Intraosseous wiring of the digital skeleton

One hundred cases of osteosynthesis done by the use of intraosseous wiring are presented. Two techniques of wiring are described, one used in transverse fractures and arthrodeses in which an additional Kirschner wire is employed, the other in which No. 0 monofilament wire can be placed perpendicular to the line of osteosynthesis. Forty-seven fractures were treated and there was union in all cases; 53 arthrodeses were performed, with failure in five, due, it is believed, to a failure to observe the essential elements of the technique, namely the need to obtain congruous bone ends and to maintain all internal fixation until there is clinical evidence of union. Overall, 83.2% of the maximum attainable total active range of motion was achieved in the 100 cases.

Graham Lister, F.R.C.S., *Louisville, Ky.*

It has been stated that early return to full function following fracture requires anatomical reduction, rigid internal fixation, and early, active, pain-free mobilization of the muscles and joints adjacent to the fracture.[1]

Understandably, in the digital skeleton, which is constructed of the smallest bones commonly fractured, these demands are most difficult to meet. However, disregard for any one of them must give a less than perfect outcome in a significant number of patients. Inaccurate reduction may result in malunion and, particularly in intra-articular fractures, in consequent loss of range of motion and early degenerative arthritis. Inadequate fixation may cause loss of reduction and may create an important cause of eventual failure to attain a full range of digital movement. Such immobilization may be due to the surgeon's doubts about the fixation or the patient's inability to cooperate, often on account of pain arising from inaccurate reduction, inadequate fixation, or impingement on the soft tissues of the metal used to achieve the fixation.

It has long been realized that the most rigid form of internal fixation is achieved if accomplished by compression of the two bone ends. Compression, it should be emphasized, "does not have any mystical osteogenic properties,"[1] but it does tend to satisfy all three basic principles enunciated above.

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Reprint requests: Graham Lister, F.R.C.S., 1001 Doctors Office Bldg., 250 E. Liberty St., Louisville, KY 40202.

In many phalangeal fractures, however, even the small fragment set recommended by the ASIF group either presents serious drawbacks or cannot be employed at all.[2] The intra-articular fracture to one fragment of which the collateral ligament or the palmar plate is attached (as in Fig. 5, *B*) often is too small to take a screw or, if sufficiently large, would require detachment from the capsule, its only source of blood supply, to permit the screw to be inserted. While oblique or spiral fractures of the diaphysis can be fixed with a cortical screw, the more common transverse fracture requires a plate if the ASIF technique is to be employed. To apply such a plate demands an adequate length of bone on either side of the fracture, to allow screw fixation, and also necessitates either that the plate lie immediately beneath the extensor apparatus or that the periosteum be extensively stripped only to prove nonetheless inadequate for complete coverage of the metal. Both alternatives may prove unacceptable.

In such situations the most widely used fixation device is the Kirschner wire. However, if used singly this rarely provides rigid fixation, and if several are used in an attempt to render the bone immobile, the fragments may be held apart rather than together. After Kirschner wire fixation, motion often is limited severely by transfixion of the soft tissues.

For these reasons a technique of intraosseous wiring similar to that employed in fractures of the jaw has been used since January, 1975, for an increasing proportion of cases requiring fixation of the digital skeleton, both for fracture union and for arthrodesis. I lay no claim to originality for this technique, for a similar method was reported by Robertson[3] in 1964.

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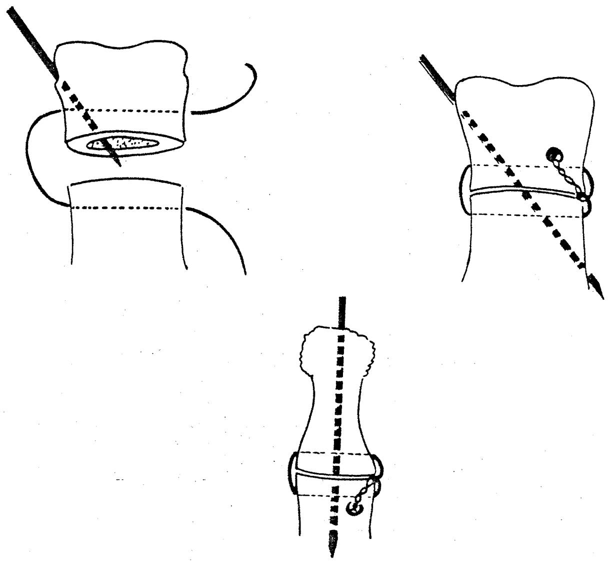


Fig. 1. In type A intraosseous wiring, the intraosseous portion of the wire runs parallel to the fracture line and, while providing rotatory and some lateral angulatory control, it does not provide anteroposterior immobilization of sufficient security as to permit early motion. For this reason, a single 0.035 in Kirschner wire is added, passing from one cortex to another across the fracture line without entering into a joint. This type of fixation is employed for arthrodeses and transverse fractures.

Material

Fracture fixation. Thirty patients with a total of 47 fractures of the digital skeleton have been treated by intraosseous wiring. Their ages ranged from 4 to 48 years, with a mean of 23 years. The fractures were made up of 12 to the proximal phalanx, eight to the middle phalanx, 24 to either or both articular surfaces of the proximal interphalangeal joint, and three to the metacarpal. For reasons to be discussed, the technique has been employed only in the metacarpal for fractures of the distal articular surface. In the proximal interphalangeal articular fractures, six patients had a single fracture, three had two fractures, and four had three or more breaks in the articular surface (all such were counted as three for the purpose of reporting). While the majority have been operated on within 48 hours of injury, four of the patients did not present until more than 3 weeks after injury and one came 80 days after injury with no evidence of union

Arthrodesis (Table I). Intraosseous wiring also has been employed in 53 interphalangeal arthrodeses in 45 patients. Their ages ranged from 17 to 74 years, with a mean of 36 years. Twenty-eight arthrodeses were of the distal interphalangeal joint, 16 of the proximal interphalangeal joint, five of the interphalangeal joint, and four of the metacarpophalangeal joint of the thumb. Eight (15%) of the arthrodeses were performed primarily, following trauma, usually in the course of digital replantation. The largest group was that done secondary to significant joint or tendon injuries, 33 arthrodeses or 62.3% of the total. Primary degenerative osteoarthritis accounted for five (9.5%) and rheumatoid disease for seven (13.2%).

Table I. Sites of and reasons for arthrodesis

	Finger		Thumb			
	PIP	*DIP*	*MP*	*IP*	*Total No.*	*%*
Trauma						
Primary	6	—	2	—	8	15
Secondary	10	19	2	2	33	62.3
Osteoarthritis	—	4	—	1	5	9.5
Rheumatoid	—	5	—	2	7	13.2
Total	16	28	4	5	53	100

Legend: PIP, proximal interphalangeal. DIP, distal interphalangeal. MP, metacarpophalangeal. IP, interphalangeal.

Technique

A variety of wires has been tested, but in the major part of the series stainless monofilament steel wire of size No. 0 (B and S gauge 26) was used. In all instances the wire was passed through two parallel holes drilled with a 0.035 in Kirschner wire. Depending upon the circumstance, these holes were either parallel to the fracture line (type A) or at right angles to it (type B). In the latter instances in which the wire crossed the fracture line and exerted direct compression upon the fragments, a single wire often was sufficient to give rigid fixation. This situation occurred in the majority of intra-articular fractures. In transverse fractures and in all arthrodeses where the *truly intraosseous* portions of the wire were parallel to the bony defect, the wire provided good rotatory stability, but the fragments were relatively insecure to angulatory forces. In these instances a single 0.035 in Kirschner wire engaging two cortices was added to resist these forces, the direction of the wire being dictated by the desire to avoid transfixing joints or mobile soft tissues. Thus the Kirschner wire was placed longitudinally in some arthrodeses and obliquely in others and in transverse fractures.

Type A wiring—arthrodesis or transverse fractures) (Fig. 1). Over the phalanges or proximal interphalangeal joint, exposure was achieved using a midline dorsal incision whereas in the distal inter-

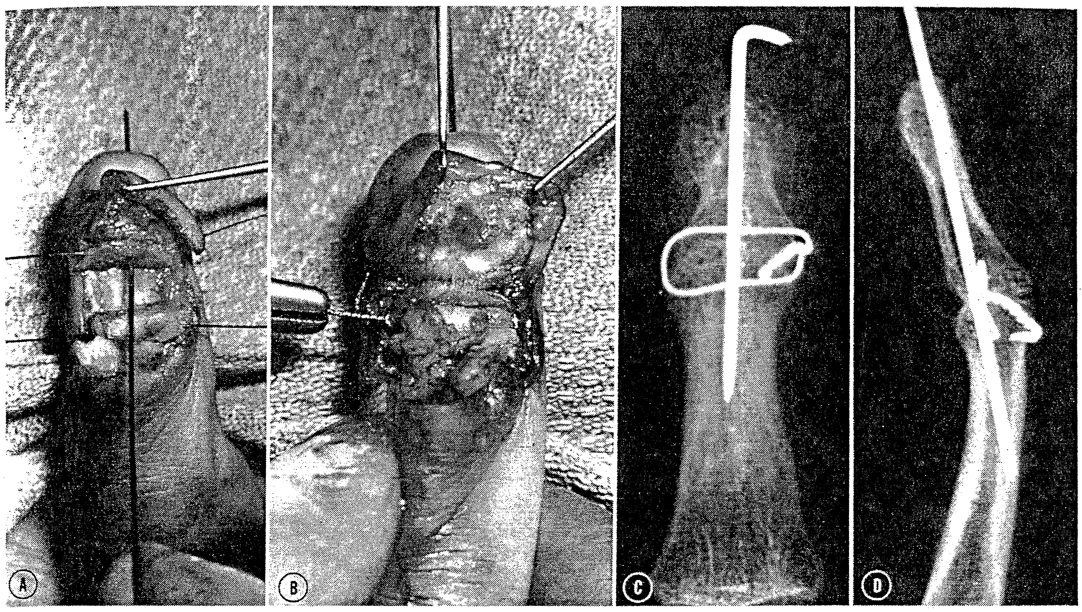


Fig. 2. A, Some 5 mm from the prepared bone ends, transverse holes are drilled with a Kirschner wire and No. 0 monofilament wire is passed in such a way that the twist of the wire will be on the noncontact side of the digit. **B,** After the arthrodesis has been reduced and the Kirschner wire driven retrograde into the cortex, the intraosseous wire is tightened down. Another hole is drilled with the remnant of the Kirschner wire, and the end of the twisted intraosseous wire is turned in to that hole to prevent it from being near the skin. **C** and **D,** The resultant fixation is seen on anteroposterior and lateral roentgenograms.

phalangeal joint an H-shaped incision was made. It is important in this latter type of incision that the vertical limbs of the H be true mid-lateral incisions, as these will lead to the junction of the distal end of the collateral ligament and the lateral interosseous ligament of the distal phalanx,[4] which is the point at which the transverse hole is to be drilled. One also should take care to carry the dissection of the distal flap as deeply as possible, that is on the extensor tendon and adjacent periosteum of the distal phalanx, thus ensuring the vascularity of the flap.

The bone then was displayed by displacing the extensor apparatus by a procedure that was appropriate to the site.

The bone ends were prepared, in the case of fractures, by removing any intervening soft tissue or small, free fragments. When the fracture was grossly comminuted and there were many free fragments which had to be removed, consideration was given to cutting the remaining bone ends to fit one another. Where there were several fragments still attached to soft tissue, type B wiring could be used. In all instances, the aim had to be rigid fixation. For arthrodesis, the joints were prepared by removing the articular cartilage and rendering the bone ends congruous, either flat at the correct angle o shaped into a "spike and cone," as recommended by Carroll and Hill.[5] The collateral ligaments were excised, as was the palmar plate.

Transverse holes then were drilled with a 0.035 in Kirschner wire parallel to the bone ends and approximately 5 mm from them, somewhat dorsal ~~to~~ the axis, for reasons to be discussed later. The No. 0 monofilament stainless steel wire was passed in such a way that the twist of the wire would be on the noncontact side of the digit, that is the ulnar side of the index, middle, and ring fingers and the radial side of the thumb and little finger. *The twist was not made yet,* however. First, the 0.035 in Kirschner wire which had been used to drill the transverse holes was driven out through the distal bone cortex (Fig. 2, *A*) until only its tip showed above the raw bone surface. The surgeon then reduced the two ends under direct vision and held them firmly together, while another surgeon drove the Kirschner wire into the proximal fragment until it was imbedded in cortical bone. The ends of the intraosseous No. 0 wire *then* were twisted around one another, cut to about 1 cm in length, grasped with a heavy needle holder, and tightened down (Fig. 2, *B*).

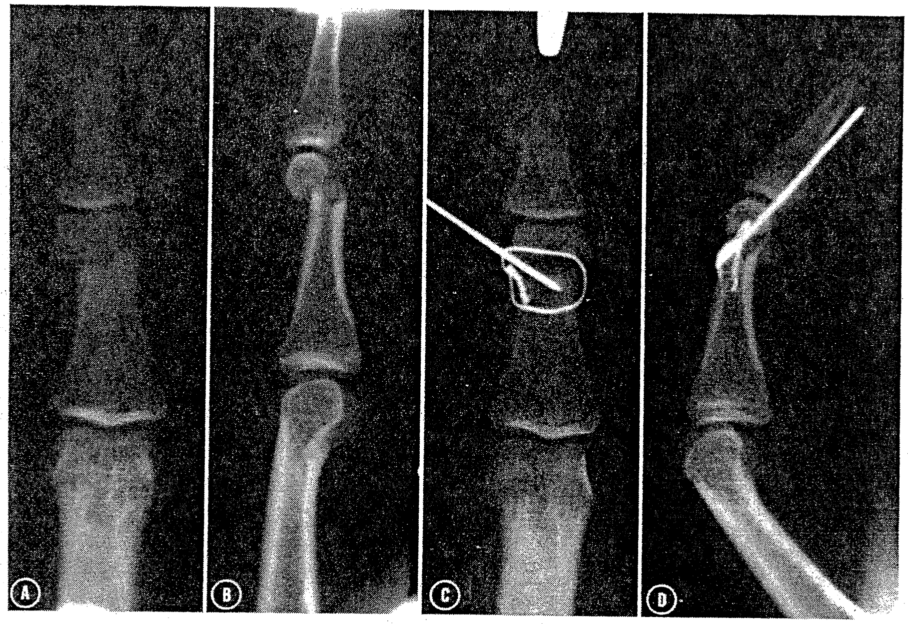


Fig. 3. A and **B,** A metaphyseal fracture of the middle phalanx, showing dorsal displacement of the distal fragment. **C** and **D,** The Kirschner wire and intraosseous wiring are seen in position.

Tightening down the wire involved two distinct actions, pulling to snug the wire on to the bone on the opposite side of the digit and twisting to tighten it. The Kirschner wire was cut and the redundant end was used to drill a hole through one cortex, conveniently close to the twisted end of the monofilament wire, which then was turned down into the hole to remove it from beneath the overlying skin. Roentgenograms confirmed the location of the wires (Fig. 3 *C* and *D*).

As stated, this technique has been used primarily for diaphyseal fractures, transverse metaphyseal fractures (Fig. 3), and for both osteosynthesis and arthrodesis in replantations. The Kirschner wire was not necessary in those five proximal interphalangeal joint fusions and one distal interphalangeal joint fusion in which intraosseous wiring was employed in conjunction with a bone graft after the fashion of Moberg[6] or the modification of Potenza.[7]

Type B wiring—(intra-articular fractures) (Fig. 4). The fracture was exposed (Fig. 4, *B*), reduced, and held with ASIF reducing forceps, checking the congruity of the articular surfaces. Two parallel holes then could be drilled at right angles to the fracture and across it. The drilling of parallel holes was facilitated by leaving the first Kirschner wire in place as a pilot for the second (Fig. 4, *C*). In the limited exposure available, it often was helpful to use a Kirschner wire with a hole in the tip by means of which the monofilament wire could be withdrawn through the path drilled by the Kirschner wire. When such was not available, a 20 gauge hypodermic needle passed along the track could easily accommodate a No. 0 wire. The intraosseous wire was tightened down and secured as before, rechecking the congruity of the articular surface as one proceeded (Fig. 4, *D*).

In many avulsion fractures, the fragment of bone attached to the collateral ligament or palmar plate is too small to drill. In such a situation, the monofilament wire is passed through the ligament close to the fragment—again employing a 20 gauge needle, and then through parallel holes adjacent to the fracture surface on the phalanx (Fig. 5). The point at which the wire emerges on the side of the phalanx opposite the fragment is clear of tendons in collateral ligament reattachment and presents no problems. In the case of palmar plate avulsion fractures, the wires must emerge under the extensor tendon. However, there is a forgiving area on the dorsum of the middle phalanx, the triangular ligament, and the surgeon should aim to bring the wires out through the ligament in the midline and about 5 mm apart.

In almost all instances, rigid reliable fixation should be achieved. External splintage then is not required, except for the patient's comfort during the immediate postoperative phase and motion can be commenced with confidence once that phase is over. In this series motion was started earlier and earlier as our confidence in the technique grew. Active exercise was started by

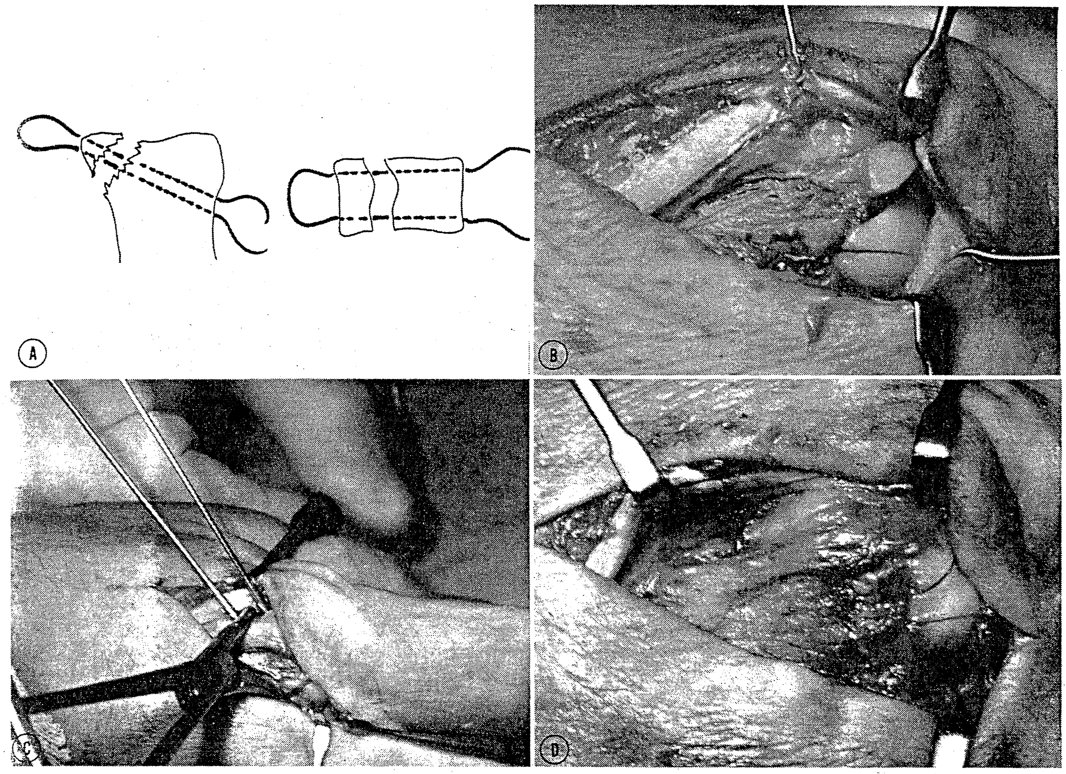


Fig. 4. A, Type B wiring is that used most frequently with the avulsion of a fragment of bone by collateral ligament, palmar plate, or tendon. In this instance, the intraosseous wire passes perpendicular to the fracture line and sufficient compression to the fracture line can be applied as to permit early motion without additional fixation. In those few instances where the fracture surfaces are extremely smooth, a little rotation can occur and it is judicious to add a single Kirschner wire. **B,** Two intra-articular fractures of the head of the index metacarpal have been exposed. **C,** Two parallel Kirschner wires have been introduced after reduction of the fragments which are held in place with ASIF reducing forceps. This facilitates the placing of parallel holes, through which the intraosseous wire can be passed. **D,** The reduction is shown after fixation by intraosseous wiring.

the third day whenever possible. In type A wiring, the Kirschner wire was removed when there was no tenderness to palpation over the site of osteosynthesis, indicating clinical union.

Results

None of the 75 patients was lost to follow-up. No secondary procedures, such as capsulectomy or tenolysis, were performed before the results reported below were obtained. All fractures united, with radiological evidence of fusion in the form of cross-trabeculation occurring after a very consistent interval ranging from 6 to 8 weeks, with an average of 7.25 weeks. The total active range of digital motion (TAM) (Table II) after all fractures was from 110° to 250°—the normal range in an uninjured finger—with a mean of 199°. After nonarticular fractures the TAM was 150° to 250°, with a mean of 210°, and after articular fractures was 110° to 240°, with a mean of 192°. No complications were encountered.

Of those thumbs subjected to arthrodesis of joints, all united. Of the 16 arthrodeses of the proximal interphalangeal joint, two (12.5%) failed (Table III). These both were primary fusions without bone grafts, performed in the course of digital replantation. Review of the films revealed marked incongruity of the bone ends. Of the 28 arthrodeses of the distal interphalangeal joint, three (9.3%) failed. In all cases the bent Kirschner wire protruding from the finger tip was removed accidentally by the patient prematurely. Thus arthrodesis failed in a total of five cases (9.4%).

In all of the arthrodeses, three complications occurred (5.7%): minor skin breakdown in one patient; protrusion of the intraosseous wire in one patient (this

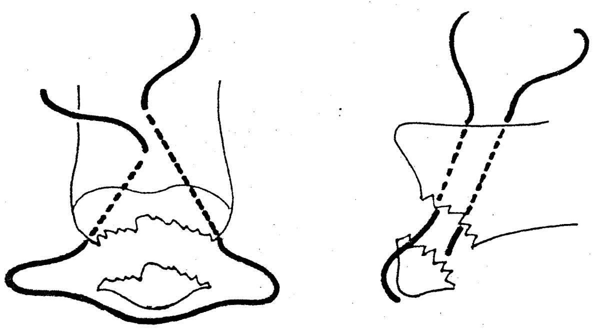


Fig. 5A. Where the fragment is too small to drill, the wire can be passed through the attached ligament hard against the bone.

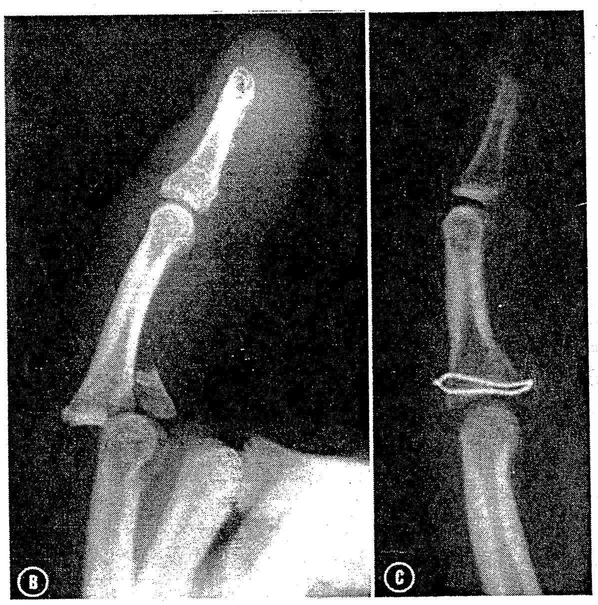


Fig. 5B. A fracture dislocation of the proximal interphalangeal joint. The fragment which remains attached to the palmar plate is too small to take a compression screw.
Fig. 5C. The intra-articular fracture was reduced, and a wire was passed through the junction of the palmar plate with the bone and then through two drill holes, bringing the wire out in the region of the triangular ligament on the dorsum of the middle phalanx. This proved to be secure and no additional fixation or external immobilization was necessary.

occurred before we routinely buried the tip of the twisted wire in bone); osteitis in one patient in whom the Kirschner wire had come out by accident and who replaced it herself, with considerable trauma to the finger.

Radiological union in the arthrodeses varied more than in the fractures—from 6 to 24 weeks, with an average of 9.6.

Table II. Fractures and range of motion following osteosynthesis

Site	No.	Total active range of motion (in degrees)		
		Distribution	*Average*	*Normal*
Articular	24	110 to 240	192	250
Nonarticular	23	150 to 250	210	250
Total	47	110 to 250	199	250

Table III. Incidence of non-union following arthrodesis

Site	*No.*	*Non-union*	*%*
Thumb			
MP	4	0	0
IP	5	0	0
Finger			
PIP	16	2	12.5
DIP	28	3	9
Total	53	5	9.4

Legend: See Table I.

Table IV. Range of motion following arthrodesis

Site	*No.*	*Total active range of motion (in degrees)*		
		Distribution	*Average*	*Normal*
PIP	16	90 to 140	124	150
DIP	28	120 to 190	167	190

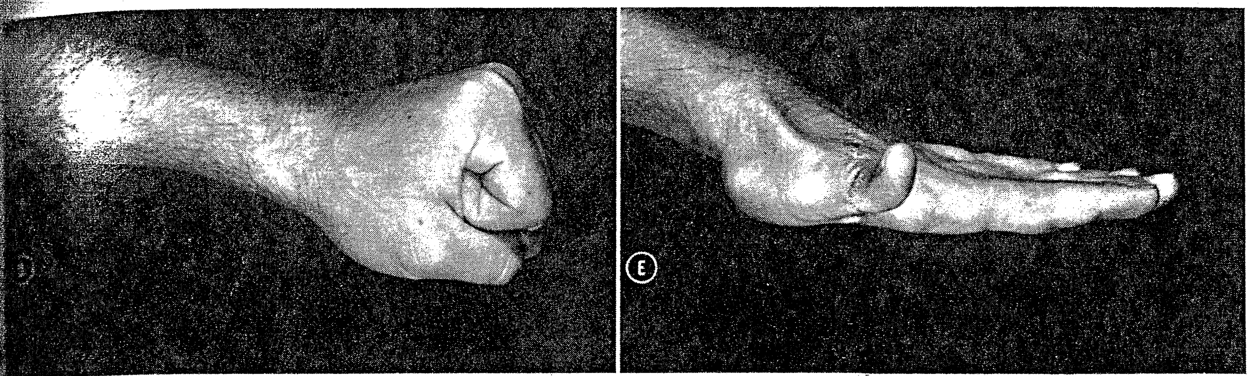
Legend: See Table I.

Composite digital motion after proximal interphalangeal fusion ranged from 90° to 140°, with a mean of 124°, as compared with a maximum attainable of 150° (Table IV). After distal interphalangeal fusion, composite motion was 120° to 190°, with a mean of 167°, as compared with a maximum attainable of 190°.

In the entire series (Table V), 100 attempts at osteosynthesis were made, with 95 (95%) achieving primary union. The total active range of digital motion which was regained averaged 83.2% of the maximum attainable.

Discussion

With regard to fracture fixation, this technique was adopted because of dissatisfaction with our own results. Nowhere in the literature is there to be found a review of phalangeal fractures which reports the unsatisfactory



Figs. 5D and **5E.** A full range of motion in the involved index finger was present 8 weeks after reduction.

Table V. Union and percentage return of motion following osteosynthesis

	No.	*Time to radiological union (wk)*		*Non-union*		*Total active range of motion (% of normal)*
		Range	*Average*	*No.*	*%*	
Fracture	47	6 to 8	7.25	0	0.	80
Arthrodesis	53	6 to 24	9.6	5	9.4	86.3
Total	100			5	5	83.2

results in terms of delayed union, malunion, or loss of function.

Reports on the rate of union with various techniques of arthrodesis certainly are available and are remarkably consistent, regardless of the method—for example, 95% with the "spike and cone" of Carroll and Hill[5] and 95% with the bone graft of Moberg[6] and, as it transpired, with the method described herein (91%.) Only Potenza[7] had shown greater success, with no failures in 40 arthrodeses. However, no reports were available on the range of motion retained in adjacent joints and all recorded techniques requiring splint immobilization of the digit for from 3 to 6 weeks. The intraosseous wiring appeared to be simple and attractive, not requiring the skill in carpentry of the Moberg method, and further it introduced a degree of compression not found in other procedures. Finally, this compression offered the possibility of secure early motion of adjacent joints.

Certain points in the technique described are worthy of added emphasis.

The bone ends must be congruous or rendered so, for the technique, especially the type B wiring, has none of the imposed stability of plating. This is not a disadvantage of the method, provided congruity is achieved, for it is not possible to hold congruous bone ends *apart* with intraosseous wiring as can be done with plates and Kirschner wires. Disregard of the shape of the bone ends accounted for the two failures of proximal interphalangeal arthrodesis, where the surgeon clearly was more concerned with survival of the replanted digits than with bone union.

When Kirschner wires are used in type A wiring, the wire must engage two cortices as well as crossing the fracture line, so ensuring sound control of angulating forces. The Kirschner wire is necessary in type A wiring if early movement is to be permitted, otherwise forces applied to the digit may stretch the wire or, much more probably, may cause the wire to cut through the bone. In either circumstance, fixation would be lost. In his original description, Robertson[3] used intraosseous wire only but also applied a plaster-of-Paris splint for from 3 to 6 weeks.

Robertson inserted two intraosseous wires in an anteroposterior direction parellel to one another. Transverse wires were adopted in this series for three reasons. First, the method was simpler and required less dissection on the palmar aspect. Second, it was felt that, in combination with the Kirschner wire, the transverse wire gave marginally better control of both lateral and anteroposterior angulation forces. Finally, by placing the wire dorsal to the axis and commencing early

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Vol. 3, No. 5 September, 1978

motion, provided the wire did not cut through the bone, any flexing of the Kirschner wire would result in tension band compression of the bone ends.

The protrusion of the Kirschner wire from the tip of the digit after distal interphalangeal fusion presents a hazard, not only because it can inflict injury, but also because it may catch on clothing and thus be pulled out prematurely. In this series this misadventure resulted in the three non-unions of distal interphalangeal arthrodeses and also in the one serious complication, osteitis, for it is improbable that this would have occurred had the patient not persisted in attempting to reinsert it until it came to rest at the osteosynthesis site.

The only situation in which type A wiring is not accompanied by a Kirschner wire is where the bone peg, as described by Moberg, is being employed. This technique is used now only where the bone ends are osteosclerotic, as when fusion by another method has failed, or grossly osteoporotic, as in rheumatoid patients. We have added the intraosseous wiring in order to eliminate the external immobilization recommended by Moberg. The wire can be passed with benefit through the bone peg and proximal phalanx proximally, but through the middle phalanx only distally. Thus tightening the wire will impact the bone peg. Care must be taken that the peg is not too large for the medulla of the middle phalanx, otherwise tightening the wire, while impacting the peg, will drive the phalanges apart.

Techniques similar to type B wiring have been employed previously for fracture fragments attached to collateral ligament, tendon, or volar plate. In those instances, however, the wire has been brought out through the skin and fixed with lead shot over a button or similar device intended to protect the skin.[8] This seems mechanically unsound or surgically unacceptable, for adequate compression can be applied only by hazarding the blood supply to the skin and other structures lying between it and the bone. For this reason the method described was adopted, in which a gratifying amount of compression can be applied to the bone without any fears for the health of other less sturdy tissues.

Intraosseous wiring is not applicable to shaft fractures of the metacarpals. Long spiral oblique fractures can be controlled better by one or preferably two compression screws. Transverse fractures offer an area of bony contact which is very small when compared with the length of bone. This means that type A intraosseous wiring gives poor fixation, even with the addition of the Kirschner wire, which, in any event, is difficult to place from cortex to cortex while still avoiding the joints. For these reasons, the author favors minifragment compression plating of transverse metacarpal fractures where internal fixation is indicated.

Since few authors have stated the range of motion achieved after osteosynthesis and those who have mainly in general terms—for example, 90% of Joshi's[9] series of 61 proximal phalangeal fractures achieved "satisfactory" results, it is not possible to evaluate comparatively the results obtained above. Our own unpublished review of proximal interphalangeal articular fractures treated by Kirschner wire fixation and immobilization for 3 weeks or more showed an almost uniformly gloomy prognosis, not only for motion of the involved joint but also for that of the distal interphalangeal joint, the average TAM being 157°. In the series presented here, partly inspired by that review, the average TAM for all phalangeal fractures was 199°, but, even more encouraging was the fact that the patients with articular fractures regained an average of 192°, only 18° less than that obtained in shaft fractures alone. We believe that even better results can be obtained with earlier motion as now being employed.

Early motion following phalangeal fractures is by no means a revolutionary concept, having been recommended following a retrospective review of a large series of phalangeal fractures by Barton,[10] and in conjunction with a variety of techniques, including extension block splinting,[11] percutaneous internal fixation,[12] and the elaborate "banjo" splinting employed by Robertson, Cawley and Faris.[13] What does deserve attention, rather, is the virtual unanimity in favor of early motion amongst all authors reviewing phalangeal fractures.

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