Five Wrist Operations That Give the Best Results

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Learning Objectives: After reading this article and viewing the videos, the participant should be able to: 1. Recognize the following five wrist operations as consistent options for different wrist injuries: carpal tunnel release, medial femoral condyle bone flap for scaphoid nonunion associated with carpal collapse and avascular necrosis, scaphocapitate arthrodesis for Kienböck disease, percutaneous screw fixation of nondisplaced scaphoid fracture, and four-corner arthrodesis. 2. Know the state-of-the-art of these five procedures. 3. State the indications of each operation. 4. List the surgical steps of these five procedures.

Summary: The wrist is a complex joint that concentrates different types of tissues (e.g., bone, cartilage, ligaments, nerves, vessels) and a broad different spectrum of diseases. Treatment of wrist injuries has improved during recent years, mainly because of improvement in strategy, techniques, microsurgical equipment, understanding anatomy and improvements in technology. In this article, we present the five operations (i.e., carpal tunnel release, medial femoral condyle bone flap for scaphoid nonunion associated with carpal collapse and avascular necrosis, scaphocapitate arthrodesis for Kienböck disease, percutaneous screw fixation of nondisplaced scaphoid fracture, and four-corner arthrodesis) that have consistently given good outcomes in patients suffering from different wrist injuries/maladies. (*Plast. Reconstr. Surg.* 147: 295e, 2021.)

In this article, we present the five operations (i.e., carpal tunnel release, medial femoral condyle bone flap for scaphoid nonunion associated with carpal collapse and avascular necrosis, scaphocapitate arthrodesis for Kienböck disease, percutaneous screw fixation of nondisplaced scaphoid fracture, and four-corner arthrodesis) that, in our experience, have consistently given good outcomes (based on patient satisfaction observed in our daily practice) in patients suffering from different wrist injuries/maladies.

CARPAL TUNNEL RELEASE: OPEN AND NEW TECHNOLOGIES

Carpal tunnel syndrome is the most commonly diagnosed site of nerve compression, with an annual incidence of 0.5 to 5.1 per 1000 and an estimated cumulative incidence of 8 percent.[1,2] [**See Video 1 (online)**, which displays mini open carpal tunnel release for median nerve entrapment. Note how the median nerve is released completely at the carpal tunnel. **See Video 2 (online)**, which displays ultrasound-guided carpal tunnel release for median nerve entrapment at the carpal tunnel. Note how the guide is positioned before the transverse ligament is cut.] Paget published the first description of carpal tunnel syndrome secondary to trauma in 1854,[3,4] and Phalen presented the first large series of carpal tunnel release in 1966[5] with an excellent report of the presentation and description of this abnormality. Although carpal tunnel release is nowadays one of the most frequently performed wrist operations (up to 1.5 per 1000 population annually),[6,7] its diagnosis and treatment are not always straightforward. The diagnosis of carpal tunnel syndrome is established by the characteristic clinical history (paresthesias and dysesthesias on the palmar side of the thumb and index and middle fingers, which get worse at night and are relieved by shaking of the hand) and physical examination (altered sensation in the palmar aspects of the thumb, index, and middle fingers, thenar muscle weakness and atrophy, and positive provocative signs such as Tinel and Phalen signs). Electrodiagnostic studies confirm the diagnosis.

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Other upper extremity neurologic conditions, including radiculopathy, brachial plexus neuritis, thoracic outlet syndrome, and other less common median neuropathies, can simulate the diagnosis of carpal tunnel syndrome.[8]

Once the diagnosis of carpal tunnel syndrome is confirmed, a period of nonoperative treatment including activity modification, splinting, nonsteroidal antiinflammatory drugs, or corticosteroid injection could be considered. If symptoms do not respond or if the patient presents with moderate or severe symptoms, surgical treatment should be recommended.

Open versus Endoscopic Carpal Tunnel Release

Endoscopic carpal tunnel release has been performed for the past 20 years.[9,10] The efficacy and safety of endoscopic carpal tunnel release are still debated. Multiple randomized, controlled trials have been performed that compare open carpal tunnel release versus endoscopic carpal tunnel release.[11–25] Significant differences related to short- or long-term symptomatic outcomes or complication rates have not been found. The endoscopic technique shows a shorter postoperative recovery period and reduced scar tenderness and allows earlier return to work compared with the open technique.[26] However, endoscopic release is more expensive and is associated with higher rates of transient and permanent nerve damage.[27] We believe the open method should remain the standard, because of its technical simplicity and low complication rate.

Open Carpal Tunnel Release

Under local anesthesia using lidocaine with 1:100,000 epinephrine (under either brachial tourniquet control or the "wide-awake" no tourniquet concept popularized by Lalonde[28–31]), the carpal tunnel release is performed [**Video 1** (online)]. The incision is usually confined to the palm, 5 mm ulnar to the interthenar depression, longitudinal, and approximately 3 to 5 cm in length. The dissection is carried through the subcutaneous fat to the palmar aponeurosis. The palmar aponeurosis is divided longitudinally, and dissection continues until the transverse fibers of the transverse carpal ligament are seen. A small opening is made proximally and ulnarly with a knife. A periosteal elevator or a small mosquito forceps can be passed from proximally to distally. With the elevator in the ulnar aspect of the carpal tunnel and the median nerve protected, the ligament is sharply cut. Alternatively, the transverse carpal ligament can be divided with a knife with careful knife control. The distal and proximal-most extent is often completed with tenotomy scissors under direct visualization. The entirety of the carpal tunnel must be released: fat is seen distally, and the release must be performed proximal to the distal wrist crease. Epineurotomy or neurolysis of the median nerve does not add any significant improvement.[32,33] Hemostasis is achieved and the incision is closed in layers. A dry sterile compressive dressing without a splint is applied.[8]

Ultrasound-Guided Carpal Tunnel Release

Mini, percutaneous, and ultra–minimally invasive approaches using ultrasound have been described in the past decade [**see Video 2 (online)**].[26,34–37] Recent developments in sonography allow demarcation of superficial soft tissues and identification of very small anatomical and pathologic details. The advantages are a smaller incision (or needle entrance) compared with classical techniques[37,38] and great safety during the procedure by visualization of small anatomical structures.[39–41] Mini–open carpal tunnel release has matched endoscopic carpal tunnel release in clinical results and morbidity[35,37,42]; however, there is concern that part of the procedure is performed blindly.[26,34,36,37,42]

A modification of ultrasound-guided carpal tunnel release is the "thread carpal tunnel release." This technique transects the transverse carpal ligament by sawing the ligament with a piece of thread looped percutaneously around the transverse carpal ligament under ultrasound guidance. This method ensures that the division occurs only inside the loop of thread around the target without injuring adjacent tissues. Cadaveric[43] and clinical[44,45] studies have shown the safety of this procedure. A recent controlled trial[46] showed the safety and effectiveness after ultrasound-guided looped thread carpal tunnel release. Further randomized clinical trials are needed to make these ultrasound-guided techniques the gold standard for the treatment of carpal tunnel syndrome.

MEDIAL FEMORAL CONDYLE BONE FLAP

Successful treatment of scaphoid nonunions requires addressing both the geometry and the vascularity of the bone. [**See Video 3 (online)**, which displays scaphoid preparation before the insetting of the medial femoral condyle bone flap for scaphoid nonunion with avascular necrosis of proximal pole and carpal collapse.] In scaphoid waist fractures, failure to correct the bony geometry may result in a "humpback" deformity, carpal collapse, and ultimately a predictable pattern of

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arthritis known as scaphoid nonunion advanced collapse wrist.[47] The proximal pole of the scaphoid is particularly susceptible to the development of avascular necrosis in the setting of nonunion given its interosseous blood supply from branches of the radial artery.[48] Patients who present with scaphoid nonunions with carpal collapse and avascular necrosis present a particular challenge, which necessitates addressing both abnormalities.

The medial femoral condyle flap was originally described by Sakai et al. as a corticoperiosteal flap for the treatment of difficult nonunions in the upper extremity.[49] Further refinement of this technique has demonstrated the capacity of this flap to include corticocancellous bone, allowing for correction of both humpback deformity (through structural support) and avascular necrosis (through neovascularization).[50]

Initial management of scaphoid nonunions includes a computed tomographic scan to assess carpal geometry. No preoperative imaging studies have been shown to reliably identify avascular necrosis. Therefore, we rely on punctate bleeding after tourniquet release, as described by Green,[51] to determine the vascularity of the proximal pole. Surgical treatment begins with a volar approach to the scaphoid, where the nonunion can be identified and débrided of callous and nonviable tissue [**See Video 3 (online)**]. We find it useful to temporarily pin the lunate to the radius in the neutral position to ensure that the scaphoid is not fixed with a dorsal intercalary segment instability deformity of the carpal bones. Once the nonunion is débrided and reduced, a bony defect in the scaphoid is measured for harvest of the medial femoral condyle bone flap. We find it easiest to make fresh, parallel cuts in the distal and proximal scaphoid to better accommodate the bone flap. The flap is based off of branches of the superficial femoral artery, most commonly the descending genicular artery[52]; however, in 23 percent of cases, the superomedial genicular artery is used.[53] Generally, a cube of bone, slightly larger than 1 cm^3, is harvested with its vascular pedicle. Once freed, the bone can be trimmed to the precise dimensions of the defect. The nonunion with the bone flap in place is secured with either a screw or multiple Kirschner wires, depending on the injury. We perform an end-to-side anastomosis to the radial artery and end-to-end anastomosis of the venae comitantes. We do not routinely use a skin paddle, although this has been described.[54] [**See Video 4 (online)**, which displays the medial femoral condyle bone flap dissection for scaphoid nonunion with avascular necrosis of proximal pole and carpal collapse. **See Video 5 (online)**, which displays the medial femoral condyle bone flap insetting and fixation for scaphoid nonunion with avascular necrosis of proximal pole and carpal collapse.]

Treatment of scaphoid fractures and nonunions with humpback deformity and the absence of avascular necrosis can be treated with a variety of nonvascularized bone grafts, most commonly volar radial cortex or iliac crest. Chang et al. reported success of use of 1,2 intercompartmental supraretinacular artery in patients with scaphoid nonunions and avascular necrosis.[55] However, the authors noted a higher failure rate in patients with humpback deformity and carpal collapse. A free vascularized medial femoral condyle bone flap addresses both of these complications.

We have found this procedure useful in a particularly difficult set of patients: those who have already failed a prior nonunion surgery and present with the combination of carpal collapse and avascular necrosis. Jones et al. initially reported a 100 percent union rate in 12 scaphoid nonunions treated with a free vascularized medial femoral condyle bone flap.[56] Nine of the patients had undergone a prior procedure. In a larger series of patients with avascular necrosis and carpal collapse, we found an 84 percent[57] and 94 percent union rate in patients who had and had not undergone a prior operation, respectively. Age, smoking status, preoperative radiographic findings, and time to surgery were not found to be significant predictors of failure to achieve union. In patients in whom scaphoid union had been achieved, all patients were able to return to work or school full-time. No patients complained of donor-site pain at final follow-up.

Although greater than 90 percent of scaphoid fractures will unite uneventfully, we have found the free vascularized medial femoral condyle bone flap to be useful in the most difficult subset of patients: those with carpal collapse and avascular necrosis who have already undergone a prior scaphoid nonunion surgery.

SCAPHOCAPITATE ARTHRODESIS FOR KIENBÖCK DISEASE

Kienböck disease typically presents with wrist pain, loss of motion, and decreased strength because of the predictable pattern of lunate fragmentation, carpal instability, and carpal collapse.[58,59] [**See Video 6 (online)**, which displays scaphocapitate arthrodesis for Kienböck disease using two memory staples.] Depending on the

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disease stage, different treatments have been proposed: lunate offloading or joint leveling, lunate revascularization, and salvage procedures.

Limited wrist arthrodesis, such as scaphotrapeziotrapezoid or scaphocapitate arthrodesis with lunate salvage, is used for patients with neutral ulnar variance or disease in more advanced stages.[60] Moreover, limited wrist arthrodesis can offer a motion-sparing salvage option in patients with a fractured lunate, if the cartilage shell of the lunate is not intact, or when chondral loss at the capitate head would contraindicate proximal row carpectomy. Although published reports on the role and outcome of scaphocapitate arthrodesis in Kienböck disease are few,[61–63] a recent study published from our institution has shown promising results.[64] Twenty-seven patients with advanced stages of Kienböck disease presented an improved grip strength with correction of carpal alignment in medium-term follow-up (60 months; range, 12 months to 16 years).

In brief, a dorsal longitudinal incision centered over the third metacarpal is made and ulnarly based retinacular flaps are elevated. A ligament-sparing dorsal capsulotomy is performed and the lunate is inspected.[65] If minimal lunate fragmentation is present, small unstable fragments are excised with lunate salvage. If moderate to severe lunate fragmentation and/or degenerative change exists at the radiolunate and/or capitolunate articulation, subtotal lunate excision, leaving the volar cortex of the lunate with preservation of the volar radiocarpal ligaments to maintain carpal stability, is performed. Next, the articular cartilage of the scaphocapitate interface is removed until bleeding cancellous bone is exposed. The scaphoid is reduced to a radioscaphoid angle of 30 to 60 degrees and provisionally maintained with a 1.6-mm Kirschner wire. Bone graft or substitute is applied to the arthrodesis site. Final fixation is provided by headless compression screws, staples, or Kirschner wires. The dorsal capsule and extensor retinaculum are repaired with nonabsorbable sutures, and the extensor pollicis longus is transposed dorsal to the retinaculum. A sterile dressing is applied and the wrist is immobilized in a short-arm, volarly based, plaster wrist orthosis [**see Video 6 (online)**].

We believe limited wrist arthrodesis, especially, or scaphocapitate arthrodesis provides a reliable surgical option for pain relief while preserving radiocarpal motion in advanced stages of Kienböck disease when the lunate cannot be revascularized or offloaded to halt the progression of disease and carpal collapse is present. The durability of scaphocapitate arthrodesis in maintaining carpal height while permitting wrist motion is well illustrated in the case series by Luegmair and Saffar that observed a mean wrist arc of motion of 87 degrees in flexion-extension and 41 degrees in radioulnar deviation, with no patients requiring conversion to a total wrist arthrodesis in 20 manual laborers (mean age, 43 years; range, 28 to 55 years) with chronic scapholunate instability with a mean follow-up of 10 years (range, 1 to 23 years).[66] At the time of most recent radiographic follow-up, carpal height was preserved, with a mean radioscaphoid angle of 54 degrees (range, 45 to 63 degrees), no evidence of ulnar translocation of the carpus, and radiographic progression of radioscaphoid arthritis in 33 percent ($n = 6$).

PERCUTANEOUS FIXATION OF NONDISPLACED SCAPHOID FRACTURE

Nondisplaced fractures involving the waist or proximal pole of the scaphoid are commonly treated conservatively. [**See Video 7 (online)**, which displays volar percutaneous scaphoid screw fixation for nondisplaced scaphoid fracture.] Reported healing time to union of a nondisplaced waist scaphoid fracture has ranged between 8 and 12 weeks.[67–71] However, wrist stiffness, loss of strength, loss of economic productivity, and muscle atrophy are inherent in this conservative treatment. In an attempt to decrease them, open exposure of the scaphoid may allow for better fixation and more rapid healing but requires division of the volar radiocarpal ligaments or dorsal capsular structures.[72–76] Considering all this, a percutaneously placed compression screw would avoid these potential pitfalls and allow for earlier motion and rehabilitation.[77] A technique for percutaneous screw fixation for fractures of the scaphoid was described in 1970.[78] In a prospective study published in 2001,[79] percutaneous, fixed, nondisplaced, scaphoid fractures had significantly shorter time to union and time to return to work. This series showed that patients who underwent percutaneous screw fixation healed their fractures at an average of 7.1 weeks, compared with 11.6 weeks for cast immobilization. Moreover, patients who had percutaneous screw fixation returned to work at an average of 8.2 weeks versus 15.3 weeks for cast immobilization. There were no nonunions and only one case of a prominent painful screw that required subsequent removal. As with any minimally invasive procedure, the learning curve is something the surgeon should be aware of. "Minimally invasive" does not mean "minimal potential complications," and previous

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experience with scaphoid fractures is highly recommended for this procedure.

This procedure is usually performed under regional anesthesia. Two rolled towels are used under the supinated wrist to allow for adequate dorsiflexion. The guidewire for the cannulated screw system is placed through the volar scaphoid tuberosity; directed proximally, dorsally, and ulnarly with the wrist hyperextended; and slightly ulnarly deviated. Image intensification is used in multiple planes to ensure that the wire is placed accurately across the fracture site and that the proximal entry site has enough bone volarly to support screws. When using this approach, the guidewire will not be placed down the anatomical axis of the scaphoid, but will be slightly diagonal to it. A second guidewire is placed parallel to the first guidewire for antirotation control if and when necessary (typically for very unstable fractures). This wire must cross the fracture and be far enough away from the initial guidewire to not interfere with the drill or screw. Screw length can be measured with the measuring device available in the screw set or indirectly with a second guide pin. We have found little variation in screw length: 18 mm for women and 20 mm for men. If a measurement is made using a measuring device, between 4 and 6 mm needs to be subtracted from the measured screw length to allow the screw to be fully buried within the scaphoid. Once the guidewires are satisfactorily placed, a 3-mm incision is made around the guide pin to allow drill and screw passage. The scaphoid is then drilled all the way across the entire scaphoid (not to the length of screw selected) with the cannulated drill, with the depth checked by fluoroscopy. The cannulated screw is placed with fluoroscopic guidance to judge fracture reduction and screw position. The antirotation guidewire is removed if used, and final fluoroscopic images are obtained, in addition to a live view of the reduction. The wound is irrigated and closed with a nylon suture, and a well-padded, short-arm thumb spica splint is applied [**see Video 7 (online)**]. Percutaneous screw fixation of minimally displaced or nondisplaced scaphoid fractures provides stable internal fixation and allows for earlier healing, quicker return to work, and maintenance of motion and grip strength.

FOUR-CORNER ARTHRODESIS

Although nearly every combination of intercarpal arthrodeses has been described, excision of the scaphoid and fusion of the remaining carpal bones in neutral alignment was a unique concept when it was introduced 35 years ago. [**See Video 8 (online)**, which displays scaphoid excision and four-corner arthrodesis for scaphoid nonunion with advanced collapse grade III.] Four-corner or four-bone arthrodesis is based on the principle that the radiolunate articulation is often spared from degenerative changes from conditions that result in rotatory subluxations of the scaphoid. The four-corner arthrodesis is a motion-sparing, limited arthrodesis that reliably results in pain relief, improved grip strength, and overall high patient satisfaction with low associated nonunion and complication rates.[80]

Despite the historical recommendations against scaphoidectomy, Watson et al.[81] described the unique concept of combining the scaphoidectomy; neutral alignment of the remaining carpal bones; and arthrodesis of the capitate, hamate, lunate, and triquetrum to maintain the neutral alignment. Arthrodesis of the capitate and lunate was difficult to achieve, with nonunion rates reported as high as 30 percent.[82] Thus, to increase the union rates, the hamate and triquetrum were added to the capitolunate arthrodesis. The resultant arthrodesis of the capitate, hamate, lunate, and triquetrum was termed a four-corner arthrodesis.

The most common pattern of degenerative arthritis of the wrist was described as scapholunate advanced collapse and represented a final common pathway for a variety of carpal conditions, of which the most common were rotatory subluxations of the scaphoid and scaphoid nonunion.[83–87] Most cases of scapholunate advanced collapse wrist represent the late sequelae of scapholunate dissociation, either traumatic or secondary to attenuation of the scapholunate ligament. Chronic scaphoid nonunions can also lead to a scapholunate advanced collapse pattern of arthritis and have been more correctly termed scaphoid nonunion advanced collapse. Despite the cause, the scapholunate advanced collapse pathway has consistently spared the radiolunate articulation, even when there is severe or chronic dorsal intercalated segmental instability stance of the lunate. This preservation of the radiolunate joint is the foundation of the four-corner arthrodesis.

This procedure is usually performed under regional anesthesia. A dorsal midline longitudinal incision centered over the third metacarpal–capitate-lunate-radius axis is the traditional approach that allows for extensile exposure of the carpus. The extensor retinaculum over the extensor pollicis longus is divided in line with the tendon, and

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an ulnarly based flap of extensor retinaculum is created by dividing the septations between the third, fourth, and fifth extensor compartments. The extensor tendons are retracted, and the dorsal wrist capsule is exposed. A longitudinal incision in the capsule can be made on the ulnar aspect of the fourth compartment to expose the carpal bones, or a ligament-sparing capsulotomy can be performed. The radiolunate articulation is inspected for degenerative wear and, if normal, the scaphoid is excised either piecemeal with a rongeur or in its entirety sharply. Care is taken to not injure the volar radiocarpal ligaments (radioscaphocapitate and long radiolunate ligaments), because injury to these structures may result in ulnar translocation of the remaining carpals. The articular surfaces of the capitolunate, capitohamate, triquetrohamate, and lunotriquetral joints are denuded of articular cartilage and further prepared by placement of 1-mm burr holes spaced evenly throughout the surfaces to be arthrodesed. Reduction of the capitolunate axis in neutral position is critical to the success of the four-corner arthrodesis. The wrist is then flexed and slightly ulnarly deviated until neutral alignment of the radius and lunate are seen. A 1-mm Kirschner wire is then drilled from the dorsal distal radius into the lunate, with the lunate held in the reduced position. With the Kirschner wire in place, the wrist is extended, and the neutral alignment of the radiolunate joint is preserved. Allograft or autologous bone graft obtained from the distal dorsal radius or the anterior iliac crest is packed into the interstices of the denuded articular surfaces. Several methods of securing the four-corner arthrodesis have been described and include fixation with Kirschner wires, staples, screws, and specially designed plates. We prefer to use a dorsal circular plate. A special conical rasp is used to create a recessed, accepting bed for the plate, which is centered at the junction of the four corners. The plate is placed in the accepting bed and rotated to allow the placement of two screws into each of the carpal bones. After the four-corner arthrodesis is secured, the ligament-sparing capsulotomy is replaced and repaired with nonabsorbable sutures. The extensor tendons are replaced, and the extensor retinaculum is repaired with the extensor pollicis longus dorsally transposed. A short arm cast can be placed for 3 to 4 weeks. A formalized hand therapy program emphasizing range of motion is instituted [**Video 8 (online)**]. Today, nearly 35 years after its formal introduction, four-corner arthrodesis has become an accepted time-tested procedure,[88] and even a gold-standard treatment for carpal arthrosis, when a bone reconstruction is not possible.

CONCLUSIONS

We have described five operations that have changed the prognosis and recovery of different wrist abnormalities. All of them results in consistent improvement in symptoms and patient satisfaction. Future new technology will have to prove at least the same consistency with a lower complication rate. We believe that considering the incidence of these five abnormalities, future research in this field should be strongly supported. Although new therapies may emerge as future options, the five operations described (some more recent and some old) have given consistently good outcomes and have made significant changes in the lives of our patients.

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