William B. Kleinman, MD
on

Salvage Procedures for the Distal End of the Ulna: There Is No Magic

Abstract

Resection of the distal end of the ulna is not a benign procedure; nor is it a panacean surgical treatment of disorders at the distal radioulnar and ulnocarpal joints.

Over the past 96 years, since Darrach first described his classic procedure, many authors have warned surgeons of the consequences of the Darrach resection. For salvaging the persistently painful distal forearm after Darrach resection, researchers have recommended a spectrum of possible surgical options. Each has its advantages and disadvantages; none substitutes completely for the painless, load-bearing capacity of a healthy distal radioulnar joint. Resection of the seat of the distal ulna eliminates the fulcrum of the ulna through which load is transferred from the hand to the forearm.

At this time, there is still no surgical "magic" available to the reconstructive surgeon for salvaging normal use of the upper limb after failed Darrach resection.

> "For salvaging the persistently painful distal forearm after Darrach resection, researchers have recommended a spectrum of possible surgical options."

For almost a century, functionally incapacitating disorders at the distal end of the ulna have been treated with simple resection of the ulna head,[1] a surgical procedure described by Darrach in 1912 for a single case of chronic volar dislocation of the distal radioulnar joint (DRUJ).[2-4] The Darrach resection has certainly stood the test of time; it is used commonly and internationally as the "quick fix" for painful arthritis or instability at the DRUJ.[5-8] But the implications of surgical resection of the distal ulna are considerable.

First and foremost is for us to appreciate that we are bipedal human beings. Most of our upper extremity activities of daily living are performed while standing or sitting, with our hinged elbows flexed, and our hand–forearm units positioned as in Figure 1. The humerus is adducted, the elbow is flexed, and the forearm is in neutral ("zero")[9] radioulnar rotation. The forearm parallels the ground, with alignment of the hand–forearm unit perpendicular to the force of gravity acting on the hand and its contents. The ginglymus elbow ulnotrochlear joint does not participate in forearm rotation. The rotating radius–carpus–hand unit rests on top of the ulna, with the fulcrum for load transfer at the DRUJ being the intra-articular seat of the distal head of the ulna. In equilibrium, the moments (length [L] × force [F]) distal and proximal to the DRUJ fulcrum must be equal (≡). The length of the forearm multiplied by the restraining forces that proximally hold the radial head at the elbow (eg, the annular ligament) must equal (≡) the load carried by the hand, multiplied by the distance of the handheld load from the DRUJ fulcrum ($F \times L \equiv F' \times L'$). The total load borne by the seat of the ulna at the sigmoid notch of the radius (the DRUJ joint reaction force) equals the sum of the moments distal and proximal to the DRUJ. The joint reaction force can easily reach 6 to 8 times body weight when sufficient weight is supported by the hand![1,10,11]

My focus in this article is on why these elementary principles of physics must be remembered when considering traditional Darrach resection for our patients with painful injury or disease at the DRUJ.

The Basic Darrach Philosophy

The basic Darrach philosophy has certainly stood the test of time since 1912 (Figure 2). Resecting the entire head of the distal ulna accomplishes decompression

Dr. Kleinman is Senior Attending Surgeon at The Indiana Hand Center, and Clinical Professor of Orthopedic Surgery, Indiana University School of Medicine, Indianapolis, IN.

Address correspondence to: William B. Kleinman, MD, The Indiana Hand Center, 8501 Harcourt Rd, Indianapolis, IN 46260 (tel, 317-471-4336; fax, 317-872-1578).

Am J Orthop. 2009;38(4):172-180.

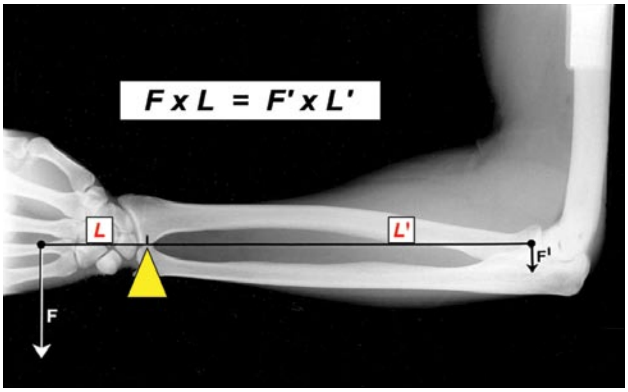

Figure 1. Ulna seat (yellow arrow at distal radioulnar joint) is fulcrum for load transfer from hand through forearm. In equilibrium, moment distal to fulcrum (force [F] × length [L]) must equal (≡) moment proximal to fulcrum (F'×L').

Figure 3. Radiograph of distal forearm shows overzealously performed Darrach resection. The osteotomy should remove the ulna head at a level that effectively clears the sigmoid, and not much more. In this example, the ulna is 1 cm too short.

Figure 4. Zero-rotation radiograph shows radioulnar (R-U) impingement 6 weeks after Darrach resection. Lateral border of osteotomized ulna impinges mechanically against medial border of radius, potentially causing painful crepitus, clicking, or locking of forearm rotation.

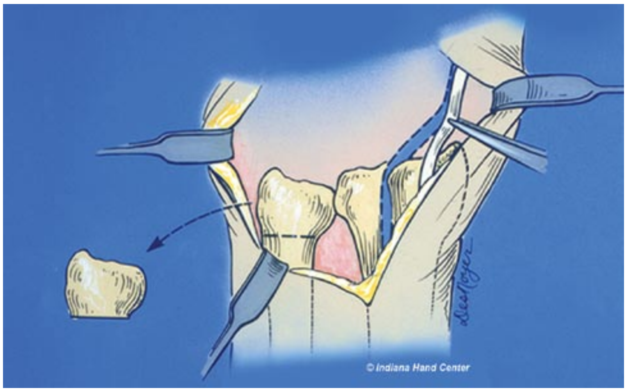

Figure 2. Schematic of classic Darrach resection shows complete removal of ulna head, including seat (at distal radioulnar joint) and pole (distal, at triangular fibrocartilage complex). Copyright 2009, Indiana Hand Center.

of a painful ulnocarpal joint; elimination of a painful DRUJ; restoration (or maintenance) of forearm rotation limited by DRUJ pathology; and improvement in strength by pain reduction. The technique as originally described involves careful subperiosteal dissection, leaving the triangular fibrocartilage complex (TFCC) intact. A sufficient length of distal ulna should be resected for the remaining proximal stump to clear the sigmoid notch of the radius, but no more. A secure, multilayer dorsal closure should be performed. The procedure seems straightforward (Figure 3) and should lead to consistently positive results.

Unfortunately, the experience that has been reported over more than 60 years demonstrates less than excellent patient outcomes through use of the simple Darrach resection.[12-18] These reports of suboptimal outcomes consistently emphasize the postoperative potential for instability ("winging") of the distal ulna stump (ie, volar drift of the radius–carpus–hand off the nonrotating postresection ulna), loss of ulna-sided carpal support, TFCC disruption, and postresection mechanical impingement (grinding contact) between the resected distal ulna and the medial border of the radius, resulting in pain and the potential for decreased strength. In a landmark 1973 article, Rana and Taylor[19] reported that 25% of their long-term follow-up patients complained of distal ulna clicking against the radius during forearm rotation, each with resection of more than 3.5 cm of distal ulna. Hartz and Beckenbaugh[20] reported that 30.6% of their higher demand, posttrauma Darrach resections suffered from mechanical symptoms of impingement during forearm rotation at long-term follow-up (Figure 4). It seems, from my experience and from many compelling reports in the orthopedic/hand literature, that a cavalier attitude toward simple surgical elimination of the DRUJ fulcrum (Figures 1, 2) might represent a fundamental lack of appreciation of DRUJ mechanics. Might the Darrach resection alone be an oversimplified approach to a rather complex mechanical problem?

Reported complications of Darrach resection include dorsopalmar forearm instability; distal radius–carpus–hand subluxation off the resected distal ulna stump (distal ulna winging); mechanical symptoms of clicking, catching, and locking; pain and weakness from bone-on-bone contact (impingement); and progressive medial carpal translation (progressive attenuation of the long radiolunate ligament secondary to absence of ulna-sided support for the carpus). A surgeon might ask: Is something inherently wrong with the Darrach procedure? Does it make biomechanical sense? Why have so many complications been reported? It is evident that simple surgical removal of the ulna seat (the DRUJ fulcrum) by Darrach resection (Figures 2, 3) leaves the 2 forearm bones mechanically unsupported distally, unstable, and subject to any or all of the potential complications just listed.

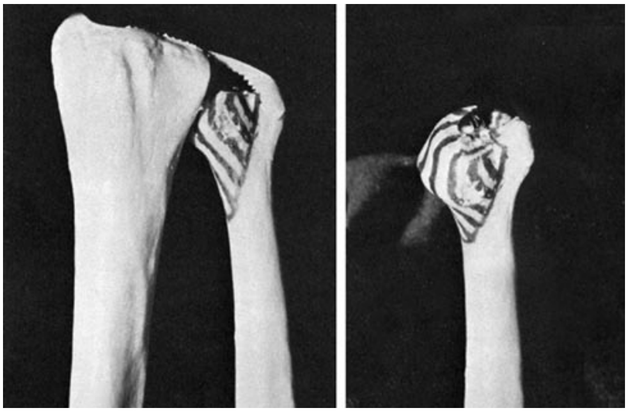

Figure 5. This figure from Bowers's original article on the hemiresection interposition technique shows the portion of the ulna head to be removed for the procedure to be effective. Medial portion of distal ulna is left untouched, preserving integrity of triangular fibrocartilage complex to minimize winging. This figure was published in *J Hand Surg Am*, Vol. 10, Bowers WH, Distal radioulnar joint arthroplasty: the hemiresection-interposition technique, 169-178. Copyright Elsevier 1985.[21]

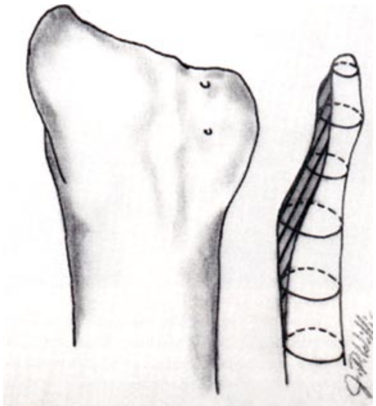

Figure 7. "Matched distal ulna resection," in this drawing from Watson's original publication, provides perfectly paralleling surfaces between medial radius and lateral ulna after resection of seat and pole of distal ulna. This figure was published in *J Hand Surg Am*, Vol. 11, Watson HK, Ryu J, Burgess R, Matched distal ulnar resection, 812-817. Copyright Elsevier 1986.[31]

Figure 8. Impingement between radius and ulna can occur after "matched" resection. Will contouring the border of the ulna to perfectly match the medial border of the radius ensure absence of pain and absence of mechanical signs of crepitus, clicking, and catching?

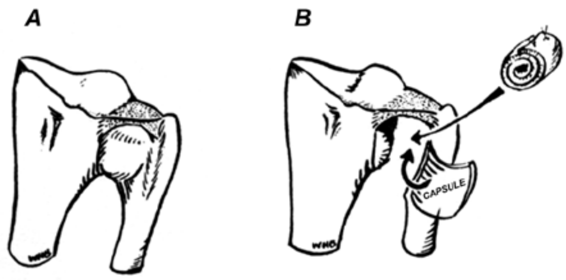

Figure 6. According to Bowers, the rolled-up palmaris longus tendon is an effective shock absorber for load transfer between radius and ulna at the distal radioulnar joint in the low-demand, rheumatoid hand. Bowers suggested that mechanical impingement could be prevented with use of the technique shown in this drawing from his original work. This figure was published in *J Hand Surg Am,* Vol. 10, Bowers WH, Distal radioulnar joint arthroplasty: the hemiresection-interposition technique, 169-178. Copyright Elsevier 1985.[21]

Alternatives to Simple Darrach Resection of the Distal Ulna

The Hemiresection Interposition Technique

In 1985, Bowers[21] reported treating low-demand rheumatoid arthritis patients with what he described as a "hemiresection interposition technique" (HIT procedure). Bowers's approach was designed to eliminate both the seat and the pole of the distal ulna while maintaining the TFCC and the entire medial bony border of the ulna. Figure 5, from Bowers's original article, shows (a) the portion of the seat and the pole designed to be resected to eliminate the ulnocarpal joint and the DRUJ and (b) the portion of the ulna to be protected to preserve the integrity and stabilizing functions of the TFCC. To reconstitute a surrogate fulcrum for load transfer from distal radius to distal ulna in the absence of a diarthrodial DRUJ, Bowers advocated placing rolled-up palmaris longus tendon graft as an interposition buffer between the sigmoid notch and the hemiresected distal ulna (Figure 6). The advantages of the HIT procedure over the Darrach resection are that HIT is designed to recreate a fulcrum for load transfer through a soft-tissue shock absorber between the 2 forearm bones; reduces the propensity for ulna winging by protecting the TFCC; and enhances radioulnar stability by anchoring the dorsal DRUJ capsule to the volar capsule, across the raw area of the resected seat and pole of the distal ulna, the intent being to further enhance distal forearm stability.[21-30] The disadvantages of the HIT procedure are that rolled-up interpositional tendon graft is not a diarthrodial joint; DRUJ load cannot be transferred effectively through rolled-up tendon; and, under sufficient load, rolled-up tendon does not preclude eventual radioulnar impingement.

Matched Distal Ulna Resection

In 1986, a year after Bowers published his technique, Watson and colleagues[31] described their "matched" distal ulna resection (Figure 7, from their original article). Recognizing the potential for mechanical impingement of the 2 forearm bones after removal of the DRUJ fulcrum, they recommended surgically contouring the resected distal ulna so that the long lateral surface of the ulna would perfectly parallel ("match") the long medial border of the radius. If significant impingement were to occur, the

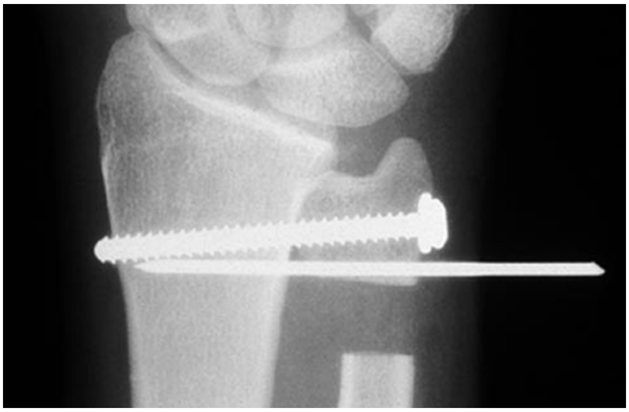

Figure 9. Advantages of Sauvé-Kapandji procedure are preservation of triangular fibrocartilage complex and enlargement (by synostosing ulna head to radius) of distal bony platform to which load from medial carpus can be transferred to forearm. Full pronosupination is preserved by creating 1-cm pseudarthrosis in ulna just proximal to fused distal radioulnar joint.

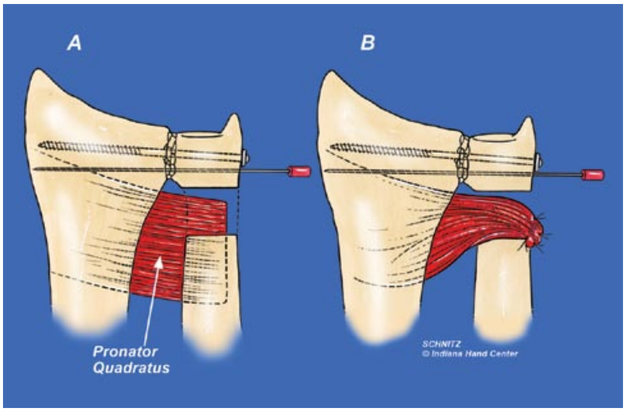

Figure 11. Transferring pronator quadratus into ulna pseudarthrosis created by Sauvé-Kapandji procedure (as popularized by Taleisnik) reduces propensity for ulna winging inherent in technique as originally described. Copyright 2009, Indiana Hand Center.

Figure 10. In wrist ulnar deviation, the principal axis of load bearing shifts medially and passes through triquetrohamate joint and triangular fibrocartilage complex and into ulna through distal pole. This load-bearing site change is important in the Sauvé-Kapandji procedure, which, unlike the Darrach or hemiresection interposition technique, provides a bony platform for ulna-sided load transfer.

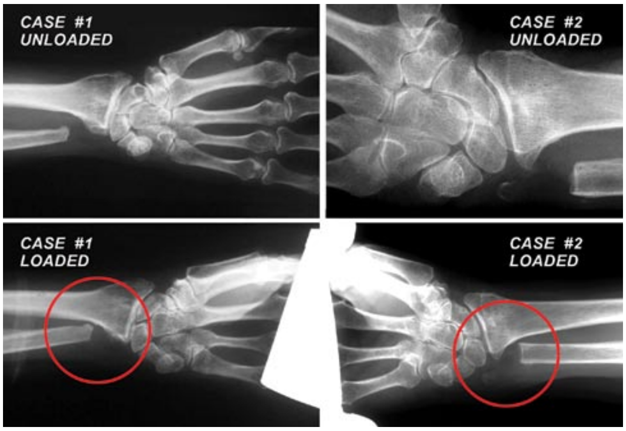

Figure 12. After Darrach resections, radiographs of 2 patients without and with loading show how weight of only 5 pounds in hand precipitates serious impingement between medial radius and resected distal ulna.

parallel surfaces of the radius and contoured ulna would maximize the contact surface area between the 2 bones, thus minimizing the potential for mechanical clicking, catching, or locking of the radius on the ulna through its arc of pronosupination.[31,32] Can simply embedding the distal end of the resected ulna into a so-called nucleus of ulnocarpal connective tissue (even in the face of paralleling bone surfaces) be a truly effective substitute for the complex load-bearing diarthrodial DRUJ (Figure 8)? Wide clinical experience with the matched distal ulna resection reveals anticipated impingement and winging problems associated with elimination of the DRUJ diarthrodial fulcrum, even in the face of a perfectly contoured lateral ulna surface.[33,34]

The Sauvé-Kapandji Procedure

The Sauvé-Kapandji procedure (Figure 9), first described in 1936[35,36] but popularized by Taleisnik in 1992,[37] involves arthrodesis of the DRUJ and creation of a pseudarthrosis at the distal neck of the ulna to allow dissipation of energy through forearm rotation. The procedure preserves the TFCC, enlarges the forearm support platform for the medial carpus, and facilitates load transfer onto an enlarged bony forearm platform as the wrist ulnarly deviates. The principal axis of hand–forearm load bearing shifts in ulnar deviation from its location at the scapholunate ligament (between the elliptical and spherical fossae of the radius) to a position at the pole of the distal ulna (Figure 10). In arthrodesing the head of the ulna to the sigmoid notch at the DRUJ, the bony platform for load transfer from the hand to the forearm is widened medially.[38-53]

The disadvantages of the Sauvé-Kapandji procedure are that inherent forearm instability observed as a complication after Darrach resection can also be seen after creation of a distal ulna shaft pseudarthrosis and that the propensity for winging and impingement of the residual proximal ulna remains.[54,55] In an effort to ameliorate

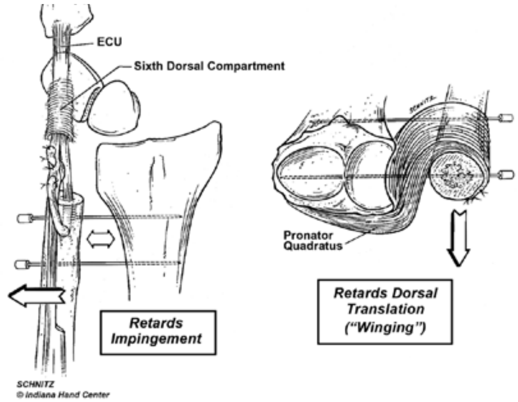

Figure 13. Kleinman/Greenberg "super-Darrach" uses 50% of extensor carpi ulnaris tendon as longitudinal tenodesis to retard impingement and uses interpositional transfer of pronator quadratus to retard impingement and winging. This tendon transfer procedure is one of many that have been used in efforts to reduce the impingement and winging inherent in the Darrach procedure as it was originally described. Copyright 2009, Indiana Hand Center.

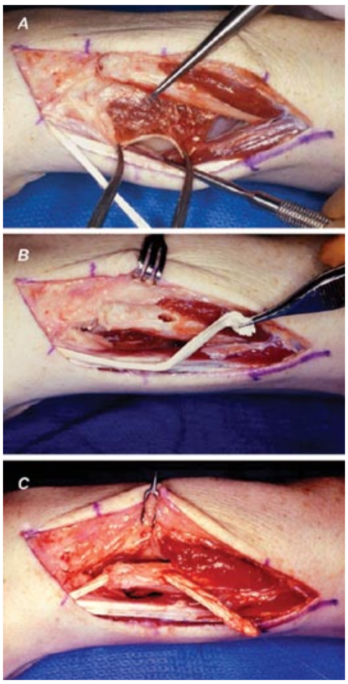

Figure 14. Kleinman/Greenberg "super-Darrach" involves detaching pronator quadratus from volar ulna (A) and transferring muscle through interosseous space to dorsal margin of ulna. Fifty percent of extensor carpi ulnaris (B) is passed distal to proximal into medullary canal of resected ulna and out through small drill hole (C) to be tensioned distally to intact 50% (Figure 16). Before pronosupination rehabilitation can begin, entire construct is held for 6 weeks with convergent radioulnar 0.062-inch Kirschner wires and long-arm cast.

this problem, Taleisnik[37] proposed adjunctive transfer of the pronator quadratus into the pseudarthrosis site (Figure 11) to minimize the propensity of the distal ulna to wing and impinge.[37]

The "Super-Darrach" Resection

The classic Darrach resection of the entire head of the ulna eliminates the ulna seat and the capacity for load to be transferred through a diarthrodial joint from the radius–carpus–hand unit onto a stable DRUJ fulcrum. The radiographs in Figure 12 show 2 different patients after Darrach resection. In the upper 2 figures, hands are unload-

Figure 15. Radiographs of asymptomatic 42-year-old weekend tennis player 6 months after "super-Darrach." On left is unloaded hand; on right, patient squeezes spring-loaded grip meter. As there are no mechanical signs of impingement and no pain, the radiograph that shows convergence of the 2 forearm bones with load is striking.

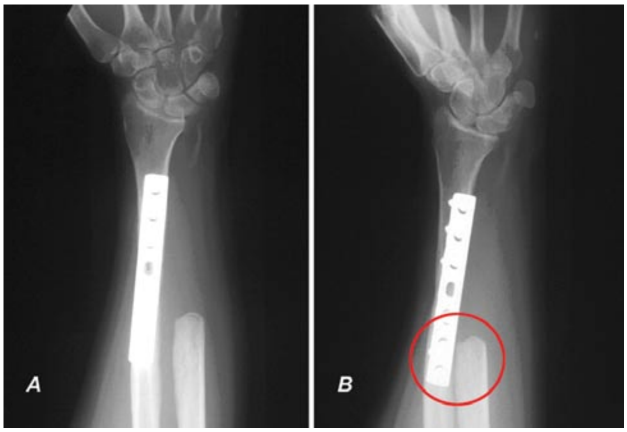

Figure 16. Some authors have recommended more resection of painful, unstable distal end of post-Darrach ulna. (A) Patient had 35% of distal ulna resected in salvage procedure but still complained of impingement pain. (B) Magnitude of impingement with only 5 pounds of weight in hand.

ed; in the lower 2 figures, hands hold a 5-pound weight. Impingement of the resected distal ulna against the medial border of the radius is clear in both cases. This dramatic change in forearm bone alignment occurs in all simple Darrach resections, whether patients are symptomatic or not. Many techniques have been used to minimize the propensity of the resected distal ulna to painfully wing or impinge, reported in approximately 30% of well-performed Darrach resections.[56-63] Each technique uses available and expendable tendon transfers in an effort to stabilize the distal stump of the postresection ulna.

In 1995, my partner and I (Greenberg and Kleinman[56]) published a novel and effective technique for salvaging the failed Darrach by double tendon transfers and prolonged percutaneous Kirschner-wire (K-wire) forearm stabilization (Figure 13). Transfer of the pronator qua-

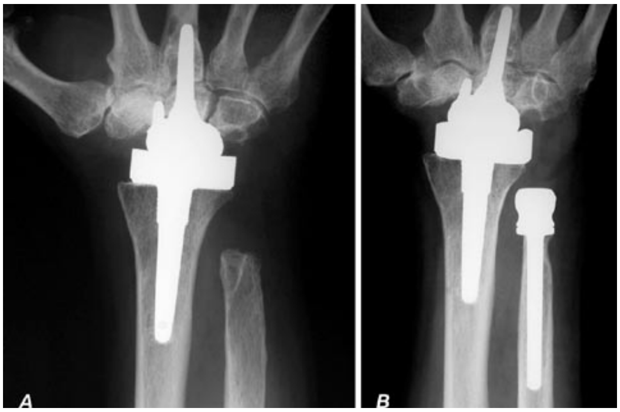

Figure 17. Preoperative (A) and postoperative (B) radiographs show nonconstrained, long-stem prosthetic replacement distal ulna. Implant was used because of painful impingement and winging of distal ulna against medial radius after total wrist arthroplasty and Darrach resection.

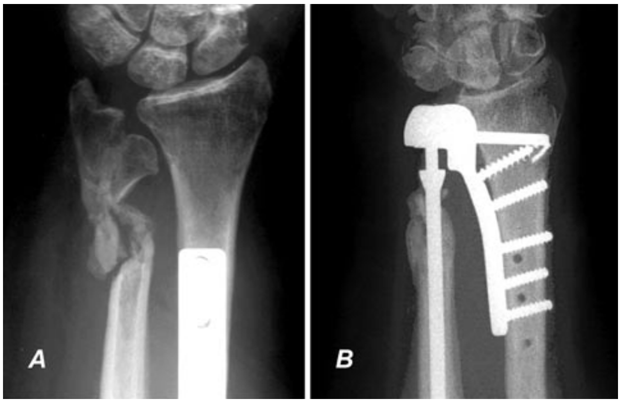

Figure 18. Preoperative (A) and postoperative (B) radiographs show a more contemporary constrained prosthesis for the distal radioulnar joint replacing the sigmoid notch and the distal ulna. In this design, by Dr. Luis Scheker, a stainless-steel cage surrounds a rotating ultra-high-molecular-weight polyethylene ball.

dratus through the interosseous space to the dorsum of the ulna retards winging. Longitudinal tensioning of 50% of the extensor carpi ulnaris retards impingement. K-wire fixation (two 0.062-inch K-wires) for 6 weeks allows the tendon transfers to heal well before rehabilitation of pronosupination begins. Using the technique shown in Figures 14A to 14C, we have reduced symptomatic post-Darrach instability in our patient population from approximately 30% to approximately 15%—a significant improvement, but certainly not a perfect solution. Figures 15A and 15B show an asymptomatic patient, after Darrach resection and double tendon transfers, squeezing a grip meter. Persistent impingement of the distal ulna and radius is clear, even in the absence of symptoms. We now incorporate double tendon transfers and temporary K-wire fixation in all our primary Darrach resections and refer to them as "super-Darrachs."

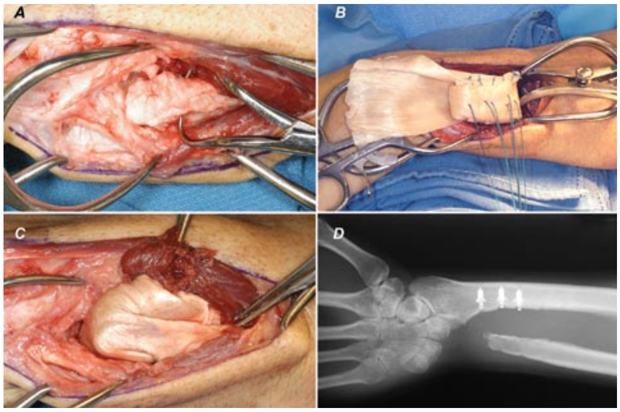

Figure 19. Achilles heel-cord allograft can be used as large interposition buffer to treat painful impingement after failed Darrach resection. (A) To ulnar border of left distal forearm, with distal end of resected ulna exposed. (B) Heel cord being sewn over end of ulna stump, with sutures attached to medial border of radius by 3 bone anchors. (C) Final appearance of allograft wrapped around ulna stump. (D) Final radiographs show large, buffered gap between radius and ulna, filled with allograft, with 3 bone anchors in medullary canal of radius.

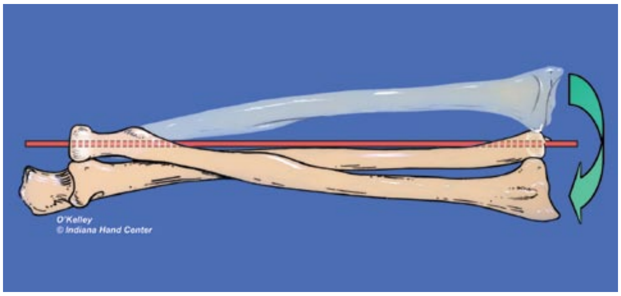

Figure 20. The ulna, a ginglymus diarthrodial joint hinged for flexion and extension at the ulnotrochlear relationship of the elbow, does not rotate. Entire arc of forearm pronosupination involves rotation of radius–carpus–hand unit around fixed ulna. Imaginary axis of rotation for forearm pronosupination passes from center of radial head at elbow through fovea at base of ulna styloid at wrist. Fulcrum for distal forearm load bearing is seat of ulna at distal radioulnar joint. Copyright 2009, Indiana Hand Center.

Management of Failed Darrach Resections

Further Resection of the Distal Ulna

Some clinicians have advocated managing failed Darrach resections with even more enthusiastic resection of the distal ulna, closer to the interosseous ligament. In 1998, Wolfe and colleagues[64] reported that patients with failed primary Darrachs experienced symptom relief after resection of 35% of the normal ulna length. In 2003, Greenberg and colleagues,[65] in association with the biomechanics laboratory at Syracuse University, reported that 25% resection of the distal ulna was all that was necessary to relieve post-Darrach mechanical impingement. Figures 16A and 16B show a patient after a 35% distal ulna resection that failed to alleviate persistent pain from radioulnar impinge-

Figure 21. Three surgical procedures were required to salvage this failed Kleinman/Greenberg "super-Darrach" resection in a 53-year-old man. (A) Severe impingement after ulna head resection and transfer of pronator quadratus and 50% of extensor carpi ulnaris. (B) Zero-rotation radiograph after failed resection of 25% of ulna. (C) Patient after resection of 50% of ulna to interosseous ligament. After failure of aggressive resection, patient consented to creation of one-bone forearm (Figures 22A, 22B) to eliminate chronic pain. Final result was painless forearm with no pronosupination.

ment. Figure 16A shows the unloaded hand; Figure 16B shows the forearm and the hand holding 5 pounds of weight. Radiographs of the dynamic changes in alignment are impressive. The philosophy of "more ulna resection is better" does not consistently hold up.

Prosthetic Replacement of the Distal Ulna

Can an effective DRUJ fulcrum be created by prosthetic replacement of the resected distal ulna? Since the early 1970s, clinical researchers have tried a variety of techniques to restore forearm stability by prosthetic replacement after Darrach resection. In 1973, Swanson[66] published encouraging early results with silicone rubber capping of the resected distal ulna. Long-term follow-up studies, however, were disappointing.[67,68] Design of the prosthesis and the material itself proved incapable of withstanding the shear and compression forces crossing the DRUJ. More recently, engineered nonconstrained and constrained prostheses have both had some success.[69-72] There are now many competitive varieties of long-stem, nonconstrained implants, such as the Mayo Clinic–designed cobalt-chromium alloy prosthesis (Figures 17A, 17B).[69] The Scheker constrained distal ulna prosthesis (Figures 18A, 18B)[70] replaces both the sigmoid notch and the head of the ulna using a long-stem, stainless-steel cage surrounding a rotating ultra-high-molecular-weight polyethylene ball. This mechanically sophisticated prosthesis allows complex rotation to occur at the reconstructed DRUJ. Even lacking a physiologic translation component, this prosthesis design has had encouraging early results, reported Scheker and colleagues.[70]

Use of Achilles Tendon Allograft

A unique alternative to prosthetic replacement for the failed Darrach resection, described by Sotereanos and colleagues[73] in 2002, uses Achilles tendon allograft. For creation of a large collagen buffer between the radius and impinging post-Darrach ulna, the authors recommended that a human heel-cord allograft be used to provide an abundant amount of connective tissue to cover the end of the resected distal ulna and to fill the interosseous space distal to the interosseous ligament (Figures 19A–19D). A series of bone anchors is introduced into the medial border of the radius to hold the allograft in place until it has healed. Although in no way providing a fulcrum as effective as the native diarthrodial DRUJ, the large bulk of connective tissue provided by the Achilles tendon allograft separates the radius and the ulna, facilitating load transfer from the radius–carpus–hand unit to the ulna and then proximal to the elbow. The technique has proved reasonably effective in salvaging failed Darrach procedures in higher demand patients and in patients too young to undergo salvage by prosthetic replacement.

Creation of One-Bone Forearm

The ultimate salvage procedure for failed Darrach resection is creation of a one-bone forearm.[74-77] Iatrogenic synostosis of both forearm bones is one of the most debilitating proce-

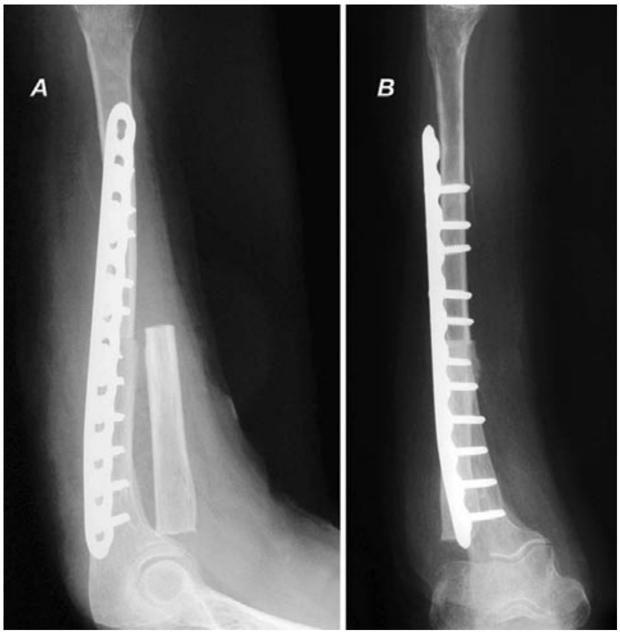

Figure 22. Anteroposterior (A) and lateral (B) radiographs of one-bone forearm, the ultimate salvage procedure for chronic, painful post-Darrach instability. In this case, proximal ulna was secured to distal radius with locking 3.5-mm compression plate. Proximal radius remains and causes no clinical problems.

dures performed by upper extremity reconstructive surgeons to relieve chronic impingement pain. Forearm pronosupination (Figure 20) is critical for healthy function of the upper extremity; without it, the ability to put and place the hand in space is severely compromised. Figure 21A shows a 53-year-old patient with a failed Kleinman/Greenberg super-Darrach resection for posttraumatic DRUJ arthropathy. In spite of dorsal transfer of the pronator quadratus (attached to the ulna in this case by 3 bone anchors) and longitudinal tensioning of 50% of the extensor carpi ulnaris, the postoperative impingement was striking. The patient was treated with resection of 25% of the distal ulna 18 months later but experienced persistent painful impingement (Figure 21B). A year later, the distal ulna stump was shortened to 55% of the opposite side, still with little improvement in symptoms (Figure 21C). In a final salvage effort, a one-bone forearm was created; the proximal ulna and the distal radius were plated together to form a single bone (Figures 22A, 22B). Mechanical pain was finally eliminated with the procedure, but upper extremity function was permanently and severely compromised by elimination of pronosupination forearm arc of motion.

Conclusions

Although resection of the distal ulna is a procedure that has stood the test of time, Darrach's technique, described almost 100 years ago, is clearly wrought with biomechanical consequences, the most common of which relate to loss of an ulna load-bearing fulcrum at the DRUJ (Figure 1). When recommending *any* bony salvage procedure at the DRUJ, the surgeon must advise the patient there is a real potential for postoperative impingement and winging at the resected distal end of the ulna. Although many creative and innovative techniques have been used in efforts to provide a substitute fulcrum for load transfer from radius to ulna, as yet there is no panacea. There is no magic.

Author's Disclosure Statement and Acknowledgements

The author reports no actual or potential conflict of interest in relation to this article.

Special thanks to Mr. Gary Schnitz, my friend and colleague, who has provided all the partners of the Indiana Hand Center with some of the finest medical illustrations in all of academic hand surgery. His brilliant work is recognized throughout the hand surgery world. His drawings have helped an untold number of students of hand surgery to more clearly understand our research, our clinical work, and our professional endeavors in general.

References

1. Kleinman WB, Graham TJ. Distal ulnar injury and dysfunction. In: Peimer CA, ed. *Surgery of the Hand and Upper Extremity.* New York, NY: McGraw-Hill; 1996:667-709.
2. Darrach W. Forward dislocation at the inferior radioulnar joint, with fracture of the lower third of the shaft of the radius. *Ann Surg.* 1912;56(5):801.
3. Darrach W. Anterior dislocation of the head of the ulna. *Ann Surg.* 1912;56(5):802-803.
4. Darrach W. Partial excision of lower shaft of ulna for deformity following Colles's fracture. *Ann Surg.* 1913;57(5):764-765.
5. Tulipan DJ, Eaton RG, Eberhart RE. The Darrach procedure defended: technique redefined and long-term follow-up. *J Hand Surg Am.* 1991;16(3):438-444.
6. Dingman PVC. Resection of the distal end of the ulna (Darrach operation): an end-result study of twenty-four cases. *J Bone Joint Surg Am.* 1952;34(4):893-900.
7. Nolan WB, Eaton RG. A Darrach procedure for distal ulnar pathology derangements. *Clin Orthop.* 1992;(275):85-89.
8. Sauerbier M, Fujita M, Hahn ME, Neale PG, Berger RA. The dynamic radio-ulnar convergence of the Darrach procedure and the ulnar head hemiresection interposition arthroplasty: a biomechanical study. *J Hand Surg Br.* 2002;27(4):307-316.
9. Palmer AK, Glisson RR, Werner FW. Ulnar variance determination. *J Hand Surg Am.* 1982;7(4):376-379.
10. Kauer JMG. The distal radioulnar joint: anatomical and functional considerations. *Clin Orthop.* 1992;(275):37-45.
11. Palmar AK, Werner FW. Biomechanics of the distal radioulnar joint. *Clin Orthop*. 1984;(187):26-34.
12. Lees VC, Scheker LR. The radiological demonstration of dynamic ulna impingement. *J Hand Surg Br.* 1997;22(4):448-459.
13. McKee MD, Richards RR. Dynamic radio-ulnar convergence after the Darrach procedure. *J Bone Joint Surg Br.* 1996;78(3):413-418.
14. Field J, Majkowski RJ, Leslie IJ. Poor results of Darrach's procedure after wrist injuries. *J Bone Joint Surg Br.* 1993;75(1):53-57.
15. Mih AD. Salvage procedures after failed surgery about the distal ulna. *Hand Clin.* 1998;14(2):279-284.
16. Newmeyer WL, Green DP. Rupture of digital extensor tendons following distal ulnar resection. *J Bone Joint Surg Am.* 1982;64(2):178-182.
17. Bieber EJ, Linscheid RL, Dobyns JH, Beckenbaugh RD. Failed distal ulna resections. *J Hand Surg Am*. 1988;13(2):193-200.
18. Blatt G, Ashworth CR. Volar capsule transfer for stabilization following resection of the distal end of the ulna. *Orthop Trans.* 1979;3(1):13-14.
19. Rana NA, Taylor AR. Excision of the distal end of the ulna in rheumatoid arthritis. *J Bone Joint Surg Br.* 1973;55(1):96-105.
20. Hartz CR, Beckenbaugh RD. Long-term results of resection of the distal ulna for post-traumatic conditions. *J Trauma.* 1979;19(4):219-226.
21. Bowers WH. Distal radioulnar joint arthroplasty: the hemiresection-interposition technique. *J Hand Surg Am.* 1985;10(2):169-178.
22. Bowers WH. Hemiresection interposition technique (HIT) arthroplasty of the distal radioulnar joint. In: Gelberman RH, ed. *The Wrist: Master Techniques* in Orthopaedic Surgery. New York, NY: Raven Press; 1994:303-318.
23. Glowacki KA. Hemiresection arthroplasty of the distal radioulnar joint. *Hand Clin.* 2005;21(4):591-601.
24. González del Pino J, Fernández DL. Salvage procedure for failed Bowers' hemiresection interposition technique in the distal radioulnar joint. *J Hand Surg Br.* 1998;23(6):749-753.
25. Fernández DL. Radial osteotomy and Bowers arthroplasty for malunited fractures of the distal end of the radius. *J Bone Joint Surg Am.* 1988;70(10):1538-1551.
26. Lanz U, Markulin M. Hemiresection interposition arthroplasty (HIT) of the distal radioulnar joint. In: Vastamaki M, ed. *Current Trends in Hand Surgery.* Amsterdam, Netherlands: Elsevier Science BV; 1995:207-212.
27. Imbriglia JE, Matthews D. Treatment of chronic post-traumatic dorsal subluxation of the distal ulna by hemiresection interpositional arthroplasty. *J Hand Surg Am.* 1993;18(5):899-907.
28. Imbriglia JE, Matthews D. The treatment of chronic traumatic subluxation of the distal ulna by hemiresection interposition arthroplasty. *Hand Clin.* 1991;7(2):329-334.
29. Minami A, Suzuki K, Suenaga N, Ishikawa J, Hemiresection-interposition arthroplasty for osteoarthritis of the distal radioulnar joint. *Int Orthop.* 1995;19(1):35-39.
30. Wicks BP, Fletcher D, Palmer AK. Failed Bowers procedure (Hemiresection Interposition Technique). Paper presented at: 45th Annual Meeting of the American Society for Hand Surgery; September 24-27, 1990: Toronto, Canada. Abstracts of papers. Paper SS-31.
31. Watson HK, Ryu J, Burgess R. Matched distal ulnar resection. *J Hand Surg Am.* 1986;11(6):812-817.
32. Watson HK, Gabuzda GM. Matched distal ulnar resection for posttraumatic disorders of the distal radioulnar joint. *J Hand Surg Am*. 1992;17(4):724-730.
33. Bain GI, Pugh DM, MacDermid JC, Roth JH. Matched hemiresection

interposition arthroplasty of the distal radioulnar joint. *J Hand Surg Am.* 1995;20(6):944-950.
34. Minami A, Iwasaki N, Ishikawa J, Suenaga N, Yasuda K, Kato H. Treatments of osteoarthritis of the distal radioulnar joint: long-term results of three procedures. *Hand Surg.* 2005;10(2-3):243-248.
35. Sauvé L, Kapandji M. Nouvelle technique de traitement chirurgical des luxations récidivantes isolées de l'extrémité inferieure du cubitus. *J Chirurg.* 1936;47(4):589-594.
36. Kapandji AI. The Sauvé-Kapandji procedure. *J Hand Surg Br.* 1992;17(2):125-126.
37. Taleisnik J. The Sauvé-Kapandji procedure. *Clin Orthop.* 1992;(275):110-123.
38. Kapandji I. The Kapandji-Sauvé operation: its techniques and indications in non-rheumatoid diseases. *Ann Chirurg Main.* 1986;5(3):181-193.
39. Slater RR. The Sauvé-Kapandji procedure. *J Hand Surg Am*. 2008;33(9):1632-1638.
40. Sanders RA, Frederick HA, Hontas RB. The Sauvé-Kapandji procedure: a salvage operation for the distal radio-ulnar joint. *J Hand Surg Am*. 1991;16(6):1125-1129.
41. Rothwell AG, O'Neill L, Cragg K. Sauvé-Kapandji procedure for disorders of the distal radioulnar joint: a simplified technique. *J Hand Surg Am*. 1996;21(5):771-777.
42. George MS, Kiefhaber TR, Stern PJ. The Sauvé-Kapandji procedure and the Darrach procedure for distal radio-ulnar joint dysfunction after Colles' fracture. *J Hand Surg Br.* 2004;29(6):608-613.
43. Mikkelsen SS, Lindblad BE, Larsen ER, Sommer J. Sauvé-Kapandji operation for disorders of the distal radioulnar joint after Colles' fracture. Good results in 12 patients followed for 1.5–4 years. *Acta Orthop Scand.* 1997;68(1):64-66.
44. Vincent KA, Szabo RM, Agee JM. The Sauvé-Kapandji for reconstruction of the rheumatoid distal radio-ulnar joint. *J Hand Surg Am.* 1993;18(6):978-983.
45. Carter PB, Stuart PR. The Sauvé-Kapandji procedure for post-traumatic disorders of the distal radio-ulnar joint. *J Bone Joint Surg Br.* 2000;82(7):1013-1018.
46. Zachee B, DeSmet L, Roosen P, Fabry G. The Sauvé-Kapandji procedure for nonrheumatic disorders of the distal radioulnar joint. *Acta Orthop Belg.* 1994;60(2):225-230.
47. Minami A, Suzuki T, Suenaga N, Ishikawa J. The Sauvé-Kapandji operation for osteoarthritis of the distal radioulnar joint. *J Hand Surg Am.* 1995;20(4):602-608.
48. Nakamura R, Tsunoda K, Watanabe K, Horii E, Miura T. The Sauvé-Kapandji procedure for chronic dislocation of the distal radio-ulnar joint with destruction of the articular surface. *J Hand Surg Br.* 1992;17(2):127-132.
49. Low CK, Chew WYC. Results of Sauvé-Kapandji procedure. *Singapore Med J.* 2002;43:135-137.
50. Gordon L, Levinsohn DG, Moore SV, Dodds RJ, Castleman LD. The Sauvé-Kapandji procedure for the treatment of posttraumatic distal radioulnar joint problems. *Hand Clin.* 1991;7(2):397-403.
51. Inagaki H, Nakamura R, Horii E, Nakao E, Tatebe M. Symptoms and radiographic findings in the proximal and distal ulnar stumps after the Sauvé-Kapandji procedure for treatment of chronic derangement of the distal radioulnar joint. *J Hand Surg Am.* 2006;31(5):780-784.
52. Lamey DM, Fernández DL. Result of the modified Sauvé-Kapandji procedure in the treatment of chronic posttraumatic derangement of the distal radioulnar joint. *J Bone Joint Surg Am*. 1998;80(12):1758-1769.
53. Millroy P, Coleman S, Ivers R. The Sauvé-Kapandji operation. Technique and results. *J Hand Surg Br.* 1992;17(4):411-414.
54. Minami A, Iwasaki N, Ishikawa J, Suenaga N, Kato H. Stabilization of the proximal ulnar stump in the Sauvé-Kapandji procedure by using the extensor carpi ulnaris tendon: long-term follow-up studies. *J Hand Surg Am.* 2006;31(3):440-444.
55. Minami A, Kato H, Iwasaki N. Modification of the Sauvé-Kapandji procedure with extensor carpi ulnaris tenodesis. *J Hand Surg Am.* 2000;25(6):1080-1084.
56. Kleinman WB, Greenberg JA. Salvage of the failed Darrach procedure. *J Hand Surg Am.* 1995;20(6):951-958.
57. Breen TF, Jupiter JB. Extensor carpi ulnaris and flexor carpi ulnaris tenodesis of the unstable distal ulna. *J Hand Surg Am.* 1989;14(4):612-617.
58. Spionner M, Kaplan EB. Extensor carpi ulnaris: its relationship to the stability of the distal radioulnar joint. *Clin Orthop.* 1970;(68):124-129.
59. Johnson RK. Muscle-tendon transfer for stabilization of the distal radioulnar joint. *J Hand Surg Am.* 1985;10(3):437.
60. Tsai TM, Shimizu H, Adkins P. A modified extensor carpi ulnaris tenodesis with the Darrach procedure. *J Hand Surg Am*. 1993;18(4):697-702.
61 Ruby LK, Ferenz CC, Dell PC. The pronator quadratus interposition transfer: an adjunct to resection arthroplasty of the distal radioulnar joint. *J Hand Surg Am.* 1996;21(1):60-65.
62. Webber JB, Maser SA. Stabilization of the distal ulna. *Hand Clin.* 1991;7(2):345-353.
63. Sauerbier M, Berger RA, Fujita M, Hahn ME. Radioulnar convergence after distal ulnar resection. Mechanical performance of two commonly used soft tissue stabilizing procedures. *Acta Orthop Scand.* 2003;74(4):420-428.
64. Wolfe SW, Mih AD, Hotchkiss RN, Culp RW, Kiefhaber TR, Nagle DJ. Wide excision of the distal ulna: a multicenter case study. *J Hand Surg Am.* 1998;23(2):222-228.
65. Greenberg JA, Yanagida H, Werner FW, Short WH. Wide excision of the distal ulna: biomechanical testing of a salvage procedure. *J Hand Surg Am.* 2003;28(1):105-110.
66. Swanson AB. Implant arthroplasty for disabilities of the distal radioulnar joint. *Orthop Clin North Am.* 1973;4(2):373-382.
67. Stanley D, Herbert TJ. The Swanson ulnar head prosthesis for post-traumatic disorders of the distal radio-ulnar joint. *J Hand Surg Br.* 1992;17(6):682-688.
68. Sagerman SD, Seiler JG, Fleming LL, Lockerman E. Silicone rubber distal ulnar replacement arthroplasty. *J Hand Surg Br.* 1992;17(6):689-693.
69. Willis AA, Berger RA, Cooney WP. Arthroplasty of the distal radioulnar joint using a new ulnar head endoprosthesis: preliminary report. *J Hand Surg Am.* 2007;32(2):177-189.
70. Scheker LR, Babb BA, Killion PE. Distal ulnar prosthetic replacement. *Orthop Clin North Am*. 2001;32(2):365-376.
71. Sauerbier M. Hahn ME, Fujita M, Neale PG, Berglund LJ, Berger RA. Analysis of dynamic distal radioulnar convergence after ulnar head resection and endoprosthesis implantation. *J Hand Surg Am*. 2002;27(3):425-434.
72. van Schoonhoven J, Fernández DL, Bowers WH, Herbert TJ. Salvage of failed resection arthroplasties of the distal radioulnar joint using a new ulnar head endoprosthesis. *J Hand Surg Am*. 2000;25(3):438-446.
73. Sotereanos DG, Gobel F, Vardakas DG, Sarris I. An allograft salvage technique for failure of the Darrach procedure: a report of four cases. *J Hand Surg Br.* 2002;27(4):317-321.
74. Hey Groves EW. *On Modern Methods of Treating Fractures*. 2nd ed. Bristol, England: John Wright & Sons; 1921.
75. Mahmud F, Nazarian DG, Zahner EJ, Carroll RE, Dick HM. Creation of a "one-bone" forearm to reconstruct large radioulnar defects. *Orthop Trans.* 1996;20(1):231.
76. Schneider LH, Imbriglia JE. Radioulnar joint fusion for distal radioulnar joint instability. *Hand Clin.* 1991;7(2):391-395.
77. Peterson CA 2nd, Maki S, Wood MB. Clinical results of the one-bone forearm. *J Hand Surg Am.* 1995;20(4):609-618.