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Four-corner arthrodesis employing the native scaphoid as the principal donor graft for advanced collapse deformity of the wrist: technique and outcomes

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Abstract

The purpose of this study was to determine the functional, radiographic, and subjective outcome of the authors' technique of four-corner arthrodesis using the en bloc excised scaphoid as the principal donor bone graft coupled with Kirschner wire fixation. The study comprised 40 consecutive patients with progressive Stage II and III scapholunate advanced collapse or scaphoid nonunion advanced collapse deformities. Preoperative and postoperative range of motion, grip strength, carpal height, and Michigan Hand Outcomes Questionnaire responses were assessed with a mean follow-up of 4.4 years. At an average of 7 weeks, all patients demonstrated radiographic fusion. Moreover, postoperatively, improvement in the Michigan Hand Outcomes Questionnaire domains of overall function, activities of daily living, work performance, pain, and satisfaction were statistically significant. Complications were few and no patient required revision surgery. In this study, the authors' technique results in a reliable four-corner arthrodesis with a low expectation of complications or revision surgery.

Level of evidence: IV

Keywords

Four-corner arthrodesis, 4CA, carpectomy, SLAC, SNAC, scaphoid bone graft

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Introduction

Four-corner arthrodesis (4CA) is a well-established and frequently employed motion-preserving procedure for scaphoid nonunion advanced collapse (SNAC) and scapholunate advanced collapse (SLAC) deformity of the wrist (Saltzman et al., 2015; Shin, 2001; Watson and Ballet, 1984; Watson et al., 1981; Wyrick et al., 1995). The objective of the arthrodesis is to achieve a stable and pain-free wrist while maintaining carpal alignment and preserving maximum wrist motion and grip strength (Watson et al., 1981, 1999). Basic requisites for successful fusion comprise precise correction of carpal malalignment, meticulous mid carpal fusion site preparation, adjunctive bone grafting, and stable fixation. Bone graft, usually harvested from the iliac crest or distal radius and, less frequently, from the excised scaphoid, is essential to promote a solid arthrodesis; and a variety of reportedly secure fixation methods, including Kirschner wires (K-wires), staples, compression screws, and locking or non-locking dorsal circular plates have been advocated to enhance outcome (Shin, 2001; Vance et al., 2005). However, with usage of variable techniques of bone grafting and differing methods of fixation, reported outcomes of 4CA have not unexpectedly been inconsistent. Some investigators have reported uniformly favourable outcomes, while others have cited unacceptably high rates of nonunion and major complications (Ashmead et al., 1994; Bain and Watts, 2010; Bedford and Yang, 2010;

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Chung et al., 2006; Garcia-Lopez et al., 2001; Kendall et al., 2005; Mantovani et al., 2010; Merrell et al., 2008; Shindle et al., 2007; Vance et al., 2005). Clearly, a consensus for reliable surgical techniques is non-existent and the optimal method of 4CA remains indeterminate.

The objective of this study is to assess the functional, radiographic, and subjective results of the authors' technique of 4CA that preferentially employs the en bloc excised native scaphoid as the principal source of bone graft coupled with minimally invasive percutaneous K-wire fixation. The null hypothesis was that this technique would not prove a consistently effective method of treatment for SLAC or SNAC wrist deformity.

Methods

Between 2007 and 2014, 40 consecutive patients with disabling SLAC/SNAC wrist deformity required 4CA. The cases included 29 SLAC and 11 SNAC wrists. All procedures were performed by the senior author employing the native scaphoid as a structural wedge graft and K-wire fixation. Postoperatively, with institutional review board approval, all patients were recalled and evaluated subjectively, objectively, and radiographically at a mean follow-up period of 4.4 years (2–8 years). The study comprised 33 men and seven women with an average age of 52 years (22–76 years). The series included 16 highly active patients with Stage II and 24 patients with Stage III SLAC or SNAC wrists. The functionally demanding group included four active surgeons, three professional athletes, 12 manual labourers, and the majority were avid participants in recreational sports or physical training programmes. Moreover, all patients were employed full-time and independent in their activities of daily living. Age, per se, was not a limiting factor in case selection; rather physiological status and patient requirements were the primary considerations in the choice of 4CA. All patients demonstrated an intact radiolunate joint with no radiographic evidence of ulnar translocation, radiolunate incongruity, or pre-existing pancarpal arthritis. No patients were lost to follow-up evaluation.

Subjective results were assessed using the Michigan Hand Outcomes Questionnaire (MHQ), with patient appraisal of overall functional outcome, and included pain relief, activities of daily living, work performance, aesthetics, and satisfaction. Pre- and postoperative wrist range of motion were measured using a goniometer and grip strength was quantified with a Jamar dynamometer (Jamar, Preston, MI). The postoperative measurements were compared with both the preoperative values and with measurement of motion and strength in the asymptomatic contralateral wrist.

Comprehensive radiographic evaluation for all patients included high quality frontal, lateral, and oblique projections supplemented with radial-ulnar deviation views. Serial studies were obtained to assess the rate and quality of union, as well as the restoration of carpal alignment, maintenance of carpal height, and preservation of radiolunate congruity. Tomography, as well as other special studies, in accord with other reports of 4CA, did not prove necessary for assessment, thus avoiding additional radiation and cost.

Results were calculated and statistically analysed using Excel software (Microsoft, Seattle, WA). For normally distributed, continuous variables, preoperative and postoperative data were compared using the paired *t*-test and data presented as means and standard deviation. The results were considered statistically significant if the p value was <0.05.

Surgical technique

A pneumatic tourniquet is used for all patients and balanced regional anaesthesia for most. A 4–5 cm dorsal incision with its apex at the scapholunate interval, sparing the critical dorsal radiocarpal ligament and the volar extrinsic ligaments, provides wide access to the radiocarpal capsule in the interval between the third and fourth extensor compartments. A capsulotomy is incised along the radial margin of the dorsal radiocarpal ligament, as advocated by Berger et al. and an ulnar-based capsule flap, extending to the radial styloid, is reflected exposing the carpal derangement and the radioscaphoid impingement (Berger et al., 1995). Invariably the scaphoid is grossly deformed, displaced volarly and radially, abutted against the radial styloid, and dissociated from the lunate. By gentle blunt and sharp dissection, the scaphoid is excised en bloc and a partial radial styloidectomy is performed with a ronguer (Figure 1(A)).

The midcarpal fusion site is thoroughly debrided, initially with a power bur, and then with a rongeur, to expose the cancellous bone of the apposing four carpal bones. A broad cancellous trough is created spanning the entire midcarpal articulation (Figure 1(B)). To maximize restoration of carpal height, the trough is shaped in a dorsal, open wedge configuration with the proximal capitate and hamate firmly coapted to the volar surfaces of the lunate and triquetrum.

By manual distraction of the carpus and volar displacement of the capitate, the lunate, and capitate are then aligned in a coaxial position with maximal correction of the dorsal intercalated segment instability (DISI) deformity. To lessen the prospect of

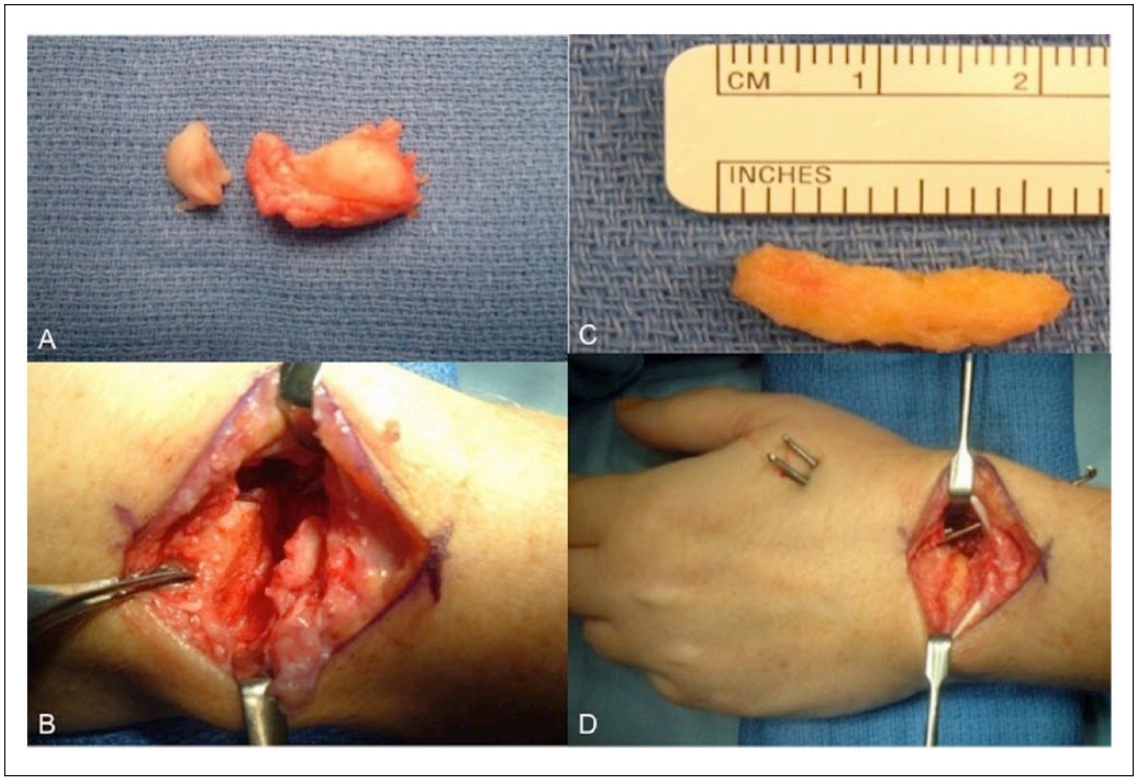

Figure 1. (A) The excised scaphoid en bloc with proximal pole nonunion. (B) The scaphoid after debridement of cartilage, subchondral bone, and sculpting of the cancellous graft. (C) The midcarpal fusion site after debridement and creation of an open wedge, broad cancellous trough spanning the midcarpal articulation. (D) Intraoperative appearance of reduced 4CA after slotting and manual impaction of the scaphoid graft into the fusion bed, and advancement of the preset wires to securely transfix the arthrodesis.

postoperative dorsal impingement, prominent dorsal rims of both the radius and the lunate are judiciously tapered to smooth surfaces. With the radial borders of the capitate and lunate in direct alignment and firmly adjoined at their volar margins, a collinear carpus is restored. The reduction is maintained with manual traction and secured with a 0.062 K-wire passed percutaneously from the distal radius to the base of the capitate, coupled with a distal wire passed proximally across the base of the fusion bed. An accurate reduction ensures an open wedge, thoroughly debrided, well-aligned midcarpal fusion site and prepares the trough for the slotted strut graft. Two or three additional wires are preset at the distal margin of the trough for insertion and secure fixation once the graft is inserted.

The scaphoid is thoroughly debrided of degenerative cartilage and sclerotic subchondral bone, procuring a purely cancellous, solid wedge, usually measuring 2 cm in length by 1.2–2 cm in width, that is sculpted to fit the semilunar contours of the fusion bed (Figure 1(C)). Slotting and impacting the graft secures the open wedge configured fusion site, which remains hinged on the firmly coapted volar joint surfaces. With this technique, substantial compressive forces are generated across the fusion site, carpal height and alignment are restored, and a substantial block of cancellous bone not only promotes fusion, but also provides a strut to maintain the wedge-shaped arthrodesis configuration. In our experience, even in cases of SNAC wrist with typically deformed fracture fragments, procurement of a sufficiently sized strut graft has always been obtained (Figure 2). Additional cancellous graft from the scaphoid, and, if necessary, cancellous bone harvested from the adjacent radius, afford a copious source of healthy bone graft.

Advancement of the preset wires securely transfixes the arthrodesis (Figure 1(D)), and radiography confirms a thoroughly grafted, well-aligned fusion with accurate K-wire fixation (Figure 3(A)). Precisely inserted K-wires secure the open wedge fusion site as well as the impacted graft, and maintain the compression created across the carpus. The capsular flap, used to enhance carpal stability, is secured to the radial border of the radioscaphocapitate ligament, and the remaining capsular tissues are repaired. The tourniquet is deflated, haemostasis achieved, and the skin incision is closed. The surgical

Figure 2. (A) Radiographic of chronic SNAC wrist resulting from failed screw fixation of a scaphoid waist fracture, referred for 4CA. (B) The intraoperative scaphoid excised en bloc, demonstrating the deformed scaphoid waist nonunion and the displaced screw. (C) Removal of the screw clearly displays the un-united but sizable scaphoid fragments. (D) For all SNAC wrists in this series, regardless of the site of fracture, a substantive scaphoid wedge graft, 2 × 2 cm (centre), and additional cancellous chips (left) have been consistently procured from the debrided fragments. If necessary, supplementary cancellous graft (right) is available from the adjacent distal radius.

repairs are protected with a long-arm thumb spica cast until radiographic union is clearly evident (Figure 3(B)). Solid bony union invariably occurs within 6–8 weeks, at which time the wires are removed in the office and rehabilitation is begun.

Results

This study comprised 40 consecutive patients, 33 males and seven females, all available for postoperative evaluation, with an average age of 52 years (22–76 years) at the time of surgery. The average follow-up time was 4.4 years, with a minimum follow-up of 1 year (1–8 years). Comprehensive pre- and postoperative measures were reviewed for comparison and the subjective MHQ was assessed.

Pain

Preoperatively, the average MHQ pain score was 85 and decreased postoperatively to 33.3 ($p < 0.01$). This marked and significant relief of pain was an essential element in successful reconstruction of a highly functional wrist (Table 1).

Motion and strength

The average arc of postoperative range of motion was 51% of the uninvolved contralateral wrist and essentially unchanged from the preoperative mobility (Table 1). Preoperative flexion was 44° (SD 18), and postoperatively it was 40° (SD 13) ($p = 0.23$). Extension was 44° (SD 20) preoperatively, and 37° (SD 14) postoperatively ($p = 0.10$). Preoperative and postoperative radial deviation was 10° (SD 6) ($p = 0.89$). Ulnar deviation was 10° (SD 6) preoperatively, and postoperative it was 14° (SD 6) ($p = 0.08$). Nonetheless, this arc achieved the objective of preserving motion, and, despite the lack of an increase, functional mobility was restored and enhanced by the consistent alleviation of pain. Highly functional and pain free motion was regained in all planes,

thereby permitting the majority of patients to resume their activities with an unimpaired wrist for periods as long as 8 years. Grip strength increased from a preoperative level of 76% to a postoperative 82% of the contralateral side ($p = 0.5$). These incremental improvements undoubtedly contributed to improved function with a high level of satisfaction reported by this group of patients.

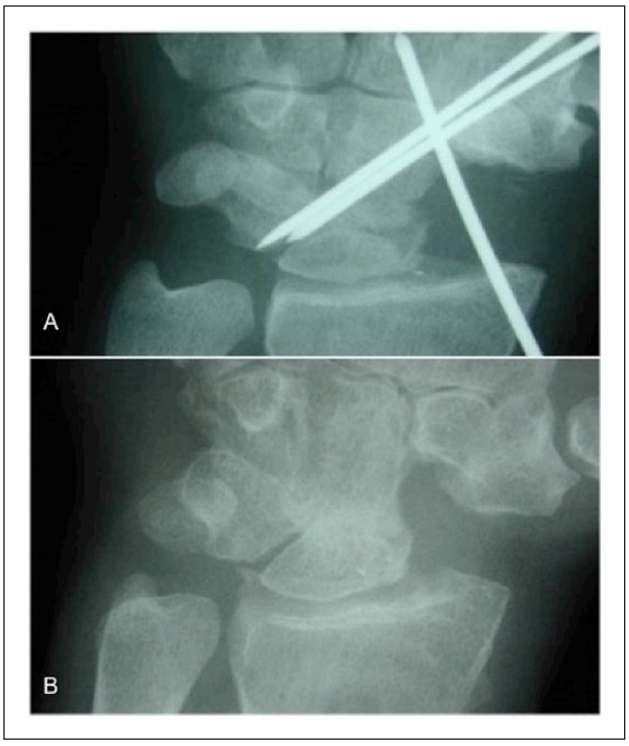

Figure 3. (A) The intraoperative radiographic demonstrating the open wedge fusion site accurately aligned, thoroughly grafted, and securely transfixed with K-wires. (B) Seven-week postoperative radiograph after K-wire removal, demonstrating a solid arthrodesis with complete incorporation of the scaphoid strut graft.

Function and satisfaction

For the group, functional improvement was a constant outcome. Preoperatively, the average MHQ overall hand function domain score was 36.7. Postoperatively, this increased to 75.0 ($p = 0.02$). Preoperatively the average MHQ activities of daily living domain score was 40.0. This increased postoperatively to 82.5 ($p < 0.05$). Additionally, the postoperative MHQ work domain increased to 82 from 43 ($p < 0.05$). Lastly, overall patient satisfaction increased to 72.9 from 19.5 ($p < 0.01$).

Radiographic

Postoperative radiographs clearly demonstrated a 100% radiographic union within 6–8 weeks (mean 7.1 weeks) of surgery (Figure 3(B)). At final evaluation, solid consolidation of the fusion site was consistently observed with no evidence of fracture or fragmentation of the scaphoid wedge graft, recurrent carpal collapse deformity, or radiolunate arthrosis. In all cases, carpal height was maintained at 45.2% (SD 4%) compared with a preoperative measure of 45.6% (SD 4.4%) ($p = 0.76$). In two patients, residual carpal malalignment resulted in radiographic evidence of dorsal impingement that can be attributed to incomplete correction of the pre-existing DISI deformity. However, both patients in this study were asymptomatic and neither has requested nor required revision surgery. Nonetheless, this was a concerning radiographic observation, since dorsal impingement can compromise outcome and result in radiocarpal degenerative joint disease.

Table 1. Functional and radiographic results.

	Preoperative	Postoperative	*P*-value
Carpal height (%)	45.6 SD 4.4	45.2 SD 4.0	0.76
Grip strength (% of contralateral)	76	82	0.50
Flexion (Deg)	44 SD 18	40 SD 13	0.23
Extension (Deg)	44 SD 20	37 SD 14	0.10
Radial deviation (Deg)	10 SD 6	10 SD 6	0.90
Ulnar deviation (Deg)	10 SD 6	14 SD 6	0.08
MHQ domains			
Overall function	36.7	75	0.02
ADL	40.0	82.5	0.04
Work	43.0	82.0	0.04
Pain	85.0	33.3	<0.01
Aesthetics	76.0	75.0	0.77
Satisfaction	19.5	72.9	<0.01

MHQ: Michigan Hand Outcome Questionnaire; ADL: activities of daily living; Deg: degrees.

Complications

Pin complications occurred in two cases (5%). Two patients developed superficial pin site infections that promptly responded to local pin care and oral antibiotics, and did not compromise the surgical outcome. No deep infections occurred and no patient required premature pin removal. This paucity of pin problems with a usage of a multitude of percutaneous K-wires for a relatively large group of patients is notable and highlights the importance of diligent pin care throughout the post-operative period.

Discussion

Since the 4CA technique was introduced by Watson in 1981, many methods of fixation have been described: K-wires, staples, compression screws, and locking and non-locking dorsal circular plates (Watson et al., 1981). Unfortunately, many of these implants have resulted in high nonunion rates, screw breakage, radio-carpal impingement, and low patient satisfaction scores, and presently no consensus exists regarding the best fixation technique (Chung et al., 2006; Kendall et al., 2005; Shindle et al., 2007; Vance et al., 2005).

In our cases, the arthrodesis was secured with 'traditional' percutaneous K-wire fixation for 6–8 weeks postoperatively. Similar to the experience reported by Ashmead et al. (1994), Watson et al. (1999), and Vance et al. (2005), K-wire fixation in this study has proved a reliable, minimally invasive, and versatile method of internal fixation that has ensured a solid fusion. Moreover, pin tract infection requiring premature removal of the wires has not been encountered. The consistently rapid and successful fusion rate achieved with 40 consecutive patients is comparable with the 100% union rate reported by Merrell et al. (2008) and Bedford and Yang (2010) in their studies employing dorsal plate fixation. As evidenced by the results of these surgeons, circular plates affording rigid fixation can be an effective method of achieving solid 4CA. Nonetheless, these plates are not compression plates, compression being a critical factor facilitating fusion, and they, like all implants, may require a second operation for removal or revision. Furthermore, successful usage of plates has not proved consistently reproducible and is not a cost effective method of treatment.

Our technique employing manual distraction to fashion a dorsal open wedge fusion site, hinged on the volar midcarpal joint, initially restores carpal height and alignment. The strut graft is then slotted in the open fusion bed and firmly impacted, thereby eliminating any distraction forces and created a substantial compression environment to promote fusion. Although Kirchner wires are not compressive devices and do not afford rigid fixation, they can be used to securely maintain compression once created. Clearly, circular plates and screws can also maintain compression, but, contrasting with our technique, create a closing fusion site apt to compromise carpal height and alignment.

The choice of donor bone graft is also a source of contention. Unique to our technique is the use of the en bloc, excised scaphoid as the primary donor graft transfixed with K-wires that not only provides a solid bony strut to maintain the open wedge fusion site, but also affords additional cancellous bone chips to promote fusion. Some authors have suggested that high nonunion rates are apt to occur with the use of the excised scaphoid as bone graft and consider it as an insufficient and poor quality source of bone (Kendall et al., 2005; Merrell et al., 2008; Vance et al., 2005). Following their disappointing experience, Merrell et al. (2008) stated: 'use of excised scaphoid bone graft should be avoided'. We believe these poor results can be attributed to technical differences in fusion site preparation and scaphoid procurement. Critical to success is thorough debridement of the eburnated articular surfaces of the mid-carpal joint and formation of a purely cancellous fusion bed. Similarly, the en bloc excised scaphoid must be thoroughly debrided of degenerative cartilage and sclerotic subchondral bone, thereby procuring healthy, cancellous bone to promote fusion. Notably, the articles reporting high nonunion rates used piece-meal, morselized scaphoid bone graft that we concur is apt to be suboptimal. In contrast, our experience bears that, with meticulous preparation, the excised scaphoid provides a reliable and sizable source of graft that consistently promotes uniform and rapid fusion. Other surgeons have also achieved similarly successful fusion rates with usage of scaphoid donor graft (Bedford and Yang, 2010; Mantovani et al., 2010; Ozyurekoglu and Turker, 2012).

The principal limitation of this report is that a retrospective study of one surgeon's experience with a singular treatment cannot demonstrate definitive evidence of this method's superiority over other surgical methods. Nonetheless, our report does provide comprehensive preoperative measures for comparison with postoperative results, affording a more substantial assessment of outcome, and does document favourable MHQ scores with statistically significant gains in function, alleviation of pain, and patient satisfaction. Moreover, compared with a thorough systematic review of ten clinical studies of 4CA, resultant grip strength, wrist mobility, and pain relief in our series are equivalent to, or supersede, the outcome reported by others (Mulford et al., 2009; Saltzman et al., 2015).

Although the optimal method of 4CA remains controversial, this study of a relatively large cohort of patients indicates that usage of the en bloc scaphoid bone graft, coupled with percutaneous K-wire stabilization, is a highly effective, reliable treatment option.

The mean 4.4-year follow-up period is somewhat limited, but affords ample time to evaluate the quality of the fusion, the visibility and integrity of the scaphoid wedge graft, and the mid-term integrity and durability of the radiolunate joint. Notably, expectations of a favourable 'long-term' outcome for 4CA previously have been reported by Ashmead et al. (1994), Bain and Watts (2010), and Minami and coworkers (1999). Despite persistently increased radiocarpal contact areas and pressures, imposed by scaphoid excision with mid-carpal arthrodesis, deterioration of the radiolunate joint has not been a significant finding (Kobza et al., 2003; Scobercea et al., 2009). These authors indicate that a good early result does not decline and that a favourable outcome should persist for at least 11 years postoperatively.

In conclusion, scaphoid structural grafting and K-wire fixation results in a uniformly successful 4CA with a low expectation of complications or revision surgery. For a functionally demanding patient, regardless of age with Stage II collapse deformity and for all with Stage III, this method has demonstrated equally favourable, or superior, functional outcomes compared with other methods with reportedly high rates of success. Advantages of the technique are its readily accessible source of viable bone graft, its minimally invasive internal fixation, and its avoidance of early and potential complications apt to occur with distant bone graft donor sites, allografts, bone graft substitutes, and stabilization with permanent implants.

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