SCIENTIFIC ARTICLE

Fractures of the Distal Radius Treated With Cross-Pin Fixation and a Nonbridging External Fixator, the CPX System: A Preliminary Report

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Purpose To present the preliminary findings of distal radius fractures (DRF) treated with percutaneous cross-pin fixation and a nonbridging external fixator, the Cross-Pin Fixation (CPX) system.

Methods Thirty-five consecutive patients with 37 DRFs were selected from a series of 51 DRFs for closed reduction, percutaneous pinning, and external fixation with the CPX system. Outcome was determined by studying (1) radiological measurements of radial height, palmar tilt, radial inclination and ulnar variance (UV); (2) grip and pinch strength; (3) wrist active range of motion; and (4) patient outcome instruments—the Patient-Rated Wrist Hand Evaluation and the Disabilities of the Arm, Shoulder, and Hand.

Results We are reporting on 21 patients, 13 females and 8 males, mean age 54 years (range, 27 to 87 y) with AO type fractures A2, B2, B3, C1, C2, and C3. Follow-up was a minimum of 1 year (range, 12 to 36 months). Wrist rehabilitation began at a mean of 10 days (range, 4 to 16 d) after surgery. There was no loss of reduction. Final mean grip and lateral pinch strength recovered 86% and 94%, respectively, and active range of motion increased to a minimum of 89% of the noninjured side. Disabilities of the Arm, Shoulder, and Hand showed change in functional status (minimal detectable change at 95% confidence level) at 4 and 12 weeks. The Patient-Rated Wrist Hand Evaluation results reported resumption of usual activities in the early postoperative period. One patient developed type I complex regional pain syndrome, which resolved, and one patient had residual transient mild superficial radial nerve sensitivity. There were no pin track infections, nonunions, or tendon injuries. All patients returned to their prior employment and activities.

Conclusions The CPX system is a minimally invasive technique of closed reduction and internal fixation for displaced, reducible extra-articular and nondisplaced and displaced reducible intra-articular fractures of the distal radius, allowing rehabilitation of the wrist and resumption of usual activities while maintaining fracture reduction. *(J Hand Surg 2009;34A:603–616.*

Type of study/level of evidence Therapeutic IV.

Key words Distal radius fractures, nonbridging external fixator, Cross-Pin fixator system.

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A. M. has partial ownership of AM Surgical, Smithtown, NY, the manufacturer of the CPX system investigated in this study.

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FRACTURES OF THE DISTAL radius are the most common fractures seen in the upper extremity and are of special importance to our aging population, who lead longer active lives.[1–6] These fractures have a tendency to collapse, leading to a loss of radial inclination (RI), radial height (RH), palmar tilt (PT), and a change in ulnar variance (UV).[7–10] Such a collapse often results in physical deformity and loss of function.[11–21] This preliminary report presents a minimally invasive technique for fixation of distal radius fractures (DRFs) that maintains fracture reduction, thereby limiting deformity and loss of function.

Historically, treatment of displaced DRFs involved performing a closed reduction and applying a cast; however, such an approach often does not maintain fracture reduction.[7,22,23] Other methods, including spanning external fixators, carry their own inherent shortcomings, in that ligamentotaxis is used to maintain reduction. Notably, ligamentotaxis does not necessarily maintain reduction in all of the radiological parameters and can lead to stiffness of the finger joints.[7,9,24,25] In addition, ligamentotaxis might not control or maintain PT.[26,27] Separately, over a period of time, the viscoelastic behavior of soft tissues causes spanning external fixators to lose their distractive forces, which can also lead to a loss of reduction.[26,28] Although external fixators have been used with internal fixation techniques, the inherent problems associated with external fixation have not been resolved.[23,26,29,30] Moreover, open reduction and internal fixation (ORIF) with a dorsal or palmar plate requires surgery and soft tissue dissection, which may result in unique problems.[23,31–36]

A minimally invasive technique is conceptually advantageous to open techniques for fracture care, because it eliminates or minimizes soft tissue dissection, postoperative adhesions, a cosmetically unappealing scar, and the concern of residual hardware or hardware removal. Such a technique should be well tolerated by the patient and have a predictable outcome.

We present our findings of DRFs treated with a minimally invasive technique: closed reduction internal fixation with percutaneous, cross K-wire fixation and a nonbridging external fixator device, termed the Cross Pin Fixation (CPX) system (Fig. 1; AM Surgical, Smithtown, NY).

MATERIALS AND METHODS

Between September 2004 and October 2007, 49 consecutive patients with 51 DRFs presented to our office for treatment. Of those, 14 were treated conservatively with casting; 7 were minors, and 7 were adults (AO classification: 4, A2.1; 2, B1.1; and 1, C1.1). The remaining 35 skeletally mature patients with 37 displaced extra-articular or nondisplaced or displaced intra-articular DRFs were treated with closed reduction and application of the CPX system. For this study, 14 patients were excluded; 12 lacked either clinical or radiologic evaluation for a minimum of 12 months, 1 was noncompliant in the early postoperative period, and another with severe osteoporosis, bone loss, and irreducibility had refused open reduction before surgery. In this patient, the CPX system was used with synthetic bone graft.

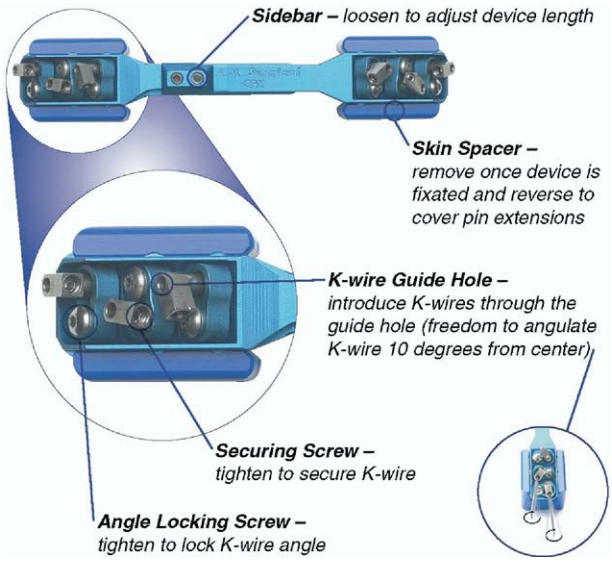

FIGURE 1: The CPX device.

We are reporting on the remaining 21 patients with 21 DRFs (Table 1). There were 13 women and 8 men, mean age 54 years (range, 27 to 87 y) with 12 dominant, 7 nondominant, and 2 mixed dominant-side injuries. Mechanisms of injury included 18 falls, 1 motor vehicle accident, and 2 other acute injuries. Twenty fractures were previously treated in the emergency room. Of these, 6 were splinted without reduction, and 14 had attempted reductions. One patient came directly to us. Initial consultation determined that 9 of the reduced fractures had displaced, 4 had unsatisfactory reductions, and 8 patients presented with displaced DRFs.

This study is a prospective study with the exception of the first 4 patients whose early postoperative period was reviewed retrospectively. The protocol included demographics, radiographic measurements, range of motion (ROM), and grip and pinch strengths, as well as scores from the Patient-Rated Wrist/Hand Evaluation (PRWHE)[37] and Disabilities of the Arm, Shoulder, and Hand (DASH),[38] which were recorded on individual client file forms, using unique assigned client numbers.

The AO classification was used to categorize frac-

tures[39–41] (Table 2). Additional fractures included 10 ulna styloid, 1 comminuted distal ulna, and 1 displaced radial head. Joint congruency of simple and complex intra-articular fractures were assessed by measuring step and gap displacement before and after surgery and on final x-ray examination to the nearest 0.1 mm using an X10 magnifying loupe with an incorporated millimeter scale (B & H Specialties, Syracuse, NY).[42,43]

Radiographic measurements were performed by an independent radiologist using software (Digimizer image analysis software, version 3.4.1; MedCalc Software, Belgium). An independent x-ray technician digitized the preoperative, initial postoperative, and final radiographs, and copied them in their respective groups onto separate CDs. The radiographs were not viewed side by side. The radiologist, blinded to the demographics of the study population, was given 1 group at a time to measure and record RI, RH, PT, and UV.

All surgical procedures were performed by the investigating physician at an outpatient, ambulatory facility. All patients provided authorization to participate in this study. There were no conversions to ORIF. For removal of hardware, patients were given the choice of having removal either in the office or at an ambulatory facility. This study was not submitted to an institutional review board.

SURGICAL TECHNIQUE

The CPX device is made of aluminum and is lightweight (41 g, with the pins). It consists of a 2-part sliding bar with 2 screws to adjust the length (11.5 to 14.5 cm). At either end of the sliding bar are 2 heads, each with 3 adjustable K-wire fixators (Fig. 1). Each K-wire fixator has 2 screws—one to control the angle of insertion of the K-wire, and the other to lock the K-wire to the fixator. From a technical standpoint, the device allows 10° of rotation of the K-wire around the center insertion point. All the screws of the CPX device are loosened before reduction of the fracture.

Surgery is performed under either regional intravenous block (4 patients) or axillary block (17 patients) and under fluoroscopic control. The fractures are reduced by using the classic maneuver, flexion and ulnar deviation,[44] or by applying longitudinal traction with finger traps. After fluoroscopic confirmation of reduction in the AP and lateral planes, a small stab wound is made near the radial styloid between the first and second dorsal compartments. A clamp is used to spread the soft tissues, and a tissue protector is introduced into the incision and held against the bone at a 40° to 45° angle. All K-wires were smooth and 1.6 mm. The first K-wire is then driven obliquely across the fracture site. While driving this K-wire, dorsal pressure is applied on the distal fragment to maintain PT while the wrist is held in ulnar deviation to maintain RI. The K-wire should exit the proximal fragment (radial shaft) in a mid-lateral plane. The first K-wire is then placed through the distalmost K-wire fixator in the device.

The CPX device is then aligned with the distal forearm in the mid-lateral plane. A second K-wire, also using a tissue protector, is then inserted through the proximal K-wire fixator, aiming at the lunate fossa. A small stab wound is made, and a clamp is used to spread the soft tissues to facilitate the introduction of the tissue protector. The K-wire angle of insertion can be varied ±10° on center to achieve the desired position. The remaining K-wires are then introduced in a similar manner, using a minimum of 2 distally and 2 proximally (Fig. 2). Intra-articular displaced fractures did not require fragment-specific fixation because the percutaneous pinning and cross-pin fixation of the fractures with the CPX device maintained reduction.

After surgery, patients are placed in soft dressings with a short arm volar splint and instructed to perform active finger ROM. Patients are initially seen after surgery for removal of the surgical dressing, radiographic evaluation, pin site care, assessment and reinforcement of active finger ROM, and fabrication of a custom wrist or forearm orthosis by the investigating occupational therapist (OT). Hand therapy, 3 times per week, commences immediately thereafter to initiate additional active finger ROM, wrist and forearm active range of motion (AROM), a formal home exercise program, and resumption of usual activities. Patients are instructed to remove the splint 6 times each day to perform their home exercise program. Pin care management is rendered during office visits by applying Hibiclens-soaked (chlorhexidine gluconate solution 4.0% w/v) gauze wraps to the pin sites.

ASSESSMENT PARAMETERS

Postoperative radiographs were taken at 2, 4, 6, 8, and 12 weeks, 6 months, and again at 1 year or final evaluation to assess radiological parameters of RI, RH, PT, and UV. Posteroanterior (PA) views were performed with the forearm in pronation, and lateral views were performed with the forearm in neutral position. The CPX device and K-wires were removed after bone healing was verified by radiographic observation of trabecular bridging across the fracture site and obliteration of distinct fracture lines. From the initial to final postoperative radiographic examination, maintenance of fracture reduction was defined as a loss of less than

TABLE 1. Clinical and Outcome Characteristics of Study Population

Pt[a] No.[b]	Gender, Age y[c]	Injured Side, Dominance	AO Class.[d]	Associated Injuries	Prior Rx[e]	No.[b] Pins Distal/Proximal
1	F, 56	L, ND	C2.2	None	ACR[p], SAC[q]	3/2
2	F, 38	R, D	C2.1	None	ACR[p], S-TS[r]	3/2
3	M, 36	L, ND	C3.1	None	ACR[p], S-TS[r]	4/2
4	M, 54	R, D	B3.1	None	ACR[p], S-TS[r]	3/2
5	F, 68	R, D	C1.1	None	ACR[p], SAC[q]	4/2
6	F, 55	L, D	C1.1	None	ACR[p], S-TS[r]	3/2
7	M, 45	R, D	B2.2	Neck and shoulder	Cast	3/2
8	F, 71	R, D	C1.1	None	Splint	2/2
9	M, 87	L, M	C1.1	Fracture: ulna shaft, elbow	ACR[p], SAC[q]	3/2
10	F, 57	L, D	A2.2	None	Splint	3/2
11	F, 56	L, D	A2.2	None	ACR[p], S-TS[r]	3/2
12	F, 55	R, D	B3.3	None	ACR[p], SAC[q]	2/3
13	M, 33	L, M	C2.1	Multiple trauma	ACR[p], S-TS[r]	3/2
14	F, 29	L, ND	C2.2	None	Splint	2/2
15	M, 55	L, ND	C3.1	None	ACR[p], S-TS[r]	3/3
16	F, 65	R, D	C2.1	None	ACR[p], S-TS[r]	2/2
17	M, 27	L, D	C3.1	None	SAC[q]	2/2
18	F, 72	R, ND	C1.1	None	Splint	2/2
19	F, 48	L, ND	C1.1	None	None	2/2
20	M, 63	L, ND	C1.1	None	ACR[p], S-TS[r]	2/2
21	F, 54	R, D	A2.2	None	ACR[p], SAC[q]	2/2

[a]Pt, patient; [b]No, number; [c]y, year; [d]Class., classification; [e]Rx, treatment; [f]d, days; [g]HW, hardware, (removed); [h]d/c, discontinued; [i]r, resolved; [j]FU, follow-up; [k]m, month; [l]PRWHE, patient rated wrist hand evaluation; [m]DASH, disabilities of the arm, shoulder and hands; [n]Un Rx, unaffected side; [o]%, percentage; [p]ACR, attempted closed reduction; [q]SAC, short arm cast; [r]S-TS, sugar-tong splint; [s]DSBRN, dorsal sensory branch of radial nerve; [t]CRPS, complex regional pain syndrome; [u]CTS, carpal tunnel syndrome; [v]s/p, status post; [w]ECTR, endoscopic carpal tunnel release.

5° RI, less than 2 mm RH, less than 10° PT[12,45–51] or an increase in ulnar variance greater than 1.5 mm.

At designated intervals, the OT recorded goniometric wrist measurements in flexion, extension, pronation, supination, and radial and ulnar deviation, as well as grip and pinch strengths, using a Jamar hydraulic hand dynamometer (Lafayette Instrument Company, Lafayette, IN) and a hydraulic pinch gauge (Baseline; FEI, Irvington, NY). These values were recorded on custom-designed occupational therapy forms. The findings were compared with the contralateral side. Scar assessment for height (flat, hypertrophic, or keloid) and mobility (mobile, adhesion: minimum, moderate, or severe) were also recorded on the forms. Wrist rehabilitation was determined by calculating the number of days from each patient's surgery to the initial therapy evaluation.

Patients completed the initial self-administered PRWHE[52–54] and the DASH[55] instruments during their initial therapy evaluation. The PRWHE was obtained at 4, 6, 8, and 12 weeks, 6 months, and again at 1 year or final evaluation. Early in the study, a follow-up DASH was obtained at 3 months, 6 months, and 1 year. Later, an 8-week and then a 4-week DASH were added. These instruments provided outcome measurements of physical function, symptoms (pain), disability, appearance, and return to usual activities.

Descriptive measurements (mean, standard deviation [SD]; median, range) were used to tabulate the preoperative and postoperative parameters of radiologic measurements, grip and pinch strength, AROM, DASH, and PRWHE scores. Data were not available for all patients at all time points. The percentages shown are the results for the number of available patients in each parameter and time point. Comparisons between injured and noninjured hands and wrists serve as controls for each patient's individual postoperative outcome.

TABLE 1. Clinical and Outcome Characteristics of Study Population (Continued)

Orthosis Applied (d)[f]	Wrist Rehab Began (d)[f]	HW[g] d/c[h] (d)[f]	Complications (r)[i]	Final FU[j] (m)[k]	PRWHE[l]	DASH[m]	Grip Strength of Un Rx.[n] (%)[o]
6	13	44		36	6.5	2.5	91
6	10	45		16	25	5	108
5	9	40		25	0	0	109
6	7	61		33	4.5	3.3	109
3	4	45	DSBRN[s]	31	0	0	90
7	14	48		29	1	0	92
5	8	40	CRPS[t] (r)	26	5.5	6.7	109
8	12	44		22	1.5	6.7	102
8	15	44	DSBRN[s] (r)	22	0	3.3	70
8	9	43		21	8	10	112
8	15	47		21	1	0	102
8	16	43		18	31.5	22	69
5	13	54	CTS[u] (r)[i] s/p[v] ECTR[w] Wrist stiffness, Rx[e] manipulation	17	43	28	28
6	12	47		12	8.5	4.2	84
6	9	41		14	7	4.2	72
6	7	45		12	1.5	7.5	131
6	10	45		12	1	2.5	83
4	7	39		12	0	2.5	110
3	12	46		12	7.5	10	65
5	9	48		12	32	26	55
5	8	43		12	0	0	103

Data were collected at baseline (initial postoperative evaluation with the OT); 2, 4, 6, 8, and 12 weeks, 6 months, and 1 year or more after surgery.

RESULTS

Table 1 reports demographic, clinical, and outcome characteristics of the study population. Mean follow-up was 20 months (range, 12 to 36 mo). All fractures were reduced by closed reduction with no conversions to open. Patients were seen a mean of 6 days (range, 3 to 12 d) after surgery for radiographs and application of a removable, custom orthosis.

Table 3 reports normal radiographic parameters and longitudinal radiographic measurements of the study population.[56–65] Before surgery the mean, intra-articular step was 0.5 mm (SD 0.7) and the gap was 1.2 mm (SD 1.1). On final evaluation there were no stepoffs, and the mean gap was 0.2 mm (SD 0.4).

TABLE 2. Distribution of Distal Radius Fractures According to AO Classification

Fracture Type	Type	No.[a]	Percent[b]
A Extra-articular	A2.2	3	14
B Simple articular	B2.2	1	5
	B3.1	1	5
	B3.3	1	5
C Complex articular	C1.1	7	33
	C2.1	3	14
	C2.2	2	10
	C3.1	3	14
Total DRF		21	

[a]No., number of fractures treated per classification.
[b]Percent, percentage of each DRF classification treated.

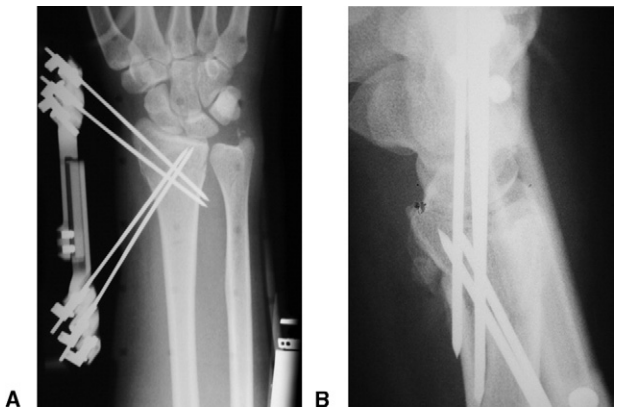

FIGURE 2: Radiograph of a DRF with the CPX device. **A** PA view, **B** lateral view.

Preoperative mean radiographic measurements were RI 21° (SD, 5.4; range, 9 to 30), RH 8.5 mm (SD, 4.4; range, 0 to 13.4), PT −3° (SD, 13.4; range, −38 to 13.5), and UV 2.2 mm (SD, 2.9; range, −4.8 to 6.3). At the initial postoperative visit, mean radiographic results were RI 25° (SD, 3.3; range, 16 to 29), RH 10.9 mm (SD, 2.6; range, 4.2 to 14.1, PT 5° (SD, 4.1; range, −3 to 13), and UV 0.6 mm (SD, 2.2; range, −3.3 to 4.4). In 3 patients the anatomy was not fully restored and remained out-of-range throughout; 1 (patient 5) lacked PT and 2 (patients 6 and 16) lacked RH.

Final mean measurements were RI 25° (SD, 3.6; range, 15 to 30), RH 11 mm (SD, 2.47; range, 4.4 to 13.9), PT 5° (SD, 4.1; range, −4 to 12) and UV 0.8 mm (SD, 2; range, −2.8 to 4.4). UV was greater than 2 mm in 6 patients and greater than −2 mm in 2 patients. Two of the 6 patients with UV greater than 2 mm were reported as not being fully restored in RH. Comparison of the initial postoperative radiographic measurements to final measurements showed no loss of reduction (Table 3).

All fractures healed with removal of the CPX device and K-wires at an average of 45 days (range, 39 to 61 d) after surgery. One patient had removal of hardware in the office, and the remaining patients elected to return to the ambulatory facility for removal of hardware under sedation. With this second procedure, there were no complications.

Table 4 reports the final PRWHE subscale for appearance of the wrist or hand on a scale of 0 to 10, with 0 being no dissatisfaction and 10 being complete dissatisfaction. Fourteen patients expressed no dissatisfaction. The remaining 7 patients expressed dissatisfaction to a value no greater than 3. Final OT evaluation of scar height determined that all proximal and distal scars were flat. Evaluation for scar mobility showed that 38 were mobile, with 1 proximal and 3 distal having mild adhesions.

Formal wrist rehabilitation and mobilization began a mean of 10 days (range, 3 to 16 d) after surgery. AROM measurements by the OT determined that the injured wrists had an initial mean extension of 22° as compared with the uninjured wrists mean of 70°. Similarly, initial volar flexion of the injured wrists was 24° as compared with the uninjured wrists mean of 70° (Table 5). Both extension and flexion values improved, as did the ability to pronate and supinate (Fig. 3). In regard to AROM measurements at final evaluation, the injured side's mean scores were DF 70° (SD 11), VF 65° (SD 8), pronation 89° (SD 2), and supination 84° (SD 8). Mean AROM of the non-injured side was DF 71°, VF 70°, pronation 87°, and supination 82°, and the injured side percentage achieved is 99%, 92%, 103%, and 103%, respectively (Fig. 4).

Mean grip and lateral pinch strengths increased postoperatively relative to the uninjured hand. At 6 months, 45 of 59 lbs (76%) of grip strength and 15 of 17 lbs (88%) of pinch strength recovered, improving to 54 of 63 lbs (86%) and 16 of 17 lbs (94%), respectively, at final evaluation (Table 6). After surgery, the overall mean PRWHE scores were 70 at baseline, improving to 33 at 12 weeks and 9 at final evaluation (Fig. 5A). Within the PRWHE, the usual activities subscale (Table 7), reporting subjective difficulty in performing personal care, household work, work, and recreation, revealed an overall mean subscale score of 28 (range, 4 to 40) at baseline, improving to a mean 18 (range, 0 to 39) at 6 weeks. The pain subscale (Table 8), reporting on 4 items rating disability in reference to pain as well as pain frequency, revealed an overall mean subscale score of 23 (range, 2 to 49) at baseline, improving to 16 (range, 0 to 40) at 6 weeks. Before hardware removal at 6 weeks after surgery, mean subjective outcome of the PRWHE revealed mild pain with mild to moderate difficulty in performing usual activities with the injured hand.

The DASH showed that the patients had a decrease in disability and symptoms as well as an improvement in functional ability (minimal detectable change at 95% confidence level, MDC_{95}) when comparing baseline scores to those at 4 and 12 weeks, and again at 1 year (Fig. 5B). A similar functional improvement (MDC_{95}) was noted when comparing the baseline score to those at 8 weeks and 6 months.

One patient exhibited altered sensibility in the superficial radial nerve distribution and was treated with desensitization and gabapentin. The symptoms resolved

TABLE 3. Radiographic Measurements[a]

	Preoperative						Initial Postoperative Visit						Final Evaluation					
Pt. No.	RI[b]	RH[c]	PT[b]	UV[c]	Step[c]	Gap[c]	RI[b]	RH[c]	PT[b]	UV[c]	Step[c]	Gap[c]	RI[b]	RH[c]	PT[b]	UV[c]	Step[c]	Gap[c]
1	21	3.1	−31	5.6	0	2.5	25.5	11.5	0	0	0	0.7	26.6	12.8	0.8	0	0	0.7
2	8.7	0	−38	4	0	0.5	20.3	11.1	7.8	−2.4	0	0	20.1	10.6	7.4	−2	0	0
3	21.2	10.6	4.3	3.6	1.6	2	23.9	12.3	1.1	1.1	0	0	23.3	11.9	0.7	1.6	0	0
4	26.2	13.4	5.5	0.8	1.7	0.8	27.2	14.1	12.5	−1.1	0	0	26.3	13.5	11.9	−1	0	0
5	17.8	4.1	−20.6	3.7	0	0.6	26.4	7.5	−3	2.3	0	0.6	27	8.3	−3.7	2.1	0	0
6	18.7	4.3	9	5.3	0	1	22.1	4.2	4.2	4.4	0	0	20.8	4.4	4.4	3.3	0	0
7	24.8	13	0	−3	0.2	0.3	26.4	13.3	9.4	−3.3	0.2	0.2	25.9	13.9	9.3	−2.8	0	0
8	24.9	12.3	−10.8	3.1	0	2	27.3	13.2	7.1	3	0	1	27.5	13	7.4	3	0	0
9	25.9	12.1	2.9	4.5	0	1.6	26.7	13.6	9.4	2.4	0	0	28.8	13.7	9.6	2.1	0	0
10	20.2	11	13.5	−2.1	0	0	24.2	13.3	1.9	−2.5	0	0	22.8	13.4	1.7	−1.8	0	0
11	27	12	3.3	1.6	0	0	29.3	13.3	7.4	0	0	0	28.4	13	7.1	0	0	0
12	14	0	−4.5	0	1	3	20.3	11	5.4	0	0	1	25	10.7	4.4	0	0	1
13	22.2	13.4	0	1.7	1.4	1.7	23.2	10.3	0	0	0	0	23.3	11.1	0	0	0	0
14	18	4.9	3.7	1.9	0	1	26.1	10.3	9.5	0	0	0	25.9	9.8	9.4	1.4	0	0
15	18.2	4.2	−4.6	5.6	2	3.5	24.7	9.3	5	2	0	2	23.2	9.7	4.1	1.9	0	1.5
16	23.1	6.3	11	6.3	0.5	2	26.2	6.9	9.3	3.9	0	0	27.5	6.8	10.3	4.4	0	0
17	9.9	11.7	2.9	−4.8	1.6	2.4	15.8	11	0	−2.6	0.8	0	14.6	10.6	0	−2.8	0	0
18	30.2	10.4	−5	2.5	0	0.2	28.7	10	4.7	1	0	0.2	30	10.56	3.6	1.8	0	0.2
19	25	10.9	−12	0	0	1	27.4	10.9	8	0.8	0	1.5	26.2	10.3	6.7	1.3	0	0
20	21.2	9.3	3	3	0	1	22.2	8.6	7.4	2.8	0	0	22.5	8.8	8	3	0	0
21	21.6	10.9	10.1	2.3	0	0	28.7	14.1	5.6	0.9	0	0	29	13.1	4.8	0.4	0	0
mean	20.9	8.5	−2.7	2.2	0.5	1.2	24.9	10.9	5.4	0.6	0.05	0.3	25	11	5.1	0.8	0	0.2
SD	5.4	4.4	13.4	2.9	0.7	1.1	3.3	2.6	4.1	2.2	0.2	0.6	3.6	2.47	4.1	2	0	0.4
median	21.2	10.6	2.9	2.5	0	1	26.1	11	5.6	0.8	0	0.6	25.9	10.7	4.8	1.3	0	0
min	8.7	0	−38	−4.8	0	0	15.8	4.2	−3	−3.3	0	0	14.6	4.4	−3.7	−2.8	0	0
max	30.2	13.4	13.5	6.3	2	3.5	29.3	14.1	12.5	4.4	0.8	2	30	13.9	11.9	4.4	0	1.5

Pt, patient; RI, radial inclination; RH, radial height; PT, palmar tilt; UV, ulnar variance.
[a]normal radiological measurements (56–65): RI 22–23° (range, 13 to 30), RH 11–12 mm (range, 8 to 18), PT 11–12° (range, 0 to 20) and UV 0 mm (range, −2 to 2 [minus numbers represent negative UV]).
[b]Measured in degrees.
[c]Measured in mm.

TABLE 4. Patient-Rated Wrist Hand Evaluation—Appearance[a]

Patient No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Dissatisfaction with appearance[b]	0	1	0	0	0	0	0	1	0	0	0	1	3	1	2	0	0	0	0	2	0

[a]Note: Patients rated their dissatisfaction with the appearance of the wrist/hand on a scale of 0 to 10.
[b]Dissatisfaction: "Rate how dissatisfied you were with the appearance of your wrist/hand during the past week."

to transient, mild, superficial radial nerve sensitivity without functional compromise. There were 3 patients with a protracted recovery. One patient, who had multiple injuries and stiffness of the wrist, later developed carpal tunnel syndrome. At 1 year after surgery, the patient had endoscopic carpal tunnel release and manipulation of the wrist, with improvement. Another patient had associated fractures of the affected upper extremity, and the third patient with multiple injuries was diagnosed with type I complex regional pain syndrome. Although the patient had altered sensibility in radial and ulnar nerve distribution and related neck and shoulder problems, there was no allodynia or hyperpathia. These symptoms resolved, requiring no formal treatment from a pain management specialist.

There were no pin track infections, tendon ruptures, or nonunions. Despite the number of pins used, the scars were minimal. All patients returned to their prior occupation or activities. Figure 6 is an example of a C2.2 DRF before surgery, after surgery, and healed.

TABLE 5. Progressive Active Range of Motion[a]

		Dorsiflexion		Volar Flexion		Pronation		Supination	
Visit	N[b]	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)
IE[c]	21	22 (15)	28 (−18[d] to 39)	24 (6)	24 (8 to 36)	69 (11)	68 (42 to 86)	21 (25)	22 (−24 to 66)
4 wk	20	36 (13)	35 (0 to 62)	29 (7)	28 (16 to 42)	75 (10)	77 (52 to 88)	44 (25)	48 (−20 to 78)
8 wk	19	46 (12)	46 (22 to 67)	40 (11)	38 (20 to 70)	80 (9)	82 (58 to 90)	62 (17)	66 (20 to 82)
12 wk	19	54 (11)	56 (38 to 72)	49 (11)	50 (34 to 80)	83 (7)	86 (60 to 90)	70 (14)	74 (40 to 86)
6 mo	17	63 (11)	60 (40 to 78)	58 (11)	56 (42 to 86)	86 (4)	86 (76 to 90)	79 (8)	80 (66 to 90)
1 y	21	69 (11)	71 (44 to 89)	64 (8)	64 (50 to 86)	89 (2)	90 (84 to 90)	84 (8)	90 (60 to 93)

[a]measured in degrees; [b]n, number of patients and fractures; [c]IE, initial postoperative evaluation; [d]–18 signifies that the patient demonstrated an 18-degree deficit to neutral.

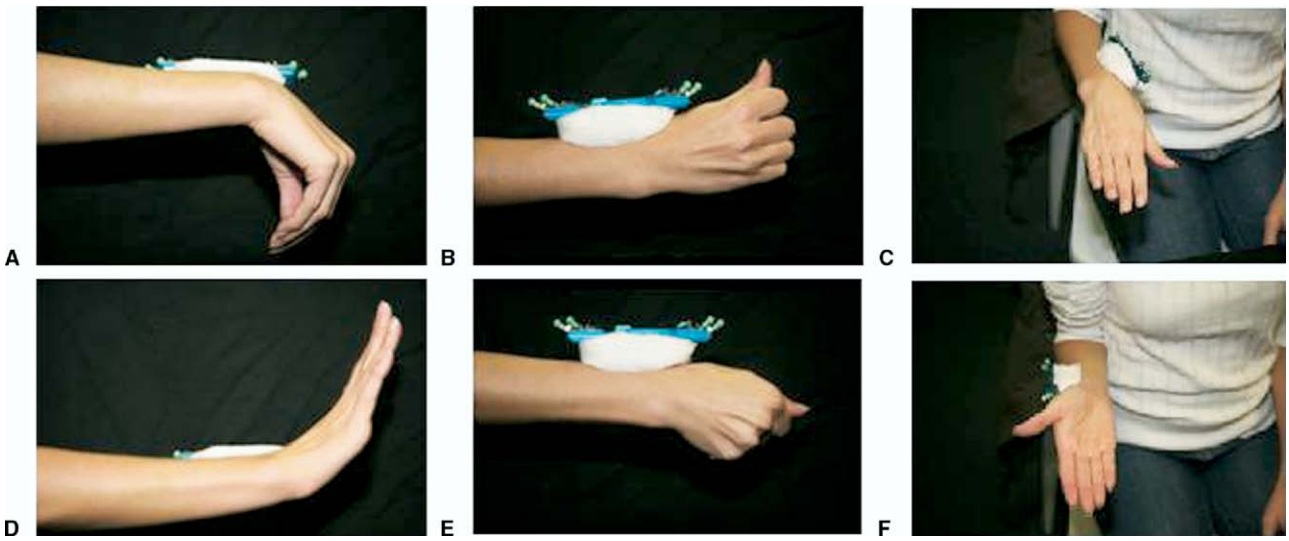

FIGURE 3: ROM with the CPX system at 6 weeks after surgery. **A** Wrist flexion, **B** wrist extension, **C** radial deviation, **D** ulnar deviation, **E** pronation, and **F** supination.

DISCUSSION

This is a report of a nonbridging external fixator (single frame) that integrates internal fixation with a multiplanar pin configuration. The advantages of nonbridging fixators as compared to bridging fixators have been reported widely in the literature.[66–77] The aim of using a nonbridging technique is to allow for mobilization of the wrist and early resumption of usual activities, while attempting to maintain reduction of the fracture.

The outcome of fractures treated with nonbridging techniques has been good, although there have been some problems. Forgan and Mammel[71] reported 4 cases, requiring premature removal of hardware owing to inflammation around the pins; in another case, the apparatus failed to hold reduction of the fracture. McQueen (20 cases) had a 33% incidence of pin track infection; 1 patient required debridement, and 1 fracture collapsed after removal of hardware, resulting in a malunion.[75] Fischer et al. (17 cases) had 1 pin track infection, 2 extensor pollicis longus tenodeses, 1 re-operation, and 1 fracture of the diaphysis.[77] Krishnan compared the results of 30 patients treated with the Delta frame (Matheys Medical Ltd., Betiäch, Switzerland) with 30 treated with a Hoffman bridging fixator (Howmedica, Staines, UK).[70] Pin track infections (32%) were the most common complication of both groups. In addition, 2 patients in each group required further surgery because of fixation failure, and 3 patients with the Delta frame had extensor pollicis longus ruptures. Despite considerable postoperative steps and gaps, the patients had a good outcome.

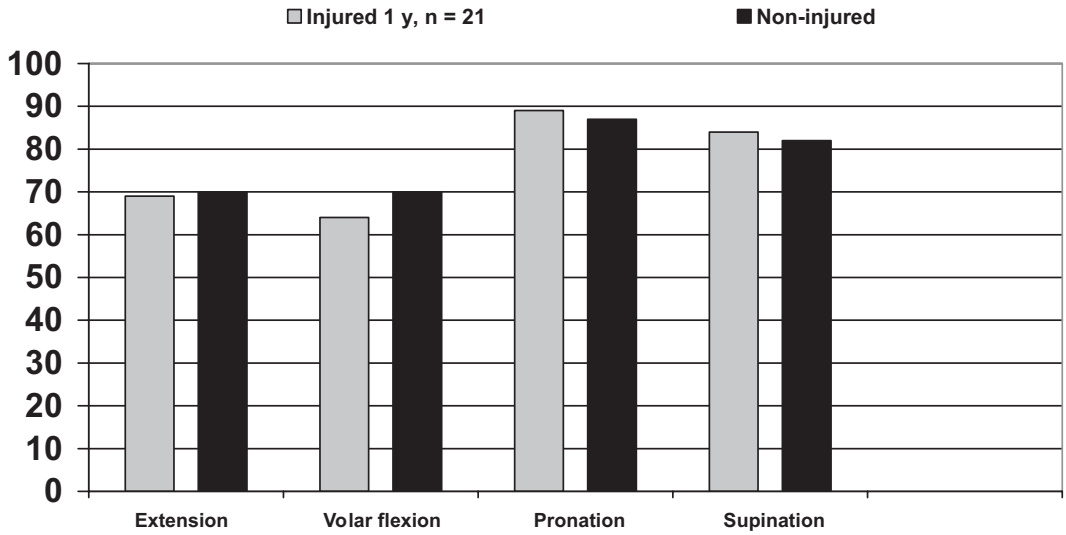

FIGURE 4: Range of motion compared to the uninjured side at final evaluation.

TABLE 6. Mean Percentage of Strength Achieved After Surgery

		Grip			Lateral Pinch		
Visit	n[a]	Injured[b]	Non-Injured[b]	Achieved[c]	Injured[b]	Non-Injured[b]	Achieved[c]
8 w	15	22	62	35	9	16	56
12 w	19	33	61	54	13	17	76
6 m	17	45	59	76	15	17	88
FE[d]	21	54	63	86	16	17	94

[a]n, number of patients and fractures; [b]mean strength, measured in pounds; [c]percentage of strength, in relation to the uninjured hand; [d]FE, final evaluation.

McQueen et al.[75] and Fischer et al.[77] used large-diameter pins for internal fixation, mostly from a dorsal-volar direction. The pins were sometimes used as joysticks to reduce the fractures. Gradl et al. (25 cases) reported a novel technique incorporating multiplanar K-wires into a nonbridging fixator.[9] There were 2 major pin track infections but no tendon ruptures or radial sensory nerve problems, although they did have loss of RH in 3 of 29 fractures when they used 3 K-wires.

Pin track infections and tendon ruptures are possibly attributed to large-diameter pins (2.5 to 4 mm) placed in a dorsal–volar direction and the movement of the skin around the pins during flexion and extension of the wrist. The dorsal–volar pins can also irritate or impinge on the extensor tendons, impede wrist rehabilitation, and lead to tendonitis and rupture of these tendons. Large-diameter pins also carry the risk of fractures of the diaphysis after their removal.[77]

The CPX system differs substantially from other nonbridging fixators. Its unilateral frame uses smooth, 1.6-mm K-wires in the mid-lateral plane. The small-diameter K-wires are inserted from the radial to the ulnar side of the fracture, thereby crossing the fracture and each other in different planes. A multiplanar cross-pin configuration is created by using a minimum of 2 K-wires proximally or distally. For unstable fractures, the device allows for additional K-wires. Furthermore, using a mid-lateral approach diminishes the chance of impaling extensor tendons and reduces mobility of the skin around the pins during ROM exercises and usual activities. This was substantiated in this study by the fact that there were no pin track infections, tendonitis, or tendon ruptures. The concern of using pins in the mid-lateral plane is the possibility of injury to the radial sensory nerve, and therefore potential development of complex regional pain syndrome. Use of the tissue protector and timely intervention with a pharmacologic agent such as gabapentin can minimize these concerns.

We concur with the observation of Gradl et al.[9]

FIGURE 5: Mean Progressive PRWHE and DASH scores.[a] **A** PRWHE, **B** DASH. [a]Compared to MacDermid's study[54]; [b]n = 18, CPX patient population, eliminating 3 patients with other associated injuries.

TABLE 7. Patient-Rated Wrist Hand Evaluation—Usual Activities[a]

		Personal Care		Household Work		Work or Usual Activities	
Visit	n[b]	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)
IE[c]	16	6 (2)	7 (2 to 10)	7 (3)	8 (2 to 10)	8 (3)	10 (2 to 10)
4[d] wk	20	5 (3)	5 (0 to 10)	6 (3)	8 (1 to 10)	6 (4)	6 (0 to 10)
6[d] wk	15	4 (3)	3 (0 to 9)	4 (4)	4 (0 to 10)	5 (4)	3 (0 to 10)
8[d] wk	16	4 (4)	4 (0 to 10)	5 (3)	5 (0 to 10)	5 (4)	5 (0 to 10)
12[d] wk	15	2 (2)	2 (0 to 5)	3 (2)	3 (0 to 5)	3 (3)	2 (0 to 10)
6[e] mo	17	0.4 (0.7)	0 (0 to 2)	1 (1)	0 (0 to 3)	2 (3)	0 (0 to 10)
FE[f]	21	0.4 (0.9)	0 (0 to 3)	0.4 (0.8)	0 (0 to 3)	1 (2)	0 (0 to 6)

[a]Scored "0" no difficulty to "10" so difficult the patient was not able to perform the activity. Qualitative descriptors for the level of difficulty are defined as follows: 9–10 very severe, 7–8 severe, 5–6 moderate, 3–4 mild and, 1–2 minimal, 0 none.
[b]n, number of patients and fractures.
[c]IE; initial evaluation (mean of 10 days ±3d).
[d]w, weeks; [e]m, month; [f]FE, Final Evaluation.

TABLE 8. Patient-Rated Wrist Hand Evaluation—Pain[a]

		Pain at Rest		When Doing a Task With Repeated Wrist/Hand Movement		Lifting a Heavy Object		When the Pain Is at Its Worst		Frequency: How Often Do You Have Pain?[b]	
Visit	N[c]	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)
IE[d]	16	3 (3)	2 (0 to 9)	6 (4)	8 (0 to 10)	9 (2)	10 (3 to 10)	6 (3)	7 (1 to 10)	4 (3)	3 (1 to 10)
4 w	20	2 (2)	1 (0 to 6)	5 (3)	4 (0 to 10)	6 (4)	7 (0 to 10)	6 (3)	5 (0 to 10)	4 (3)	3 (1 to 10)
6 w	15	1 (2)	1 (0 to 5)	5 (3)	5 (0 to 10)	7 (4)	9 (0 to 10)	5 (3)	5 (0 to 10)	2 (2)	2 (0 to 5)
8 w	16	1 (1)	1 (0 to 3)	4 (2)	3 (1 to 8)	6 (3)	7 (1 to 10)	5 (3)	5 (0 to 9)	2 (2)	2 (0 to 5)
12 w	15	1 (2)	1 (0 to 6)	3 (2.5)	4 (0 to 9)	4 (3)	5 (0 to 10)	5 (3)	5 (0 to 10)	3 (3)	2 (0 to 10)
6 m	17	0.6 (1)	0 (0 to 3)	2 (2)	1 (0 to 6)	3 (2)	2 (0 to 8)	3 (3)	2 (0 to 9)	2 (2)	1 (0 to 6)
FE[e]	21	0.2 (0.5)	0 (0 to 2)	1 (1.5)	1 (0 to 5)	1 (2)	1 (0 to 7)	2 (2)	1 (0 to 7)	1(1)	1 (0 to 4)

[a]Patients described their average wrist/hand symptoms over the past week using a scale of 0 to 10. Qualitative descriptors for disability items related to pain are defined as follows; (0) none, (1 to 2) minimal, (3 to 4) mild, (5 to 6) moderate, and (7 to 8) severe or (9 to 10) very severe. If the patient did not perform an activity, they estimated the amount of pain or difficulty they would expect.

[b]Descriptors for pain frequency scored using a 0–10 scale are as follows: (0) none, (1–2) rarely, (3–4) occasionally, (5–6) frequent, (7–8) and (9–10) constant pain.

[c]n, number of patients and fractures; [d]IE, Initial Evaluation; [e]FE, Final Evaluation; w, weeks; m, months.

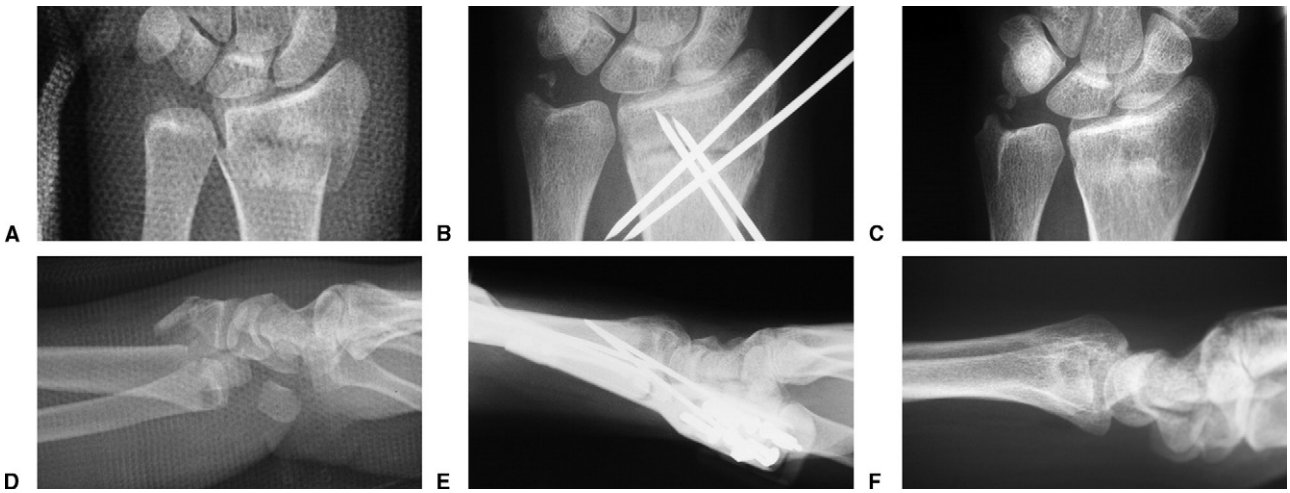

FIGURE 6: AO classification C2.2 DRF (patient 14) treated with the CPX system. **A** Preoperative PA, **B** preoperative lateral, **C** postoperative PA, **D** postoperative lateral, **E** healed PA, and **F** healed lateral.

that multidirectional pins lead to broader distribution of the load, giving more stability to the construct in osteopenic bone. The cross-pin configuration of the CPX system achieves 3-dimensional stability, capturing larger fragments and buttressing the smaller fragments.[78–80] This was confirmed in this study by the fact that multi-fragment, dorsal, and volar shear fractures remained stable without supplemental or fragment-specific fixation. Strauss et al.[81] substantiated the stiffness of the CPX system in a biomechanical study comparing the CPX system with a standard volar locking plate on fresh-frozen human distal radiuses with cyclic loading of 10,000 cycles. There was no significant difference in mechanical stiffness between the two.

In our study population, based on radiographic maintenance criteria, there was no loss of reduction. Although some final radiologic measurements were out of range, patients maintained reduction throughout the treatment period with early wrist mobilization and resumption of usual activities. There were no angular

collapses, increases in steps and gaps, fixation failures, or re-operations, and all patients returned to their prior activities or employment.

Patients with final radiographic measurements out of range included 6 patients with ulnar variance greater than 2 mm. Four who were otherwise restored in RH had ulnar positive variances before surgery that was maintained throughout treatment, and 2 patients were positive due to lack of full reduction. These 2 patients had radial height out of range. On final follow-up, none of these patients complained of ulnar sided wrist pain or required any further treatment.

Although 4 patients had negative UV, our percentages were less than those found in the study by Gelberman et al., which reported 139 of 476 (29%) in a normal white population.[62] Two patients with UV greater than minus 2 mm had preoperative UV of minus 3 and minus 4.8 mm, which, on reduction, was maintained throughout treatment. In addition, 1 patient who had a pre-reduction PT of −21° remained out of range after reduction and at final follow-up, at −3° and −4° respectively. In 1 young patient, an increase of 1.4 mm in UV was a surprise to us, as the older patients in this study with osteopenic bones maintained reduction. We believe that the increase in UV might have been related to the patient's extremely high level of activity in the postoperative period when compared to the other patients.

This study, when compared to those by McQueen[75] and Krishnan,[82] showed fewer complications and greater ROM throughout the healing process. Although Gradl et al.[9] reported that patients had recovered greater initial ROM, patients treated with the CPX system had slightly greater ROM on final evaluation when we eliminated the 3 patients with other associated injuries. In addition, the PRWHE and DASH scores of the same patient population displayed slightly greater functional ability when compared to MacDermid's study.[54] When compared to the ORIF report by Trumble (43 cases) and Orbay (31 cases), our system had slightly better ROM and grip strength.[83,84] The step and gap results were similar.

This system is indicated for extra-articular and reducible intra-articular fractures. We did treat some dorsal and volar shear fractures. Of these, a B2.2 and B3.3 were of special concern to us. These fractures were reduced by longitudinal traction and held, we suspect, because of the multiplanar fixation. Despite this, we believe that further studies are needed to recommend the CPX system for these types of fractures, especially for B3.3 fractures.

Radiographic evaluation with the CPX device is unobstructed in the PA view. Although it is somewhat obstructed on lateral view, there remains some value in accessing the fracture, as the device is not totally radiopaque. One of the drawbacks of external fixators is the size and appearance of the device. The CPX system was well accepted by patients, which could be attributed to its low profile and facilitation of usual activities. In our series, the device was removed in the ambulatory facility. This cost could be eliminated by removing the device in the office.

The CPX system is a minimally invasive technique that allows stable fixation of DRF, early wrist mobilization, and resumption of usual activities, while providing a predictable outcome. Finally, because hand surgeons are familiar with percutaneous cross-pin fixation of fractures, the learning curve for this technique should be manageable.

REFERENCES

1. Orbay J, Badia A, Khoury RK, Gonzalez E, Indriago I. Volar fixed-angle fixation of distal radius fractures: the DVR plate. Tech Hand Up Extrem Surg 2004;8:142–148.
2. 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.
3. Bradway JK, Amadio PC, Cooney WP. Open reduction and internal fixation of displaced, comminuted intra-articular fractures of the distal end of the radius. J Bone Joint Surg 1989;71A:839–847.
4. Kambouroglou GK, Axelrod TS. Complications of the AO/ASIF titanium distal radius plate system (π plate) in internal fixation of the distal radius: a brief report. J Hand Surg 1998;23A:737–741.
5. Fernandez DL, Jupiter JB. Fractures of the distal radius: a practical approach to management. New York: Springer-Verlag, 2002:24–25, 130–132.
6. Itoh S, Tomioka H, Tanaka J, Shinomiya K. Relationship between bone mineral density of the distal radius and ulna and fracture characteristics. J Hand Surg 2004;29A:123–130.
7. Bindra RR. Biomechanics and biology of external fixation of distal radius fractures. Hand Clin 2005;21:363–373.
8. Nesbitt KS, Failla JM, Les C. Assessment of instability factors in adult distal radius fractures. J Hand Surg 2004;29A:1128–1138.
9. Gradl G, Jupiter JB, Gierer P, Mittlmeier T. Fractures of the distal radius treated with a nonbridging external fixation technique using multiplanar K-wires. J Hand Surg 2005;30A:960–968.
10. Slutsky DJ, Herman M. Rehabilitation of distal radius fractures: a biomechanical guide. Hand Clin 2005;21:455–468.
11. Culp RW, Osterman AL. Arthroscopic reduction and internal fixation of distal radius fractures. Orthop Clin North Am 1995;26:739–748.
12. Knirk JL, Jupiter JB. Intraarticular fractures of distal end of the radius in young adults. J Bone Joint Surg 1986;68A:647–659.
13. Bassett RL. Displaced intraarticular fractures of the distal radius. Clin Orthop Relat Res 1987;214:148–152.
14. Melone CP Jr. Open treatment for displaced articular fractures of the distal radius. Clin Orthop Relat Res 1986;202:103–111.
15. Cooney WP. Open reduction of distal radius fractures: indications, classification and functional assessment: In: Saffar P, Cooney WP, eds. Fractures of the distal radius. 1st ed. London: Martin Dunitz, 1995:118–125.
16. MacDermid JC, Donner A, Richards RS, Roth JH. Patient versus injury factors as predictors of pain and disability six months after a distal radius fracture. J Clin Epidemiol 2002;55:849–854.

17. MacDermid JC, Richards RS, Roth JH. Distal radius fracture: a prospective outcome study of 275 patients. J Hand Ther 2001;14: 154–169.
18. Catalano LW, Cole RJ, Gelberman RH. 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:1290–1302.
19. McQueen MM. Non-spanning external fixation of the distal radius. Hand Clin 2005;21:375–380.
20. McQueen MM, Hajducka C, Court-Brown CM. Redisplaced unstable fractures of the distal Radius: a prospective randomized comparison of four treatment methods. J Bone Joint Surg 1996;78B:404–409.
21. Rogachefsky RA, Lipson SR, Applegate B, Ouellette EA, Savenor AM, McAuliffe JA. Treatment of severely comminuted intra-articular fractures of the distal end of the radius by open reduction and combined internal and external fixation. J Bone Joint Surg 2001; 83A:509–519.
22. Hanel DP, Jones MD, Trumble TE. Wrist fractures. Orthop Clin North Am 2002;33:35–57.
23. Gutow AP. Avoidance and treatment of complications of distal radius fractures. Hand Clin 2005;21:295–305.
24. Agee JM. Distal radius fractures. Multiplanar ligamentotaxis. Hand Clin 1993;9:577–585.
25. McQueen MM, Michie M, Court-Brown CM. Hand and wrist function after external fixation of unstable distal radial fractures. Clin Orthop Relat Res 1992;285:200–204.
26. Slutsky DJ. Nonbridging external fixation of intra-articular distal radius fractures. Hand Clin 2005;21:381–394.
27. Bartosh RA, Saldana MJ. Intraarticular fractures of the distal radius: a cadaveric study to determine if ligamentotaxis restores radiopalmar tilt. J Hand Surg 1990;15A:18–21.
28. Woo SL, Gomez MA, Akeson WH. The time and history-dependent viscoelastic properties of canine medial collateral ligament. J Biomech Eng 1981;103:293–298.
29. Fernandez DL, Jupiter JB, eds. Surgical techniques. In: Fractures of the distal radius: a practical approach to management. New York: Springer-Verlag, 2002:93–100.
30. 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.
31. Osada D, Viegas SF, Shah MA, Morris RP, Patterson RM. Comparison of different distal radius dorsal and volar fracture fixation plates: a biomechanical study. J Hand Surg 2003;28A:94–104.
32. Hastings H II, Leibovic SJ. Indications and techniques of open reduction internal fixation of distal radius fractures. Orthop Clin North Am 1993;24:309–324.
33. Jupiter JB, Lipton H. The operative treatment of intraarticular fractures of the distal radius. Clin Orthop Relat Res 1993;292:48–61.
34. Leibovic SJ, Geissler WB. Treatment of complex intra-articular distal radius fractures. Orthop Clin North Am 1994;25:685–706.
35. Fernandez DL, Jupiter JB. Fractures of the distal radius. A practical approach to management. New York: Springer-Verlag, 1996:159–220.
36. 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.
37. MacDermid JC, Tottenham V. Responsiveness of the disability of the arm, shoulder, and hand (DASH) and patient-rated wrist/hand evaluation (PRWHE) in evaluating change after hand therapy. J Hand Ther 2004;17:18–23.
38. Beaton DE, Katz JN, Fossel AH, Wright JG, Tarasuk V, Bombardier C. Measuring the whole or the parts? Validity, reliability, and responsiveness of the disabilities of the arm, shoulder and hand outcome measure in different regions of the upper extremity. J Hand Ther 2001;14:128–146.
39. Müller ME. Distal radius. In: Muller ME, Nazarian S, Koch P, Schatzker J, eds. AO classification of fractures. Berlin: Springer-Verlag, 1987:106–115.
40. Müller ME (ed). Comprehensive classification of fractures. Pamphlet 1. Bern: ME Müller Foundation, 1995:1–24.
41. Kreder HJ, Hanel DP, McKee M, Jupiter J, McGillivary G. Swiontkowski MF. Consistency of AO fracture classification for the distal radius. J Bone Joint Surg 1996;78B:726–731.
42. Cole RJ, Bindra RR, Evanoff BA, Gilula LA, Yamaguchi K, Gelberman RH. Radiographic evaluation of osseous displacement following intra-articular fractures of the distal radius: reliability of plain radiography versus computed tomography. J Hand Surg 1997;22A: 792–800.
43. Kreder HJ, Hanel DP, McKee M, Jupiter J, McGillivary G, Swiontkowski MF. X-ray film measurements for healed distal radius fractures. J Hand Surg 1996;21A:31–39.
44. Charnley J. The closed treatment of common fractures. Edinburgh and London: E & S Livingstone Ltd, 1968:130–133.
45. McQueen M, Caspers J. Colles fracture: does the anatomical result affect the final function? J Bone Joint Surg 1988;70B:649–651.
46. Kopylov P, Johnell O, Redlund-Johnell I, Bengner U. Fractures of the distal end of the radius in young adults: a 30-year follow-up. J Hand Surg 1993;18B:45–49.
47. Taleisnik J, Watson HK. Midcarpal instability caused by malunited fractures of the distal radius. J Hand Surg 1984;9A:350–357.
48. Bickerstaff DR, Bell MJ. Carpal malalignment in Colles' fractures. J Hand Surg 1989;14B:155–160.
49. Abbaszadegan H, Jonsson U, von Sivers K. Prediction of instability of Colles' fractures. Acta Orthop Scand 1989;60:646–650.
50. Cassidy C, Jupiter JB, Cohen M, Delli-Santi M, Fennell C, Leinberry C, et al. Norian SRS cement compared with conventional fixation in distal radial fractures. A randomized study. J Bone Joint Surg 2003; 85A:2127–2137.
51. Posner MA, Ambrose L. Malunited Colles' fractures: correction with a biplanar closing wedge osteotomy. J Hand Surg 1991;16A:1017–1026.
52. MacDermid JC, Turgeon T, Richards RS, Beadle M, Roth JH. Patient rating of wrist pain and disability: a reliable and valid measurement tool. J Orthop Trauma 1998;12:577–586.
53. MacDermid JC, Richards RS, Donner A, Bellamy N, Roth JH. Responsiveness of the short form-36, disability of the arm, shoulder, and hand questionnaire, patient-rated wrist evaluation, and physical impairment measurements in evaluating recovery after a distal radius fracture. J Hand Surg 2000;25A:330–340.
54. MacDermid JC, Roth JH, Richards RS. Pain and disability reported in the year following a distal radius fracture: a cohort study. BMC Musculoskelet Disord 2003;31:4:24.
55. Solway S, Beaton DE, McConnel S, Bomvardier C. The DASH outcome measure user's manual. Toronto, ON: Institute for Work and Health, 2002:1–22.
56. Fernandez DL, Jupiter JB, eds. Surgical techniques. In: Fractures of the distal radius: a practical approach to management. New York: Springer-Verlag, 2002:58–60.
57. Azegami S. Radiological evaluation of distal radius fracture: what junior doctors want to know. Accessed March 29, 2008. Available from http://www.orthogate.org/articles/education/radiological-evaluation-of-distal-radius-fracture-azegami.html.
58. Friberg S, Lundstrom B. Radiographic measurements of the radiocarpal joint in normal adults. Acta Radiol Diagn (Stockh) 1976;17: 249–256.
59. Mann FA, Kang SW, Gilula LA. Normal palmar tilt: is dorsal tilting really normal? J Hand Surg 1992;17B:315–317.
60. Goldfarb CA, Yin Y, Gilula LA, Fisher AJ, Boyer MI. Wrist fractures: what the clinician wants to know. Radiology 2001;219:11–28.
61. Altissimi M, Antenucci R, Fiacca C, Mancini GB. Long-term results of conservative treatment of fractures of the distal radius. Clin Orthop Relat Res 1986;206:202–210.
62. Gelberman RH, Salamon PB, Jurist JM, Posch JL. Ulnar variance in Kienböck's disease. J Bone Joint Surg 1975;57A:674–676.
63. Palmer AK, Glisson RR, Werner FW. Ulnar variance determination. J Hand Surg 1982;7:376–379.

64. Saito H, Shibata M. Classification of fracture at the distal end of the radius with reference to treatment of comminuted fractures. In: Boswick JA, ed. Current concepts in hand surgery. Philadelphia: Lea & Febiger, 1983:129–145.
65. Pogue DJ, Viegas SF, Patterson RM, Peterson PD, Jenkins DK, Sweo TD, et al. Effects of distal radius fracture malunion on wrist joint mechanics. J Hand Surg 1990;15A:721–727.
66. Bishay M, Aguilera X, Grant J, Dunkerley DR. The results of external fixation of the radius in the treatment of comminuted intra-articular fractures of the distal end. J Hand Surg 1994;19B:378–383.
67. Jenkins NH, Jones DG, Johnson SR, Mintowt-Czyz WJ. External fixation of Colles' fractures: an anatomical study. J Bone Joint Surg 1987;69B:207–211.
68. Melendez EM, Mehne DK, Posner MA. Treatment of unstable Colles' fractures with a new radius mini-fixator. J Hand Surg 1989; 14:807–811.
69. Mehta JA, Slavotinek JP, Krishnan J. Local osteopenia associated with management of intra-articular distal radial fractures by insertion of external fixation pins in the distal fragment: prospective study. J Ortho Surg (Hong Kong) 2002;10:179–184.
70. Krishnan J, Wigg AE, Walker RW, Slavotinek J. Intra-articular fractures of the distal radius: a prospective randomised controlled trial comparing static bridging and dynamic non-bridging external fixation. J Hand Surg 2003;28B:417–421.
71. Forgon M, Mammel E. The external fixateur in the management of unstable Colles' fracture. Inter Orthop 1981;5:9–14.
72. McQueen MM, Hajducka C, Court-Brown CM. Redisplaced unstable fractures of the distal radius: a prospective randomised comparison of four methods of treatment. J Bone Joint Surg 1996;78B:404–409.
73. McQueen MM. Redisplaced unstable fractures of the distal radius: a randomised, prospective study of bridging versus non-bridging external fixation. J Bone Joint Surg 1998;80B:665–669.
74. McQueen MM. Metaphyseal external fixation of the distal radius. Bull Hosp Jt Dis 1999;58:9–14.
75. McQueen MM, Simpson D, Court-Brown CM. Use of the Hoffman 2 compact external fixator in the treatment of redisplaced unstable distal radial fractures. J Orthop Trauma 1999;13:501–505.
76. Krishnan J. Distal radius fractures in adults. Orthopedics 2002;25: 175–180.
77. Fischer T, Koch P, Saager C, Kohut GN. The radio-radial external fixator in the treatment of fractures of the distal radius. J Hand Surg 1999;24B:604–609.
78. Clancey GJ. Percutaneous Kirschner wire fixation of Colles' fracture. J Bone Joint Surg 1984;66B:1008–1014.
79. Rogge R, Adams B, Goel VK. An analysis of bone stresses and fixation stability using a finite element model of simulated distal radius fractures. J Hand Surg 2002;27A:86–92.
80. Graham TJ, Louis DS. Biomechanical aspects of percutaneous pinning for distal radius fractures: In: Saffar P, Cooney W, eds. Fractures of the distal radius. 1st ed. London: Martin Dunitz, 1995: 31–32.
81. Strauss EJ, Banerjee D, Kummer FJ, Tejwani NC. Evaluation of a novel, nonspanning external fixator for treatment of unstable extra-articular fractures of the distal radius: biomechanical comparison with a volar locking plate. J Trauma 2008;64:975–981.
82. Krishnan J, Chipchase LS, Slavotinek J. Intraarticular fractures of the distal radius treated with metaphyseal external fixation. Early clinical results. J Hand Surg 1998;23B:396–399.
83. Trumble TE, Schmitt SR, Veccer ND. Factors affecting functional outcome of displaced intra-articular distal radius fractures. J Hand Surg 1994;19A:325–340.
84. Orbay JL, Fernandez DL. Volar fixation for dorsally displaced fractures of the distal radius: a preliminary report. J Hand Surg 2002;27:205–215.