REVIEW ARTICLE

Osteoarthritis of the Wrist

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Osteoarthritis of the wrist is one of the most common conditions encountered by hand surgeons. It may result from a nonunited or malunited fracture of the scaphoid or distal radius; disruption of the intercarpal, radiocarpal, radioulnar, or ulnocarpal ligaments; avascular necrosis of the carpus; or a developmental abnormality. Whatever the cause, subsequent abnormal joint loading produces a spectrum of symptoms, from mild swelling to considerable pain and limitations of motion as the involved joints degenerate. A meticulous clinical and radiographic evaluation is required so that the pain-generating articulation(s) can be identified and eliminated. This article reviews common causes of wrist osteoarthritis and their surgical treatment alternatives. (J Hand Surg 2007;32A:725–746. Copyright © 2007 by the American Society for Surgery of the Hand.)

Key words: Wrist, osteoarthritis, arthrodesis, carpectomy, SLAC.

There are several different causes, both idiopathic and traumatic, of wrist osteoarthritis. Untreated cases of idiopathic carpal avascular necrosis, as in Kienböck's[1] or Preiser's[2] disease, may result in radiocarpal arthritis. Congenital wrist abnormalities, such as Madelung's deformity,[3,4] can lead to radiocarpal, ulnocarpal, and distal radioulnar joint (DRUJ) incongruities, producing altered loading patterns and premature cartilage degeneration throughout the wrist. Another nontraumatic form of wrist osteoarthritis occurs at the scaphotrapezium-trapezoid (STT) joint; this is usually idiopathic in origin and is present when all of the other joints of the wrist are normal.[5]

Traumatic causes of wrist arthritis include injuries to ligament and bone. Although injury to many of the other wrist ligaments can lead to progressive wrist arthrosis, chronic scapholunate tears in particular are known to produce intercarpal instability, altered wrist kinematics and joint loading, and degeneration of the radiocarpal joint. As described by Watson and Ballet,[6] scapholunate advanced collapse (SLAC) wrist arthritis progresses in a predictable fashion, ultimately leading to pancarpal arthritis. Fracture and subsequent nonunion of the scaphoid also leads to a series of predictable degenerative changes, first involving the radial styloid tip and then progressing to the more proximal radioscaphoid joint and eventually leading to pancarpal arthritis (Fig. 1). This sequence of events is analogous to SLAC wrist and has been termed scaphoid nonunion advanced collapse (SNAC). Wrist osteoarthritis can also occur secondary to an intra-articular fracture of the distal radius or ulna or from an extra-articular fracture resulting in malunion and abnormal joint loading.

The surgical treatment of the osteoarthritic wrist rests on basic principles that take into account the location of the arthritis and the most reliable procedure that might eliminate the patient's pain, improve his/her function, and prevent further progression of the pain-generating degenerative process.

Diagnosis

Before deciding which reconstructive surgery is appropriate for a particular patient, a meticulous physical examination and a radiographic assessment of which wrist joints are pain generators are essential. The importance of palpating the joints of the wrist to try to ascertain the area of the most tenderness or crepitus cannot be overstated. Possible culprits include any one or combination of the radiocarpal joint, ulnocarpal joint, DRUJ, or any of the intercarpal joints, including degeneration within a row (such as the trapeziotrapezoid or pisotriquetral joints) or between the proximal and distal rows (ie, the midcarpal joint). A key question is whether a planned surgery will cure a patient of his/her chief complaint. In cases in which the pain generator may be less

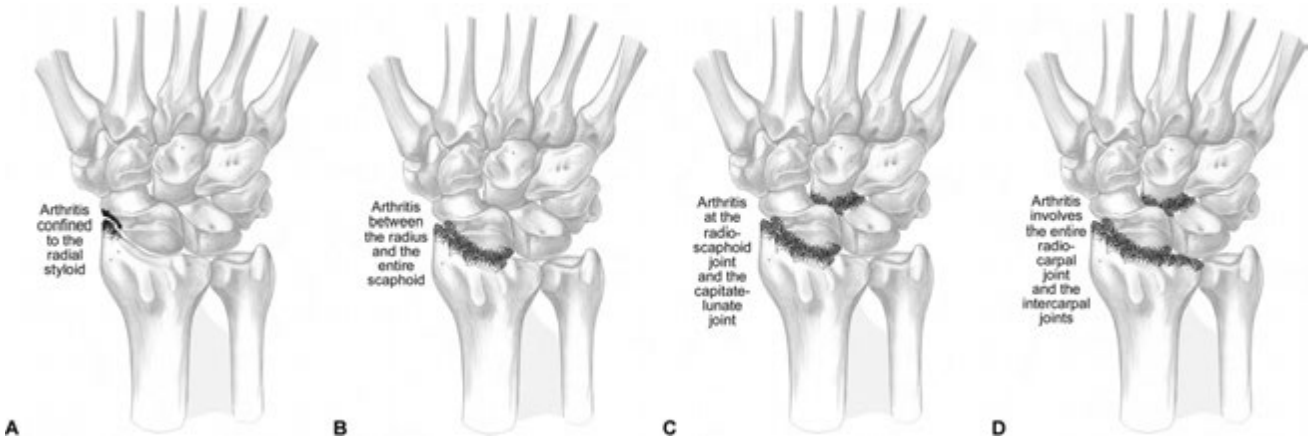

Figure 1. With both chronic scapholunate ligament injury and scaphoid nonunions, progressive osteoarthritis can occur with (A) stage I, affecting the radial styloid–scaphoid junction, (B) stage II, affecting the entire radioscaphoid joint, and (C) stage III, affecting the entire radioscaphoid joint and the capitolunate articulation, (D) Stage IV, osteoarthritis affects both the radiocarpal and intercarpal joints and may involve the DRUJ. (Reproduced with permission.[120])

obvious, prognostic anesthetic and/or cortisone injections can be exceedingly helpful. Carpometacarpal osteoarthritis, especially of the thumb, must also be kept in mind in the differential diagnosis as a pervasive cause of hand arthritis, but it is usually fairly easy to distinguish from more proximal areas of disease on clinical examination.

Because the surgical procedures that are performed on the osteoarthritic wrist are directly related to which joints are preserved and which are destroyed, a meticulous examination of posteroanterior (PA) and lateral radiographs is also critical. One must thoroughly examine the radioscaphoid and radiolunate joints for evidence of narrowing, osteophyte formation, and/or subchondral sclerosis or cyst formation. In addition, the head of the capitate, which is the primary articulation for the midcarpal joint, must be evaluated closely.[7] As a further step, the surgeon should carefully evaluate each of the other individual joints throughout the wrist to ensure that there is no evidence of focal arthritis present (Fig. 2). Subtle triquetral or ulnar-sided lunate sclerosis or cyst formation may be signs of ulnocarpal wear. Although more advanced imaging studies such as magnetic resonance imaging or bone scintigraphy are rarely necessary, they may play a role in the workup of more subtle cases of wrist osteoarthritis.

Treatment

Frequently, patients with wrist osteoarthritis can be helped by nonsurgical means. The use of splint or cast immobilization, nonsteroidal anti-inflammatory medications, and selective intra-articular injections of corticosteroids may provide patients with improved function and decreased pain. In many patients with more advanced disease, however, the pain relief granted by nonsurgical methods is limited. As can be the case in patients with progressive wrist osteoarthritis, such as those with SLAC or SNAC wrists or evolving lunate collapse from Kienböck's disease, nonsurgical modalities may be sufficient at first but often become increasingly ineffective at alleviating pain as time goes on. If a patient has debilitating wrist pain referable to an osteoarthritic joint or joints on imaging studies, surgical intervention should be considered.

The goal of performing surgery for such a patient is to eliminate the pain associated with the arthritic joint(s) while trying to preserve as much motion as

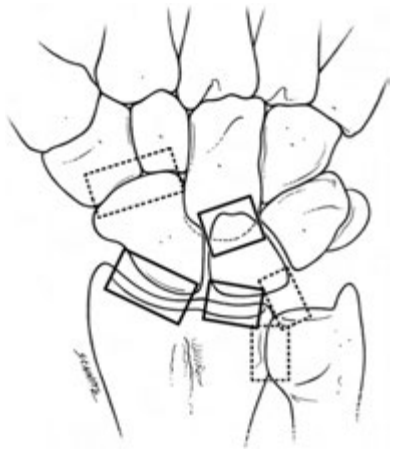

Figure 2. When examining a posteroanterior radiograph, the primary joints (solid rectangles) to carefully evaluate for degenerative changes are the radioscaphoid, radiolunate, and capitate head. The secondary joints (dotted rectangles) affected include the STT, ulnolunate (with impingement), and radioulnar.

Table 1. Postoperative Motion After Wrist Procedures

Type of Procedure	Usual Final Motion (Flexion/Extension Arc), % Relative to the Unaffected Side
Arthrodeses involving the midcarpal joint	50–67
Arthrodeses involving the radiocarpal joint	
Without excision of distal scaphoid	33–40
With excision of the distal scaphoid	50–67
PRC	50–75

possible in the adjacent joints by maintaining congruity between the undamaged articular surfaces of the wrist. In the most severe cases of arthritis, which involve the entire carpus and distal radius, a total wrist arthrodesis has traditionally been required.[8–11] This surgery would eliminate all movement at the radiocarpal and ulnocarpal joints. A total wrist arthroplasty (TWA) may also be possible, although this has been more typically used in patients with rheumatoid arthritis because of the permanent activity restrictions required.[12] If the radiolunate joint appears to be intact, as in the classic description of a SLAC (or SNAC) wrist, then a scaphoid excision and four-corner arthrodesis may be an appealing option. If the capitate head is preserved, a proximal row carpectomy (PRC) also becomes attractive. If there is isolated ulnocarpal joint or DRUJ pathology, surgically addressing the ulna via shortening or partial or complete resection may be appropriate.

Based on several biomechanic studies[13,14] of the wrist, general postoperative motion parameters for a patient who has had a motion-preserving reconstructive procedure are well delineated. Simulated wrist arthrodesis and carpal excision studies[13,14] in cadavers have shown that any fusion involving the midcarpal joint will allow a postoperative arc of motion in the range of 50% to 67% of that of the unaffected side. Arthrodeses involving the radiocarpal joint, which preserves motion at the midcarpal joint, will allow a residual arc of motion of 33% to 40% of a normal motion arc unless the distal pole of the scaphoid is excised as well, which adds an additional 15% to 25%.[15] Elimination of the proximal carpal row will preserve approximately 50% to 75% of the normal motion arc (Table 1). These biomechanic data should be kept in mind when reviewing the clinical outcome literature from the various surgical treatment options for wrist osteoarthritis. Other important factors to keep in mind when determining which treatment is most appropriate for a particular patient is age (both absolute and physiologic) and functional demands. Although most reconstructive procedures likely have enough longevity to provide satisfactory pain relief for the lifetime of an elderly patient, the same cannot be said with certainty for a younger person.

Surgical Approach

A common surgical approach to the osteoarthritic wrist, as in scaphoid excision and four-corner arth-

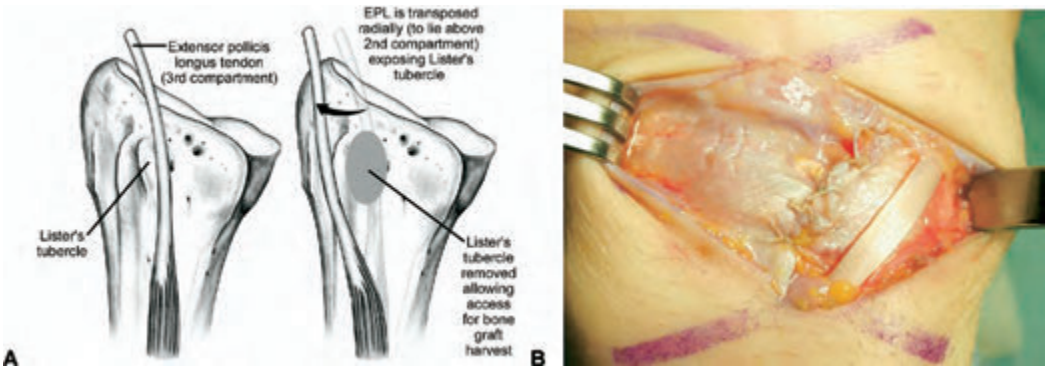

Figure 3. (A) When exposing the dorsal wrist during a total wrist arthrodesis, a longitudinal incision is used and the third compartment is opened, allowing a radial transposition of the EPL tendon and exposing Lister's tubercle, which can be removed for harvesting autogenous bone graft. (Reproduced with permission.[121]) (B) The EPL tendon is left superficial to the closed retinaculum at the end of the procedure, which avoids adhesions and potential rupture from sharp bone edges at the bone graft site.

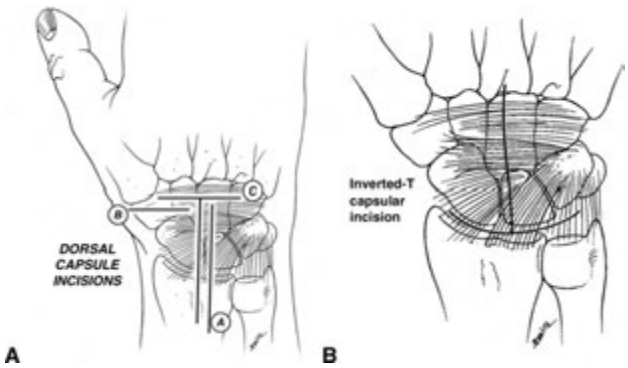

Figure 4. (A) A longitudinal (A), transverse (B), or combination "T" approach (C), can be used for the dorsal capsulotomy during a PRC or limited wrist arthrodesis. (B) Alternatively, an inverted "T" incision can be used. (Reproduced with permission.[122])

rodeses, proximal row carpectomies (PRC), total wrist arthrodeses, and total wrist arthroplasties, uses a longitudinal incision in line with the third metacarpal to the distal radius.[11,16] This incision is taken down through the skin and subcutaneous tissues to the dorsal retinacular structures. The third dorsal compartment is opened and the extensor pollicis longus (EPL) tendon is transposed radially, exposing Lister's tubercle, which is often removed to obtain autogenous bone graft (Fig. 3). In the floor of the third compartment and extending distally between the second and fourth compartments, a subcapsular dissection exposing the dorsal carpus can easily be obtained and extended out to the third metacarpal. Alternative capsular incisions include a transverse approach (good for limited arthrodeses of smaller magnitude) and a dorsal "T" incision (useful for more extensive limited arthrodeses or proximal row carpectomies (Fig. 4). The dorsal capsule may be incised longitudinally or transversely in a ligament-sparing fashion. The relatively recent description of the ligament-sparing exposure provides an incision orientation that may minimize scarring across the ligaments of the dorsal wrist and improve end flexion range of motion after reconstructive procedures (Fig. 5).[17] A longitudinal or transverse capsular incision provides excellent exposure to the carpal bones themselves and to Lister's tubercle, an excellent source of local autogenous bone graft. It should be noted that the posterior interosseous nerve resides on the floor of the fourth dorsal compartment and is often resected, presumably to help with postoperative pain control. Complete exposure of the third metacarpal in a total wrist arthrodesis is important but is not necessary during more limited wrist arthrodeses.

Transverse dorsal skin incisions are useful during more limited wrist arthrodeses when exposing a region of more localized intercarpal arthritis such as the STT joint. The advantage of limited transverse incisions is that their appearance after surgery is excellent with little, if any, scar formation. The disadvantage of this incision is that it can be extended only with difficulty, and exposure with protection of the sensory nerve branches can be problematic. If there is any possibility of needing more exposure at the arthrodesis site, alternative incisions are more appropriate.

During our surgical approach to the osteoarthritic wrist, we generally follow several basic principles, which are described as follows.

Wrist Approach: Basic Principles

- Keep the capsular incisions precise and maintain the integrity of the capsule as much as possible to allow a careful repair.
- Preserve the extrinsic and intrinsic ligaments of the wrist that are not affected by the procedure to prevent secondary instability from occurring.
- In motion-preserving procedures, try to use transverse (or ligament-sparing) capsular incisions

Figure 5. (A) A ligament-sparing exposure preserving portions of the dorsal intercarpal ligaments and radiocarpal ligaments provides excellent exposure to the dorsal aspect of the wrist during both PRC and limited wrist arthrodesis. (Reproduced with permission.[123]) (B) The capsular flap is elevated off the carpus (C) to the radial side exposing the carpus.

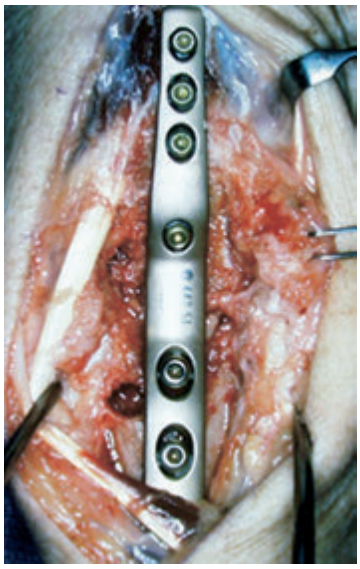

Figure 6. A specialized, precontoured dorsal plate with autogenous bone graft is used for total wrist arthrodesis in most patients, although fusion may be obtained with the use of a sliding bone graft from the distal radius, multiple pin fixation, or smaller plates.

when possible to improve postoperative range of motion.

- Be careful during exposure to protect fibers of the sensory branch of the radial and ulnar nerves, which can be vulnerable during these exposures.
- Excise the posterior interosseous nerve in the floor of the fourth compartment to assist in denervation of the carpus.
- In the extended longitudinal exposure of the wrist during total wrist arthrodesis, leave the EPL tendon transposed dorsally after the procedure.
- When undertaking a total or limited wrist arthrodesis, use only good-quality autogenous cancellous bone graft obtained from the distal radius, proximal ulna, or iliac crest. Carefully place this graft into the joints to be fused after all of the degenerative cartilage and hard subchondral bone has been fully removed to expose the native cancellous carpus. Use of excised carpal bones as a source of graft is generally insufficient, yielding limited, hard, poor-quality material; this should be used only to augment good-quality graft placement.
- Use fluoroscopic examination during surgery to ensure that hardware placement and osseous alignment is appropriate before wound closure and that any hardware used for fixation during reconstruction does not impinge on the overall postoperative range of motion.

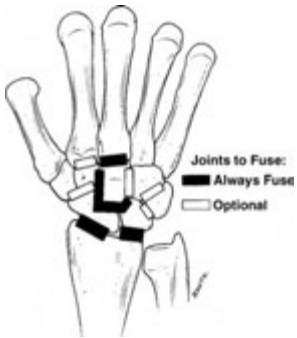

Figure 7. During total wrist arthrodesis, a complete column of bone graft should extend from the radius to the metacarpal being packed into at any joint that underlies the plate. All such joints should have the hard subchondral cortical bone removed, exposing cancellous bone before the placement of the autograft. (Reproduced with permission.[11])

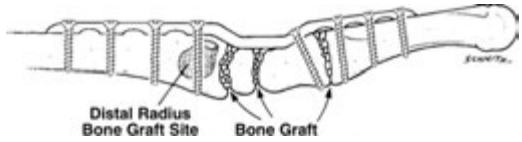

Figure 8. Careful packing of autogenous bone graft followed by plate fixation is performed. (Reproduced with permission.[11])

Total Wrist Arthrodesis

First reported in the beginning of the 1900s by Ely,[18,19] who was treating wrists diseased with tuberculosis, total wrist arthrodesis has since become the standard surgical treatment for patients with severe pancarpal degenerative joint disease who still wish to undertake considerable heavy labor.[11,16] Generally, good function occurs after surgery, although patients report trouble with personal hygiene and working in tight spaces.[20,21] Grip is quite strong after this procedure, provided that the arthrodesis is placed in an alignment that allows some extension of the wrist, generally in the range of 10° to 15°. The use of autogenous bone graft with dorsal plate fixation has been shown to produce predictably excellent fusion rates from 93% to 100% (Fig. 6).[11,16,22] Although distal radius bone graft is usually sufficient, iliac crest bone graft can also be used (Figs. 7, 8). Specialized precontoured dorsal plates have become ubiquitous and decrease the need for long-term postoperative immobilization (Fig. 9). During the initial postoperative period, the patient should be encouraged to work aggressively on his/her digital motion and pronation/supination of the wrist to optimize long-term functional recovery. Although the literature is rather consistent in showing an outstanding fusion rate with current techniques, reports of the ability of total wrist arthrodesis to

Figure 9. Postoperative (A) PA (B) and lateral radiographs show a well-aligned total wrist arthrodesis using a dorsal fusion plate.

successfully relieve pain are a bit more variable.[23–25] Not recognizing concomitant DRUJ arthritis or ulnocarpal impaction are potential complications of this procedure.[16,26,27]

Total Wrist Arthroplasty

Because many of the activities of daily living (eg, combing hair, fastening buttons, writing) are made considerably easier with some wrist motion,[12] TWA has become an increasingly attractive surgical alternative in lower-demand individuals who have debilitating pancarpal osteoarthritis. Patients who have had a total wrist arthrodesis on one side and a TWA on the other prefer the motion-sparing procedure.[28,29]

Designed by Swanson, the first total wrist implant was made of silicone and provided good pain relief. Long-term follow-up data have shown a high incidence of implant failure,[30–33] and issues regarding reactive synovitis and secondary osteolysis have been reported.[34,35] Although a new generation of articulated wrists were designed to improve on previous implants and provide an enhanced arc of motion, they suffered from instability problems.[12] Through innovative research and by learning from past mistakes, total wrist designs have since become increasingly sophisticated, with attempts made to optimize component fixation and their articulating

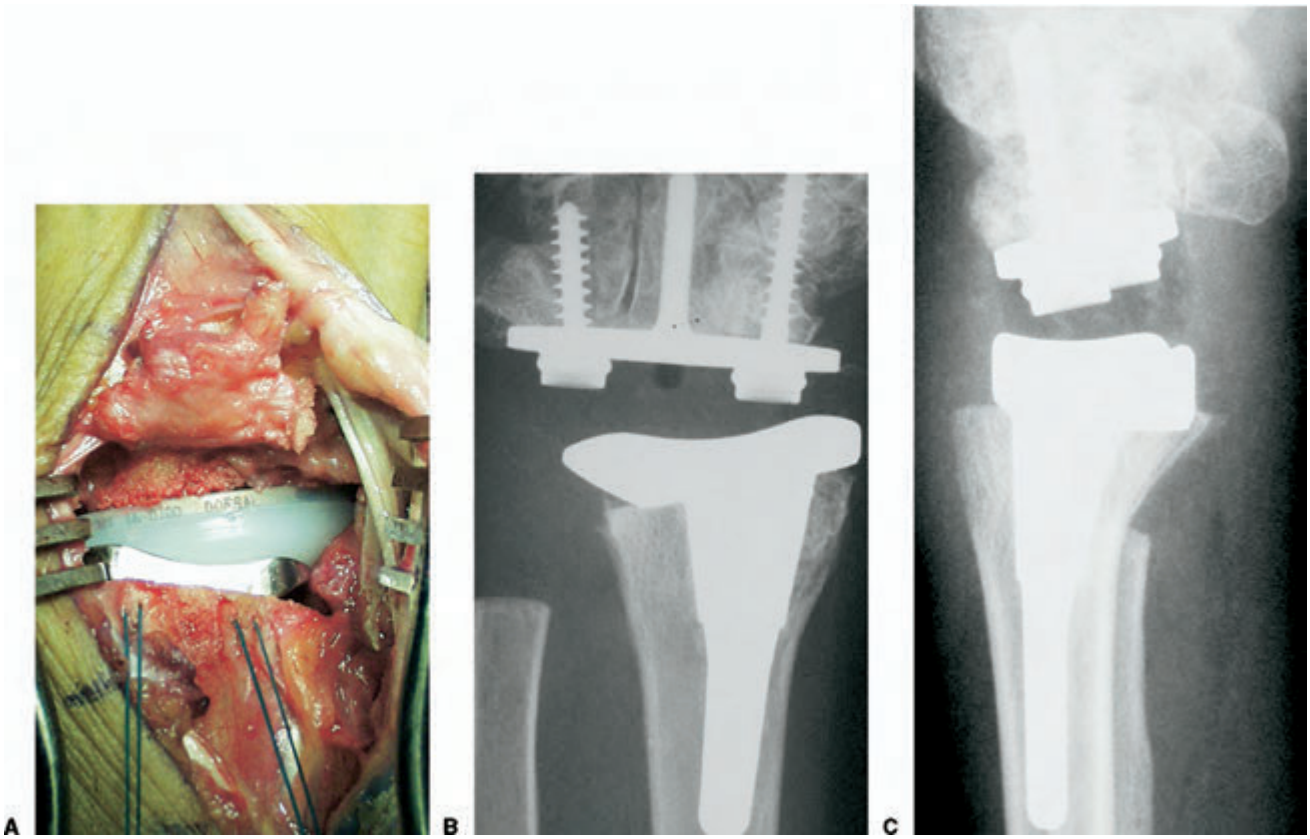

Figure 10. (A) A fourth-generation–design total wrist implant placed without cement into a 65-year-old patient with osteoarthritis. (B) Posteroanterior and (C) lateral radiographs show excellent alignment with an interference fit of the radial and carpal components.

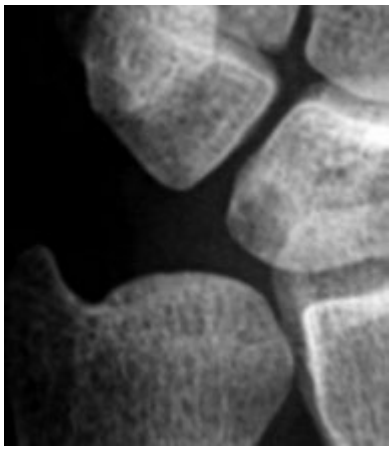

Figure 11. A PA radiograph shows ulnocarpal abutment syndrome with secondary cystic formation in the lunate and ulnar head at the site of impaction. This finding is nearly always associated with a central TFCC tear.

geometry.[36–39] Although most data are understandably from patients with rheumatoid arthritis, TWA has been shown to predictably provide pain relief in most patients while maintaining approximately a 60° arc of wrist motion split evenly between extension and flexion.[12,36] Although many patients with posttraumatic osteoarthritis are young and active and therefore may shy away from TWA because of its postoperative activity restrictions, which traditionally include avoidance of impact loading of the wrist and infrequent lifting of objects heavier than 10 lb (4.5 kg), a lower demand patient may be an ideal candidate for this procedure.[12] Newer designs may also be implanted with or without resection of the distal ulnar head providing more versatility for use in patients with osteoarthritis (Fig. 10).

Distal Ulna

In the ulnar neutral wrist, the ulnocarpal articulation bears 20% of the load transferred across the wrist joint.[40] When ulnar variance increases, which may occur in the setting of shortened distal radius malunions, Palmer and Werner[40] showed that the load transmission across the ulna increases and that abnormal mechanical loading of the ulnocarpal cartilages ensues. Furthermore, when the relative position of the distal radius or ulna is altered by fracture or injury to the triangular fibrocartilage complex (TFCC), radioulnar or ulnocarpal ligaments, or other soft tissues surrounding the distal ulna, the precise articulation between the shallow sigmoid notch of the radius and the convex ulnar head is disrupted, and osteoarthritis may result.

Arthritis involving the ulnocarpal joint and/or DRUJ is often associated with rheumatoid arthritis and other inflammatory disorders[41] because of the propensity of these conditions for destroying the integrity of the ulnocarpal wrist ligaments.[42] Developmental abnormalities, such as Madelung's growth deformity of the volar and ulnar distal radius,[3,4] may lead to a marked loss of radial height and malalignment of the radiocarpal joint, with progressive DRUJ disruption and ulnocarpal impaction. Traumatic insults to the distal radius, ulnar head, or the ligaments of the ulnar wrist may also lead to altered ulnocarpal joint and DRUJ loading and serve as a precursor for osteoarthritis. A key to treating osteoarthritic conditions of the ulnar wrist is determining precisely what the pain-generating articulation is, often with the help of differential anesthetic or cortisone injections.

If ulnocarpal arthrosis is thought to be the primary pain generator, surgical treatment should be aimed at performing either a distal radius osteotomy to restore radial height (as in the setting of a distal radius shortened malunion) or shortening the distal ulna to effectively unload what is a diseased, eburnated joint (Fig. 11). This constitutes the rationale behind performing an ulnar diaphyseal shortening osteotomy[43,44] or a wafer resection, which can be performed either open[45] or arthroscopically (Fig. 12).[46] A distal ulna wafer resection may

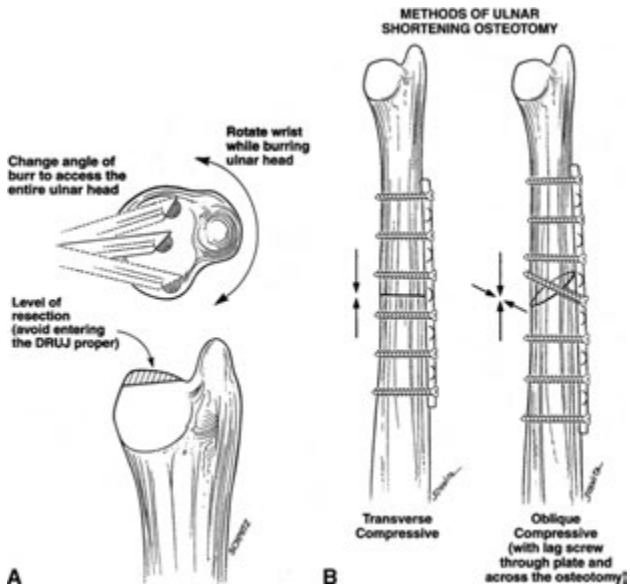

Figure 12. (A) A arthroscopic wafer procedure is performed through a debrided TFCC tear, with care taken to fully rotate the forearm during burring of the distal ulna to completely flatten out the entire distal ulnar prominence. (B) Alternatively, a formal ulnar shortening osteotomy can be performed. (Reproduced with permission.[124])

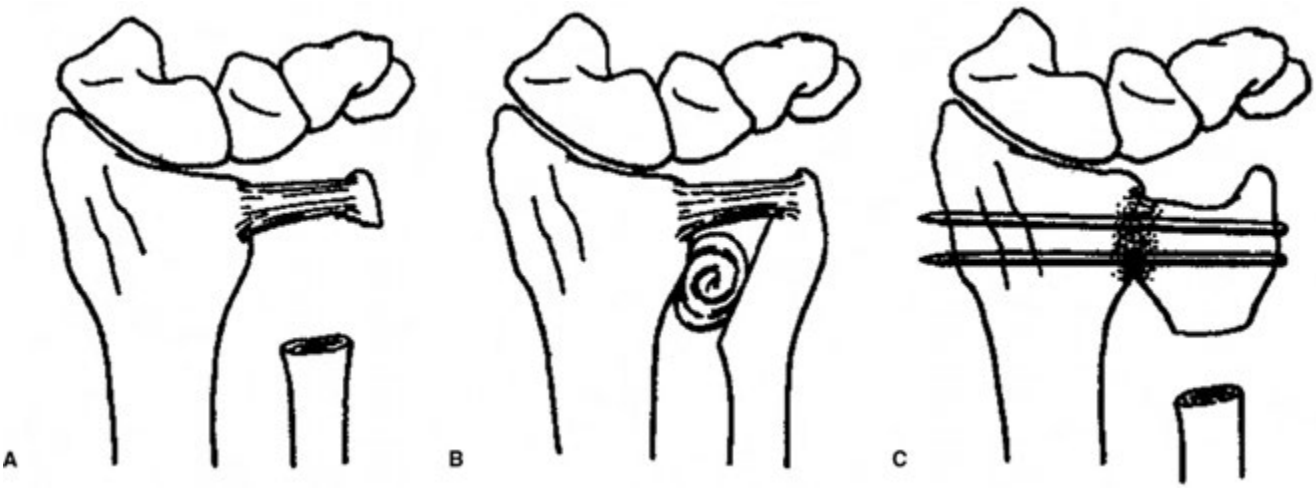

Figure 13. (A) Resection of the distal ulnar head (Darrach procedure) may be performed for osteoarthritis. Care should be taken to make the level of resection proximal to the sigmoid notch of the radius in order to minimize the possibility of post-operative impingement. (B) Hemiresection of the distal ulnar head, with or without tendon interposition, is performed in a patient with good ulnar soft-tissue-stabilizing structures. (C) Alternatively, a Sauve-Kapandji may be performed by fusing the DRUJ and resecting a segment of ulnar proximal maintaining the soft-tissue envelope. (Reproduced with permission.[125])

not be appropriate in patients with considerable ulnar positivity (ie, >3–4 mm).[47] A complete excision of the ulnar head, or so-called Darrach procedure,[48] is a traditional surgery used to eliminate ulnocarpal joint and/or DRUJ sources of pain that has been associated with serious postoperative complications such as instability of the distal ulna stump.[49–53] Partly as a response to this problem of radioulnar convergence and impingement seen after resecting the distal ulna,[50,54] endoprosthetic replacement of the ulnar head has attracted a great deal of interest and shows promise.[55–58]

If osteoarthritis of the DRUJ is thought to be a patient's primary pain generator, a partial resection of the distal ulna such as those described by Watson[59–60] or Bowers[61] should be strongly considered (Fig. 13). Although the Watson matched distal ulna resection and the Bowers hemiresection interposition arthroplasty differ with respect to whether or not interposing soft tissue in the area of the excised bone is advantageous, their basic concepts are similar. To avoid the pitfalls of radioulnar convergence that can occur after a traditional Darrach procedure, both of these hemiresection techniques emphasize keeping the ulnar styloid and attached TFCC intact while resecting enough of the radial aspect of the distal ulna to avoid postoperative impingement. Alternatives to distal ulna hemiresection include fusing the DRUJ and creating a more proximal pseudarthrosis through which pronation/supination may occur (the so-called Sauve-Kapandji procedure)[62–64] or replacing the ulnar head with an endoprosthesis.[58]

Limited Wrist Arthrodesis

Limited wrist arthrodeses involve fusing a part of the carpus in a local fashion and maintaining motion through a portion of the wrist joint that is not affected by the arthritis itself.[65] After determining which joints of the wrist are the arthritic pain generators, treatment can be undertaken to fuse the affected articulations while allowing motion to occur at the remaining wrist joints that are free from arthritis. Although some motion is lost after any partial fusion of the wrist, by maintaining perfect congruity between the remaining uninvolved joints, excellent long-term pain relief and wrist stability can be achieved.[13,14] In most cases, local bone graft taken from the distal radius is more than sufficient to provide an adequate fusion.[11] If there is any doubt that local bone graft is sufficient or of appropriate quality, bone graft should be taken from the iliac crest to

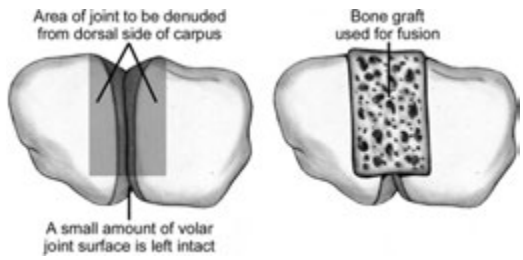

Figure 14. During a limited wrist arthrodesis, at least one half to three quarters of the joint surfaces are denuded to bleeding cancellous bone, with only a small portion of the volar joint kept to preserve carpal spacing. (Reproduced with permission.[126])

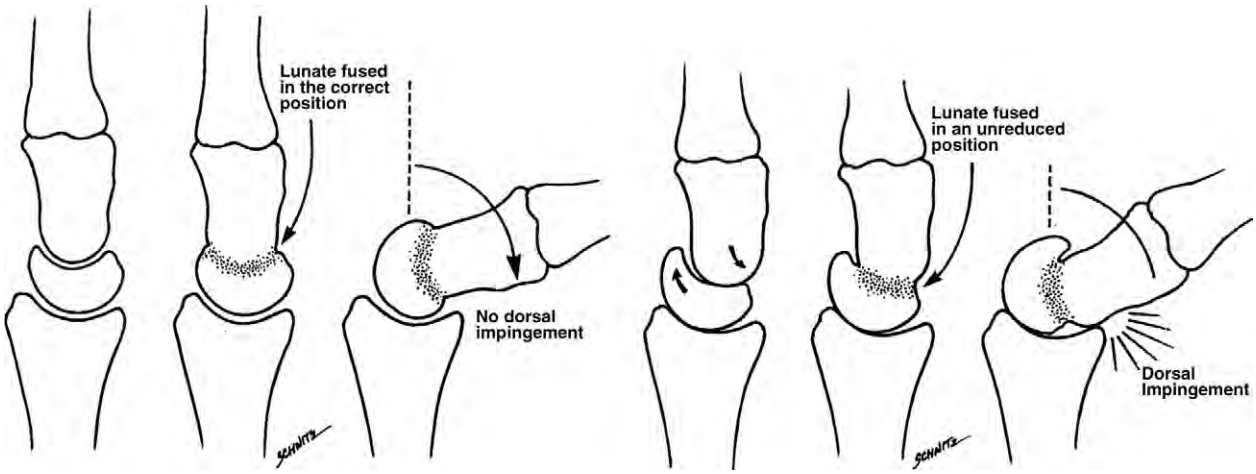

Figure 15. When undertaking limited wrist arthrodesis, complete reduction of the lunate out of its abnormal position is required. Failure to do so will cause dorsal impingement during wrist extension. With appropriate reduction of the lunate before arthrodesis, lack of impingement is confirmed with wrist flexion and extension. (Reproduced with permission.[123])

augment the fusion. Using a patient's scaphoid for bone graft during a scaphoid excision, four-corner arthrodesis may be problematic because of the frequently sclerotic nature of the scaphoid in patients with SLAC and SNAC wrists. This may explain some of the remarkably high nonunion rates in recent articles reviewing four-corner arthrodeses performed with dorsal circular plates and predominantly scaphoid autograft[66,67] compared with limited wrist arthrodeses using K-wires and distal radius cancellous autograft.[68] Bone graft substitute materials, although perhaps appropriate as an augment to autogenous bone graft, are not at this time sufficient unto themselves. Future bioengineering and research will likely expand the role of bone growth factors and synthetic replacements during these procedures.

To maximize union rates and minimize complications, limited wrist arthrodeses should try to adhere to the following technical principles.

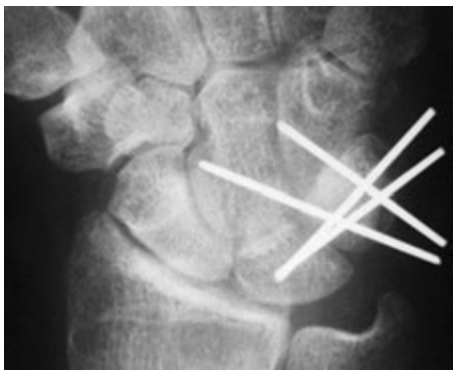

Figure 16. K-wires are commonly used to provide fixation during intercarpal arthrodeses.

Limited wrist arthrodesis: technical principles

- Take down at least half of the joint surfaces being fused while leaving a small portion of the volar joint intact to preserve carpal spacing (Fig. 14).
- Denude osteoarthritic surfaces through the hard subchondral bone to expose cancellous trabeculae to provide more predictable fusion surfaces.
- Use high-quality autogenous cancellous graft, usually from the distal radius, and pack it tightly into the spaces exposed at the joints being fused.
- Use rigid fixation to allow earlier range-of-motion exercises and to decrease stiffness in the postoperative period.
- Check hardware placement with fluoroscopy during surgery to ensure that the hardware does not penetrate into the joints that are not being fused and that the length of the hardware will not cause soft-tissue or bony impingement problems.
- Make certain that the carpal bones are in their normal positions before arthrodesis. This is specifically important with the lunate, which is commonly tilted into a dorsal (DISI) or volar intercalated segmental instability (VISI) pattern. In chronic scapholunate ligament tears, for example, the lunate will often be in a DISI pattern and needs to be brought out of this extended position. Using a 1.6-mm (0.062-in) K-wire as a joystick, the lunate should be placed in its normal alignment before obtaining fixation (Fig. 15).
- During the postoperative period, take serial radiographs to ensure that a successful fusion has occurred.

Figure 17. Staples (both static and memory types) can provide excellent fixation of the carpal bones being fused. Care should be taken to avoid any possible dorsal impingement with wrist extension between the staple edge and the distal radius.

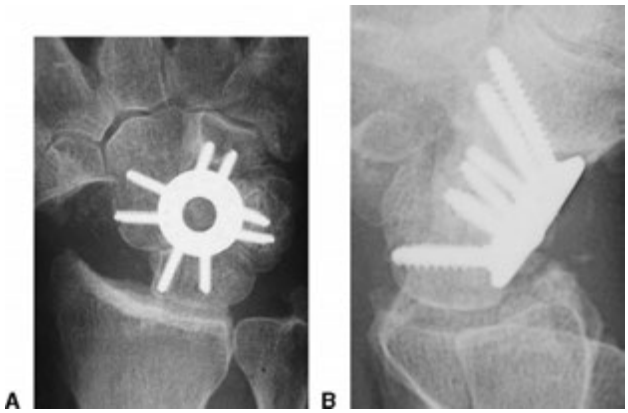

Figure 19. Postoperative (A) PA and (B) lateral radiographs show excellent position of the carpal bones in this four-corner arthrodesis. Two screws affix each of the 4 bones being fused, and the height of the 4 bones is restored to its native position.

Limited wrist arthrodesis: modes of fixation. Deciding which definitive method of fixation to use is controversial and highly surgeon dependent.

- K-wires have long been regarded as a mainstay in the treatment of hand and wrist arthrodeses. They are inexpensive, easy to use, and provide reliable fixation (Fig. 16). Although there are several potential disadvantages to K-wire fixation, including the requirements for cast immobilization and eventual pin removal, the risk of pin protrusion, sensory nerve irritation, and pin track infection, results have generally been quite good with this technique.[68–70]
- Standard staples either inserted with manual implantation or power implantation provide limited compression but provide good stability between bones.[71] Because staples can protrude on the dorsal aspect of the carpus, they may impinge during wrist extension, and care must be taken to ensure that this is minimized (Fig. 17). Newer staples that provide a memory compression force may provide more optimal outcomes.
- Screws can provide extremely stable compression across an arthrodesis site.[72,73] Headless screws that are buried beneath the carpal bones offer minimal impingement risk. Getting optimal placement of these types of screws can be problematic because of orientation difficulties (Fig. 18).
- Dorsal circular plates have been designed to lie in a recessed fashion on the carpus to minimize impinge-

Figure 18. Headless screws can be used for limited wrist arthrodesis and provide the advantage of no protruding hardware. (Reproduced with permission.[127])

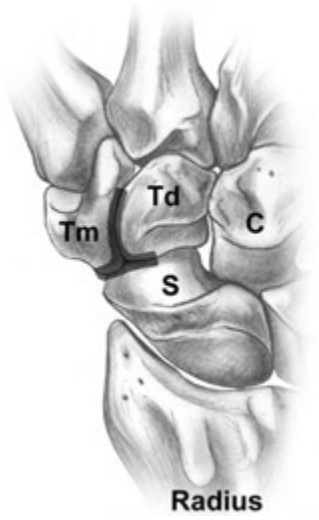

Figure 20. The area of arthrodesis at the STT joint forms an inverted "T". C, capitate; Tm, trapezium; Td, trapezoid; S, scaphoid. (Reproduced with permission.[128])

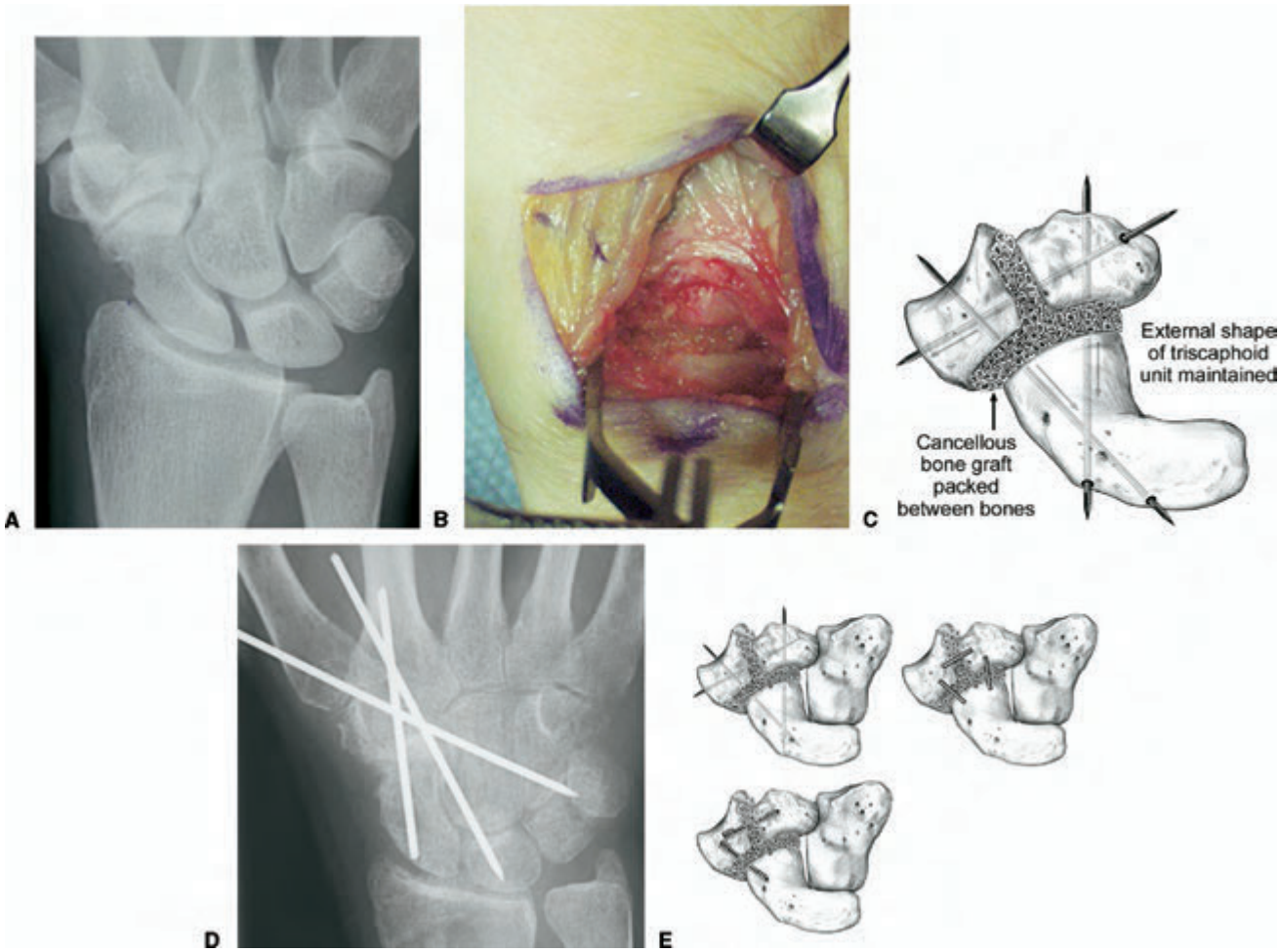

Figure 21. (A) A preoperative PA radiograph shows moderate STT arthrosis. (B) An intraoperative demonstration of bone graft placement into the STT interval. (C) The grafting technique. (Reproduced with permission.[122]) (D) A postoperative PA radiograph showing fixation with 3 K-wires. (E) Various methods of fixation including K-wires, staples, and headless screws can be used. (Reproduced with permission.[122])

ment during wrist extension while providing rigid fixation to minimize the duration of cast immobilization. Such plates theoretically promote circumferential compression of the bones being fused when screw tightening occurs while allowing for the placement of autogenous bone graft through the center of the plate at the arthrodesis site (Fig. 19).[74] The initial enthusiasm for dorsal circular plates during limited wrist arthrodeses[75] has been tempered by several other investigators' reports[66,67,76,77] of high nonunion and complication rates.

It is important to note that rigid hardware in and of itself will not achieve a successful arthrodesis without appropriate technique and bone graft. There remains no consensus on the ideal method of fixation to achieve a successful intercarpal arthrodesis.

We will now discuss the common limited wrist arthrodesis in turn.

Scaphotrapezium-trapezoid arthrodesis. The STT joint is a relatively common site of focal arthritis, especially in elderly women.[5,78] A limited dorsal transverse incision is often used, because the entire joint can be visualized through a relatively small 3-cm incision followed by a transverse capsular exposure.[5,78,79] After the STT joint is entered and the remaining cartilage denuded, local autogenous bone grafting from the distal radius is harvested. Watson et al[68] and Wollstein and Watson[79] argue that relatively more autograft is required for STT arthrodeses than for SLAC wrist reconstructions, because it is particularly important to maintain the external dimensions of the STT joint (Fig. 20). Internal fixation with K-wires has high union rates and relief of pain (Fig. 21).[68,79] Although arthrodesis is a standard treatment for STT osteoarthritis, its use in treating rotatory subluxation of the scaphoid has proved to be

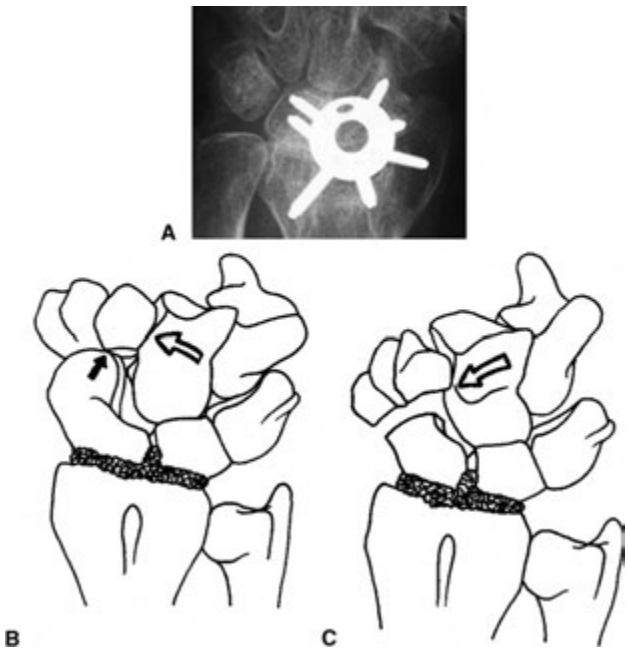

Figure 22. (A) A postoperative PA radiograph shows a radioscapholunate arthrodesis. (B) Excision of the distal scaphoid is now recommended, because this minor additional procedure unlocks the fused radiocarpal joint from the midcarpal joint, improving eventual motion. (Part B reproduced with permission.[130])

much more controversial.[78,80–82] A radial styloidectomy should always be performed along with this procedure to allow maximum motion after fusion has been accomplished, with great care taken to not harm the volar radiocarpal ligaments.[83,84] One can expect, on average, approximately 65% of normal motion after surgery.

Scaphocapitate arthrodesis. Scaphocapitate arthrodesis is generally used for ligament instability involving the scapholunate joint. For all intents and purposes, this procedure provides the same functional outcome as an STT arthrodesis by maintaining a relatively extended position of the scaphoid, allowing reduction of the scapholunate interval. This procedure is rarely used for osteoarthritis.[85]

Radioscapholunate arthrodesis. Radioscapholunate arthrodesis is commonly used after severe distal radius fractures that have resulted in degeneration along the entire radiocarpal joint while the midcarpal joint remains well preserved.[86,87] Fixation of the radius, scaphoid, and lunate is achieved with a variety of fixation methods, including K-wires, powered staples, or a dorsal circular recessed plate. In general, local autogenous bone graft is sufficient, although this may need to be augmented with synthetic substitutes. One can expect about 33% of normal motion to occur, but this can be increased substantially to 50% to 60% of normal motion by excising the distal half of the scaphoid during the procedure (Fig. 22).[15,88]

Scapholunocapitate arthrodesis. Scapholunocapitate arthrodesis can be used for patients with scapholunate instability and in those rare patients with isolated midcarpal degenerative joint disease who have a good radiocarpal joint.[89] The scapholunate joint needs to be reduced carefully and completely before arthrodesis. It is important to perform a radial styloidectomy with this procedure to prevent impingement during motion. Internal fixation with K-wires or dorsal plates[75] can be used (Fig. 23). One can expect approximately 33% to 50% of normal wrist motion after this procedure.

Four-corner (capitate–lunate–hamate–triquetrum) arthrodesis. Scapholunate advanced collapse wrist is the most common degenerative arthritis pattern in the wrist, and it follows a predictable order of progression after injury to the scapholunate ligament.[6] Scaphoid nonunion advanced collapse wrist is essentially identical in its natural history, although less common. Degenerative changes begin at the articulation between the radial styloid and the distal scaphoid and progress predictably to the entirety of the radioscaphoid joint, followed by the development of midcarpal arthritis. The radiolunate joint is typically preserved. Degeneration of the radiolunate joint, as is characteristic of advanced Kienböck's disease, represents a contraindication to four-corner arthrodesis. As developed and popularized by Watson,[6,68] the

Figure 23. A patient who had a scapholunocapitate arthrodesis 5 years earlier shows no secondary arthritic changes on follow-up examination radiographs (PA shown).

Figure 24. Preoperative (A) PA and (B) lateral radiographs show isolated midcarpal arthrosis. (C) An intraoperative photograph demonstrates an *in situ* four-corner arthrodesis using a recessed circular plate and distal radius bone graft. An intraoperative fluoroscopy of the wrist in PA (D) and lateral (E) projections shows appropriate plate alignment without hardware impingement.

SLAC wrist reconstruction involves complete excision of the scaphoid and arthrodesis of the capitate, lunate, hamate, and triquetrum. In non-SLAC cases, in which there is isolated midcarpal osteoarthritis and a pristine radioscaphoid joint (Fig. 24), a four-corner arthrodesis *in situ* without scaphoid excision is a viable treatment.

To perform a SLAC wrist reconstruction, we use a dorsal longitudinal skin incision followed by either a longitudinal or transverse (ligament-sparing) capsular incision. During excision of the scaphoid, care is taken to preserve the long radiolunate ligament, which prevents ulnar translation of the carpal mass (Fig. 25).[90] Before setting the alignment of the four-corner arthrodesis, one must be careful to fully reduce the lunate out of its DISI position (Fig. 26). Provisional fixation with K-wires can be used, and definitive fixation is obtained with either K-wires, staples, headless screws, or a recessed circular dorsal plate. Scapholunate advanced collapse wrist reconstruction has been well studied and has produced excellent results in the literature.[7,65,68,91–93] Several recent articles[66,67,76,77] suggest that dorsal circular plates are inferior to more traditional methods of fixation. Vance et al,[66] for example, reviewed 58 patients who had four-corner arthrodesis fixed with either dorsal plates or traditional pin, staple, or screw techniques. They found a significantly higher rate of complications such as nonunion or impingement in the circular plate fixation group (48%) versus the

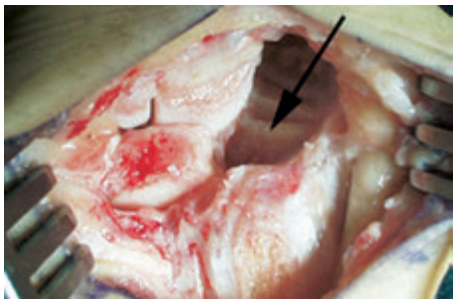

Figure 25. During a four-corner arthrodesis with scaphoid excision, care must be taken when excising the scaphoid to prevent injury to the long radiolunate ligament (arrow). If an osteotome is used to fragment the scaphoid for excision, it should be oriented in line with the fiber direction of the long radiolunate ligament.

traditional fixation group (6%). Proponents of dorsal plate fixation note that the bone graft used in this study was not equally distributed between the 2 study groups. Whereas morselized bone graft from the excised scaphoid alone was used in 20 of the 27 patients in the plate fixation group, presumably nonsclerotic–quality cancellous distal radius or iliac crest autograft was used in 25 of the 31 patients in the traditional fixation group. The report by Kendall et al[67] of 18 four-corner arthrodeses performed by 4 hand surgeons with dorsal circular plate fixation showed a 63% nonunion rate. One possible explanation for this high nonunion rate is that the plate may have obscured determination of potential union. Another possible explanation is that morselized scaphoid graft alone was again used as the source of bone graft in 16 of the 18 wrists. It is unclear whether the high nonunion rates in these studies were due to the type of fixation used or to the type of bone graft that was predominantly harvested. What is clear from reviewing these articles is the technical demands of the dorsal circular plate, including the importance of recessing the plate below the level of the dorsal lunate cartilage to avoid impingement during wrist extension (Fig. 27).

Based on the literature, one can expect approximately 75% to 80% of normal grip strength and 40% to 60% of normal motion after four-corner arthrodesis.[68,91–95] Before reviewing the results obtained from PRC, it is important to note when a PRC is generally contraindicated. When the cartilage of the capitate head is normal, as in stages I and II SLAC or SNAC wrists, either scaphoid excision and four-corner arthrodesis or PRC represent viable treatment options (Fig. 28). When there is degeneration of the capitate head, however, as in stage III SLAC or SNAC wrists, a PRC is generally contraindicated except in very low-demand patients (Fig. 29).

Proximal Row Carpectomy

Proximal row carpectomy is an excellent salvage procedure for the wrist with considerable radiocarpal arthritis provided that the capitate has not had degenerative changes.[96,97] Proximal row carpectomy is performed through either a transverse or longitudinal incision. The bones of the proximal row are removed on either side of the tendons of the fourth dorsal compartment (Fig. 30). During excision of the proximal row, one must be extremely careful to preserve

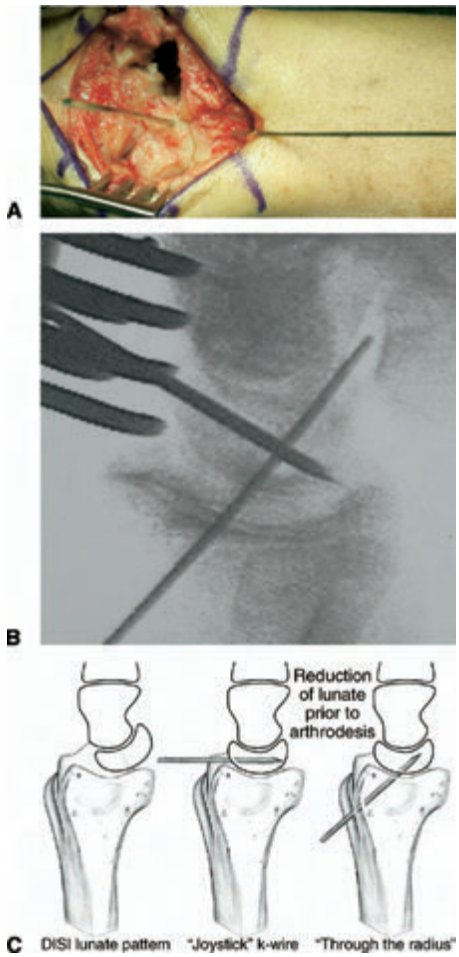

Figure 26. (A) An intraoperative photograph of the lunate being brought out of its malaligned DISI position by using a K-wire as a joystick and then pinning the lunate in its reduced position through the dorsal aspect of the radius. (B) A fluoroscopic image is used to confirm the position of the lunate before proceeding with the surgery. (C) The initial joystick K-wire is then removed, allowing unfettered access to the dorsal carpus while maintaining the lunate position via the distal radius K-wire, which is in the volar half of the lunate allowing free dorsal access to the joints being fused. (Part C reproduced with permission.[126])

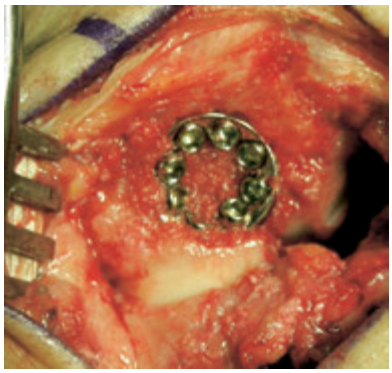

Figure 27. An intraoperative photograph of a dorsal plate fully recessed below the dorsal lunate cartilage so as to avoid impingement during wrist extension.

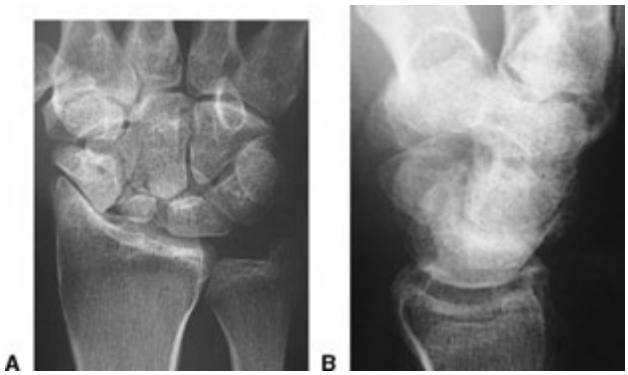

Figure 29. (A) Posteroanterior and (B) lateral radiographs of a patient with stage III SNAC wrist in which the capitate head cartilage appears compromised and a PRC is contraindicated.

the integrity of the radioscaphocapitate ligament, which prevents ulnar translation of the capitate off the distal radius.[90,98] This ligament is especially vulnerable when removing the scaphoid in a piecemeal fashion with an osteotome and mallet (Fig. 31). The osteotome should be aligned with the orientation of the fibers of the radioscaphocapitate ligament so that, in the case of inadvertently deep penetration, the osteotome will split rather than transect the fibers.

After removing the scaphoid, lunate, and triquetrum, the distal carpal row migrates proximally so that the head of the capitate articulates with the lunate fossa of the distal radius (Figs. 32, 33).[99,100] Although the arcs of curvature of the capitate and the lunate are not entirely congruent and some point loading occurs during motion, the results of PRC have generally been excellent.[92,94,95,97,100–104] Based on 2 separate cohorts of patients,[102,103] each with a minimum follow-up period of 10 years, one can conclude that patients having a PRC will achieve over 80% of normal grip strength and 60% of normal motion. Although secondary degenerative changes at the radiocapitate articulation may eventually be seen on plain radiographs, they do not usually preclude a successful clinical outcome in most patients, especially in functionally lower-demand patients.[103] Younger, active patients are at a greater risk for developing secondary degenerative changes at the proximal capitate head (Fig. 34). DiDonna et al[103] found that there were 4 failures in 22 wrists studied that required arthro-

Figure 28. (A) Posteroanterior and (B) lateral radiographs of a patient with stage II SLAC wrist in which the capitate head cartilage is pristine and a PRC should be considered as a treatment option.

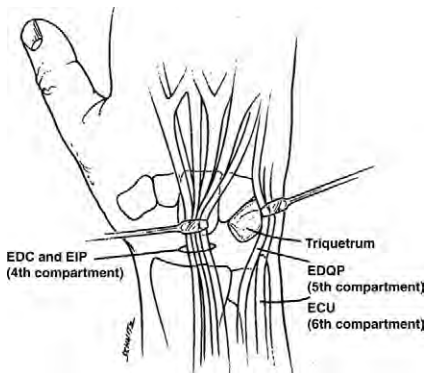

Figure 30. In stepwise fashion, the scaphoid, lunate, and triquetrum are exposed and removed via either the radial or ulnar side of the fourth dorsal compartment. ECU, extensor carpi ulnaris; EDC, extensor digitorum communis; EDQP, extensor digiti quinti proprius; EIP, extensor indicis proprius. (Reproduced with permission.[122])

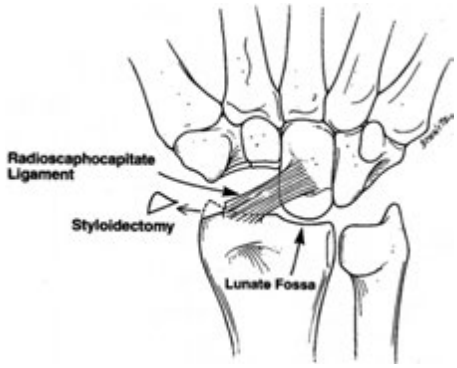

Figure 31. While removing the scaphoid when during a PRC, care must be taken not to injure the radioscaphocapitate ligament in the volar depths. (Reproduced with permission.[131])

desis at an average time of 7 years after the initial PRC.[103]

Comparing patients with post-traumatic wrist arthritis who had a PRC with those who had a total wrist arthrodesis, De Smet et al[105] found no difference in grip strength but less disability in the PRC group. A more frequent comparison in the wrist osteoarthritis literature has been between the 2 most common motion-sparing procedures used today: PRC versus scaphoid excision and four-corner arthrodesis. Thus far, only relatively short-term outcome data are known.

Proximal Row Carpectomy Versus Scaphoid Excision and Four-Corner Arthrodesis

There are no prospective, randomized trials comparing scaphoid excision and four-corner arthrodesis with PRC as alternative motion-sparing treatments of

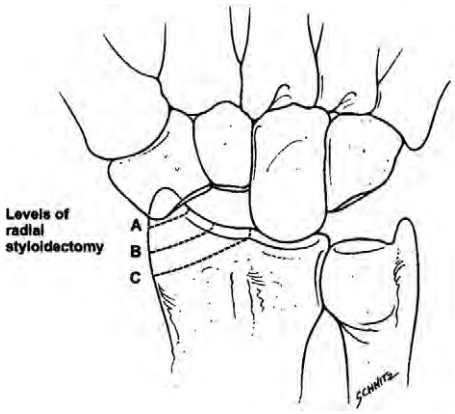

Figure 32. After PRC, reduction of the capitate head into the lunate fossa of the distal radius is accomplished. A radial styloidectomy may also be performed, usually at level "A" depicted in the figure. Care must again be taken to preserve the radioscaphocapitate ligament attachment at the distal radius. (Reproduced with permission.[122])

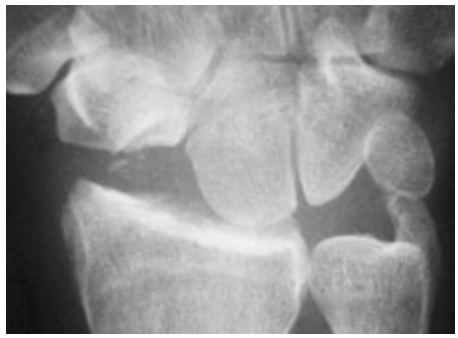

Figure 33. A postoperative PA radiograph shows excellent alignment of the capitate head in the lunate fossa after PRC.

SLAC or SNAC wrist arthritis. In fact, there are only 3 studies[92–94] to our knowledge that compare the clinical outcomes of these surgeries in a head-to-head fashion. Before reviewing these articles, it is important to first understand the theoretic advantages of each procedure. Advocates of PRC cite its relatively lower technical demands, decreased postoperative immobilization, and—perhaps most of all—its inherent lack of nonunion risk.[95,104] Proponents of four-corner arthrodesis cite its theoretic advantage of maintaining wrist height; a more physiologic range of motion through a preserved, congruent radiolunate articulation; and lack of eventual degenerative changes in the radiolunate joint.

Three studies attempt to compare the clinical results of PRC with those of scaphoid excision and four-corner arthrodesis. The first, by Tomaino et al in 1994,[92] retrospectively reviewed 24 wrists treated for symptomatic SLAC wrist at an average of 5.5 years after surgery. At the time of follow-up evaluation, all patients in the study had satisfactory pain relief, grip strength, and function except for 3 patients in the

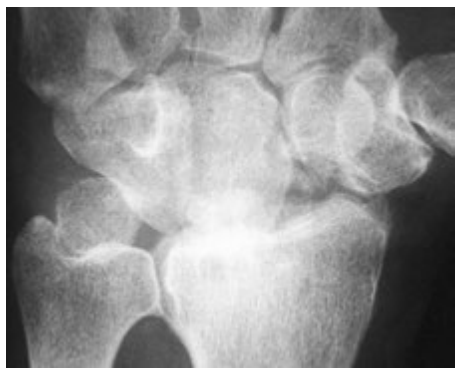

Figure 34. A PA radiograph at the 3-year follow-up examination of an active 35-year-old patient who had had a PRC. Note the considerable secondary degenerative changes at the capitate head.

PRC group. One of these patients developed progressive radiocapitate arthritis necessitating a total wrist arthrodesis. There were no statistically significant differences in subjective and objective results between the 2 groups other than residual range of motion: PRC preserved a greater arc of motion compared with limited wrist arthrodesis, mostly because of significantly greater wrist extension. In light of these comparable outcomes between the 2 procedures, Tomaino et al[92] concluded that either procedure is a justifiable choice for reconstructing the SLAC wrist. While they favor scaphoid excision and four-corner arthrodesis when capitolunate arthritis exists (stage III SLAC), they recommend the less technically demanding PRC for stage I or II SLAC disease.

One year later, Wyrick et al[94] published a similar study comparing 11 wrists that had a PRC and 17 wrists that had a scaphoid excision and four-corner arthrodesis. The PRC group was followed up at a mean of 37 months and these wrists had an average grip strength of 94% of the opposite wrist and a total arc of motion of 115°, which was 64% of the contralateral wrist motion. These data compare favorably with the limited wrist arthrodesis group, followed up at a mean of 27 months, in which the average grip strength was 74% of the opposite wrist and the total arc of motion was 95°, or 47% of the opposite wrist. Using the grading criteria of Minami et al[106] for intercarpal arthrodeses, the PRC group was found to have 11 of 11 successful outcomes versus the four-corner arthrodesis group, which had 5 of 17 failures. Although their data showed more polarity than those of Tomaino et al[92] a year earlier, Wyrick et al[94] similarly recommend PRC as their motion-sparing procedure of choice in wrists without capitolunate degeneration.

The most recent article comparing the outcomes of these 2 reconstructive procedures was written by Cohen and Kozin in 2001.[93] Unlike its predecessors, this study examined 2 cohorts of patients who were from separate institutions that performed exclusively either PRC or scaphoid excision and four-corner arthrodesis. The length of follow-up study was again fairly short: 19 months for the PRC group and 28 months for the four-corner arthrodesis group. As was the case in the study of Tomaino et al,[92] Cohen and Kozin[93] found no statistically significant differences between the groups with respect to flexion–extension arc of motion (81° in the PRC group, 80° in the four-corner arthrodesis group) and grip strength (71% of the opposite wrist in the PRC group, 79% in the four-corner arthrodesis group). Furthermore, pain relief and patient satisfaction were similar between the 2 groups based on a plethora of outcome measures. Their data, however, showed a significantly greater ulnar–radial deviation arc in the four-corner arthrodesis group (70% of the opposite wrist) compared with the PRC group (51% of the opposite wrist). In all, the study of Cohen and Kozin[93] supports the notion that there are minimal differences between the short-term clinical outcomes of these 2 procedures. It would certainly be interesting in the future to determine the incidence of eventual degenerative changes for each of these procedures to determine if any factors influence the incidence of secondary arthrosis (eg, age or gender of the patient at the time of the initial procedure).

After our discussion of the workhorses of the surgical treatment of wrist osteoarthritis—namely, scaphoid excision, four-corner arthrodesis, and PRC—it is important to recognize 2 other types of carpectomies that may play a role in treating patients with wrist osteoarthritis: pisiform excision and distal scaphoid excision.

Pisiformectomy

Pisiform excision is the standard surgical treatment for pisotriquetral osteoarthritis. Embedded within the substance of the flexor carpi ulnaris tendon, the pisiform is a sesamoid bone that lies volar to the triquetrum. Pisotriquetral arthrosis is most commonly post-traumatic in nature and has been delineated through cadaveric dissections showing cartilage eburnation on the periphery of the pisiform.[107,108] Tenderness due to pisotriquetral arthritis can be provoked clinically by passive wrist extension or by the pisiform tracking test, during which the pisiform is made to grind radially and ulnarly up against the triquetrum while the wrist is flexed to relax the flexor carpi ulnaris tendon.[109] Multiple semilateral plain radiographs (with the wrist in full extension and the forearm in 30° of supination, with the wrist in neutral and the forearm in 30° of supination, and with the wrist fully flexed and the forearm in 45° of supination while the thumb is maximally abducted) are recommended to visualize the pisotriquetral joint.[109] Perhaps the best tool in helping the clinician reach the correct diagnosis is pain relief with the injection of a local anesthetic into the pisotriquetral joint. With several studies[110–115] supporting its efficacy, pisiform excision has become the treatment of choice for patients with pisotriquetral arthritis refractory to conservative measures. In their evaluation of 20 wrists

that had pisiformectomy, Lam et al[114] reported that 15 patients had complete relief of symptoms and 5 still had residual mild discomfort. Furthermore, they showed that there were no significant differences between the strengths and ranges of motion of the wrists that had the procedure and the contralateral side. In describing his surgical technique, Rayan[109] emphasizes identification and protection of the ulnar nerve, careful subperiosteal dissection of the pisiform, and meticulous repair of the soft-tissue confluence and flexor carpi ulnaris tendon overlying the site after the bone is excised.

Distal Scaphoidectomy

Complete excision of the scaphoid has been discussed previously in the context of SLAC wrist reconstruction. Excision of only the distal pole of the scaphoid was also briefly mentioned, in the context of improving motion after a radioscapholunate arthrodesis. Indeed, distal scaphoidectomy has been shown in both a cadaveric model[15] and a clinical study[88] to increase flexion and radial deviation after radioscapholunate arthrodeses.

Another possible role for distal scaphoid excision is in the treatment of isolated STT joint osteoarthritis.[116] Although arthrodesis remains the most widely accepted treatment for STT arthritis, distal scaphoid excision may represent an interesting alternative requiring less postoperative immobilization (Fig. 35). Distal scaphoidectomy has also been proposed as an alternative to more extensive procedures in patients who have chronic scaphoid nonunions and resultant distal radioscaphoid or intercarpal osteoarthritis. In cases of symptomatic scaphoid nonunions that have failed traditional fixation and bone grafting attempts, a relatively simple technical procedure to eliminate this focal area of osteoarthritis is an excision of the distal scaphoid pole. Although there are certainly concerns about promoting instability of the proximal carpal row, there are a few studies[117–119] that suggest that distal scaphoid excision may be efficacious in the treatment of recalcitrant scaphoid nonunion with concomitant arthritis. In 2006, Ruch and Papadonikolakis[119] reported on 13 patients with scaphoid nonunions who were treated with distal scaphoidectomy after prior surgical treatment at a mean follow-up time of 5 years. They showed an increase of mean wrist flexion and extension by 23° and 29°, respectively; a dramatic decrease in pain; and an average increase in the capitolunate angle before and after surgery of only 2°. This is in contrast to prior work by Garcia-Elias et al[116] that showed an increase in the capitolunate angle of 9° after distal scaphoid excision. Ruch and Papadonikolakis[119] concluded that distal scaphoid excision is a valuable treatment option for certain patients in whom multiple attempts at union have failed and who have no associated complete scapholunate ligament tears.

Summary

Osteoarthritis of the wrist is a commonly encountered condition and has a variety of causes, from idiopathic to traumatic. With a meticulous clinical examination and analysis of radiographs, careful attention paid to the patient's age and functional needs, and adherence to basic surgical principles, successful treatment of the osteoarthritic wrist can be expected.

Despite the successful outcomes that can be achieved in treating patients with wrist osteoarthritis, one should be careful to counsel patients that any of the surgical treatment options presented have positives and negatives, not all of which are evident in the immediate perioperative recovery period. Some procedures are fairly simple and have limited morbidity associated with their use, such as PRC and distal scaphoidectomy; however, their long-term durability is not always ensured. Other more technically involved procedures, such as scaphoid excision and four-corner arthrodesis, may have a higher morbidity and complexity initially, as well as a longer recovery

Figure 35. (A) Intraoperative photograph showing considerable degenerative changes at the distal pole of the scaphoid. (B) Resection of the distal half of the scaphoid is performed (C) with the resection level confirmed by intraoperative fluoroscopy.

period, but may provide better durability in a younger patient. Longer term follow-up data comparing the results of alternative surgeries for wrist osteoarthritis will surely help the hand surgery community to most effectively and accurately educate patients on these matters in the future.

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