

Unstable Fracture Dislocations of the Proximal Interphalangeal Joint

Treatment with the Force Couple Splint

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The force couple splint maintains concentric joint reduction while allowing early active range of motion exercises. Sixteen cases were treated with a force couple created across the proximal interphalangeal (PIP) joint, levering the dislocated base of the middle phalanx palmarly, while simultaneously lifting the distal end of the proximal phalanx dorsally to restore joint reduction. The splint is constructed from three Kirschner wires and is activated by a single rubber band. The effect of this force couple is present through a complete range of joint motion, thereby allowing active flexion and extension of the joint during bone and soft tissue healing. The force couple splint is capable of producing good to excellent results in patients with unstable acute fracture dislocations of the PIP joint.

Unstable fracture dislocations of the proximal interphalangeal (PIP) joint of the finger are difficult to manage and frequently result in permanent joint stiffness, joint subluxation, and traumatic arthritis. The limited range of motion of the involved finger tethers its flexor and extensor tendons and thereby extends its own impaired function to adjacent fingers.

When an axial load is applied to the finger, such as when a baseball hits the digit "end on," the finger collapses in a zigzag manner. Flexion of the distal joint transmits tension forces into the lateral bands, thereby ensuring that the PIP joint will accept the longitudinal load in an extended or hyperextended position.

When sufficient force is available in this axial direction, the palmar base of the middle phalanx is sheared off as the PIP joint dislocates into extension. As the distal joint is forced into flexion, excessive tension in its extensor tendon can lead to failure either by a rupture of the tendon or avulsion of bone from its insertion into the distal phalanx. With displacement of greater than 30% of the palmar base of the middle phalanx, a stable reduction is difficult to maintain. With lesser degrees of bony displacement, a stable reduction is frequently possible.

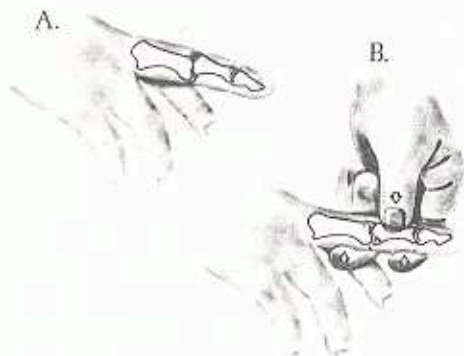
Because of the tendency of the proximal interphalangeal joint to develop stiffness with injury and immobilization, the force couple splint (FCS) was developed to maintain concentric joint reduction while allowing early active range of motion exercises. With this technique, a force couple is created across the PIP joint levering the base of the middle phalanx palmarly while simultaneously lifting the distal end of the proximal phalanx dorsally to restore joint reduction. The splint is constructed from three Kirschner wires and is activated by a single rubber band. The effect of this force couple is present through a complete range of joint motion thereby allowing active flexion and extension of the joint during bone and soft tissue healing.

REVIEW OF LITERATURE

In 1946, Robertson *et al.*⁶ treated seven fracture dislocations of the PIP joint by tri-

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Received: December 13, 1985.



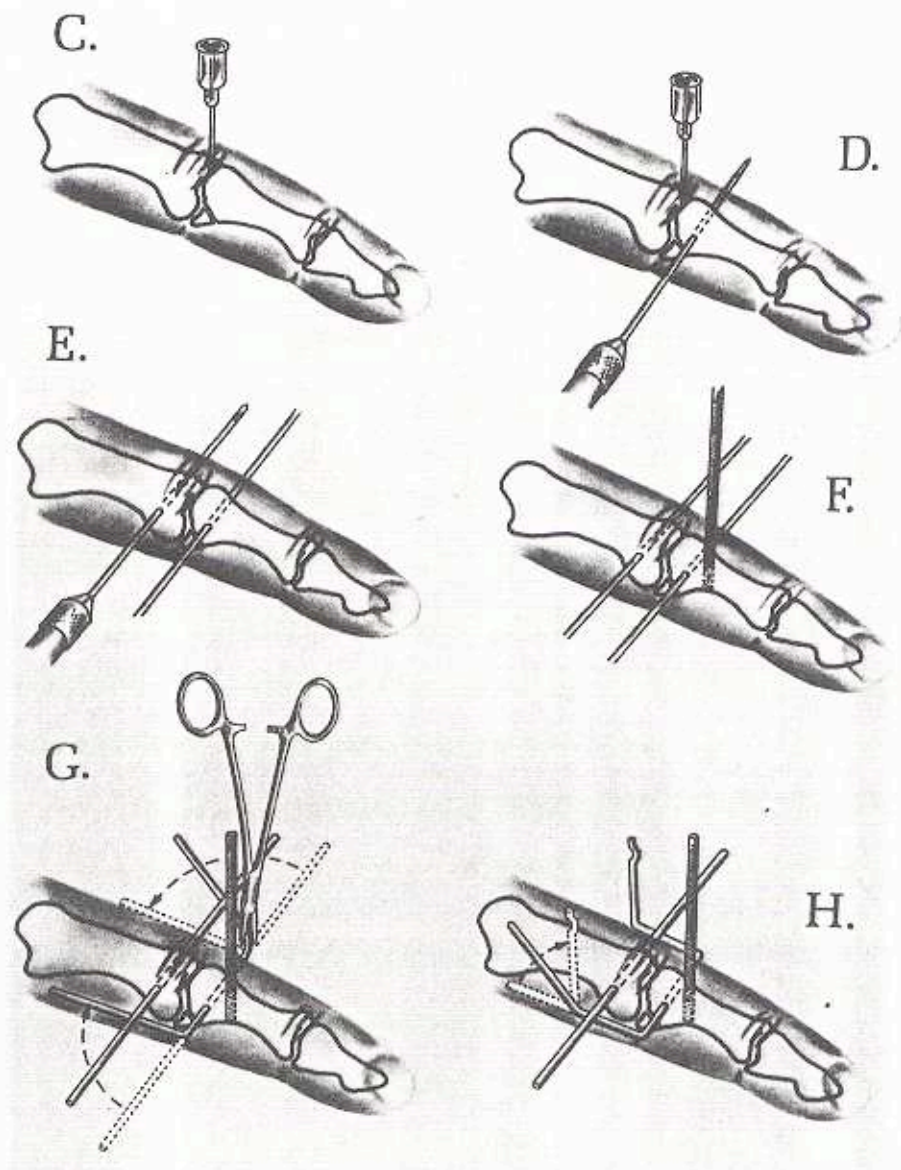
FIGS. 1A AND 1B. (A) A typical unstable fracture dislocation of a proximal interphalangeal joint is depicted. Note that the palmar part of the base of the middle phalanx is retained in normal anatomic relation to the proximal phalanx. (B) The fracture and dislocation have been reduced by the surgeon's left hand, using three-point fixation with his thumb, index, and long fingers. It is absolutely necessary that the smooth Kirschner wires pass palmar to the lateral bands of the extensor mechanism to avoid pinning of the extensor tendon to the skeleton. This can be accomplished only with the proximal interphalangeal joint reduced and in an extended position.

directional skeletal traction in a banjo frame; six of their cases were acute fractures. In 1966, Wilson and Rowland⁸ reported their results of 15 patients treated by open reduction and internal fixation. In four patients, a central articular fragment was elevated, and in two, a malunited palmar lip was treated with an osteotomy and a bone graft. In 1970, McCue *et al.*⁴ reported on 15 athletes treated three weeks or more after injury by open reduction and internal fixation with all patients obtaining 65° or more of active motion. In 1972, McElfresh *et al.*⁵ described closed reduction followed by extensor block splinting in 16 patients with all but one having an acute injury. Their single nonacute case had recurrent joint dislocation two months later. Wiley⁷ excised the bony fragments and attached a slip of superficialis tendon to the defect in the palmar base of the middle phalanx. In 1978, Donaldson and Millender² reported their results in four chronic cases treated by open reduction using

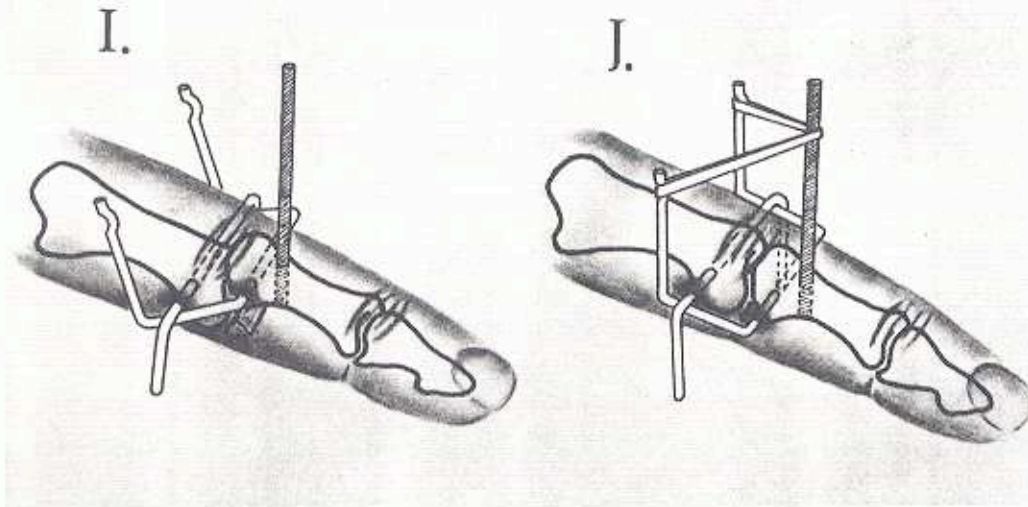
minimal dissection combined with immobilization for 11 days and early active range of motion using an extension block. They reported an average range of motion of 86°. In 1978, Agee¹ presented a preliminary report on two patients using an external fixator that produced a force couple to reduce the joint dislocation. Eaton³ prefers to excise a comminuted base of the middle phalanx and regain joint stability by palmar plate advancement; in 1980 they reported on ten years experience with 24 patients with acute or chronic injuries. Overall, their results for both groups were quite good. In 1981, Zemel *et al.*⁹ reported 14 chronic fracture dislocations treated by osteotomy of the malunited palmar lip using a bone graft and K-wire fixation to increase their average range of motion by 38°.

MATERIAL

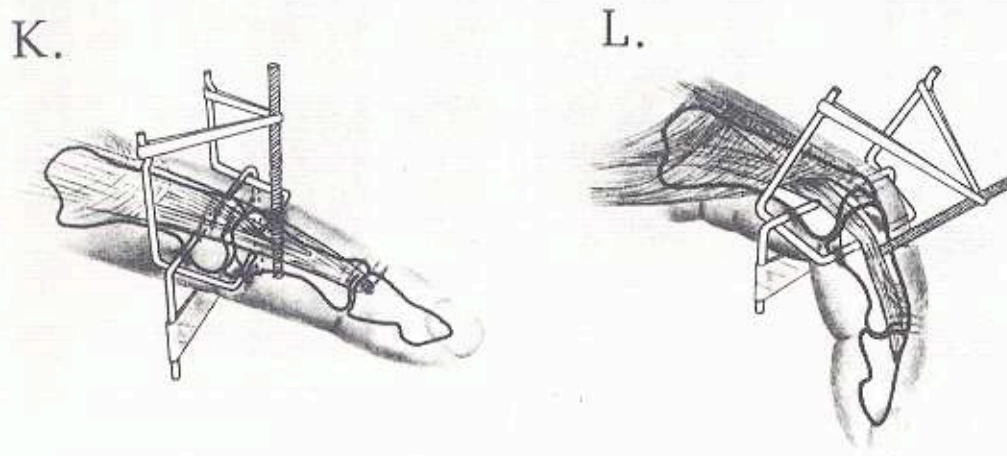
I have treated 18 patients with the force couple splint. One was lost to follow-up examination at two months postoperation. Another patient, a 60-year-old alcoholic with a seven-month-old complete dislocation of the PIP joint, developed a staphylococcal infection postoperation and the joint was subsequently fused. Of the 16 patients available for study, ten were males and six were females. They ranged in age from 15 to 51 years with an average age of 26 years. Two left and 14 right hands were involved. There were three index, eight long, and five ring fingers. Seven patients had associated mallet deformities of the distal joint; two of these had avulsed a fragment of bone from the dorsal base of the distal phalanx. All injuries were either unstable, acute fracture dislocations, or chronic subluxations; all demonstrated dorsal displacement of the middle phalanx on the proximal phalanx with an associated displacement from 25% to 50% of the palmar articular base of the middle phalanx (average, 42%). Nine patients had a depressed central articular fragment. Nine injuries were seen acutely at nine days or less after injury (average, 4 days); eight patients were seen at from 2.5 to four months after injury (average, 7 weeks). Postoperative follow-up study ranged from seven weeks to 66 months with an average of 21 months. In the acute group, two patients had open reduction and internal fixation of displaced fragments combined with application of the force couple splint. Five patients in the chronic group and one in the acute group required open reduction of the joint dislocation.



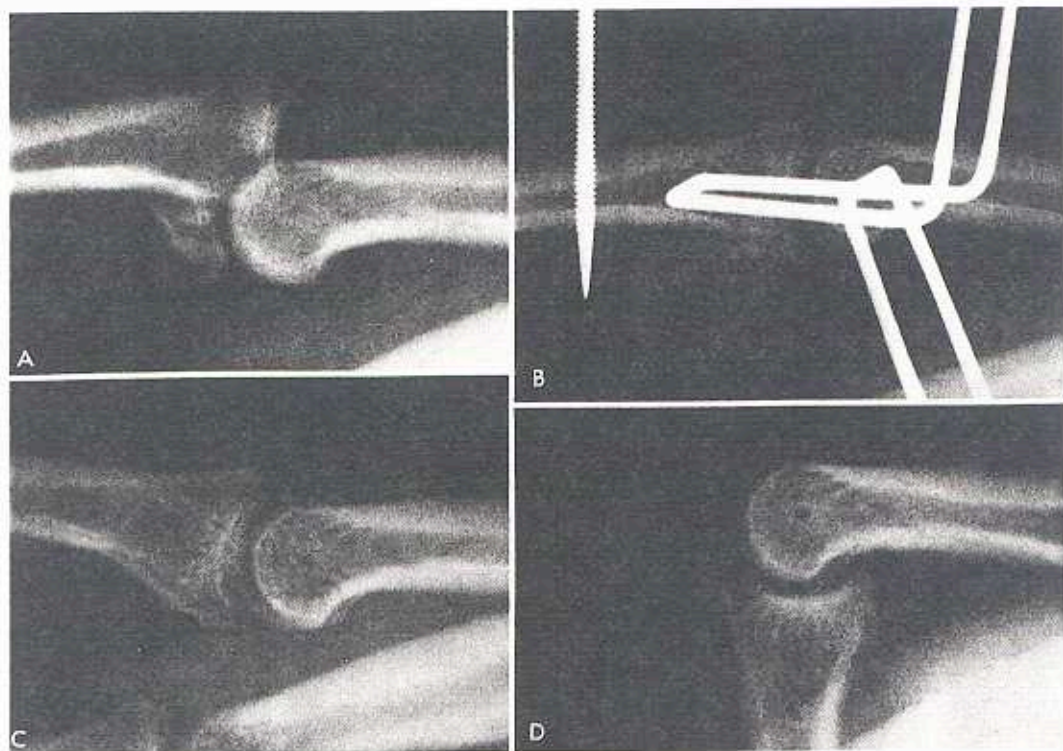
FIGS. 1C-1H. (C) The surgeon's left hand has been deleted for clarity. The joint line is identified with a small-gauge hypodermic needle inserted dorsally (some prefer an image intensifier for this purpose). (D) The distal Kirschner wire (0.045-inch diameter) is forced through the skin just dorsal to the midlateral line of the finger, passing palmar to the lateral band onto the intact bone of the dorsal part of the base of the middle phalanx. This K-wire is inserted in the proximal one-third of the bone and may be at or just distal to the level of the palmar lip fracture. It is drilled through the bone perpendicular to the long axis of the finger and parallel to the plane of the fingernail. (E) The same technique is used to place the proximal K-wire (0.045-inch diameter) exactly parallel to the first K-wire and through the center of the head of the proximal phalanx; *avoid a position more proximal than the metaphyseal flare*. (F) A threaded K-wire (0.062-inch diameter) is drilled from dorsal to palmar in the proximal one-half of the middle phalanx. The tip of the threaded pin should pass through, but not beyond, the palmar cortex of the middle phalanx. (G) On both sides of the finger, the distal K-wire is bent 90° just external to the skin line to pass proximal and palmar to the proximal K-wire. This is best done with a large needle holder or with needle-nose pliers. (H) A second 90° bend in the distal K-wire is made as depicted. Note that this second bend is made 5-10 mm proximal to the proximal K-wire. This final segment of the distal K-wire extends dorsally approximately 3 cm above the midlateral line of the finger. A hook is bent into the end of this K-wire to retain the rubber band.



FIGS. II AND IJ. (I) Recurrent dislocation of the joint occurs when three-point fixation by the surgeon's hand is removed. Note that the proximal K-wire is bent 90° palmarward on either side of the finger to embrace the proximal course of the distal K-wire. It extends 3 cm toward the palmar surface of the finger and is retained in that position by a strap of adhesive tape that connects one side of the K-wire with the other. (J) A small-gauge rubber band connecting the vertical arms of the distal K-wire with the single vertical threaded pin completes a mechanical link between the proximal and middle phalanges, creating a force couple that reduces the dislocation by levering the base of the middle phalanx palmarward while lifting the distal end of the proximal phalanx dorsally.



FIGS. IK AND IL. This mechanical system allows almost full range of active motion of the proximal interphalangeal joint during healing. (K) Notice that the proximal and distal K-wires pass palmar to the extensor tendon mechanism and that active flexion of the joint (L) results in lateral band descent onto the dorsal surfaces of the K-wires.



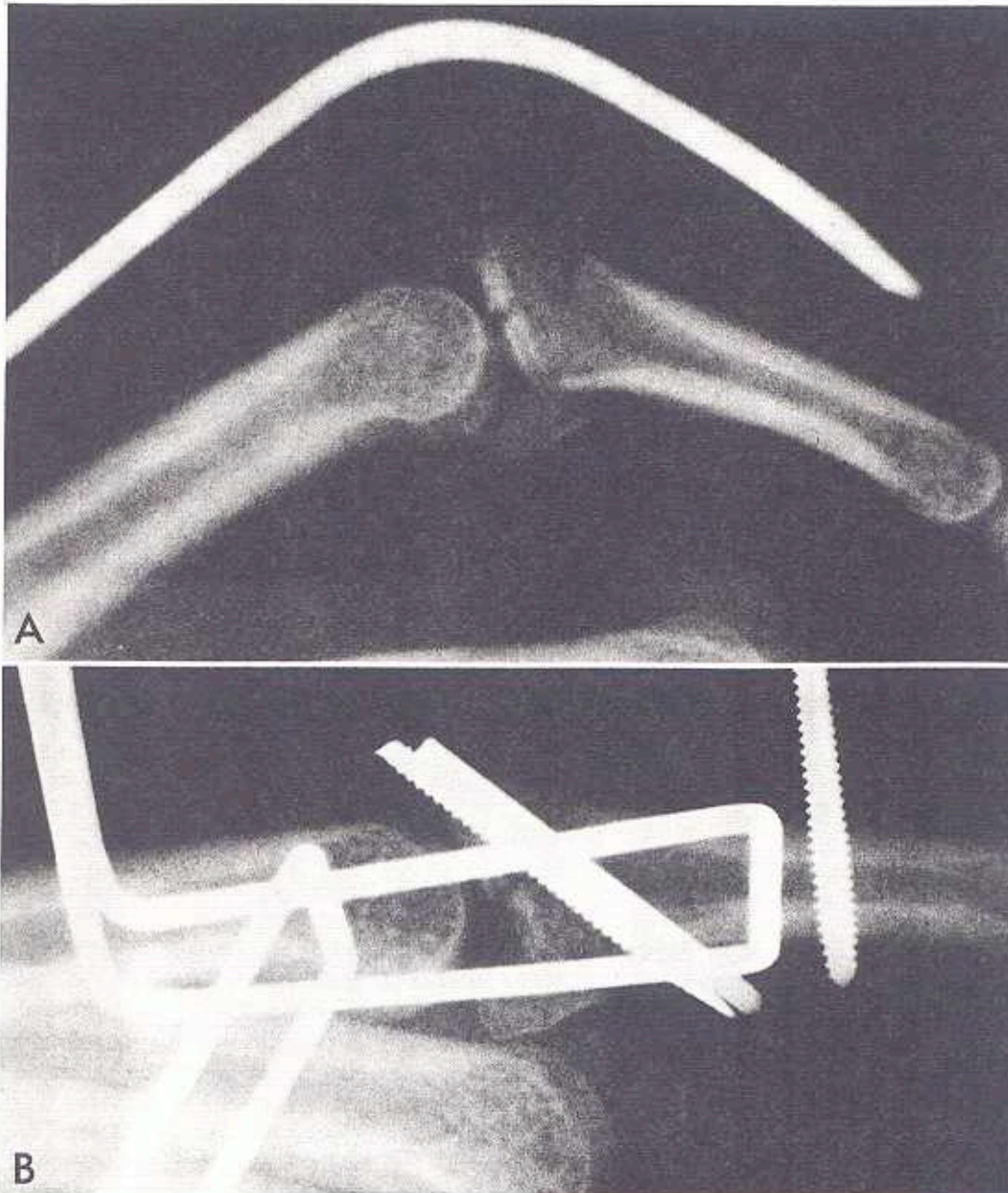
FIGS. 2A-2D. (A) Case 9, typical PIP fracture dislocation. (B) Concentric reduction of the dorsal base of the middle phalanx after application of force couple splint. (C and D) Extension and flexion range of motion at 4 years after injury.

SURGICAL TECHNIQUE

The technique depicted in Figures 1A-1L was developed on fresh cadaver hands. After inserting and forming the Kirschner wires into a mechanical linkage, a small rubber band is placed with tension adequate to maintain reduction; excessive tension must be avoided (Figs. 1I and 1J). When closed reduction is possible, the force couple splint is applied percutaneously preferably under digital block anesthesia thereby allowing the patient to demonstrate the joint's active range of motion. The quality of joint reduction is assessed with anteroposterior (AP) and lateral roentgenograms of the joint in the extended position and an additional lateral roentgenogram in the flexed position. The flexion and extension lateral roentgenograms are examined closely to assure

that the intact dorsal base of the middle phalanx is concentrically reduced as evidenced by its parallel gliding motion with respect to the head of the proximal phalanx. A rocking motion of the middle phalanx on the proximal phalanx is to be avoided as it predisposes to high joint surface pressures and secondary traumatic arthritis as well as recurrent joint subluxation. Unfortunately, a "crisp and clean" gliding action is only possible with acute injuries. The force couple splint maintains joint reduction during bone and soft tissue healing thereby minimizing joint stiffness by allowing active range of motion exercises. A soft dressing is used for a day or two then all restricting dressings are removed in favor of an antibiotic ointment that is applied daily to the pins where they exit the skin.

The smooth K-wire limbs of the device are



FIGS. 3A-3D. (A) Case 4, comminuted fracture of the base of the middle phalanx. (B) Lateral roentgenogram following open reduction and internal fixation combined with application of force couple splint. (C and D) Active range of motion good in spite of persistent depression of the central fragment.

adjusted as needed to keep them centered on the finger, thereby avoiding pressure on the skin. The device is maintained for a minimum

of five weeks with advancing degrees of comminution and instability requiring six to eight weeks. Interval roentgenograms are obtained

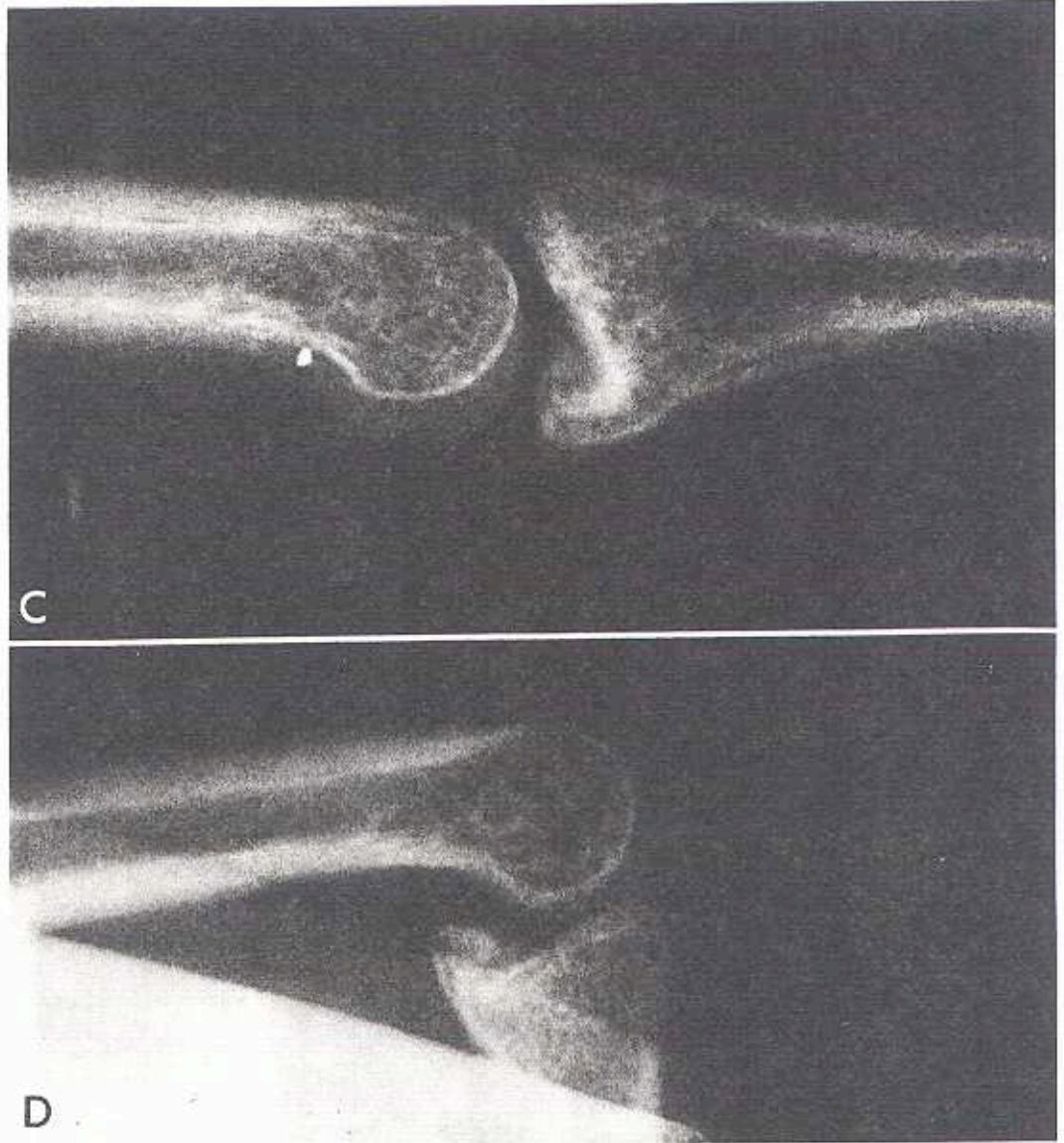


FIG. 3. (Continued)

until bone and soft tissue healing is judged to be adequate. The effect of the force couple is then removed by detaching the rubber band; flexion-extension lateral roentgenograms are repeated to confirm joint stability before removal of the force couple splint. In chronic injuries, open reduction is performed under axillary block anesthesia through a midlateral

incision dividing the lateral retinacular ligament along with the dorsal part of the collateral ligament and adjacent joint capsule. Frequently the dorsal side of the opposite collateral ligament has to be divided through a separate midlateral incision. A probe is used to free the palmar side of the joint, and a small sharp osteotome is used to mobilize the

TABLE 1. Summary of 16 Cases of Unstable Fracture

Case	Age	Sex	% of Surface Involvement	Associated Injury	Age of Fracture	Depressed Central Fragment	Follow-up Period (Months)	Mechanism of Injury
1	24	F	50	DIP fracture	2 days	Yes	3.5 months	Baseball
2	32	M	40	Mallet	2 days	Yes	42 months	Baseball
3	17	M	40	None	3 days	Yes	7 weeks	Baseball
4	22	F	50	Mallet	3 days	Yes	13 months	Baseball
5	19	M	40	None	7 days	Yes	13 months	Basketball
6	18	F	50	None	Acute	Yes	6 months	Unknown
7	25	F	40	None	9 days	No	10 months	Horse rein
8	15	M	50	None	3 days	Yes	12 months	Football
9	29	M	40	Mallet	2 days	No	48 months	Baseball
10	51	M	50	None	2.5 weeks	No	48 months	Handball
11	49	M	25	Mallet	4 weeks	No	6 months	Baseball
12	34	M	40	Fractured DIP	5.5 weeks	Yes	4.5 months	Baseball
13	18	M	25	Mallet	6 weeks	No	66 months	Wrestling
14	27	F	33	None	2 months	No	18 months	Baseball
15	18	M	50	None	7 weeks	No	36 months	Baseball
16	21	F	50	None	4 months	Yes	6.5 months	Baseball

avulsed fragment from the palmar base of the middle phalanx taking care to preserve its blood supply. If portions of the collateral ligaments necessary for adequate stability cannot be maintained, the splint cannot be used as it will convert the dorsal dislocation to a palmar one. With adequate reduction of the intact dorsal base of the middle phalanx with respect to the condyles of the proximal phalanx, the

force couple splint is applied as depicted allowing the smooth transverse Kirschner wires to exit through the surgical incision. When possible, the soft tissues are repaired and, following hemostasis, the skin is closed loosely with interrupted nylon. Roentgenograms are obtained in AP, lateral extension, and lateral flexion to evaluate the adequacy of joint reduction. A soft dressing is applied to the finger

Dislocations of the PIP Treated with FCS

<i>Traumatic Anthritis</i>	<i>Preoperative Active Rom</i>	<i>Prior Treatment</i>	<i>Force Couple Splint (FCS) Open Reduction?</i>	<i>Final Rom Extension/Flexion</i>	<i>Active Rom</i>	<i>Comments/Complications</i>
No follow-up	N/A	None	Percutaneous FCS	20/97	77	
Early	N/A	None	Percutaneous FCS	3/85	82	
Early	N/A	None	Percutaneous FCS	0/90	90	Patient reinjured finger; recurrent fracture dislocation
None	N/A	None	ORIF dorsal base: FCS	0/107	107	Articular base middle phalanx in 3 pieces
None	N/A	None	Percutaneous FCS	0/97	97	Base of middle phalanx with central impaction
None	N/A	None	Percutaneous FCS	0/95	95	
Early	10/47	None	Open reduction: FCS	9/99	90	
None	N/A	Extension block	ORIF volar base: FCS	0/108	108	ORIF palmar base with 2 threaded K-wires
None	N/A	None	Percutaneous FCS	-5/111	116	Loss of DIP flexion from vertical K-wire position
Osteo pre-existing	26/75	None	Percutaneous FCS	17/84	67	Aching discomfort in mornings
None	20/45	Splint	Percutaneous FCS	25/80	55	
Early	20/58	Extension block	Open reduction: FCS	20/112	92	FCS revised to external fixator (see text)
Early	None	None	Open reduction: FCS	0/53	53	Cerebral palsy made ROM exercises difficult
Early	20/47	Extension block	Open reduction: FCS	0/83	83	Previous fracture of PIP and DIP
Severe	20	None	Open reduction: FCS	0/103	103	
Moderate	22/75	Flexion splint	Open reduction: FCS	25/50	25	Resubluxation at 8 weeks; at 6 months had osteotomy

for several days; the wounds are then dressed open with an antibiotic ointment to permit active range of motion exercises.

CASE REPORTS

A 29-year-old school teacher (Case 9) suffered a fracture dislocation of his dominant ring finger PIP joint when a baseball struck the end of his finger (Fig. 2A). Two days after injury, a force couple splint

was applied to the finger under digital block anesthesia with roentgenographic control (Fig. 2B). With the pain relief afforded by the digital block, he demonstrated 90° of active range of motion. When the device was removed at five weeks postoperation, the PIP joint lacked 14° of extension and flexed actively to 85°. Four years after injury, he had no complaints of pain with the joint demonstrating -5° to 111° of active motion of the involved PIP joint compared to -5° to 111° of active motion of the opposite ring finger PIP joint (Figs. 2C and 2D).

Roentgenograms revealed maintenance of a nearly normal joint surface and cartilage space. He had a significant loss of flexion of the distal joint secondary to profundus tendon adhesions caused by excessive palmar penetration of the threaded vertical K-wire (Fig. 2B).

A 22-year-old, right-handed student (Case 4) suffered a "three part" fracture of the base of her right ring finger when a baseball hit its extended tip end-on (Fig. 3A). Three days after injury, an open reduction and internal fixation was performed on the dorsal third of the joint surface stabilizing that fragment with respect to the shaft of the middle phalanx. A force couple splint was then applied percutaneously producing concentric reduction of the dorsal base of the middle phalanx with respect to the condyles of the proximal phalanx (Fig. 3B). Although the central third of the joint surface remained depressed, the palmar third healed in a satisfactory position with the patient obtaining 100° of active PIP joint motion (Figs. 3C and 3D).

RESULTS

Data from the 16 patients are displayed in Table 1. Total active range of motion averaged 83° for all patients with a range from 25°–116°. When the nine "acute" cases are considered separately, the average active range of PIP joint motion increases to 95°. The remaining eight "chronic" case's average active range of motion is 68° (range, 25°–103°). Four of the chronic subluxations (Cases 12, 14, 15, and 16) required open reduction of the joint dislocation before the force couple splint could maintain reduction of the joint. Three of these were improved by an average of 64° while the fourth, Case 16, suffered a 28° loss. (Case 13, a patient with cerebral palsy, was omitted from these calculations as he could not cooperate with range of motion measurements or with therapy.)

Three cases demonstrated early radiographic evidence of traumatic arthritis as evidenced by either cartilage space narrowing or spur formation or both. Four of the chronic patients had significant radiographic evidence of traumatic arthritis (Case 12, 14, 15, and 16) when last examined radiographically. In many cases, the follow-up period is not adequate to predict the eventual degree of joint degener-

ation. As expected, the joints requiring open reduction demonstrated a significantly greater degree of traumatic arthritis at the time of follow-up examination.

Only six patients regained full extension. No patient had more than 25° loss of extension. Of the seven acute cases that had a depressed central fragment, only Cases 1 and 2 obtained less than 90° of motion. Case 1, a 24-year-old woman, had only 77° of active motion when lost to follow-up study at 3.5 months after injury.

COMPLICATIONS

RECURRENT SUBLUXATIONS

One patient with an acute fracture (Case 3) reinjured his finger 2.5 weeks after the force couple splint was removed and suffered a recurrent subluxation of the joint. Ultimately, he obtained 0°–80° of motion when last seen at five months after reinjury. Case 16 was treated for a four-month-old dislocation; she had a recurrent subluxation when the force couple splint was removed at 7.5 weeks. Six months later, she had an open reduction combined with an osteotomy and bone graft designed to realign the malunited palmar lip fragment. She developed a stiff finger with only 25° of active motion. In a third case, the force couple splint converted an original dorsal dislocation to a palmar dislocation. The force couple splint was converted to a miniature external fixator by custom machining parts to match the patient's existing percutaneous K-wires. Active range of motion of 20°–112° was recorded at 4.5 months postoperation when the patient was last examined.

INFECTIONS

One patient, a 60-year-old alcoholic, had a staphylococcal infection following open reduction of a seven-month-old fracture dislocation. This failure was omitted from the series. None of the 16 patients included in this study had a pin tract infection.

LOSS OF DISTAL INTERPHALANGEAL JOINT FLEXION SECONDARY TO FLEXOR TENDON ADHESIONS

In several cases, the vertical threaded K-wire extended beyond the palmar cortex of the middle phalanx. Although the lost motion was not accurately recorded, this complication was significant in Case 9. The vertical threaded K-wire should not extend beyond the palmar cortex of the middle phalanx.

- DISCUSSION

Fracture dislocations of the PIP joint with injury to a third or less of the palmar base of the middle phalanx can usually be treated successfully with closed reduction and extension block splinting as described by McElfresh *et al.*⁵ When 30%–40% or more of the palmar base of the middle phalanx is sheared off or centrally displaced, the potential to regain a gliding type of joint motion is progressively lost and is replaced by a "tilting joint" in which the sharp palmar edge of the intact portion of the articular base "digs into" the condyles of the proximal phalanx. As with other intra-articular injuries, the ideal treatment would include restoration of a stable and congruent joint surface that would allow early, active range of motion; technical problems associated with the degree of bone and soft tissue injury frequently make anatomic reduction and internal fixation difficult if not impossible to achieve.

In acute cases of fracture dislocation in which 30% or more of the joint surface is involved, the force couple splint is capable of maintaining a concentric reduction of the intact dorsal base of the middle phalanx with respect to the condyles of the proximal phalanx. It accomplishes this by a method that permits active range of motion exercises during bone and soft tissue healing, thereby minimizing joint stiffness while increasing the potential for biologic remodeling of the articular surface.

In these PIP joint injuries, the dorsal displacement of the middle phalanx typically leaves a triangular portion of the base of the middle phalanx normally aligned to the condyles of the proximal phalanx. This is secondary to the relatively intact palmar plate and accessory portions of the collateral ligaments. When the dorsal base of the middle phalanx is intact, reduction of the dislocation by the force couple splint realigns the palmar fragment(s) with the proximal metaphysis. If a depressed central fragment is present, its position remains unimproved unless it is openly elevated. Even with this limitation of the force couple splint, only two of the seven acute cases with a depressed central fragment did not regain at least 90° of active motion; one of those (Case 1), lost to follow-up study at 3.5 months, would be expected to improve active range of motion above 77°.

When the force couple splint is used to treat "nonacute" fracture dislocations of the PIP joint, the average range of motion is decidedly less than those in the acute group (95° versus 68°). Early in the series, two of the nonacute cases (10 and 11) had the force couple splint applied without the benefit of an open reduction. Case 10 was compromised both by the delay in treatment (2.5 weeks) as well as the moderately severe osteoarthritis present in the joint at the time of injury. Case 11 obtained only 55° of motion probably owing to recurrent subluxation; this and Case 16, which obtained only 25° of motion, are considered failures.

The force couple splint offers an effective approach for treating acute dorsal fracture dislocations of the PIP joint. It is particularly suited for treating those unstable injuries with loss of 30% or more of the palmar base of the middle phalanx as lesser degrees of instability are probably best treated by extension-block splinting. When used to treat chronic subluxations with associated malunited fractures, it must be combined with the soft tissue release of an open reduction taking care to preserve at least a portion of the collateral ligament on

each side of the joint. Several failures in this limited series of seven nonacute subluxations argue in favor of more experience before it can be recommended over other currently available approaches such as palmar plate arthroplasty as described by Eaton,³ or osteotomy and bone graft as described by Zemel *et al.*⁹

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