structure represented by the two bones of the forearm, the interosseous membrane, the orbicular ligament, and the triangular fibrocartilage—to mention only the major mechanical components. We are increasingly recognizing the often undesirable consequences of disturbing this system through excisions, malalignments, and malrotations.

If one is to advocate therapeutic lengthening or shortening of one of the forearm bones there should, therefore, be firm evidence that it will advantageously influence a clinical problem and that the procedure can be accomplished reasonably without introducing other mechanical liabilities.

Hultén introduced the observation that individuals with an ulna that was shorter than the radial articular surface at the lunate fossa measured perpendicular to the longitudinal axis of the forearm were at greater risk to develop Kienböck’s avascular necrosis of the lunate. Although it has long been recognized that the relative elongation of the ulna secondary to collapse of the radius at the fracture site following Colles’ fracture leads to a variety of distal radioulnar difficulties, it was not generally recognized that a congenitally elongated ulna of a millimeter or two could produce a degenerative lesion between the ulnar head and the ulnar articular surface of the lunate through a defect in the triangular fibrocartilage until the recent contributions of Mikic and Palmer.

It takes little additional thought to imagine that other difficulties at the distal radioulnar joint are also influenced by a positive or negative ulnar variance. Indeed, there is statistical evidence that scapholunate dissociation is more common in the negative variance and some suggestion that triangular fibrocartilage tears are associated with a positive variance. There are a number of conditions that may affect this relative length besides congenital variations including fractures, epiphysiodysis, Madelung’s deformity, and other congenital deformities.

As the primary functional advantage of having a two-bone forearm is rotational, at least as far as the primates are concerned, it is inevitable that we should also see problems associated with this motion. Although one would expect this rotation to occur about a fixed axis running from the center of the radial head proximally to the center of the ulnar head distally, the complex curvature of the forearm bones, the asymmetry of the radial head, and the eccentric insertion of the triangular fibrocartilage cause the rotational axis to describe a quasiconical surface from pronation to supination. This also results in the ulnar head describing a dorsal to palmar translation within the shallow sigmoid notch of the radius during this motion. This articular surface is usually offset from a parallel to the rotational axis by 20 degrees or more, and also slides distally about 1 mm, on average, from...
supination to pronation. When the forearm is excessively loaded in torque so as to exceed its rotational constraints or complexly loaded in compression and torque, the articular surfaces may undergo sufficient shear stress to develop symptomatic chondromalacia. This is a condition that one can scarcely find mentioned in the literature, but is a definite entity. There appears to be an increased susceptibility to this problem in individuals with a lax ligamentous habitus, in our experience.

The ulnar head bears compressive stress on its distal surface ("pole") and primarily shear stress on its radial convex surface ("seat"). The triangular fibrocartilage is composed of a central cartilaginous surface bordered by two fibrous ligamentous components arising from either side of the sigmoid notch that coalesce to insert in the fovea of the ulnar head and the proximal portion of the ulnar styloid. It extends distally, fusing with a "meniscal homologue" to insert on the triquetrum enveloped by the fibrous extension of the periosteum from the ulnar styloid. It is supported dorsally by the floor of the fifth and sixth dorsal extensor sheaths and palmarly by the ulnocarpal ligament. The triangular fibrocartilage has numerous functions, including: 1) transmission of compression from the carpus to the ulnar head, 2) resistance to tension induced by distraction from the radius, 3) constraint of the distal radioulnar joint in rotation, 4) constraint of the carpus to the ulna, and 5) continuation of the radiocarpal joint.

Palmer and coworkers have shown the percentage of joint compressive force carried by the ulna varies with its length relative to the radius. The have also shown that the thickness of the triangular fibrocartilage varies inversely with the negative ulnar variance in a roughly linear fashion. This tends to provide a margin of safety when considering an ulnar lengthening as the thicker triangular fibrocartilage is more apt to conform to the additional compression and should be more resistant to attritional penetration.

**ULNAR SHORTENING**

Ulnar recession has been of benefit in our experience for conditions associated with an ulnar positive variance. This includes ulnolunate impingement and triangular fibrocartilage tears. The symptoms are generally associated with pain and tenderness between the ulnar head and triquetrum. Crepitus may be present on ulnar deviation. This may be accentuated by displacing the ulnar head palmarly when the forearm is in pronation and then stressing ulnar deviation. Roentgenograms in younger individuals are generally unrewarding, but when the ulnar head has eroded through the triangular fibrocartilage, a characteristic sclerosis and erosion between the ulnar head and lunate is recognizable, usually in patients past the fifth decade (Figs. 1A and B). Ulnar recession allows this to be decompressed while not significantly altering the radioulnar contact. When the positive variance exceeds several millimeters, the ulnar head is usually dorsally displaced over the ulnar aspect of the carpus. When the ulna plus is marked and the head dorsally subluxed, additional soft tissue imbrication following ulnocarpal repositioning and pinning is desirable.

Triangular fibrocartilage tears also respond to ulnar recession (Figs. 2A to F). A positive arthrogram should be supported by diagnostic clinical signs of triangular fibrocartilage dysfunction as perforations of the cartilage become increasingly common after the fourth decade and are expected in the sixth decade. Tenderness between ulnar head and triquetrum accentuated by ulnar deviation when the ulnar head is depressed is suggestive, as is a palpable or audible click with forceful motions of the wrist. It is possible to have an incomplete rent in the proximal surface of the triangular fibrocartilage as well, which is associated with a negative radiocarpal arthrogram. An arthrogram of the distal radioulnar joint showing a proximal rent, especially if pain is relieved by a simultaneous lidocaine infusion, is diagnostically helpful. Tears of the lunotriquetral interosseous membranes, triquetrohamate impaction injuries, and fourth and fifth carpometacarpal sprains are not infrequently associated with these lesions. Even with the most careful and discerning examination, it is not always possible to elicit or properly weigh the various findings in ulnar column pain.

Congenital conditions, such as "forme fruste" of Madelung's deformity, and post-traumatic conditions, such as premature epiphysodesis, also produce symptomatic ulnar plus variance (Fig. 3A). Particularly in the former, one often sees, in addition, a marked palmar angulation of the lunate fossa. This predisposes to a secondary remodeling deformity of the lunate, which slides into the defect between the deficit radius and the dorsally displaced and elongated ulnar head. It is possible to perform an osteotomy palmarly a short distance proximal to the lunate fossa so that the fossa may be reformed (Fig. 3B). A
Ulnar Lengthening and Shortening

Figure 1. A 67-year-old industrial worker with increasing pain and crepitus of the right wrist. A, Positive ulnar variance of 2 mm. B, High resolution. Note sclerotic cystic changes in ulnolunate area. (From Darrow JC, Linscheid RL, Dobyns JH, et al: Distal ulnar recession for disorders of the distal radioulnar joint. J Hand Surg 10A:482-491, 1985; with permission.)

Occasionally, the distal ulna appears to have an excessive angulation in its distal third, which is best recognized on a sagittal forearm roentgenogram (Fig. 8B). If this appears clinically to be associated with dorsal subluxation of the ulnar head in pronation, the angulation may be corrected at the time of recession (Figs. 8C, D, and E).

The seat of the ulnar head, that convex surface that articulates with the sigmoid notch of the radius, is also susceptible to painful lesions. The most common lesion is chondromalacia of the ulnar head produced by shear stress when it is driven against the dorsal rim of the sigmoid notch during forceful pronation (Fig. 4). This is the same mechanism that produces dorsal subluxation or dislocation of the ulnar head and, indeed, these would seem to be all part of the same spectrum of injuries. In the acute stage, the diagnosis is readily established by balloting the ulnar head in the sigmoid notch in a series of tests between full supination and pronation.

Placement of the forearm in a rotational position where the injured cartilage is not subjected to shear stress for 4 to 6 weeks will usually result in a satisfactory result in the acute situation. Cast immobilization in a long arm cast in moderate supination is most commonly used. This also allows ligamentous attenuation to heal at physiologic length.

Sometimes, however, repetitious rotation of the forearm will lead to a chronic condition. The group most at risk for this is those individuals with a lax ligamentous habitus, particularly young women (Figs. 4A, B, and C). Their ulnar heads are often markedly prominent in pronation (Fig. 4D). We have seen two examples where, at exploration, the articular cartilage was partially peeled off the ulnar head (Fig. 4E). This would catch and block the normal palmar return of the ulnar head during supination.

When the ulnar head is ballotable, there is not infrequently a concomitant laxity of the carpus relative to the radius manifest as a supination of the carpus. Normally, the unocarpal ligament running obliquely from the palmar surface of the triquetrum to the ulnar styloid is largely re-

section of the ulna removed for the concomitant ulnar recession is used to block open the partial radial osteotomy.

Tenderness trum accentuated ulnar head is del-
Figure 2. Torn triangular fibrocartilage in a 56-year-old woman. She had had pain and crepitus aggravated by ulnar deviation for 10 months. A. Initial appearance of roentgenogram. B. Arthrogram shows the dye flowing through the triangular fibrocartilage into the distal radioulnar joint. C. Positive ulnar variance of 2 mm. Note the position of the triquetrum. D. Radial deviation. E. Appearance after surgery (4 mm of recession). Negative ulnar variance is 3 mm. F. Lateral, normal alignment of distal ulna: excellent relief of symptoms. (From Darrow JC, Linscheid RL, Dobyns JH, et al: Distal ulnar recession for disorders of the distal radioulnar joint. J Hand Surg 10A:482-491, 1985; with permission.)

sponsible for maintaining a stable relationship. Assuming the ligament is otherwise intact, it may be relatively elongated and provide less stability when the ulnar has a plus variant. Ulnar recession in this instance tends to tighten the ulnocarpal as well as the distal extension of the triangular fibrocartilage, thus increasing the stability of the ulnar column.

Ulnar recession is of primary value in decompressing those impingement problems associated with an ulnar variant or in those chondromalacia-related problems in the distal radioulnar joint (Fig. 4F). In the latter, the ulnar head not only recedes relative to the radius, but also may displace laterally because of the obliquity of the sigmoid notch. This acts to decompress the area as well as to change the bearing surfaces. There seem to be infrequent sequelae to this procedure. To our knowledge, no instance of Kienböck’s disease has resulted from intentionally producing an ulnar minus variant. It should be stressed, however, that the amount of recession is carefully planned not to exceed a minus variance of 3 mm.
Ulnar Lengthening and Shortening

gravitated by ulnar deviation and associated triquetrum. D,) F, Lateral, normal obliquity of the ulnar head not present intentionally. It should be decreased a minus variance.

Figure 3. A 21-year-old student who had increasing pain in her wrists during gymnastics is shown. A, Positive ulnar variance of 13 mm. B, Lateral view shows dorsal subluxation and increased angulation of distal ulna and increased palmar angulation of radial articular surface, suggestive of forme fruste Madelung's deformity. C–E, Operative procedure. Ulnar recession of 10 mm. Radial osteotomy and plating were accomplished using the T-plate of the Association for the Study of Internal Fixation. A five-hole dynamic compression plate maintained alignment of the ulna. (From Darrow JC, Linscheid RL, Dobyns JH, et al. Distal ulnar recession for disorders of the distal radioulnar joint. J Hand Surg 10A:482–491, 1985; with permission.)
A 40-year-old woman with ligamentous laxity had snapping, painful distal radioulnar joints bilaterally. A previous Darrach procedure on the right wrist required subsequent stabilization. A, The left wrist is now crepitant. B, The thumb is easily passively approximated to the forearm. C, Both genu and cubitus recurvatum were present. D, Roentgenogram is essentially normal. There is positive ulnar variance of 1 mm and a positive "piano key" sign. E, Intraoperative photograph shows that the convex surface of the articular cartilage head of the ulna is avulsed from its proximal attachment and is being stressed during pronation. F, Ulnar recession of 3 mm resulted in increased stability and lack of crepitance and pain on pronation. (From Darrow JC, Linscheid RL, Dobyns JH, et al: Distal ulnar recession for disorders of the distal radioulnar joint. J Hand Surg 10A:482–483, 1985; with permission.)
ULNAR LENGTHENING

After describing some of the benefits accruing from ulnar shortening, it seems somewhat paradoxical that one could recommend the opposite procedure as well. Nevertheless, there are conditions that appear to be favorably influenced by ulnar lengthening. Shortly after Hultén’s description of the ulnar minus variant associated with Kienböck’s disease,18,30 it was suggested that either ulnar lengthening or radial shortening might benefit that condition.38 Numerous reports suggest this efficacy,1,40 particularly the long-term follow-up of Moberg.32 Hereafter, one may assume that radial shortening is synonymous with ulnar lengthening.37

The rationale of ulnar lengthening for Kienböck’s disease is to decompress that area of the lunate that is undergoing collapse because of the joint compressive force acting on the affected subcortical trabeculae. This is primarily the part articulating with the lunate fossa. The ulnar aspect of the proximal articular surface is often minimally involved (Fig. 5). If the ulna is elongated, the triangular fibrocartilage is compressed and acts to support the ulnar aspect of the lunate and the articular facet of the triquetrum. Of necessity, this also induces a mild radial deviation that increases the joint compressive force on the scaphoid. Arthrograms taken at the time of ulnar lengthening show an increased joint space1 (Figs. 6A and B). Ulnar lengthening does not change the secondary features such as lunate collapse, scaphoid palmar flexion, or extrusion of the lunate fragments by the intruding capitale. It does, however, usually produce prompt and sustained pain relief. Like most treatments, the results are better in the earlier stages of the process. To date, the effectiveness of this approach over a 5-year period has been 85 per cent satisfactory.1,40

Recently, we have used this approach for another condition which we chose to call “nondissociative carpal instability” (NDCI),57 but it has also been called midcarpal instability,21 ulnar column instability,43,44 and the CLIP syndrome.36 Though still not well understood, this condition causes weakness and usually a pronounced snap as the wrist angulates from radial deviation to ulnar deviation.22,23 Under the image intensifier, this corresponds to a sudden switch of the proximal carpal row from palmar flexion to dorsiflexion. This conjunct rotation of the proximal row, which is usually seen as a smooth gradual transition in normal wrist motion, occurs cataclysmically in NDCI. We noted in several patients that, if the triquetrum were supported by thumb pressure from the ulnar aspect, the transition could be made less abrupt. In those patients with an ulnar minus variant, elongating the ulna appears to offer similar support to the carpus. We believe that the lunate translates down the inclined plane of the radius under compression, rendering the radiolunate ligaments taut, thus preventing the gradual rotation at the lunate. By supporting the proximal carpal row from the ulnar side, the unstable state is corrected and allows a normal conjunct rotation.

There is some reason to believe that better support from the ulnar aspect would remove some of the stress from the scapholunate ligament after repair of this ligament in scapholunate dissociation as well, though clinical use has as yet not been demonstrated.

SURGICAL PROCEDURES

These procedures have been made possible by the development of reliable hardware that allows for reasonable precision in length alteration, alignment, and angulation to be achieved.33 Although there have been a few delayed unions when accurate cuts, full apposition, and adequate compression have been achieved,
union is predictable between 6 and 10 weeks. The procedures are introduced in outline form below. 

Ulnar Recession

1. Preoperative measurement and planning.
2. Incision along distal subcutaneous aspect of ulna and over the ulnar head (Fig. 7A).
3. Application of a DCP plate bent to conform to the distal ulna with two screws in distal holes (Fig. 7B).
4. Alignment marks and an osteotomy mark proximally with saw cut (Fig. 7B).
5. Transverse osteotomy (Fig. 7B).
6. Optional inspection of distal radioulnar joint by outward swing of distal ulna (Fig. 7C).
7. Resection of predetermined length of ulna (Fig. 7C).
8. Alignment of distal segment and its attached DCP plate (Fig. 7D).
9. Fixation with compression screw and insertion of remaining screws (Fig. 7D).
11. Cast change, roentgenogram check at 6 weeks.

Ulnar Lengthening

1. Preoperative measurement and planning (Fig. 8).
2. Exposure of distal ulna.
3. Three-quarter transverse osteotomy cut.
4. Application of Zimmer four- or six-hole slotted plate with screws placed away from cut.
5. Completion of osteotomy.
7. Tighten screws.
8. Obtain bicortical iliac crest graft of proper thickness (3 to 6 mm) perpendicular to crest.
9. Place graft in gap, cancellous aspect toward radius.
10. Loosen distal screws one turn to obtain compression.
11. Tighten screws.
12. Trim redundant graft with bone biter.
13. Place remaining graft material around osteotomy site.
15. Cast off and roentgenogram at 6 weeks.

If radial shortening is performed, we currently prefer a palmar metaphyseal osteotomy with fixation by an ASIF T-plate.
Intraoperative arthrography of the wrist after complete osteotomy and before fixation of the ulna. A, Incision over the subcutaneous border of the distal ulna curved dorsally for exploration of the distal radioulnar and ulnocarpal joints. B, Applying the dynamic compression plate with two screws distally, marking of alignment, loosening the plate by removing one screw, and completing the osteotomy. C, The plate is reapplied distally, the interosseous membrane is released, and the distal radioulnar joint is inspected by swinging the ulna outwardly. D, Compression plating after repair and recessional osteotomy. In the latter part of this study, the fixation plates were changed from a 3.5 mm screw hole to a 2.7 mm hole size, with a corresponding increase from five to eight or nine holes. (From Darrow JC, Linscheid RL, Dobyns JH, et al: Distal ulnar recession for disorders of the distal radioulnar joint. J Hand Surg 10A:482-491, 1985; with permission.)

Figure 8. Technique for lengthening the ulna by interpositional bone grafting and stabilization with a slotted plate. Lengthening of the osteotomized ulna and insertion of the graft is facilitated by using a laminar spreader to distract the fragments. Note that the plate is applied before distraction. TFC = triangular fibrocartilage. (From Armistead RB, Linscheid RL, Dobyns JH, et al: Ulnar lengthening in the treatment of Kienböck's disease. J Bone Joint Surg 64A:170-178, 1982, with permission.)

Figure 7. A, Incision over the subcutaneous border of the distal ulna curved dorsally for exploration of the distal radioulnar and ulnocarpal joints. B, Applying the dynamic compression plate with two screws distally, marking of alignment, loosening the plate by removing one screw, and completing the osteotomy. C, The plate is reapplied distally, the interosseous membrane is released, and the distal radioulnar joint is inspected by swinging the ulna outwardly. D, Compression plating after repair and recessional osteotomy. In the latter part of this study, the fixation plates were changed from a 3.5 mm screw hole to a 2.7 mm hole size, with a corresponding increase from five to eight or nine holes. (From Darrow JC, Linscheid RL, Dobyns JH, et al: Distal ulnar recession for disorders of the distal radioulnar joint. J Hand Surg 10A:482-491, 1985; with permission.)

KIENBOCK'S DISEASE - ULNAR LENGTHENING
SUMMARY

Alteration in length of the distal ulna may provide an attractive alternative to more destructive procedures commonly used for the treatment of mechanical and degenerative problems at the distal radioulnar joint. Ulnar recession has shown effectiveness in ulnolunate impingement, triangular fibrocartilage tears, and symptomatic ulnar plus variance. It has also been effective in chondromalacia of the ulnar head in the sigmoid notch and in unstable distal radioulnar joints where recession alters the bearing surface and tightens the ulnocarpal ligamentous complex. Ulnar lengthening has been efficacious in relieving the symptoms of Kienböck's disease by decompressing the involved portion of the lunate and distributing joint compressive force on the triquetrum and medial lunate articular surfaces. It may also be of value in some instances of NDCI associated with an ulnar minus variant.

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Ulnar Lengthening and Shortening


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Detailed Anatomy of the Articular Disc of the Distal Radioulnar Joint

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The articular disc of the distal radioulnar joint anatomy was studied in 109 wrist joints from 64 fresh adult cadavers. The disc is a strong fibrocartilaginous semicircular biconcave structure well adapted to its various functional roles. The length of the disc at its radial attachment varied between 12 and 20 mm (in most cases, 14–16 mm), and the width, measured between the apex and the radial base, varied from 7 to 14 mm, (in most cases, 9–11 mm). The thickness of the dorsal and palmar margins and the ulnar apex varied from 3 to 6 mm (in most cases, 4–5 mm), whereas the thickness of the central part varied from 0.5 to 3 mm (in most cases, 1 mm) and in a number of cases was perforated. Because the incidence of perforations increases progressively with the age of the subjects, the perforations were assumed to be degenerative in nature. Although the articular disc is a definable anatomic entity, it is intimately attached to surrounding elements to form a complex anatomic and functional structure.

The articular disc of the distal radioulnar joint (discus articularis), known in the old nomenclature as the triangular fibrocartilage (fibrocartilago triangularis), is a forgotten structure, usually described in standard textbooks of anatomy in a generalized way with little detail. More attention has been paid to it by surgeons who have gradually recognized its importance in the pathology of the wrist joint. Recently, the articular disc and its surrounding structures have been studied more thoroughly, however, there is still significant controversy regarding its morphology and biomechanics. In an attempt to improve current knowledge on this subject, a detailed study of the morphologic characteristics of the articular disc was made.

MATERIALS AND METHODS

One hundred nine wrist joints were studied in 64 fresh adult cadavers ranging in age from 21 to 94 years. Preparation was carried out within six to 48 hours after death. The joints were dissected from the dorsal aspect and were thoroughly examined, after which the articular discs were completely removed, inspected, and measured with calipers and a ruler. The length, width, and thickness of all discs were measured, after which all specimens were preserved in 4% formalin. In addition, ten wrist joints from ten cadavers were completely excised by cutting the bones 6 cm proximally and distally. These joints were used for sectioning in the horizontal plane and for studying the bone attachments of articular discs. Ten macerated bones from the medical school collection were also surveyed to observe the distal ends of the radius and ulna.

RESULTS

The articular disc is a strong fibrocartilaginous structure, triangular or somewhat semicircular in shape, stretched between the lower ends of the radius and ulna, and interposed between the ulnar head proximally and the lunate and triquetral bones distally.
The disc has two articular surfaces, the upper ulnar and lower carpal, and two circumferential or capsular margins, dorsal and palmar. On the medial ulnar part, there is the apex; laterally or radially, there is the base of the disc.

The length of the disc measured at its base near the radial attachment varied between 12 and 20 mm (Fig. 2). In most cases it measured 14–16 mm (Fig. 3). The width of the disc measured between the apex and radial base varied from 7 to 14 mm, in most cases being 9–11 mm (Figs. 4 and 5).

The disc has a biconcave shape in both the sagittal (Fig. 6) and frontal planes (Fig. 7), because its upper and lower articular surfaces are deepened and adapted to the convexity of the ulnar head proximally and the lunate and triquetral bones distally. However, the concavity of the carpal surface is much less pronounced. The peripheral margins of the disc are much heavier and stronger than the central part, where it is thinner and occasionally perforated.

The thick and strong marginal part of the disc in the sagittal plane (Fig. 6) has the shape of an approximately equilateral triangle, the base of which is turned toward the dorsal or volar capsular side, and its apex is turned toward the central thin area of the disc. The sections in the frontal plane (Figs. 1 and 7) had peripheral parts that were thickened and had a triangular shape. The ulnar part was much larger than the radial.

The thickness of the dorsal and palmar margins and of the ulnar apex varied from 3 to 6 mm, in most cases being 4–5 mm (Fig. 8). The thickness of the radial margin was between 1 and 4 mm; however, in 75% of the cases, it was about 2 mm. The thickness of the central area varied from 0.5 to 3 mm, and in most cases was about 1 mm. Sometimes the central area was so thin that it was transparent (Fig. 2), and in a number of cases it was perforated. Perforations of various shape and size occurred in 7.6% of the subjects in the third decade of life, 18.1% in the fourth, 40% in the fifth, 42.8% in the sixth, and 53.1% in those older than 60 years of age. In one wrist of a 70-year-old subject, calcifications of the articular disc were noted macroscopically.

In younger persons the carpal surface of the disc is whitish or yellow-whitish, smooth, and glistening. The border between the articular surfaces of the radius and of the disc is difficult to define (Fig. 9). On the upper surface that articulates with the ulnar head, the disc is also whitish or yellow-whitish, smooth, and shiny in younger persons; however, in older subjects it appears more often matted and irregular. In later decades of life, more obvious degenerative changes occur on both sides of the disc; however, they are always much more severe on the ulnar side as reported earlier.

The disc is attached by its base to the distal edge of the ulnar notch of the radius (incisura ulnaris radii). The massive dorsal and palmar margins are firmly attached to the triangular, flattened facets at the distal ends of the dorsal and palmar edges of the ulnar notch in the radius, which could be identified on both macerated bones (Fig. 10) and fresh specimens (Fig. 11). The apex of the disc is broadly inserted into a depressed area of the ulnar head between the inferior articular facet and the root of the ulnar styloid process itself (Fig. 1). The width of this depression, called the basistyloid fovea (Fig. 12), varied from 3 to 5 mm. Several vascular foramina, usually two in number, could consistently be found in the depression (Fig. 12). The fovea continues proximally with a groove at the dorsomedial side of the distal ulna, which provides the floor for the extensor carpi ulnaris tendon sheath (Fig. 12). The most proximal fibers of the ulnar part of the disc are attached into the basistyloid fovea, while the fibers of the carpal part running in the distal and medial directions are attached to the styloid process. Between these two insertions, the anterior part of a vascularized loose connective tissue forms the dorsal and radial walls of the prestyloid recess (Figs. 1, 7, 9, 13, and 14). Whereas the insertion of the
Articular Disc of Distal Radioulnar Joint

To the radius, especially of the dorsal and palmar margins, is fixed and firm, the insertion to the ulna is slightly lax and of a more fibrous or ligamentous nature. Medially the disc is continuous with the fibers of the ulnar collateral ligament arising from the sides of the styloid process (Fig. 1). The ligament runs distally and just distal to the styloid process it becomes thickened and meniscuslike and inserts distally into the carpus. The styloid process varied both in shape and size. In 21 of 109 dissected wrists (19%), it was long and its tip was covered by articular cartilage (Figs. 13 and 14). Otherwise, the tip of the styloid was free, embedded in the prestyloid recess, and covered by the synovium. In this area, closely related to the styloid process, ulnarly and volarly of the apex of the articular disc, a recess (recessus praestyloideus), varying in shape and size, was found in all dissected joints (Figs. 1, 9, and 14). Sometimes it was just a conical hollow (Fig. 1), and sometimes it was a real synovial cavity (Figs. 9 and 14). The aperture of the recess varied in diameter from 1 to 5 mm, and sometimes it was hidden and covered by the synovial fringes. It is rich in synovium and well vascularized. Occasionally, there is a red ring around the aperture. The width of the cavity itself could be 5 mm, and the depth could be 10 mm.

The thickenened dorsal and palmar margins of the disc are united to the dorsal and palmar radioulnar ligaments, which cannot be sharply separated. These ligaments are strengthened parts of the articular capsule of the distal radioulnar and wrist joints that are attached to the dorsal and palmar margins of the articular disc.

Very peripheral parts of the ulnar and carpalsurfaces of the disc (about 1 mm) are covered by the synovial membrane coming from the capsule. At the radial attachments of the dorsal and palmar margins of the disc, the synovial lining is present a little further toward the central part making small, tonguelike, well-vascularized fringes.

Volarly, the articular disc is associated with the prominent, strong, intracapsular palmar ulnocarpal ligament (Fig. 14) that runs from the base of the ulnar styloid process and the anterior margin of the articular...
Mikić

Clinical and Related Research

number of discs

length of discs in mm

FIG. 3. The distribution of values of the length of the articular disc at the radial base.

disc itself obliquely distal and lateral to the lunate, triquetral, and capitate bones. Dorsally and medially, the articular disc is closely related to the floor of the strong sheath of the extensor carpi ulnaris muscle (Fig. 9) that extends from its groove on the ulna over the dorsum of the triquetrum to the dorsal base of the fifth metacarpal.

DISCUSSION

The articular disc is undoubtedly an interesting and important structure of the wrist joint. From a phylogenetic point of view, it is a young formation because it has evolved in primates during the progressive retreat of the ulna from its primitive articulation with the carpal bones. The exclusion of the ulna from this joint was an essential prerequisite for increased mobility of the hand and particularly for an increased range of pronation-supination movements. During its evolution, the ulnar part of the wrist joint has been subjected to radical change. The distal radioulnar joint formed with its articular disc that plays an important role in the biomechanics of the forearm and wrist joint as a whole.

The articular disc forms the congruent surfaces for both of them, allowing different types of movements on its upper and lower sides.

The rotational movements of the ulnar head during pronation and supination on the corresponding surface of the articular disc produce a much more intensive biomechanical force than the gliding movements of the carpal bones on the lower side of the disc, which is probably the reason that degenerative changes are much more frequent and more advanced on the ulnar side of the disc.

The articular disc has a significant role in

FIG. 4. Excised articular disc of a 43-year-old subject viewed from the carpal side. The widths of the discs were measured between the ulnar apex (U) and the radial base (R). The central zone of this disc was rather thick and measured 2 mm.
The transmission of the axial load of the fore- 
arm to the carpus and vice versa. The work of Koebke has provided sound morpho-
lologic evidence of compressive forces acting be-
tween the lunatum and ulnar head, which 
means that the disc is also subjected to con-
siderable compressive strain. Partially the 
compressive force is transmitted through the 
central part of the disc; however, some of the 
compressive loading is converted to tensile 
loading within the peripheral margins of the 
disc. The disc fills the gap between the ulnar 
head and carpal bones and acts as a cushion 
for the ulnar carpus to prevent ulnocarpal 
5.3 and 4.6, 5.0 Thus, the thickness is an im-
portant feature of the articular disc and is 
apparently determined by the length of the 
ulna relative to the radius (ulnar variance). 
The wrist, with a more positive ulnar variant, 
tends to be associated with a relatively thin-
ner articular disc and vice versa, 4.6, 5.0 which 
also influences the distribution of the load 
across the disc. In a positive ulnar variant, 
the compressive load through the center of 
the disc to the ulnar head is greatly in-
creased, 5.4.6, 5.0 whereas in a negative variant 
more of the force is probably converted to 
tension.5

A number of authors have confirmed that 
the most important functional role of the ar-
ticular disc is in stabilizing the distal rai-
diulnar joint. It is not, of course, the only sta-
bilizer of this joint, and there still exists some 
controversy concerning the significance of 
various structures, especially the radioulnar 
ligaments in this function. 2.8, 11.12.13-17, 33, 31, 
4.0, 4.1, 4.9, 5.0, 5.4, 5.8, 6.2 There is no doubt that the ar-
ticular disc is ideally placed and that its shape 
and structure correspond well to this bio-
mechanical role. In this regard the disc could be 
schematically divided into two zones: a pe-
ripheral zone and a central zone. The periph-
eral zone is represented by the massive palmar and dorsal margins, which are thick, mechanically very strong, and firmly attached both to the radius and the ulna. They are often referred to as the volar and dorsal radioulnar ligaments,\(^9\) which are incorrect because they are integral parts of the articular disc itself. These misnomers are also confusing because the radioulnar ligaments are separate structures that by themselves are too weak to provide inherent stability of the ulna; however, they are intimately attached to the disc, and obviously both of these structures act simultaneously.\(^22\) Therefore, the palmar and dorsal margins, reinforced by the radioulnar ligaments, appear to be the essential functional parts of the disc and are structurally adapted to bear traction forces,\(^5,9,21\) the integrity of which is indispensable for the stability of the distal radioulnar joint. The central zone of the disc, which is usually thin and often degeneratively changed and perforated,\(^37\) is mechanically weak and provides negligible stability.

One interesting feature of the disc is that its apex is fastened by two strong bands of fibers, one in the basistyloid fovea and the other on the styloid process of the ulna. Loose connective tissue situated between these two points of insertion is highly vascularized, because it is linked with the vascular foramina of the basistyloid fovea. Sometimes it is referred to as the ligamentum subcruentum.\(^1,24\) That denomination is incorrect and should not be used because the structure concerned is not a ligament but merely a part of the ulnar attachment of the articular disc. It seems to be important for the blood supply of the disc and of the prestyloid recess. The richness of the prestyloid recess in highly vascularized synovium could offer an explanation for the early development of rheumatoid changes in this area.\(^24,30\) The foveal insertion of the disc is situated at the position of the axis of the forearm rotation and provides sufficient tension of the disc margins during the whole range of the pronosupination and prevents the ulnar head from dislocation.\(^9,15,52\) The traction exerted on the styloid proc-
Articular Disc of Distal Radioulnar Joint

The articular disc is a clearly definable anatomic entity, although it is intimately connected with its surrounding structures. These intimate anatomic and functional ties of the articular disc and the neighboring elements led Palmer and Werner to introduce the concept of the triangular fibrocartilage complex, incorporating the dorsal and palmar radioulnar ligaments, the ulnar collateral ligament, the meniscus homolog, the extensor carpi ulnaris sheath, and the articular disc itself. There is also a close relationship between the articular disc and the palmar ulnocarpal ligament. This connection must also have a contributory role in stabilizing the distal radioulnar joint, and the palmar ulnocarpal ligament should also be one of the components of the triangular fibrocartilage complex.

The articular disc is liable to regressive alterations that occur mostly in the thinner, central part of the disc, whereas the thicker margins are almost always saved, an important fact from a functional point of view. The central part of the disc is occasionally perforated, but published accounts concerning the nature and incidence of the perforation vary considerably. Because the incidence of perforations increases with age and all perforated discs show severe degenerative changes,
FIG. 11. The lower end of the radius of a 45-year-old subject (fresh specimen). The articular disc is attached by its base to the distal edge seen between the ulnar (U) and lunate (L) articular facets. The massive dorsal and palmar margins of the disc are attached to the triangular, flattened facets (F) seen on the dorsal and palmar ends of this edge. There is also a low ridge between the scaphoid (S) and lunate (L) articular facets.

these changes are fundamentally of a degenerative nature and part of the aging processes that could be influenced by various factors. Palmer and Werner have noted that relative excess in ulnar length is associated with an increased incidence of disc perforation and ulnolunate erosion.

Calcification of the articular disc could also be representative of the aging process, although it could indicate one of several systemic disease processes. It was found in only

FIG. 12. The head of a macerated ulna seen from the carpal side. There is a depression (basistyloid fovea) between the discal articular facet (D) and the massive styloid process (S) where two vascular foramina could be also seen. The tip of the styloid process is covered by the compact, marblelike bone that is characteristic of the bone that was covered by the articular cartilage.

Calcification of the articular disc could also be representative of the aging process, although it could indicate one of several systemic disease processes. It was found in only

FIG. 13. The excised articular disc (D) of a 38-year-old subject with the prestyloid recess from where the styloid process (S) covered by the articular cartilage is protruded.

FIG. 14. The interior of the ulnar part of the wrist joint viewed from the dorsocarpal side. R = radius, L = lunate, T = triquetrum, D = articular disc, PUL = palmar ulnocarpal ligament. The head of a pin has been put into the large prestyloid recess for size comparison. The tip of the styloid process covered by the articular cartilage is standing out of the prestyloid recess.
Articular Disc of Distal Radioulnar Joint

The specimen in this series. According to Spinner,17 in the course of reviewing 1500 roentgenograms of the wrist, only two cases of calcification of the articular disc were noted (an incidence of less than 0.2%).

REFERENCES

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