The Outcome of Intra-Articular Distal Radius Fractures Treated With Fragment-Specific Fixation

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Purpose: To assess the clinical, radiographic, and functional outcome of treating intra-articular distal radius fractures with fragment-specific fixation.

Methods: A retrospective review of 81 patients with 85 intra-articular distal radius fractures who were treated with fragment-specific fixation was performed. Minimum time to follow-up evaluation was 1 year, with a mean time of 32 months. The immediate postoperative films were compared with those taken at the final follow-up evaluation. Radiographs of the uninjured wrist were also obtained at the final follow-up evaluation for comparison. Patients were examined for wrist and finger range of motion, deformity, and grip strength, and they completed a standard Disabilities of the Arm, Shoulder, and Hand outcome survey.

Results: According to Gartland and Werley scoring there were 61 excellent and 24 good results. Flexion and extension of the surgically treated wrist at the final follow-up evaluation averaged 85% and 91%, respectively, of the uninjured wrist; grip strength averaged 92% compared with the uninjured side. The average Disabilities of the Arm, Shoulder, and Hand outcome score for the injured wrist was 9. Sixty-two percent of patients achieved a 100° arc of flexion and extension and normal forearm rotation by postoperative week 6. Radiographic alignment was maintained between immediate postoperative and final follow-up films, and there were no cases of symptomatic arthritis at the final follow-up evaluation.

Conclusions: Fragment-specific fixation is a reasonable alternative for treating intra-articular fractures of the distal radius. At final follow-up evaluations, patients had good to excellent results with respect to range of motion, grip strength, radiographic alignment, and satisfaction scores. Stable fixation allowed starting active and passive motion of the wrist without compromising postoperative alignment. (J Hand Surg 2006;31A:1333–1339. Copyright © 20062006 by the American Society for Surgery of the Hand.)

Type of study/level of evidence: Therapeutic IV.

Key words: Distal radius, fracture, fragment-specific fixation.

The management of displaced intra-articular distal radius fractures has most recently focused on restoration of radial length, articular congruity, and palmar tilt.[1–6] A variety of surgical methods have been described to achieve these goals, including external fixation, intrafocal pinning, limited open reduction methods with bone graft, and formal open approaches using a variety of buttress-style plates.[1,3–5,7–15] Precise restoration of the distal radius bony geometry has become a greater priority in maximizing both the short- and long-term functional outcomes for these patients. There has also been a growing emphasis on minimizing postoperative immobilization to reduce injury-related stiffness and to shorten the overall recovery period.

The fragment-specific approach uses metal pins and plates that are shaped to exactly fit the normal contours of the distal radius. Despite their small size, the fragment-specific implants are designed to withstand the forces of immediate wrist motion and are

intended to be used as part of an early wrist motion program after surgery.[16,17] The implants are designed to achieve very precise reduction and stabilization of even severely comminuted articular fractures without encroaching on adjacent joints or tendons.

A small series of patients with intra-articular and extra-articular distal radius fractures treated with fragment-specific fixation has been reported with good results by Konrath and Bahler.[18] Complications included radial sensory nerve paresthesias in 29% and a repeat surgery rate of 18%. The high complication rate reported in that series has not been our experience and may be due to the study's small patient population. Our study is a considerably larger review, has a longer follow-up period, and focuses exclusively on intra-articular distal radius fractures. A larger study would more precisely reflect complication rates and functional and satisfaction outcomes. This study and the one by Konrath and Bahler[18] are the only 2 papers in the literature to date that specifically examine the outcome of fragment-specific fixation for the treatment of intra-articular distal radius fractures.

The purpose of this article is to assess the clinical, radiographic, and functional outcome of treating intra-articular distal radius fractures with fragment-specific fixation.

Materials and Methods

One hundred sixteen consecutive patients who had fragment-specific fixation for unstable intra-articular distal radius fractures were identified as the study population and were contacted by the investigators. Of these, 81 patients with 85 distal radius fractures were available to participate in this study. Two patients had external fixation performed at another institution before presentation. All remaining patients had a preliminary closed reduction and immobilization. Indications for surgical treatment included radial shortening of equal to or greater than 5 mm, articular incongruity or diastasis equal to or greater than 2 mm, and loss of palmar tilt of more than 20°. All surgery was performed by a single surgeon (LSB) who initially had no experience with the fragment-specific fixation system (Trimed Inc., Valencia, CA). All patients completed a postoperative course of treatment until discharge from care at an average of 6 months. Study participants were asked to return to a clinic setting for a final examination by the senior author (LSB) where they were interviewed and examined. The average time to final follow-up evaluation for the study population was 32 months (range, 12–55 mo). A retrospective review, conducted by authors (KPM and LDS) who did not perform the surgery, was performed for each patient's treatment course, and data were collected from patients' charts and radiographs. Before engaging in this study, approval was obtained from our hospital's Institutional Review Board.

Of the 81 patients who participated in the study, there were 23 men and 58 women with a mean age of 50 years (range, 17–79 y). Injury and intraoperative radiographs were used to classify the fractures according to Muller et al.[19] There were 8 B2, 1 B3, 31 C1, 27 C2, and 18 C3 fractures. All fractures were closed. The mechanism of injury was a fall in 81 patients, a motor vehicle collision in 3, and an assault in 1. The injury was work related in 7 patients. Associated injuries occurred in 8 patients and included an elbow dislocation, a closed head injury, and fractures of the metacarpals, scaphoid (2), radial shaft, radial neck, ankle, femur, and pelvis. Three patients had bilateral injury and were right hand dominant. One patient had a staged bilateral injury because she had sustained a contralateral injury 2 years after her initial repair. Of the remaining 77 unilateral fractures, 45 involved the right wrist (41 dominant, 5 nondominant) and 32 involved the left wrist (40 dominant, 5 nondominant). Three patients smoked at least a half pack per day.

The average time between injury and surgery was 9 ± 6 days. Surgical time was 93 ± 24 minutes. Demineralized bone matrix was used in 50 cases, and freeze-dried cancellous chips were used in 15 cases. No patients received external fixation. All patients were entered into a formal hand therapy program after surgery, and range-of-motion data were also collected from occupational therapy records.

Radiographic Evaluation

Orthogonal radiographs of both wrists were obtained at the final follow-up evaluation, and the following radiographic parameters were measured: volar tilt, radial inclination, ulnar variance, and articular congruity. The immediate postoperative radiographs of the injured extremity were also reviewed and compared with the final follow-up radiographs to assess for continued reduction. In addition, the final radiographs of the injured wrist were compared with those of the noninjured wrist.

Clinical Outcome

At the final follow-up evaluation the physical examination included bilateral range-of-motion and grip-

strength measurements. Patients completed a Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire. Functional outcomes were also determined using the method described by Gartland and Werley.[8] Each patient's medical record and examination at the final follow-up evaluation were used to identify cases of hardware removal, other hardware-related complications, nerve-related complaints, and any cases of postoperative infection. Return-to-work data were also collected.

Clinical characteristics including patient age, gender, hand dominance, smoking history, fracture classification, time to surgery, intraoperative time, postoperative motion, and the presence of a complication were examined to determine if there were any predicting factors of a worse outcome. These data were collected by reviewing each patient's medical records and through the interview and examination process at the final follow-up evaluation.

Statistical Analysis

Patients' clinical characteristics (age, gender, hand dominance, smoking history, fracture classification, time to surgery, intraoperative time, postoperative motion, and the presence of a complication) and the radiologic parameters of the fractures were described using means and SDs for continuous variables and frequencies for categoric variables. Postoperative radiographic parameters and DASH scores were analyzed with linear regression models. Log transformations of DASH scores and extension and flexion motion were used because the original data did not satisfy the normality assumption. Comparisons of radiographic parameters were performed between the immediate and final follow-up evaluations and between the injured and noninjured sides within each patient. Mixed-effects models with a random effect for patient were used for these analyses because of the clustering of outcomes within patient to account for both interperson and intraperson variability. The association of the predictors with the outcomes in all the linear regression models was first assessed by using univariate models as a data reduction tool. Predictors were considered significant at p less than 0.2 and were included in the final predictive models. The Gartland-Werley score had a value of either 1 or 2, and logistic regression models were used to determine predictors. With 24 of the 85 fractures scoring 2, the score statistic was used to determine the best 2-predictor model. Statistical analyses were conducted using software (SAS version 9.1, SAS Institute Inc., Cary, NC). Results were considered significant at p less than .05.

Surgical Technique

The surgical procedure was consistent for all radius fractures in this study, although the exact size and number of metal implants depended on the nuances of each fracture and the preference of the treating surgeon. Our surgical technique was similar to previously described methods for using fragment-specific fixation.[20–21]

The immediate postoperative dressing was a bulky compressive bandage that incorporated a forearm-based plaster splint. The first 15 wrists were immobilized with a forearm-based splint for 2 weeks. The next 5 wrists were immobilized for 10 days, and after patient number 20, the remaining 61 patients were seen in the office on postoperative day 3 for bandage removal and commencement of active and passive wrist motion. Formal hand therapy supervision was started coincident with the first dressing change. Seventy-six percent of our patients started a hand motion program by postoperative day 3.

Results

Radiographic Evaluation

Comparison between immediate postoperative radiographs and those taken at final follow-up evaluation showed no significant change in alignment for the radiographic parameters measured (Table 1). Articular step-off for the surgically treated wrists at the final follow-up evaluation averaged 0 mm. For the radiographs taken at the final follow-up evaluation of the injured and noninjured wrists (Table 2), there was no significant difference for radial inclination and radial height. The injured wrists on average had 4° less of palmar inclination and were 1.2 mm more ulnar positive compared with the uninjured wrists.

Table 1. Injured Radiographic Parameter Comparison

Parameter	Injured Wrist After Surgery	Injured Wrist at Final Follow-Up Evaluation	p
Volar tilt, °	7 ± 9	9 ± 7	.10
Radial inclination, °	24 ± 5	25 ± 6	.13
Radial height, mm	11.20 ± 2.50	12.00 ± 2.80	.24
Ulnar variance, mm	0.11 ± 2.10	0.80 ± 2.30	.09

Table 2. Final Follow-Up Radiographic Parameters Comparison

Parameter	Injured Wrist at Final Follow-Up Evaluation	Noninjured Wrist at Final Follow-Up Evaluation	p
Volar tilt, °	9 ± 7	13 ± 6	.02
Radial inclination, °	25 ± 6	26 ± 3	.34
Radial height, mm	12.0 ± 2.8	12.3 ± 1.9	.36
Ulnar variance, mm	0.8 ± 2.3	−0.4 ± 1.4	.01

This difference can be attributed to the reduction obtained during surgery, because the radiographic alignment was maintained at the follow-up evaluation. Evaluating degenerative changes according to Knirk and Jupiter[2] showed 12 wrists with grade I changes of mildly decreased joint space.

Clinical Outcome

The presence of a complication was a predictor for a worse outcome, as indicated by a higher DASH score ($p = .03$). Age at surgery was a significant predictor of wrist motion at the follow-up evaluation, with younger patients obtaining a greater percentage of wrist flexion. ($p = .001$). None of the other parameters were predictors for outcome scores or motion.

Postoperative range-of-motion data indicated that 52 patients (62%) regained a 100° arc of motion in flexion and extension by postoperative week 6. These patients also had normal finger motion and near-full pronation and supination. At the final follow-up evaluation, patients had obtained 91% of wrist extension (mean, 69° ± 11°) and 85% of flexion (mean, 60° ± 11°) in the injured wrist compared with the uninjured wrist. Grip strength measured with a dynamometer averaged 92% of the contralateral side in patients with unilateral injury. All patients had normal finger motion and were able to flex to touch the fingertips to the distal palmar crease. The DASH scores averaged 9 (range, 0–40). According to Gartland and Werley[8] scoring there were 61 excellent and 24 good results. Thirty-six patients were employed at the time of injury. Patients with isolated distal radius fractures that were not work related returned to work at an average of 4 weeks. The average time to return for work-related injuries was 21 weeks.

Complications included hardware removal requiring a second surgical procedure in 5 patients. The reason for hardware removal was pain in the area of either a radial styloid or dorsal plate. Pain resolution occurred in all patients who had plate removal. Plates did not appear to be blocking wrist motion in any of these repeat-surgery patients. The most common scenario for plate removal was irritation of the skin or first extensor tendon compartment at the radial styloid area. Plates were removed between 8 and 32 weeks after the initial procedure, at an average of 15 weeks. In 1 of these patients the hardware removal was combined with a distal ulnar resection at 5 months after the initial procedure. The patient had considerably limited and painful rotation of the forearm before the distal ulna resection, which improved the rotational arc to within 10° of the rotational arc of the contralateral side.

Three patients required removal of loose K-wires, which was accomplished in the office setting. One of these represented a loose dorsal K-wire; the remaining 2 patients had radial styloid wires that were backing out. None of the patients who required hardware removal of any sort sustained change in fracture alignment. After plate removal in the operating room, wrists were immobilized for an additional 5 days. One patient had backing out of a radial pin but was not symptomatic and required no treatment.

Ten patients reported radial sensory numbness or paresthesias, which diminished over the first 3 months after surgery. None of these patients required any additional surgery to address this issue, although in 5 patients the use of oral or topical gabapentin (Neurontin, Pfizer, New York) for a period of 4 to 8 weeks seemed to greatly diminish discomfort in the radial sensory distribution. The affected area was consistently located in the skin overlying the thumb carpometacarpal region and radial styloid. At the final follow-up evaluations resolution had occurred in all but 2 patients, whose numbness in this area did not affect wrist function.

There were no wound infections, but antibiotics were given to the 2 patients who were initially treated with external fixation. In 2 cases, additional immobilization of the wrist was required to allow for considerable swelling to diminish. One patient developed a large postoperative hematoma due to the use of anticoagulant medication during the perioperative period that required 2 weeks of unplanned wrist immobilization to protect the soft tissues during resolution of the hematoma.

Discussion

The fragment-specific approach is based on an anatomic approach to reduction of the fractured distal radius. It depends on identification of distal radius fracture pieces that are commonly present—specifi-

cally the radial styloid, ulnar corner, dorsal wall, and palmar rim.[21,23] Although elements of this terminology are similar to previous classification systems,[3,8,9,24] the fragment-specific nomenclature focuses attention on the practical geometry of the fracture and the selection of specific metal implants that are required to achieve reduction and rigid fixation. The use of 1.4-mm (0.045-in) K-wires, an integral part of the fragment-specific approach, has also been shown by other researchers[25,26] to be a valuable adjunct in the surgical stabilization of intra-articular distal radius fractures. Stabilization of these reproducible fracture segments represents discrete surgical steps in the procedure itinerary, which proceeds in a methodic fashion to accurately reconstruct the distal radius shape and articular relationships. The metal plates and wire forms specifically fit the contour of fracture pieces and thereby allow a surgeon to puzzle the fracture back together.

Our data show that acceptable reductions can be consistently achieved and maintained by using a fragment-specific approach. Palmar tilt averaged within 4° of the unaffected side, and ulnar variance changed on average by 1.2 mm. The average measurements for radial height and inclination angle were within 1 mm and 1°, respectively, of the uninjured side, and articular congruity was unchanged. Although a longer follow-up period may be required to fully assess the development of post-traumatic arthritis in the wrist, our patient population did not develop symptomatic arthritis relating to the fracture.

A more interesting question is whether fragment-specific fixation is a better way to surgically manage distal radius fractures compared with currently available surgical alternatives. Intrafocal pinning, external fixation, and the use of plating systems all have their advocates, and in selected series, outcomes with any of these systems can be excellent. We believe, however, that the results of fragment-specific fixation are consistent and predictable, and the fragment-specific approach allows for almost any fracture pattern in the distal radius. Rather than being designed to address one particular fracture pattern, a fragment-specific approach can be tailored to handle any distal radius fracture, from the unstable extra-articular type to the severely comminuted intra-articular crushing-type injury. Although preoperative imaging certainly aids in predicting the fracture morphology, many fractures will have greater instability at the actual time of surgical exploration, and the versatility of the fragment-specific approach is quite helpful.

Goods results have been reported with volar fixed-angled devices for distal radius fractures, and their use has gained popularity.[15] It has been acknowledged, however, that the stability of comminuted fractures of some distal radius fractures is determined not only by the reduction of the major fragments but also of the smaller fragments.[22] Fragment-specific fixation has been shown in a biomechanic study[17] to better stabilize the ulnar-sided fragment than volar fixed-angle plates. Fragment-specific fixation, however, also allows greater flexibility for the fixation of numerous fracture fragments and patterns.

Even if the final functional, motion, grip, and arthritis outcomes of the fragment-specific approach were ultimately no better than other available alternatives, we believe that a powerful feature of a fragment-specific approach is the ability to pursue early motion. Early motion in our series refers to commencement of unprotected hand use on postoperative day 3. Contrary to our initial reluctance to allow a recently surgically treated patient to actively and passively stress the fracture site, our patients who undertook motion on postoperative day 3 did not have any extraordinary problems with pain or swelling. Although there are no matched controls for these patients, objective measurements of wrist motion showed that most patients were able to obtain quite functional extension and flexion (with almost normal forearm rotation) within the first 6 weeks of surgery. Compared with external fixation, this represents the time at which most patients would have the fixator removed and be just beginning a formal therapy program.

Biomechanic studies have shown that these small implants are able to sustain physiologic loads consistent with early range of motion and were in fact more stable than K-wire–augmented external fixation and volar fixed-angle plating.[16,17] Our study confirms the ability of the implants to maintain reduction of the fracture fragments with early range of motion. Seventy-five percent of our patients started wrist motion on postoperative day 3, and motion at this time did not produce any wound complications.

It should be clearly noted that our data cannot identify early motion (ie, within 3–14 d of surgery) as a reason for good patient outcomes. It is likely that meticulous technique in securing an anatomic reduction and stable fixation may be the core issues that make good outcomes possible. Furthermore, the small sample size of those wrists immobilized for 14 and 10 days after surgery precludes drawing any conclusions about a direct relationship between the exact length of immobilization and outcome. The

practical benefits of being able to use the wrist early after surgery and avoid weeks in a cast or external fixator, however, had a positive—albeit subjective—impact on the patients' recovery courses. Patients were pleased that they could perform activities of daily living so soon after surgery without the restrictions of a cast.

Careful measurement of immediate postoperative and final follow-up radiographs was performed in an effort to determine whether early motion in any way compromised the fracture reduction obtained in the operating room. Statistical analysis of these data suggested that the fracture hardware was strong enough to withstand early stress loading and that fracture alignment was well maintained.

Complications of the fragment-specific approach were primarily limited to issues requiring hardware removal. Although none of our patients sustained extensor tendon ruptures, it is clear that a prominent K-wire or the distal tip of a self-tapping cortical screw can be a source of persistent discomfort and potentially cause a tendon rupture over time. Our rate of hardware removal as a formal second procedure was 6%, and we believe that careful attention to the exact placement of the radial styloid plate will help reduce this number. Furthermore, hardware-related problems including a 3% occurrence of K-wire loosening (requiring office removal) can likely be improved by attending to the details of proper pin and screw length selection and meticulous bending of the K-wires as they are terminally inserted into the distal pin-plate holes.

With respect to our reported complication rate, it should be noted that more than 25% of our initial study population did not return for follow-up evaluation after discharge from medical care. Consequently, it is possible that the incidence of complications we are reporting here may be lower than the actual proportion, because some patients with complications may have been lost to follow-up study.

One of the 85 surgically treated wrists required distal ulnar resection to address painful forearm rotation. In this case, little to no bone graft was used to support the distal articular and medial corner of the radius, and modest collapse over time at the fracture site necessitated a secondary procedure. We have endorsed more routine use of supportive bone graft (usually cancellous allograft) to help buttress the distal and medial articular margins, especially in osteopenic patients.

Part of the surgical approach to the radius in our patients used a longitudinal incision exposing the radial styloid region and first dorsal compartment. Although a fair number of patients reported some radial sensory numbness or paresthesias in the postoperative period, none of these complaints required subsequent surgical exploration. The affected area was typically a few centimeters in diameter near the base of the thumb, and sensibility alteration in this area usually resolved completely in the first 6 months after injury. We do, however, now routinely explain to patients that swelling or intraoperative traction may produce temporary numbness or discomfort in this area.

Some technical details of the fragment-specific approach warrant discussion. Surgical times are longer than what might be expected for application of an external fixator. Although a surgeon's comfort and facility with this system rapidly improves with experience, the learning curve for this technique is steep, and our patients usually had a general anesthetic in part because of anticipation of potentially much longer procedure times. Even in more experienced hands, a comminuted fracture requiring multiple implants usually requires at least an hour of tourniquet time. Although it seems that the longer surgical time required by the fragment-specific approach is well compensated by the overall shorter recovery time that these patients require, the procedure itself requires meticulous attention to the details of fracture fragment reduction. Use of a fragment-specific approach accomplishes the assembly of severely disorganized periarticular fractures, and as a result, the procedure is characterized by some inherent tweaking or puzzling together of the fracture. Although it has been our experience that the surgical time required for this method is well worth it, the precise handling of tiny fracture segments is a feature of the surgery that may not appeal to every surgeon.

Our experience with fragment-specific fixation suggests that not only can precise articular relationships be restored and maintained but also early wrist motion can be pursued with little risk to the fracture reduction or soft-tissue integrity.

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References

1. Catalano LW III, Cole RJ, Gelberman RH, Evanoff BA, Gilula LA, Borrelli J Jr. Displaced intra-articular fractures of the distal aspect of the radius. Long-term results in young adults after open reduction and internal fixation. J Bone Joint Surg 1997;79A:1290–1301.
2. Knirk JL, Jupiter JB. Intra-articular fractures of the distal end of the radius in young adults. J Bone Joint Surg 1986; 68A:647–659.
3. Missakian ML, Cooney WP, Amadio PC, Glidewell HL. Open reduction and internal fixation for distal radius fractures. J Hand Surg 1992;17A:745–755.
4. Short WH, Palmar AK, Werver FW, Murphy DJ. A biomechanical study of distal radius fractures. J Hand Surg 1987; 12A:529–534.
5. Trumble TE, Schmitt SR, Vedder NB. Factors affecting functional outcome of displaced intra-articular distal radius fractures. J Hand Surg 1994;19A:325–340.
6. Young BT, Rayan GM. Outcome following nonoperative treatment of displaced distal radius fractures in low-demand patients older than 60 years. J Hand Surg 2000;25A:19–28.
7. Cooney WP III, Dobyns JH, Linscheid RL. Complications of Colles' fractures. J Bone Joint Surg 1980;62A:613–619.
8. Gartland JJ Jr, Werley CW. Evaluation of healed Colles' fractures. J Bone Joint Surg 1951;33A:895–907.
9. Jupiter JB, Fenandez DL. Comparative classification for fractures of the distal end of the radius. J Hand Surg 1997; 22A:563–571.
10. Sanders RA, Keppel FL, Waldrop JI. External fixation of distal radius fractures: results and complications. J Hand Surg 1991;16A:385–391.
11. Carter PR, Frederick HA, Laseter GF. Open reduction and internal fixation of unstable distal radius fractures with a low-profile plate: a multicenter study of 73 fractures. J Hand Surg 1998;23A:300–307.
12. Fitoussi F, Ip WY, Chow SP. Treatment of displaced intra-articular fractures of the distal end of the radius with plates. J Bone Joint Surg 1997;79A:1303–1312.
13. Freeland AE, Luber KT. Biomechanics and biology of plate fixation of distal radius fractures. Hand Clin 2005;21:329–339.
14. Jakob M, Rikli DA, Regazzoni P. Fractures of the distal radius treated by internal fixation and early function. A prospective study of 73 consecutive patients. J Bone Joint Surg 2000;82B:340–344.
15. Orbay JL, Fernandez DL. Volar fixed-angle plate fixation for unstable distal radius fractures in the elderly patient. J Hand Surg 2004;29A:96–102.
16. Dodds SD, Cornelissen S, Jossan S, Wolfe SW. A biomechanical comparison of fragment-specific fixation and augmented external fixation for intra-articular distal radius fractures. J Hand Surg 2002;27A:953–964.
17. Taylor KF, Parks BG, Segalman KA. Biomechanical stability of a fixed-angle volar plate versus fragment-specific fixation system: cyclic testing in a C2-type distal radius cadaver fracture model. J Hand Surg 2006;31A:373–381.
18. Konrath GA, Bahler S. Open reduction and internal fixation of unstable distal radius fractures: results using the Trimed fixation system. J Orthop Trauma 2002;16:578–585.
19. Muller ME, Nazarian S, Koch P, Schatzker J. Comprehensive classification of fractures of long bones. Berlin: Springer-Verlag, 1990:106–115.
20. Bae DS, Koris MJ. Fragment-specific internal fixation of distal radius fractures. Hand Clin 2005;21:355–362.
21. Schumer ED, Leslie BM. Fragment-specific fixation of distal radius fractures using the Trimed device. Tech Hand Upper Extrem Surg 2005;9:74–83.
22. Harness NG, Jupiter JB, Orbay JL, Raskin KB, Fernandez DL. Loss of fixation of the volar lunate facet fragment in fractures of the distal part of the radius. J Bone Joint Surg 2004;86A:1900–1908.
23. Swigart CR, Wolfe SW. Limited incision open techniques for distal radius fracture management. Orthop Clin North Am 2001;30:317–327.
24. Melone CP Jr. Articular fractures of the distal radius. Orthop Clin North Am 1984;15:217–236.
25. Dunning CE, Lindsay CS, Bicknell RT, Patterson SD, Johnson JA, King GJ. Supplemental pinning improves the stability of external fixation in distal radius fractures during simulated finger and forearm motion. J Hand Surg 1999;24A: 992–1000.
26. Wolfe SW, Austin G, Lorenze M, Swigart CR, Panjabi MM. A biomechanical comparison of different wrist external fixators with and without K-wire augmentation. J Hand Surg 1999;24A:516–524.