Decision Making for Partial Carpal Fusions

Gregory Ian Bain, PhD, FRACS^{1,2,3,4} Duncan Thomas McGuire, FCS (Orth), MMed (Orth)^{3,4}

¹ Department of Orthopedics and Trauma, University of Adelaide, Adelaide, South Australia, Australia

² Discipline of Anatomy and Pathology, University of Adelaide, Adelaide, South Australia, Australia

³ Department of Orthopedics and Trauma, Modbury Public Hospital, Adelaide, South Australia, Australia

⁴ Department of Orthopedics and Trauma, Royal Adelaide Hospital, Adelaide, South Australia, Australia

Address for correspondence and reprint requests Associate Professor Gregory Bain, PhD, FRACS, 196 Melbourne St., North Adelaide, South Australia, 5006, Australia (e-mail: greg@gregbain.com.au).

J Wrist Surg 2012;1:103–114.

Abstract

Limited wrist fusions are effective surgical procedures for providing pain relief while preserving motion of the wrist in patients with localized arthritis of the carpus. In deciding which motion preserving procedure to perform, the etiology of the arthritis, which joints are involved, and which are spared should be determined. The main principle is to fuse the involved joints and to allow motion through the uninvolved joints. In this article, we discuss the various traumatic and nontraumatic conditions causing arthritis of the wrist and the treatment options for those conditions. Common indications for limited wrist fusions include scapholunate advanced collapse and scaphoid nonunion advanced collapse. Options for treating these conditions include three- and four-corner fusions as well as a proximal row carpectomy. This paper discusses which procedures are the most appropriate as well as the outcomes of these procedures. If the basic principles of limited wrist fusions are adhered to, a good outcome can be obtained. The authors' surgical technique and decision-making processes are discussed.

Keywords

- carpal fusion
- wrist salvage
- SLAC wrist
- SNAC wrist
- Kienböck disease

Limited wrist fusions have become a well-accepted surgical procedure for patients with localized arthritis of the wrist. The overriding principle is that the arthritic painful components of the joint are fused, allowing the wrist to mobilize via the intact component of the joint.

Initial results and their complications raised concerns about the high incidence of nonunion, persistent pain, restricted range of motion, and difficulties performing activities of daily living.¹ However, much of the early limited wrist fusions involved scaphotrapezotrapezoid (STT) joint fusion, lunotriquetral fusion, or scapholunate fusion.² It was commonly stated that limited wrist fusion was a staged total wrist fusion. However, with appropriate indications and using sound surgical principles, good long-term outcomes can be obtained.³

Etiology of Arthritis

- Genetic factors
- Anatomical predisposition (skeletal morphology, e.g., lunate type; developmental deformity, e.g., Madelung)
- Generalized disease (e.g., rheumatoid arthritis, inflammatory arthritis, crystal deposition disease)
- Trauma (acute and chronic)
- Localized disease such as avascular necrosis (AVN) (Kienböck and Preiser disease)

In the normal wrist, the proximal carpal row is the intercalated segment between the radius and the distal carpal row. The obliquity of the STT joint causes an obligatory flexion of the scaphoid. The obliquity of the hamate triquetral joint

Fig. 1 A type 1 lunate has a single distal facet articulating with the capitate. A type 2 lunate has two distal facets for the capitate and hamate.

creates an obligatory extension of the triquetrum. The lunate remains in balance due to the controlling scaphoid and triquetrum and the position of the wrist.

Any breach within the proximal carpal row (e.g., scaphoid fracture or tear of the scapholunate or lunotriquetral ligaments) will disrupt this balance. The trapezium will flex the distal scaphoid, and the hamate will extend the triquetrum. With a scaphoid fracture or scapholunate instability, the lunate will be extended by the triquetrum. With lunotriquetral instability, the lunate will be flexed by the scaphoid.

The way in which this proximal carpal row will articulate is dependent upon the morphology of the midcarpal joint.⁴ The wrist with a type 1 lunate has a single articulation, which is like a hip joint.⁵ The scaphoid will tend to rotate as it articulates over the capitate. A type 2 lunate has a double articulation at the midcarpal joint, which is more like a knee joint, and the scaphoid moves mainly in the flexion/extension arc.⁵ This provides greater stability of the proximal carpal row and affects the kinematics, response to injury, and development of arthritis. A wrist with STT osteoarthritis (OA) or a scaphoid fracture is less likely to develop to a dorsal intercalated segmental instability (DISI) deformity if it has a type 2 lunate.^{4,6,7} With a type 2 lunate, there is increased risk of degenerative OA between the hamate and the ulnar facet of the lunate.⁸ It is our observation that STT joint OA is more common with type 1 lunate and often has a DISI deformity (►Fig. 1).

The natural history of degenerative OA is dependent upon the cause. However, it has been well described with certain

pathologic conditions for there to be a progressive degeneration of the carpus over a period of time.

Examples of this include:

1. Scapholunate Advanced Collapse (SLAC) Wrist

This condition is caused by disruption of the scapholunate ligament with development of degenerative OA between the radial styloid and the proximal scaphoid. Secondary degenerative changes then develop in a predictable way. This was first described in 1984.⁹ Rotary radioscaphoid malalignment produces abnormal loading, which leads to cartilage degeneration at the tip of the radial styloid and then progresses proximally until the whole of the radioscaphoid joint is involved.¹⁰ This then causes disproportionate capitolunate loading, resulting in secondary carpal collapse, usually starting at the lunocapitate joint. In advanced cases, the remainder of the carpus may become involved, but the radiolunate joint is usually spared due to the congruent and spherical shapes of the proximal lunate and lunate fossa.¹⁰ This represents the key to maintaining a reasonable range of movement. The lunate often falls into a DISI pattern. Watson and Ballet classified this pattern of degeneration into three stages (►Fig. 2).⁹

2. Scaphoid Nonunion Advanced Collapse (SNAC) Wrist

This occurs due to a nonunion of a scaphoid fracture with associated degenerative OA of the radial styloid and the distal scaphoid fragment. It has been shown that the natural history of a scaphoid nonunion is to progress to OA of the wrist.¹¹ The pattern of this collapse is similar to that of SLAC wrist with initial degenerative changes between the radial styloid and the distal fragment of the scaphoid. Degenerative changes then develop in the scaphocapitate joint and the midcarpal joint. However, degenerative changes between the radius and proximal scaphoid fragment develop only late in the disease.¹² This pattern of degeneration has also been classified into three stages (►Fig. 3) (►Table 1).

3. Scaphotrapezotrapezoid (STT) Joint Arthritis

This is a common pattern of degenerative arthritis. It occurs in 2 to 16% of the population and is particularly common in postmenopausal women.¹³ STT joint arthritis occurs more commonly in the patient with a type 1 lunate and is often associated with a DISI pattern.¹⁴ The patient would develop secondary degenerative OA at the dorsal

Fig. 2 Anteroposterior radiographs showing the progressive stages of scapholunate advanced collapse wrist: Stage 1 (a), Stage 2 (b), Stage 3 (c) (Images provided by Steven Tham.)

Fig. 3 Anteroposterior radiographs showing the progressive stages of scaphoid nonunion advanced collapse wrist: Stage 1 (a), Stage 2 (b), Stage 3 (c) (Images provided by Steve Tham.)

Table 1 Stages of SLAC and SNAC disease and recommended treatment modalities

Stage	SLAC—anatomical area effected	SNAC—Anatomical area effected	Treatment options
1	Radial styloid	Radial styloid	Radial styloidectomy and Soft tissue reconstruction/scaphoid reconstruction
2	Scaphoid fossa (and radial styloid)	Scaphocapitate articulation (and radial styloid)	Scaphoid excision and partial carpal fusion (LC, LCH, LCHT) or Proximal row carpectomy or Scaphocapitate arthrodesis
3	Lunate/capitate articulation (and radial styloid and scaphoid fossa)	Lunate/capitate articulation (and radial styloid and scaphocapitate articulation)	Scaphoid excision and partial carpal fusion (LC, LCH, LCHT)
4	Pan wrist arthritis	Pan wrist arthritis	Total wrist arthrodesis

Abbreviations: LC, lunate-capitate; LCH, lunate-capitate-hamate; LCHT, lunate-capitate-hamate-triquetrum; SLAC, scapholunate advanced collapse; SNAC, scaphoid nonunion advanced collapse.

aspect of the midcarpal joint. A CT scan of the scaphoid with sagittal cuts will commonly show extension of the scaphoid with narrowing of the STT joint space. STT joint arthritis occurs less commonly in a wrist with a type 2 lunate and is less likely to be associated with a DISI pattern (►Fig. 4).¹⁴

4. Lunotriquetral Advanced Collapse (LTAC)

This is lunotriquetral ligament instability with associated volar intercalated segment instability deformity. Plain

Fig. 4 Sagittal CT scan showing scaphotrapeziotrapezoid osteoarthritis with scaphoid extension. (© Gregory Ian Bain. Used with permission.)

radiographs demonstrate that the lunate and the scaphoid are both in marked flexion. This is often misdiagnosed as SLAC wrist because the scaphoid and lunate interval appears to be abnormally widened due to the hyperflexed proximal carpal row.¹⁵ These patients will often develop degenerative changes within the midcarpal joint (►Fig. 5).

5. Midcarpal Degenerative Osteoarthritis

This can be a primary condition and occurs with a type 2 lunate, which articulates with the ulnar facet of the lunate and can lead to degenerative OA.¹⁶

6. Ulnar Carpal Impaction

In ulnar carpal impaction, the ulnar is relatively long with impingement on the triangular fibrocartilage with associated chronic degenerative tears and chondral changes of the proximal aspect of the lunate and triquetrum. These patients may have changes within the lunotriquetral ligament but usually not lunotriquetral instability. In late cases, chondral changes extend onto the lunate and then cause secondary changes in the lunate facet of the distal radius.

7. Posttraumatic Degenerative Osteoarthritis

The most common example of this would be following distal radius fractures where there are chondral changes of the distal radius and often triangular fibrocartilage complex (TFC) and scapholunate ligament tears. More

Fig. 5 Radiographs of the wrist showing lunotriquetral advanced collapse.

complex injuries, such as perilunate dislocations and perilunate fracture dislocations, are all associated with degenerative OA, and the distribution would be dependent on the anatomic areas that sustained chondral damage at the time of the injury.

8. Inflammatory Arthritis

Rheumatoid arthritis will often cause a synovitis, joint space narrowing, and, in the later stages, can cause secondary deformities. Common secondary deformities include supination, volar and ulnar translocation, and radial deviation of the carpus. A caput ulna syndrome is common. The joints most commonly involved are the radiocarpal joint and the distal radioulnar joint. In later stages, the involvement can include also the midcarpal joint. Seronegative inflammatory arthropathies that may involve the wrist are psoriasis, systemic lupus erythematosus, and scleroderma. These diseases often have distinct features and specific patterns of deformity unique to the disease.

9. Pseudogout

Pseudogout is a common clinical condition, particularly in older patients. The patient will often have chondral calcification identified on plain radiographs in the triangular fibrocartilage. The crystalline deposits will often be seen at arthroscopy involving the intercarpal ligaments with associated ligamentous instability. The crystalline deposition is often within the articular cartilage as well. This is an important condition because it is common, and the results of limited wrist fusions in this group of patients in our experience are not as good as those with degenerative arthritis.

10. Kienböck Disease

In Kienböck disease, the patient will often have fragmentation of the lunate and degenerative changes identified at

Fig. 6 Arthroscopic classification of Kienböck disease. (Used with Permission from JTHUES.)

the proximal articular surface of the lunate with secondary changes of the lunate facet. The authors have developed an articular-based approach to assessment and management of Kienböck disease that takes into account the spectrum of degenerative changes that can occur.¹⁷ Patients who have a coronal fracture of the lunate will develop degenerative changes at the distal aspect of the lunate and the proximal aspect of the capitate. It is common for patients with Kienböck disease to develop collapse of the lunate and the entire carpus (►Fig. 6).

11. Complex Carpal Injuries

These injuries involve bony and ligamentous injuries and may occur through the greater, lesser, translunate, and inferior arcs of the wrist^{18–20} (►Fig. 7). These injuries are usually managed by fixation of fractures and repair of ligament injuries. Salvage procedures are usually reserved for late cases with arthritis, persistent pain, or loss of function of the wrist. However, a primary salvage procedure can be performed when the articulation is not reconstructible or where the prognosis for standard fixation is unlikely to be effective. Consideration of the prerequisites of each of the motion preserving procedures should be considered before making the decision to proceed. These injuries can be very complex and need acute assessment. The carpal grid concept described below may also help in identifying the appropriate salvage option for each injury. With greater arc injuries, the lunate

Fig. 7 Illustration showing the greater (line 1), lesser (line 2), translunate (line 3), and inferior arcs (line 4). (© Gregory Ian Bain. Used with permission.)

Fig. 8 Greater arc injury treated with acute scapholunate advanced collapse wrist procedure. (© Gregory Ian Bain. Used with permission.)

and lunate facet are often intact, allowing a SLAC wrist procedure to be performed (►**Fig. 8**). Lesser arc injuries have scapholunate and lunotriquetral ligament injuries; therefore, a four-corner fusion (4CF) or proximal row carpectomy (PRC) could be performed, depending on the individual articulations involved. Translunate arc injuries are complex injuries, which will include a lunate fracture. These can be difficult to reconstruct, and a PRC may be the best salvage option if the prerequisites are available (►**Fig. 9**). Inferior arc injuries may require a radioscapulohumeral fusion to stabilize the radiocarpal joint.

Preoperative Assessment

Etiology or the primary diagnosis of the condition affecting the wrist must be sought, whether it be traumatic, generalized arthritis, crystalline deposition, or some other cause.

Anatomical localization of the diseased area is important to identify, for example, the radiocarpal, midcarpal, and distal radioulnar joint.

Associated diseases or conditions such as carpal tunnel syndrome, ulnar nerve entrapment, and other deformities of the hand and muscular skeletal system should be sought. Investigations may be required to exclude a generalized form of arthritis. This is important so as not to miss another potential cause for the patient's pain.

Imaging should include plain radiographs. In more complex cases, CT scans and MRI scans may be important to assist in confirming the etiology, anatomic locations, and complexity of the condition.

Diagnostic injections are often used in orthopedic surgery to assist in identifying those areas from which the pain originates. Certainly cortisone injections may be of some clinical value. However, in the patient with arthritis of the wrist, it is unlikely that selective injections will be of diagnostic value because the intracarpal ligament or triangular fibrocartilage are often disrupted so that the injections are not localized.

Management

Nonoperative Treatment

Nonoperative treatment should be considered and includes modification of activities, analgesics, nonsteroidal anti-inflammatory medication, corticosteroid injections, wrist splints, and isometric strengthening exercises.

Arthroscopy

Arthroscopy can be performed for pathologic or anatomic diagnosis, as a staging procedure, and for therapeutic purposes. A pathologic diagnosis can be obtained with biopsies of synovitis to identify rheumatoid arthritis or crystal

Fig. 9A,B (a) Intra-lunate arc injury treated with (b) acute proximal row carpectomy.

arthropathy. We have also used it in selective cases where there has been some doubt regarding the anatomic distribution and severity of chondral defects. This is usually to identify whether a limited wrist fusion or a PRC would be the best surgical procedure. It is also used in Kienböck, disease, where it assists in localizing the anatomic areas in which there are chondral changes and then can be used as a guide or algorithm for surgical management.²¹ It has a therapeutic role in debridement of synovitis, chondral lesions, associated ligamentous injuries, and capsular releases.^{22,23}

Operative Treatment

Surgical treatment should be reserved for those patients who continue to have pain despite a trial of nonoperative modalities. There are several surgical options available. It is important to discuss these in detail with the patient to ensure that the best surgical option is provided for the patient. An understanding of the patient's primary condition, the anatomic areas involved, and the patient's expectations are vital. A 55-year-old self-employed tradesman who is keen to return to the workforce may be better positioned with an arthroscopic debridement than a limited wrist fusion. Alternatively, a patient may be better positioned to consider a PRC or limited wrist fusion, depending on the recovery and rehabilitation for the individual. If the patient is a heavy smoker, this may compromise the union of a limited wrist fusion.²⁴

Selection of the Correct Motion Preserving Procedure

It is key to ensure that the best procedure is performed to ensure a satisfactory outcome. The principle is to fuse or remove those articulations that are degenerate and causing pain and to allow the wrist to articulate with the remaining normal articulations. When assessing the type of motion preserving procedure to perform, we have found the carpal grid assists in ensuring that we perform the correct limited wrist fusion (► Fig. 10). In some clinical cases, such as in complex carpal instability, it may be worthwhile drawing out the carpal grid to aid the selection of the correct procedure.

It is well known that including the scaphoid within the limited wrist fusion, such as in STT joint fusion, will alter the

Fig. 10 The grid concept for planning wrist surgery. With scaphotrapezotrapezoid fusion, the flexing scaphoid compromises the mechanics, leading to nonunion and impingement. Removal of the flexing scaphoid simplifies the grid. The midcarpal and radiocarpal joints work as stand-alone joints. Respect the grid and use a closing fusion technique. (© Gregory Ian Bain. Used with permission.)

biomechanics of the carpus significantly. This may lead to degenerative OA over the radial styloid or nonunion of the fusion mass.²⁵ Excising the scaphoid ensures that these clinical problems are overcome. The scaphoid is in a unique position because it bridges between the proximal and distal carpal rows, and it is for this reason that with limited wrist fusions, the scaphoid will often cause persistent problems.

Once the scaphoid has been removed, assessment of the carpus is simpler. It can then be seen how the remaining articulations will function if the fusion is performed at the radiocarpal or midcarpal joint.

Proximal Row Carpectomy vs Four-Corner Fusion

PRC and 4CF are commonly used salvage procedures in the treatment of stage II SLAC and SNAC wrists. Both procedures are effective at preserving motion and relieving pain. Both have their own prerequisites, unique benefits, and complications, and as a result, there is controversy as to which is the better surgical procedure when both are viable options (► Fig. 11).

There are many reports in the literature comparing the outcomes between PRC and 4CF in the treatment of SLAC and SNAC wrists, with most claiming good results for both procedures.^{26,27} A meta-analysis reported the following conclusions²⁸:

Fig. 11 Prerequisites for proximal row carpectomy: Lunate facet, capitate surface, and radioscapocapitate (RSC) ligament (a). Prerequisites for midcarpal fusion (four-corner fusion): Lunate facet, proximal lunate, and short radio lunate ligament (SRL) ligament (b). Prerequisites for radiocarpal fusion (radioscapholunate fusion): Midcarpal lunate and scaphoid surface, RSC ligament (c). (© Gregory Ian Bain. Used with permission.)

Table 2 Comparison of PRC and 4CF

	Proximal row carpectomy	Four-corner fusion
Common indications	SLAC (stage 1 and 2) SNAC (stage 1 and 2) Kienböck (Lichtman IIIB, Bain 2B)	SLAC (all stages) SNAC (all stages) LTAC
Pain relief	84%	85%
Patient satisfaction	80%	90%
Range of motion (of contralateral hand)	60%	50%
Grip strength (of contralateral hand)	70%	75%
Complications		
Development of OA	3.7%	1.4%
CRPS	1%	1%
Sepsis	0.4%	0.6%
Nonunion		5.5%
Dorsal impingement		2.6%
Hardware problems		3.3%
Conversion to total wrist fusion	4%	3%

Abbreviations: 4CF, four-corner fusion; CRPS, chronic regional pain syndrome; LTAC, lunotriquetral advanced collapse; OA, osteoarthritis; PRC, proximal row carpectomy; SLAC, scapholunate advanced collapse; SNAC, scaphoid nonunion advanced collapse.

-Both procedures are good options for patients with symptomatic and appropriately staged SLAC or SNAC wrists.

-Grip strength, pain relief, and subjective outcomes are similar in both treatment groups.

-4CFs have better patient satisfaction, lower incidence of OA, and a lower conversion rate compared to full wrist fusion.

-PRC is technically a simpler procedure with a lower complication rate and greater range of motion (► **Table 2**).

Three-Corner Fusion (3CF)

A 3CF is a modification of the 4CF where the triquetrum is excised in addition to the scaphoid. The benefit of excising the triquetrum is that ulnar deviation is improved (► **Table 3**).²⁹ The lunate is then fused to the capitate and the hamate to stabilize the midcarpal joint (► **Fig. 12**). Other advantages of the 3CF are that the excision of the triquetrum provides excellent bone graft and prevents ulnocarpal impingement and triquetral impingement.

The authors' technique for a 3CF is a dorsal longitudinal approach through the third extensor compartment. The extensor pollicis longus (EPL) tendon is retracted radially and protected through the entire procedure. The capsule of the wrist is incised with a Mayo ligament-sparing technique. The scaphoid and triquetrum are excised using a rongeur. Care should be taken not to damage the radioscaphocapitate ligament or the ulnar nerve lying ulnar to the pisiform bone when excising the scaphoid and triquetrum. The wrist is then flexed and the capitate, hamate, and lunate articular surfaces are exposed, denuded of cartilage, and shaped to a conforming fit. Morselized bone graft from the triquetrum is then placed between the lunate and capitate. The midcarpal fusion is stabilized using two memory staples. One staple is placed between the lunate and capitate and the other between the lunate and hamate (► **Fig. 13**). The radial sided staple is placed first to avoid excessive ulnar deviation. A bed is prepared in the bone to inset the staples to avoid impingement against the dorsal rim of the radius. The dorsal rim of the distal radius may be trimmed to accommodate the staples if an

Table 3 Wrist motion after midcarpal stabilization, then excision of the scaphoid and then excision of the triquetrum (Bain et al 2009)²⁹

Procedure	Flex	Ext	F-E arc	UD	RD	RU arc
Baseline	62(7)	59(8)	121(11)	27(4)	21(4)	48(7)
Four-corner fusion	52(6)	48(8)	100(9)	24(4)	18(3)	42(7)
Four-corner fusion with scaphoid excision	55(7)	55(7)	110(8)	26(5)	28(4)	54(8)
Three-corner fusion with excision of scaphoid and triquetrum	59(8)	57(8)	116(10)	32(6)	29(4)	61(10)

Abbreviations: ext, extension; F-E arc, flexion-extension arc; flex, flexion; RD, radial deviation; RU arc, radial to ulnar deviation arc; UD, ulnar deviation. Note: All data are in degrees of movement(standard deviation).

Fig. 12 Cadaveric study: Comparison of motion with four-corner fusion and three-corner fusion. (© Gregory Ian Bain. Used with permission.)

impingement persists. The wound is closed in layers, leaving the EPL outside the extensor retinaculum.

A volar approach has also been described for a 3CF.³⁰ The proposed benefits are that it is a simplified, straightforward procedure and is without the complication of dorsal impingement that can occur with dorsal hardware. It allows scaphoid excision, radial styloidectomy, and correction of a DISI deformity. One difference between this approach and the dorsal approach is that the triquetrum is not excised through this approach. The fusion is accomplished with two headless compression screws between the lunate and capitate, and the lunate and hamate. Cancellous bone graft from the excised scaphoid and radial styloid is packed into the midcarpal region to aid fusion.

Fig. 13 Fluoroscopic image of a three-corner fusion performed with memory staples. (© Gregory Ian Bain. Used with permission.)

Limited Wrist Fusion in Kienböck Disease

Much literature has been published on the various treatment options for Kienböck disease. In deciding on management, the disease should be staged and the ulnar variance determined. The staging can be assessed by the traditional Lichtman radiographic staging and by the arthroscopic grading.¹⁷ In Lichtman stage I, II, and IIIA, treatment is focused on allowing revascularization of the lunate to occur.³¹ Once carpal instability occurs as in stage IIIB (radioscaphoid angle greater than 60°), then a limited carpal fusion (usually a scaphoid-capitate fusion or an STT fusion) or a PRC can be considered.³¹ In Lichtman stage IV disease, the radioscaphoid joint is involved and therefore the options are limited to a PRC if the condition of the cartilage of the proximal capitate and lunate fossa of the radius are acceptable.³¹ The treatment algorithm based on the arthroscopic grading system considers the number of nonfunctional articular surfaces.¹⁷ The authors' choice of salvage procedure is either a PRC or radioscapholunate (RSL) fusion. For grade I disease, a PRC or RSL fusion is recommended, for grade IIA, an RSL, and for grade IIB, a PRC. For grades III and IV, more extensive fusions or hemiarthroplasty is recommended. One consideration that the authors emphasize is that in patients with a type 2 lunate, the proximal edge of the capitate is likely to be pointed and this makes it unlikely that a good long-term result will be obtained because only a small part of the capitate will be articulating with the radius. In these cases, an RSL fusion is preferred.

Other Limited Wrist Fusions

Radioscapholunate Fusion

This procedure is a viable option in patients with degenerative, posttraumatic, or inflammatory arthritis limited to the radiocarpal joint (→Fig. 14).³² This fusion alters the carpal kinematics, however, and limits wrist flexion and extension. This reported results vary, including reports of a high incidence of nonunion, occurrence of scaphoid fractures, and postoperative deterioration of the midcarpal joint.³³ Despite the high complication rate, it remains a viable alternative to

Fig. 14 Rheumatoid wrist with ulnar translocation and preservation of the midcarpal joint. (© Gregory Ian Bain. Used with permission.)

Fig. 15 Cadaveric study: effect of excision of the distal pole of the scaphoid and excision of the triquetrum. Radioscapholunate fusion performed with memory staples. (© Gregory Ian Bain. Used with permission.)

total wrist arthrodesis if the midcarpal joint is normal. When performing this fusion, it is critical to ensure that the distal articular surface of the scaphoid and lunate are congruent.³⁴ Excision of the distal scaphoid and entire triquetrum will increase the motion. (►Fig. 15).

The authors' technique is to debride the articulation between the distal radius and the reciprocal articular surfaces of the scaphoid and the lunate. Two 1.1-mm K-wires are advanced between the scaphoid and the lunate with the distal articulation in view, ensuring that it is perfectly reduced. K-wires are then passed from the proximal pole of the scaphoid and the lunate into the distal radius. This will often provide adequate stability, but if there is concern, then pin plates or locking plates can be utilized. Cancellous bone graft harvested from the excised triquetrum and distal pole of the scaphoid is then packed around the fusion sites. Alternatively, memory staples may be placed between the distal radius and proximal pole of the scaphoid and between the distal radius and lunate to achieve a stable fixation with compression. Following the stabilization, the position is confirmed to be satisfactory with the aid of fluoroscopy.

Scaphotrapeziotrapezoid (STT) and Scaphocapitate (SC) Fusion

The main indications for STT fusion are isolated STT arthritis, rotary subluxation of the scaphoid, and Kienböck disease.^{25,31} This fusion is the mainstay of treatment for isolated STT arthritis and has shown good results in the literature.³⁵ However, the use of this fusion for the treatment of rotary subluxation of the scaphoid is more controversial and has been historically associated with a higher complication rate.^{36,37} These complications are predominantly nonunion and development of arthritis in neighboring joints. The scaphocapitate fusion is biomechanically the same as an STT fusion because the capitate, trapezium, and trapezoid are linked. Therefore, the indications and functional outcomes are similar.³⁸ However, the STT fusion is technically more difficult and has a higher complication rate than the SC fusion because it has a smaller fusion mass.³⁹

Lunotriquetral (LT) Arthrodesis

Lunotriquetral arthrodesis is now rarely performed. The planned fusion mass is small, and therefore it has a high nonunion rate (up to 57%) and a poor outcome.^{40–42} The published results for treatment of LT instability with ligament reconstruction and LT fusion are both poor.⁴³ The authors prefer to perform a midcarpal fusion because this is a reliable procedure. The authors prefer to remove the scaphoid to prevent radial styloid impingement and also the triquetrum to prevent ulnocarpal impingement.

Technical Aspects of Surgery

The principles of limited wrist fusions are very important (►Table 4).

Exposure

A dorsal longitudinal incision is usually utilized. For the SLAC wrist procedure and radioscapholunate fusion, it is the authors' preferred technique to incise the extensor retinaculum through the third extensor compartment. The authors use a Mayo "Z" capsulotomy because it provides adequate exposure and may increase the range of flexion postoperatively because the scar can lengthen. Some surgeons excise the posterior interosseous nerve. The articulations should be explored to ensure that the planned procedure is appropriate. It is important to confirm that the planned articulations have a functional articular surface to ensure a good long-term outcome can be obtained.

Bony Preparation

The planned fusion sites should be debrided. The authors use hand-held instruments such as a rongeur or a curette and avoid high-speed burrs due to concerns regarding heat necrosis. The authors use a closing fusion technique, which involves debriding the full thickness of the articular surfaces from front to back to allow the surfaces to close (►Fig. 16). Other authors have previously described leaving part of the volar cortex intact and inserting an intercalary graft, which will maintain the height of the fusion (open fusion technique). This has the advantage of maintaining the carpal height, which may improve grip strength. However, the closing fusion technique is intrinsically more stable, is simpler to

Table 4 Principles of limited wrist fusions

Localized disease
Stand-alone joint
Mechanical debridement
Surface area of fusion mass
Respect the grid
Containment (e.g., triquetrum excision)
Closing fusion
Bone graft augmentation
Aim at extension

Fig. 16 Drawing of an open and closing fusion. (© Gregory Ian Bain. Used with permission.)

perform, and is more likely to lead to a fusion mass in view of the fact that stability is easily obtained. It is important that both sides of the fusion mass are correctly shaped. The authors' technique is to use a cup and cone concept. This ensures a larger surface area, it is technically simpler to perform, and, most importantly, it allows the surgeon to angle the fusion mass into the desired position up until the final fixation is performed. If a flat fusion mass is planned, then the direction of the fusion mass is predetermined.

Containment

The concept of containment of the joint is an important one. The remaining articulation can be contained to maintain stability. However, edges of the joint can be excised to increase the arc of motion. The best example of this is when performing a radioscapulohumeral fusion, where the distal aspect of the scaphoid is excised to increase the range of radial deviation and flexion (►Figs. 11, 15, and 17). We have performed a cadaveric study, which demonstrates that excision of the triquetrum increases the range of ulnar deviation and extension in a RSL fusion.³⁴ When performing a

Fig. 17 The concept of containment. (© Gregory Ian Bain. Used with permission.)

SLAC wrist procedure, it would be standard practice to excise the scaphoid. However, we also excise the triquetrum as part of the carpal fusion to increase the range of extension and ulnar deviation. There are two other secondary advantages of excision of the triquetrum.

1. The triquetrum provides excellent bone graft to supplement the fusion site, in contrast to the scaphoid, which is often sclerotic or fractured.
2. It is our experience that one of the most common problems following limited wrist fusions is persistent ulnar-side wrist pain. Because we have been excising the triquetrum as part of the surgical procedure, it is very uncommon to require any ulnar-side wrist surgery. Excision of the triquetrum unloads the TFC and prevents ulnar carpal impaction in the same way as an ulnar-shortening procedure.

Positioning of the Fusion Mass

This is critical for determining the final functionality of the carpus. We have performed a study where we looked at a group of volunteers whose wrists were positioned in preset positions and grip strength measured. As can be noted, the patients' grip strength is increased in extension arc (►Fig. 18). The self-selected position to obtain maximal grip strength was on average 28 degrees of wrist extension. It is our aim at the time of performing limited wrist fusions to achieve approximately $\frac{2}{3}$ of the arc in extension and $\frac{1}{3}$ in flexion.

Positioning of the Midcarpal Joint

In a midcarpal fusion, this can be technically challenging. Techniques that may assist are to insert a K-wire from the radius through to the lunate. This will stabilize the lunate and then allow the surgeon to fix the midcarpal joint, but this will compromise the only articulation that remains available between the radius and carpus. It is important to ensure that the distal carpal row is well balanced over the proximal carpal row. It is our experience that when performing a 4CF or 3CF, the carpus may tend to tilt into radial deviation, and so care should be taken to avoid this. It is instinctive to place the

Fig. 18 Graph demonstrating the effect of wrist position on grip strength.

capitate on the dorsal aspect of the lunate, which will lead to impingement. The author advises that the position of the DISI at time of surgery is not as critical as stated by other authors. The reason is that the lunate is positioned by the volar carpal ligaments and will return to the predetermined position depending on these ligaments. What is important is the position in which the lunocapitate joint is positioned. The authors' recommended approach is to position the capitate and hamate over the lunate in a similar way in which the native wrist is positioned, depending upon whether this is a type 1 or type 2 lunate. The capitate should not be translated dorsally, but should sit over the central lunate, and be tilted dorsally by approximately 20 degrees.

Options of Fixation

These include K-wires and a wide array of screws, staples, and plates. Originally, various types of dorsal plates had a high complication rate with dorsal impingement of the plate on the radius, nonunion of the carpal mass, and loss of fixation.²⁸ Newer plates with variable angle-locking screws are likely to have a better outcome. However, obtaining compression across these plates is not simple. The authors' preferred technique has been to use memory staples.¹⁵ This does provide increased stability initially and is technically simpler than the newer plate options. Supplemental triquetrum bone graft is packed into the midcarpal fusion mass. We do not use bone morphogenetic protein (BMP)⁴⁴ or bone graft substitutes (BGS) and prefer good, old-fashioned, cancellous bone graft.

Postoperative Management

Postoperatively, the patient is usually admitted overnight with the arm elevated. The patient is then reviewed in the clinic the following week. It would be common practice to apply a fiberglass cast for 4 to 8 weeks. However, it is the authors' preferred technique, since using the memory staples, to provide the patient with a removable splint. Some of the newer plating methods will provide increased stability, in which case similar postoperative regimes could be employed. After 6 weeks, the patient can perform general simple activities but should avoid heavy or repetitive activities until radiologic confirmation of union. The final steady state position is unlikely to be reached for a period of 12 to 24 months.

Functional Outcomes with LWF

Following limited wrist fusions, patients report limitations in being able to perform activities of everyday life. Most limitations are with activities that involve hand and forearm rotation and grip strength. Most patients develop compensatory mechanisms, such as altering the type of grip or using two hands for certain tasks, although there are tasks which some cannot do, for example, doing up a bra strap.⁴⁵ Overall, patients are satisfied with their functional outcome compared with their function preoperatively.²⁸

Conclusion

Motion preserving procedures are a good surgical option in patients who have localized degenerative or arthritic changes

of the carpus. It is important that appropriate patient selection is performed. This should be based on patient factors, the primary etiology, and the anatomic distribution of the arthritis. If the principles of surgery are maintained, then it is likely that in the long term a good outcome can be obtained.

References

- 1 McAuliffe JA, Dell PC, Jaffe R. Complications of intercarpal arthrodesis. *J Hand Surg Am* 1993;18(6):1121-1128
- 2 Siegel JM, Ruby LK. A critical look at intercarpal arthrodesis: review of the literature. *J Hand Surg Am* 1996;21(4):717-723
- 3 Bain GI, Watts AC. The outcome of scaphoid excision and four-corner arthrodesis for advanced carpal collapse at a minimum of ten years. *J Hand Surg Am* 2010;35(5):719-725
- 4 Galley I, Bain GI, McLean JM. Influence of lunate type on scaphoid kinematics. *J Hand Surg Am* 2007;32(6):842-847
- 5 Fogg QA. Scaphoid variation and an anatomical basis for variable carpal mechanics [thesis]. Adelaide: University of Adelaide, Dept of Anatomical Sciences; 2004:161-221
- 6 Moritomo H, Viegas SF, Nakamura K, Da Silva MF, Patterson RM. The scaphotrapezotrapezoidal joint. Part I: An anatomic and radiographic study. *J Hand Surg Am* 2000;25(5):899-910
- 7 Haase SC, Berger RA, Shin AY. Association between lunate morphology and carpal collapse patterns in scaphoid nonunions. *J Hand Surg Am* 2007;32(7):1009-1012
- 8 Viegas SF, Wagner K, Patterson R, Peterson P. Medial (hamate) facet of the lunate. *J Hand Surg Am* 1990;15(4):564-571
- 9 Watson HK, Ballet FL. The SLAC wrist: scapholunate advanced collapse pattern of degenerative arthritis. *J Hand Surg Am* 1984;9(3):358-365
- 10 Watson HK, Ryu J. Evolution of arthritis of the wrist. *Clin Orthop Relat Res* 1986;202(202):57-67
- 11 Inoue G, Sakuma M. The natural history of scaphoid non-union. Radiographical and clinical analysis in 102 cases. *Arch Orthop Trauma Surg* 1996;115(1):1-4
- 12 Peterson B, Szabo RM. Carpal osteoarthritis. *Hand Clin* 2006;22(4):517-528, abstract vii
- 13 Armstrong AL, Hunter JB, Davis TRC. The prevalence of degenerative arthritis of the base of the thumb in post-menopausal women. *J Hand Surg [Br]* 1994;19(3):340-341
- 14 McLean JM, Turner PC, Bain GI, Rezaian N, Field J, Fogg Q. An association between lunate morphology and scaphoid-trapezium-trapezoid arthritis. *J Hand Surg Eur Vol* 2009;34(6):778-782
- 15 van Riet RP, Bain GI. Three-corner wrist fusion using memory staples. *Tech Hand Up Extrem Surg* 2006;10(4):259-264
- 16 Burgess RC. Anatomic variations of the midcarpal joint. *J Hand Surg Am* 1990;15(1):129-131
- 17 Bain GI, Begg M. Arthroscopic assessment and classification of Kienboeck's disease. *Tech Hand Up Extrem Surg* 2006;10(1):8-13
- 18 Johnson RP. The acutely injured wrist and its residuals. *Clin Orthop Relat Res* 1980;149(149):33-44
- 19 Mayfield JK. Patterns of injury to carpal ligaments. A spectrum. *Clin Orthop Relat Res* 1984;187(187):36-42
- 20 Bain GI, McLean JM, Turner PC, Sood A, Pourgiezis N. Translunate fracture with associated perilunate injury: 3 case reports with introduction of the translunate arc concept. *J Hand Surg Am* 2008;33(10):1770-1776
- 21 Bain GI, Durrant A. An articular-based approach to Kienboeck avascular necrosis of the lunate. *Tech Hand Up Extrem Surg* 2011;15(1):41-47
- 22 Verhellen R, Bain GI. Arthroscopic capsular release for contracture of the wrist: a new technique. *Arthroscopy* 2000;16(1):106-110
- 23 Luchetti R, Atzei A, Fairplay T. Arthroscopic wrist arthrolysis after wrist fracture. *Arthroscopy* 2007;23(3):255-260

- 24 Chen F, Osterman AL, Mahony K. Smoking and bony union after ulna-shortening osteotomy. *Am J Orthop* 2001;30(6):486–489
- 25 Wollstein R, Watson HK. Scaphotrapeziotrapezoid arthrodesis for arthritis. *Hand Clin* 2005;21(4):539–543, vi
- 26 Vanhove W, De Vil J, Van Seymortier P, Boone B, Verdonk R. Proximal row carpectomy versus four-corner arthrodesis as a treatment for SLAC (scapholunate advanced collapse) wrist. *J Hand Surg Eur Vol* 2008;33(2):118–125
- 27 Dacho AK, Baumeister S, Germann G, Sauerbier M. Comparison of proximal row carpectomy and midcarpal arthrodesis for the treatment of scaphoid nonunion advanced collapse (SNACwrist) and scapholunate advanced collapse (SLACwrist) in stage II. *J Plast Reconstr Aesthet Surg* 2008;61:1210–1218
- 28 Mulford JS, Ceulemans LJ, Nam D, Axelrod TS. Proximal row carpectomy vs four corner fusion for scapholunate (Slac) or scaphoid nonunion advanced collapse (Snac) wrists: a systematic review of outcomes. *J Hand Surg Eur Vol* 2009;34:256–263
- 29 Bain GI, Sood A, Ashwood A, Turner PC, Fogg G. Effect of scaphoid and triquetrum excision after limited stabilisation on cadaver wrist movement a laboratory study. *J Hand Surg Eur Vol* 2009; 34:614–617
- 30 Dutly-Guinand M, von Schroeder HP. Three-corner midcarpal arthrodesis and scaphoidectomy: a simplified volar approach. *Tech Hand Up Extrem Surg* 2009;13(1):54–58
- 31 Lichtman DM, Lesley NE, Simmons SP. The classification and treatment of Kienböck's disease: the state of the art and a look at the future. *J Hand Surg Eur Vol* 2010;35(7):549–554
- 32 Murray PM. Radioscapholunate arthrodesis. *Hand Clin* 2005;21(4):561–566
- 33 Nagy L, Büchler U. Long-term results of radioscapholunate fusion following fractures of the distal radius. *J Hand Surg [Br]* 1997; 22(6):705–710
- 34 Bain GI, Ondimu P, Hallam P, Ashwood N. Radioscapholunate arthrodesis—a prospective study. *Hand Surg* 2009;14(2-3):73–82
- 35 Watson HK, Wollstein R, Joseph E, Manzo R, Weinzwieg J, Ashmead D IV. Scaphotrapeziotrapezoid arthrodesis: a follow-up study. *J Hand Surg Am* 2003;28(3):397–404
- 36 Kleinman WB, Carroll CT. Scaphotrapeziotrapezoid arthrodesis for treatment of chronic static and dynamic scapholunate. *J Hand Surg Am* 1990;15(3):408–414
- 37 Ishida O, Tsai TM. Complications and results of scapho-trapezio-trapezoid arthrodesis. *Clin Orthop Relat Res* 1993;287(287): 125–130
- 38 Weiss KE, Rodner CM. Osteoarthritis of the wrist. *J Hand Surg Am* 2007;32(5):725–746
- 39 Delétang F, Segret J, Dap F, Dautel G. Chronic scapholunate instability treated by scaphocapitate fusion: A midterm outcome perspective. *Orthop Traumatol Surg Res* 2011
- 40 Vandesande W, De Smet L, Van Ransbeeck H. Lunotriquetral arthrodesis, a procedure with a high failure rate. *Acta Orthop Belg* 2001;67(4):361–367
- 41 Shin AY, Battaglia MJ, Bishop AT. Lunotriquetral instability: diagnosis and treatment. *J Am Acad Orthop Surg* 2000;8(3): 170–179
- 42 Kirschenbaum D, Coyle MP, Leddy JP. Chronic lunotriquetral instability: diagnosis and treatment. *J Hand Surg Am* 1993; 18(6):1107–1112
- 43 De Smet L, Janssens I, van de Sande W. Chronic lunotriquetral ligament injuries: arthrodesis or capsulodesis. *Acta Chir Belg* 2005;105(1):79–81
- 44 Carragee EJ, Hurwitz EL, Weiner BK. A critical review of recombinant human bone morphogenetic protein-2 trials in spinal surgery: emerging safety concerns and lessons learned. *Spine J* 2011;11(6):471–491
- 45 Bialocerkowski AE. Activity limitations and compensatory mechanism use following limited wrist fusion. *Arthritis Rheum* 2008; 59(10):1504–1511