Original Article
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Effectiveness of Percutaneous Pinning of Acute Partial Scapholunate Injury during Volar Locking Plating for Distal Radius Fractures: A Comparative Study of Pinning and Conservative Treatment

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Background: We hypothesized that concurrent temporary fixation of scapholunate ligament (SL) injury during volar locking plate (VLP) fixation of distal radius fractures (DRFs) would improve restoration outcomes based on both radiological and clinical results. Here, we performed a prospective, comparative study investigating the effectiveness of temporary percutaneous reduction/pinning during VLP fixation in DRFs.

Methods: The first 43 consecutive SL injuries were treated concurrently after VLP fixation by closed pinning (group 1); the next 36 consecutive injuries were treated nonoperatively (group 2). Patients were followed up for at least 5 years after treatment. Basic demographic data, radiological measurements, arthroscopic findings of SL injury, and other clinical outcomes were evaluated.

Results: The mean follow-up period was 7.2 years. No significant differences in basic demographic data were evident between groups. Fracture patterns were not distinctively different between groups. The initial scapholunate angle measured immediately after surgery was 23° ± 3° in group 1 and 38° ± 13° in group 2, indicating a significantly hyperextended scaphoid position in group 1. The final scapholunate angles were also significantly different between groups although the final angle in group 2 (58° ± 11°) was within normal limits. Final visual analog scale scores, Disabilities of the Arm, Shoulder and Hand scores, Gartland and Werley system scores, and wrist motions were not different between groups; however, grip strength at the time of final follow-up was closer to that of the contralateral uninjured wrist in group 1. Arthrosis was less advanced in group 1.

Conclusions: Temporary fixation for SL injury with a DRF can be an effective option for the maintenance of scapholunate angle. The non-fixed group exhibited a more pronounced collapse of the scapholunate angle although the angle was still within normal limits, and clinical outcomes were similar between groups regardless of the fixation status.

Keywords: *Radius, Fracture, Scapholunate ligament, Arthroscopy*

An acute partial scapholunate ligament (SL) injury is commonly observed in a distal radius fracture (DRF). The concurrent incidence has been reported to range from 4.6% to 30% in some studies.[1,2] This type of injury cannot be diagnosed easily by simple radiography. Scapholunate dissociation is not obvious on plain radiographs for approximately 3–12 months. Rarely, volar flexion of the scaphoid, seen as a ring pole, is distinct before reduction of the dorsally displaced radius, suggesting an SL injury; however, it can be restored immediately after reduction of the DRF. With the development of new arthroscopic inspection methods and procedures for wrist injuries, SL ruptures have been linked to

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DRFs in relatively young patients with high-energy injuries.[3-6)]

A variety of volar locking plate (VLP) systems for DRFs have been introduced over the past two decades, with a majority of DRFs, including intra-articular fractures, now being treated using these plates. Among the benefits of VLPs, early motion after surgery is the most important, which facilitates an increased range of motion and improved functional abilities (e.g., grip strength), as no persistent changes have been observed after more than 2 years.[7)] Cases where scapholunate diastases can be definitively diagnosed by radiography are typically managed using methods, such as closed fixation or open repair, based on the preference of the treating surgeon.[8)] However, subtle or neglected SL injuries have a lower likelihood of healing after any type of surgical fixation for the radius alone.

Based on these observations, we hypothesized that concurrent temporary fixation for partial SL injuries during VLP fixation of distal radial fractures (DRFs) would improve restoration outcomes based on radiological and clinical results.[9,10)] We performed a prospective, comparative study investigating the effectiveness of temporary percutaneous reduction/pinning during VLP fixation in DRFs.

METHODS

Patient Selection

From February 2010 to March 2014, we prospectively followed up DRFs with SL injuries. We conducted this study in compliance with the principles of the Declaration of Helsinki. The protocol of this study was reviewed and approved by the Institutional Review Board of Chungnam National University Hospital (IRB No. 2016-05-003). Written informed consents were obtained prior to treatment.

Patients were included if they met the following criteria: (1) DRF treated by VLP fixation, (2) arthroscopic evidence of typical SL injuries after volar plating, (3) availability of complete medical records and radiologic data, and (4) postoperative follow-up period of at least 5 years. The indications for VLP fixation were fractures with post-reduction (1) radial intra-articular shortening greater than 3 mm, (2) dorsal tilt greater than 10°, or (3) intra-articular displacement or step-off greater than 2 mm.[11)]

We excluded patients with the following characteristics: (1) treated by a dorsal approach due to irreducible intra-articular fragment, (2) concurrent arthroscopic findings of lunotriquetral ligament injury or traumatic triangular fibrocartilage complex tear requiring surgical repair, (3) any concurrent carpal fractures or perilunate dislocation, (4) previous SL injuries or chronic lesions of SL identified by arthroscopy, (5) other ipsilateral upper extremity injuries, (6) worker's compensation coverage, (7) multiple medical comorbidities, (8) open fracture including neurovascular injuries, (9) history of previous wrist surgery, (10) presence of arthritic changes in the radiocarpal and distal radioulnar joint at the time of surgery, or (11) concomitant ulnar fracture (styloid base or ulnar head). Among a total of 224 patients with DRFs, 92 patients were initially enrolled and 13 were lost to follow-up. Thus, 43 consecutive SL injuries, treated concurrently by closed pinning using Kirschner wires (K-wires; group 1 [fixation group]) and the next 36 consecutive injuries, treated nonoperatively (group 2 [non-fixation group]), were investigated (Fig. 1).

Surgical Technique

All surgical procedures were performed by a single hand surgeon (SMC). In groups 1 and 2, 37 and 28 patients, respectively, received a brachial plexus block, while the remaining patients in each group received general anesthesia and an upper arm tourniquet. The distal part of the radius was exposed through a volar approach. A DVR anatomic plate (Biomet, Warsaw, IN, USA) was used in 59 patients (35 patients in group 1 and 24 patients in group 2). A volar angle-stable plate (Aptus Radius; Medartis, Basel, Switzerland) was used in 20 patients (8 patients in group 1 and 12 patients in group 2). In 6 patients (3 patients in group 1 and 3 in group 2), arthroscopically assisted fragment reduction and K-wire fixation were performed in addition to VLP fixation. After treatment of DRFs, we performed arthroscopic examination in all patients. For diagnosis of acute SL injuries by arthroscopy, we attempted to hyperextend the scaphoid. Using the joystick technique, percutaneous temporary scapholunate fixation

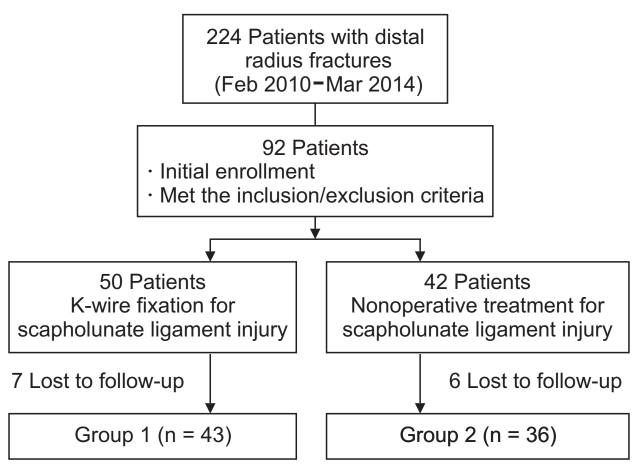

Fig. 1. Flowchart of the study. K-wire: Kirschner wire.

was performed using two 1.4-mm K-wires; congruency between the scaphoid and lunate was inspected under arthroscopic view at the midcarpal portal (Figs. 2-4). On the other hand, we just diagnosed SL injuries, without pinning, in group 2. In group 1, the wrist was immobilized in a short arm splint after surgery. Active range of motion of the digits was started immediately. Two weeks after surgery, the sutures were removed, and the wrist was placed in a removable splint for another 2 weeks. At that time, physiotherapy with active and passive wrist mobilization out of the splint began. Extruded K-wires were removed at postoperative 6 weeks. In group 2, the intraoperative long arm splint was maintained for 4 weeks with the forearm in neutral rotation.

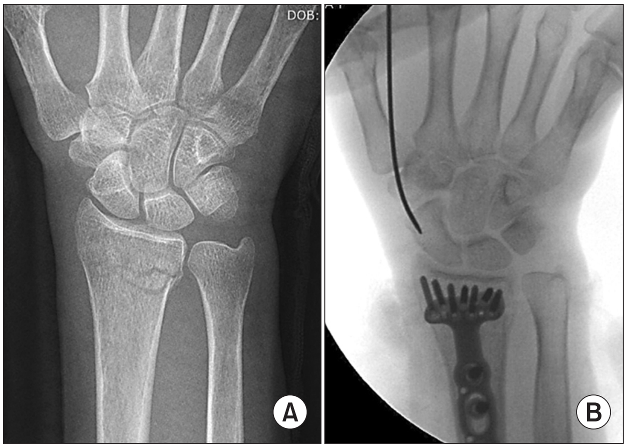

Fig. 2. (A) Before reduction. (B) Manual reduction of the scaphoid by a Kirschner wire (K-wire) before temporary fixation of scapholunate ligament injury.

Patient Demographics

The following patient demographics were evaluated: age, sex, dominance of the injured wrist, and bone mineral density (BMD). BMD was measured using dual X-ray absorptiometry with Lunar Prodigy enCORE software ver. 8.8 (GE Medical Systems, Milwaukee, WI, USA) at the last outpatient visit just before the surgery. The lowest T scores of the proximal part of the femur (except for the value for the Ward triangle) and the lumbar spine were averaged and recorded as BMD. DRFs were classified using the AO classification system. Arthroscopic SL injuries were classified using a modified Geissler classification.[5] SL injuries were classified as partial if there was a hematoma (grade 1) and/or a loss of collagen continuity (grade 2), as determined using a probe. More complete injuries (grades 3–4) were characterized by a larger step-off in carpal alignment, as observed from the midcarpal joint (Table 1).

Radiologic Evaluations

Radiologic assessments were performed monthly for 3 months after surgery and then every 3 months for 1 year. A final evaluation was conducted at least 5 years post-

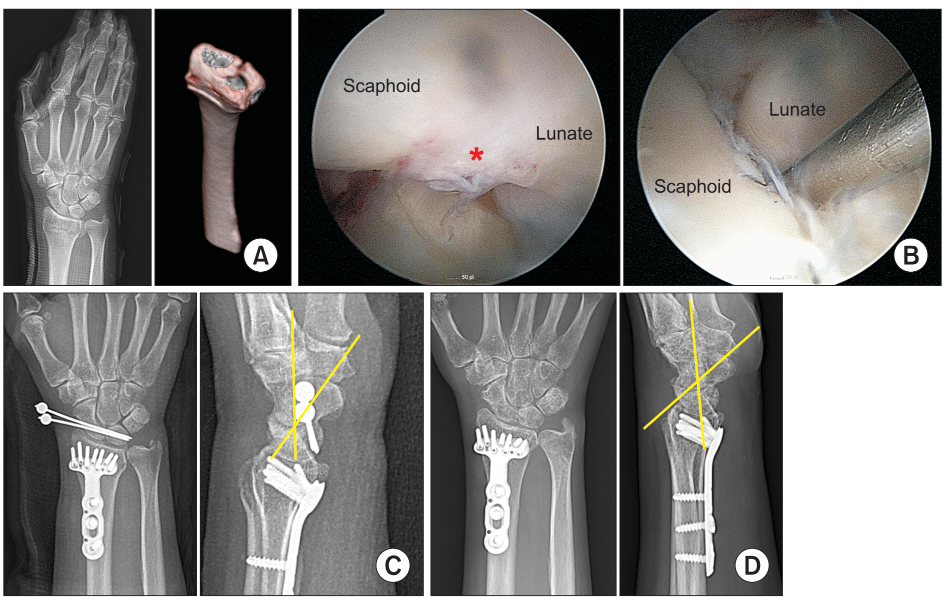

Fig. 3. (A) A 46-year-old woman with an intra-articular type C1 fracture (group 1). (B) After management of a distal radial fracture using volar locking plate fixation, scapholunate ligament injury was diagnosed by arthroscopy (asterisk of left image: 3–4 portal). The Geissler injury grade was 3 (right image: midcarpal radial portal as a viewing portal). (C) Percutaneous K-wire fixation was performed at a scapholunate angle of 35°. (D) At the time of final follow-up (74 months postoperatively), the scapholunate distance was < 2 mm, and the angle was 51°. The arthritis grade was 1.

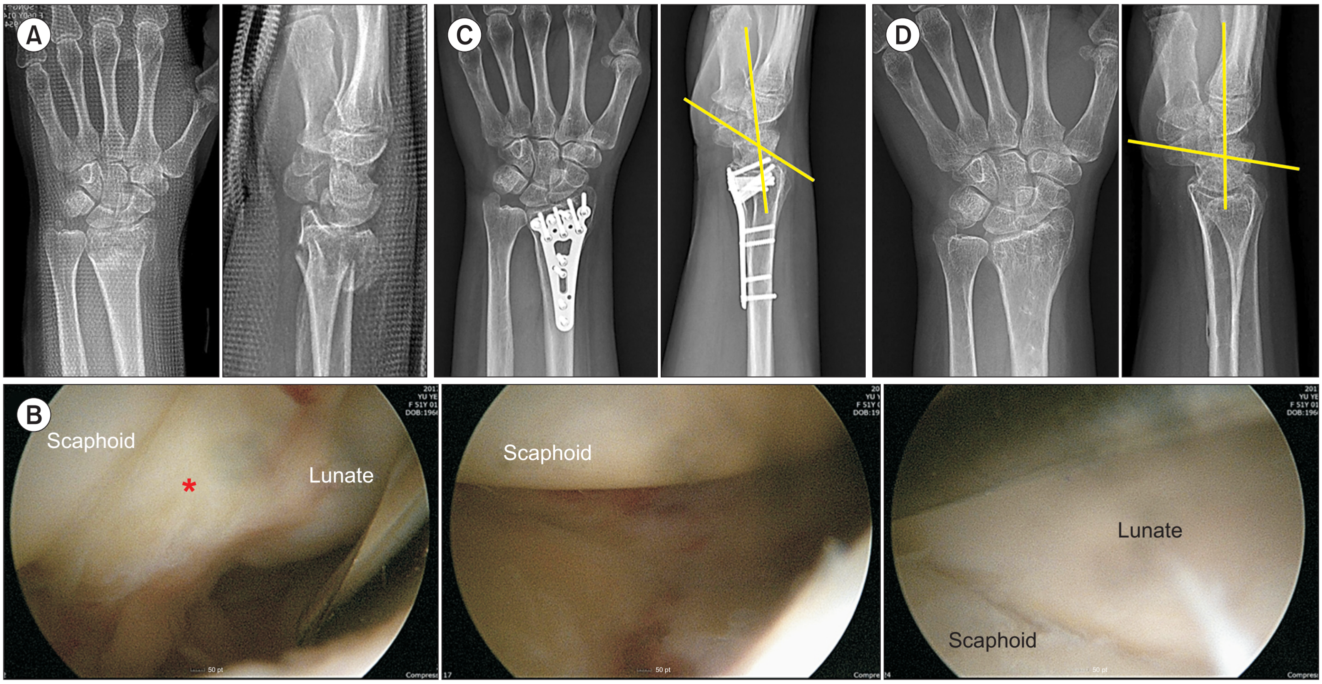

Fig. 4. (A) A 55-year-old patient with an intra-articular type C2 fracture (group 2). (B) After management of a distal radial fracture using volar locking plate (VLP) fixation, scapholunate ligament injury (asterisk) was diagnosed by arthroscopy (left and middle images: 3–4 portal as a viewing portal). The Geissler injury grade was 2 (right image: midcarpal radial portal as a viewing portal). (C) Immediately after VLP, the scapholunate angle was measured at 52°. (D) At the time of final follow-up (80 months postoperatively), the scapholunate distance was < 2 mm, and the angle was 81°. The arthritis grade was 2.

Table 1. A Modified Geissler Score for Scapholunate Ligament Injuries

Grade	Description
1	Attenuation or hemorrhage of interosseous ligament as seen from radiocarpal space. No incongruity of carpal alignment in midcarpal space.
2	Attenuation or hemorrhage of interosseous ligament as seen from radiocarpal space. Incongruity or step-off of carpal space. There may be a slight gap (less than width of probe) between carpal bones.
3	Incongruity or step-off of carpal alignment as seen from both radiocarpal and midcarpal space. Probe may be passed through gap between carpal bones.
4	Incongruity or step-off of carpal alignment as seen from both radiocarpal and midcarpal space. There is gross instability with manipulation. A 2.7-mm arthroscope may be passed through the gap between carpal bones ("drive-through sign").

operatively. The time of bony union and the presence of delayed union or nonunion of the distal radius were evaluated. Radiologic alignment was characterized by measurements of volar tilt, radial inclination, step-off of the distal radius, and ulnar variance using standard measurement techniques.[5] In addition, ulnar variance was evaluated by comparing it with the contralateral ulnar variance. Scapholunate angle was measured on the lateral radiograph, using a line tangent to the volar aspects of the proximal and distal scaphoid poles and another line perpendicular to a tangent of the lunate poles.[12] The scapholunate gap was measured on the posteroanterior radiograph using the midpoints of the opposing scaphoid and lunate surfaces.[13,14] Posttraumatic arthritis was evaluated according to the system of Knirk and Jupiter.[15] Normal findings, slight joint space narrowing, marked joint space narrowing with an osteophyte, and bone-on-bone with osteophyte/cyst formation were regarded as grades 0, 1, 2, and 3, respectively. Radiologic evaluations were performed by two orthopedic surgeons (HDS and BKA) other than the surgeon who performed the surgery, and each radiograph was re-evaluated 1 day later by both surgeons.

Inter- and Intraobserver Reliability of Radiologic Measurements

Intraclass correlation coefficients of continuous variables served as indices of inter- and intraobserver repeatability.[16] Kappa values were calculated for categorical variables such as classification.[17] Fleiss and Cohen[17] considered kappa values > 0.75 as excellent, 0.40–0.75 as good, and < 0.40 as poor.

Evaluation of Clinical Outcomes

Functional outcomes were evaluated at the time of final follow-up (at least 5 years postoperatively). Data were collected by an independent observer (an orthopedic surgeon, IHG) who was not an author of this study. Clinical outcomes were compared between groups using a visual analog scale (VAS) score for postoperative pain, Disabilities of the Arm, Shoulder and Hand (DASH) scores, the demerit system of Gartland and Werley[18] as modified by Sarmiento,[19] the range of active wrist motion, and grip strength. Active motion of the wrist joint was measured using a standardized technique, in which a goniometer was placed dorsally and laterally. The final functional result was rated according to the demerit system of Gartland and Werley[18] as modified by Sarmiento.[19] Grip strength was measured with a Jamar hydraulic hand dynamometer (Sammons Preston/Ability One, Germantown, WI, USA). Impairment was expressed as a ratio (%) between the affected and unaffected regions.

Statistical Analysis

We prospectively evaluated patients using a two-sided significance level of 0.05 and a power of 80%. Sample size was calculated to detect significant differences of primary outcome (scapholunate angle, 15°).[20] For the scapholunate angle (primary outcome), a minimum of 29 patients, which was the largest sample size among all outcomes, was required to satisfy the condition of 80% power, assuming up to 20% loss to follow-up and 15° difference between groups. Differences in continuous variables were analyzed by independent samples *t*-test or the Welch-Aspin test. Categorical variables were investigated by Fisher's exact test or chi-square test. The correlations of the fracture pattern with arthritis grade were analyzed using linear-by-linear association. Analysis of radiologic measurements relative to the contralateral side were performed by paired samples *t*-test. Data were analyzed using SPSS ver. 22.0 (IBM Corp., Armonk, NY, USA). A p-value < 0.05 was considered statistically significant.

RESULTS

The following patient characteristics were similar in the two groups: age, sex, wrist dominance, fracture patterns, mean T-score of BMD, and SL injury classification (Table 2). The mean follow-up period was 85 ± 16 months and 88 ± 11 months for groups 1 and 2, respectively. All radii showed union at a mean of 11 ± 4 weeks, with no cases of delayed union or nonunion.

Arthroscopic severity grades were similar between groups (Table 2). The initial scapholunate angle upon completion of surgery was 23° ± 3° and 38° ± 13° in groups 1 and 2, respectively, due to the hyperextended scaphoid position in group 1. The final scapholunate angle at the time of follow-up was also significantly different between the two groups (39° ± 8° for group 1 vs. 58° ± 11° for group 2); however, the final angles in group 2 patients were within the normal limits. Final VAS, DASH, and Gartland and Werley system scores did not differ between the groups. Wrist motion also did not significantly differ between the groups. However, grip strength at the final follow-up in group 1 was closer to that of the contralateral uninjured wrist, compared to grip strength in group 2 (85% ± 5% vs. 80% ± 7%, respectively; $p < 0.01$). Radiological parameters for radial fractures were similar between groups (Table 3). Complications associated with initial injury/surgical treatment such as infection (superficial and osteomyelitis), tendon rupture (including delayed rupture), soft-tissue dehiscence, and permanent numbness or hyperesthesia (including allodynia) were not seen.

In terms of arthritis grade, the inter- and intraobserver mean repeatability coefficients were 0.94 and 0.92, respectively; the coefficients for measurements of postoperative scapholunate angle/distance, final scapholunate angle/distance, volar tilt, radial inclination, step-off, and ulnar variance were all satisfactory ($p > 0.75$).

DISCUSSION

We found that definitive SL injuries were somewhat common but could not be easily detected during ordinary surgery based on radiological examination alone, including computed tomography scans. Furthermore, our results revealed that the scapholunate angle increased gradually, regardless of fixation. The SL injury was routinely observed in the joint cavity and the ligament was lined with synovium, indicating that the injured and weakened SL would have relatively low likelihood of healing, relative to other ligaments. Therefore, although the percutaneous closed method offers only a temporary reduction of the scapholunate joint, fixation would increase the window during which the SL can heal, while limiting volar flexion of the scaphoid, relative to splinting or casting. In our fixation group, the scapholunate angles were slightly reduced

Table 2. Patient Demographics

Variable	Group 1 (n = 43)	Group 2 (n = 36)	*p*-value
Age (yr)	53 ± 7	54 ± 7	0.29
Sex (male : female)	5 : 38	5 : 31	0.99
Wrist dominance (dominant : nondominant)	18 : 25	18 : 18	0.5
AO classification			0.96
A2	8	7	
A3	12	11	
B2	1	2	
B3	2	2	
C1	8	7	
C2	9	6	
C3	3	1	
Mean T score	–1 ± 1	–2 ± 1	0.07
Follow-up period (mo)	85 ± 16	88 ± 11	0.44
Geissler classification			0.99
2	24	20	
3	19	16	

Values are presented as mean ± standard deviation.
Group 1: Kirschner wire fixation group for scapholunate ligament injury, Group 2: nonoperative treatment group for scapholunate ligament injury.

at the time of final follow-up from their initial fixed position; however, the angles remained within the normal range.

Radiologic diagnosis of SL injuries in the context of DRFs can be challenging, even when combined with adequate medical history and proficient clinical assessment of tenderness over the dorsal aspect of the scapholunate articulation.[3-6,19] Radiologic and clinical criteria for the diagnosis of SL injuries have both been extensively described.[21] Despite these well-defined criteria, significant differences among institutions and a lack of consensus on the treatment of SL injuries persist.[22] Differences in rates of operative treatment of SL injuries may be due to the use of different criteria for radiologic diagnosis,[23-26] differences in patients' mean age among studies, and patient preference. The stark contrast in diagnosis was best described by Ozkan et al.[27], who found that radiologists diagnosed SL injuries in 200 out of 2,923 patients who underwent open reduction and internal fixation for their DRFs, whereas the surgeons treating these patients only identified 4 cases. In the current study, we identified and followed up 79 "pure" SL injury patients (35%) who met all inclusion/exclusion criteria among a total of 224 patients with DRFs. As suggested in previous studies, we regarded arthroscopic diagnosis as the definitive method for identifying an SL injury.[3,28,29)]

The need for additional surgical repair of partial SL injuries in DRFs remains controversial. First, cadaveric studies have already demonstrated that for scapholunate diastasis to manifest, several ligamentous injuries have to occur at the same time[30] and that an increased scapholunate distance and altered carpal relationships do not necessarily indicate pathology.[31] Since an SL injury in the setting of a DRF does not always lead to carpal malalignment, not every SLI requires treatment. Second, as the treatment of DRFs is now predominantly VLP fixation, restoration of the anatomy of the radius is likely to have a positive influence on the carpus and its intercarpal relationships.

In presenting these findings, it is important to emphasize that partial SL injuries identified under an arthroscopic view exhibited significant heterogeneity. Dorsally displaced extra-articular DRFs showed obvious signs of SL injuries and definitive scapholunate diastasis before reduction of the fracture. However, following VLP reduc-

Table 3. Final Radiologic and Clinical Outcomes

Variable	Group 1 (n = 43)	Group 2 (n = 36)	*p*-value
Radiologic parameter of scapholunate			
Postoperative scapholunate angle (°)	23 ± 3	38 ± 13	< 0.01
Postoperative scapholunate distance (mm)	2 ± 0	2 ± 0	0.28
Final scapholunate angle (°)	39 ± 8	58 ± 11	< 0.01
Final scapholunate distance (mm)	2 ± 0	2 ± 0	0.34
Functional score			
Final pain score on VAS	0 ± 1	1 ± 1	0.59
Final DASH score	7 ± 3	8 ± 2	0.49
Gartland and Werley system (Sarmiento's modification)	3 ± 1	3 ± 1	0.19
Grip strength ratio to contralateral side (%)	85 ± 5	80 ± 7	< 0.01
Final active range of motion (°)			
Flexion	50 ± 12	50 ± 11	0.95
Extension	61 ± 10	60 ± 10	0.82
Radial deviation	18 ± 4	18 ± 4	0.58
Ulnar deviation	21 ± 8	23 ± 8	0.22
Radiologic parameter of radial fractures			
Volar tilt (°)	9 ± 3	9 ± 3	0.8
Radial inclination (°)	19 ± 2	19 ± 3	0.64
Step-off (mm)	0 ± 1	0 ± 1	0.81
Ulnar variance (mm)	0 ± 1	0 ± 1	0.31
Grade of arthrosis			< 0.01
0	37	19	
1	4	9	
2	2	8	

Values are presented as mean ± standard deviation.
Group 1: Kirschner wire fixation group for scapholunate ligament injury, Group 2: nonoperative treatment group for scapholunate ligament injury, VAS: visual analog scale, DASH: Disabilities of the Arm, Shoulder and Hand.

tion, radiologic analyses showed significantly improved scapholunate articulation, with extra-articular DRFs showing less aggravated scapholunate angles during follow-up in both groups. The treatment options for partial SL injuries are arthroscopic debridement or thermal shrinkage, pinning or physiotherapy with re-education of the flexor carpi radialis. It is clinically difficult to treat SL ruptures and the results are inconsistent.[32,33] Even if an SL injury is diagnosed acutely, the ligament remnants are often short and retracted, making it difficult to reattach the ends. The SL complex is also exposed to great tension and torsion and must be able to sustain great loads. Because of these factors, it is not unusual for SL repairs to deteriorate with time. Based on all the available evidence, the best treatment for an SL injury seems to be early surgical intervention, performed directly when the diagnosis is made. This will provide the best opportunity to restore the anatomy and prevent unfavorable attritional changes in the SL and the secondary stabilizers of the wrist. The dorsal SL plays a very important role in the stabilization of the loaded carpus, but its importance should not be overemphasized. In low-demand patients, good status of the secondary stabilizers with compensatory effects from the adjacent capsule-ligamentous structures and the dynamic strength of specific muscles may sometimes effectively ensure good carpal stability, at least for some years.[34)]

Over time, chronic scapholunate instability may progress to scapholunate advanced collapse (SLAC), a debilitating condition that can limit daily activities. In our study, grade 2 or 3 arthritis findings[14)] were different to the typical SLAC pattern, with scapholunate diastases > 3–4 mm being largely absent. The mean follow-up period of this study was 7 years, which is typically not long enough to observe progression to SLAC lesions. Clinical outcomes including DASH, the demerit system of Gartland and Werley (as modified by Sarmiento), range of wrist motions, and grip strength were not significantly different between the groups, giving rise to two overarching hypotheses. First, longer follow-up times (> 10 years) would reveal any differences in clinical outcomes associated with SL injury treatment. Second, the outcome analysis may have been influenced by the elderly population enrolled in this study. A properly healed radius is generally sufficient to meet the lower day-to-day demands of older patients. Clinical outcomes may, therefore, not be reflective of the radiologic differences seen between our patient groups.

There were several limitations to this study. First, a randomized design was not employed due to the nature of the study; during the final evaluation of clinical outcomes, the scar made by percutaneous pinning immediately distal to the radial styloid process was indicative of enrollment in the fixation group. Also, postoperative radiologic evaluations were not performed by individuals blinded to the variables. Second, even though the overall radiologic outcomes of DRFs were satisfactory in both groups, individual differences in clinical outcomes were more strongly influenced by DRFs than SL injuries. A few patients were not aware of having an SL injury, despite providing informed consent and receiving a full explanation preoperatively. Thus, the number of concurrent SL injuries, as a clinical outcome, could not be accurately determined. There were technical difficulties in accurate measurement of the scapholunate angle on lateral radiographs; therefore, an error within a few degrees would be inevitable. Finally, as mentioned previously, a longer follow-up period of at least 10 to 15 years with minimal loss to follow-up will be necessary to fully assess the efficacy of SL fixation.

The present study showed that temporary scapholunate fixation for partial SL injuries in patients with DRFs is an effective method for maintenance of the scapholunate angle. While the non-fixation group revealed a higher rate of collapse of the scapholunate, final clinical outcomes were all satisfactory, regardless of the fixation status.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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