APPLICATION OF MULTIPLANAR LIGAMENTOTAXIS TO EXTERNAL FIXATION OF DISTAL RADIUS FRACTURES

John M. Agee, M.D.
Director
Hand Biomechanics Lab. Inc.
77 Scripps Drive, Suite 104
Sacramento, CA 95825
(916)920-8051

INTRODUCTION

Distal Radius Fractures

Of all fractures that can occur in the hand and wrist, those of the distal radius have the greatest potential to impair function. Fractures of the distal radius are most frequently generated by the high-energy impact to the outstretched hand as a result of a fall. Numerous classification systems for distal radius fractures have been devised[14,18,19,26,30,31,33,37-39,41]. As first described by Colles[13], these extra-articular fractures of the distal radial metaphysis are associated with dorsal displacement of the distal fragment. In many of these fractures, the dorsal cortex and distal fragment are comminuted. Frequently, serious disruption of the distal radial articulations occurs and malalignment of the distal radioulnar joint may result from fracture displacement[34]. Anatomic reduction of comminuted fractures of the distal radius is often a challenge, as these inherently unstable fractures are prone to collapse and displacement[14,22,24,55].

Ligamentotaxis

Fractures of the distal radius have the potential to disrupt the mechanical function of the hand drastically. Unfortunately, the same ligaments and tendons that surround the fracture and serve to mold its reduction frequently present barriers to open reduction. The molding of fracture fragments into alignment by traction force applied across the fracture through the surrounding soft tissue is known as ligamentotaxis[52]. Although the capsular and ligamentous structures generally are preserved following comminuted fractures of the distal radius[53], they can be injured at the time of fracture[35]. Because of these injuries, the integrity of the wrist ligaments may not always be adequate to maintain reduction by ligamentotaxis[55]. Böhler[7] employed uniplanar ligamentotaxis in the form of skeletal traction to maintain length during fracture healing. Anderson and O'Neil[3] were first to maintain fracture reduction with an external fixator using the same principle of ligamentotaxis. DePalma's cadaveric study[16] and numerous clinical studies[8,14,15,22,30,48,49] have documented the value of intact soft tissue in obtaining and maintaining skeletal length during the fracture healing process. However, clinical studies have frequently revealed that longitudinal traction alone cannot adequately restore joint congruity and palmar tilt to the distal radius. These clinical observations have been confirmed in a cadaveric study in which traction forces applied parallel to the radius could not restore the distal radial articular surface to normal[5].

TREATMENT OF DISTAL RADIUS FRACTURES

Both osteoarticular[14] and soft tissue[14,45] complications can result from distal radius fractures. Cooney et al.[14] reported a complication rate for distal radius fractures of over 31% and found that the incidence was correlated with the severity of the fracture. In addition to complications resulting from the initial injury, some complications are related to the method of treatment. The adequacy of fracture reduction is one factor that affects the complication rate[57]. The most favorable treatment of distal radius fractures requires techniques that avoid such complications as hand stiffness, carpal tunnel syndrome and fracture malunion. This section briefly outlines historical approaches to the treatment of distal radius fractures and is followed by a discussion of the anatomical and biomechanical principles upon which state-of-the-art fracture reduction and fixation technology is based.

Plaster Cast

An early standard approach to the treatment of distal radius fractures, as well as other wrist fractures, was closed reduction and immobilization with a plaster cast[17]. This technique does not always adequately maintain fracture reduction as fixed traction is not obtained. A common problem is shortening of the radius at the fracture site. Active finger motion and use of the hand are compromised by the cast.

Pins and Plaster

As early as 1929, Böhler[7] recommended that fracture reduction be maintained by the use of transfixing pins incorporated into a plaster cast. This method uses skeletal traction to maintain length during healing of the fracture.

Although this technique usually does not restore normal palmar tilt[15,22], it is still in wide use today[12,22,29,42,46].

Open Reduction and Internal Fixation

There are some instances when bone stability or articular congruity are not obtained by closed reduction of the distal radius fracture[40]. In these instances, open reduction followed by internal fixation is an option. This approach to fracture management is often technically difficult and is frequently accompanied by numerous complications.

Closed Reduction and External Fixation

Numerous complications were associated with the early use of an external fixator for fracture management. These complications were, in part, related to a lack of understanding of the biomechanical principles involved in the proper use of external fixators. During the past four decades, numerous external fixator designs have evolved[9,24,25,27,52,54]. These designs were often based upon the principle of uniplanar ligamentotaxis by which longitudinal traction was applied to maintain skeletal length. Anderson and O'Neil[3] were first to report incorporation of the principle of ligamentotaxis into maintenance of fracture reduction by external fixation. In combination with pins and plaster or external fixation, a multitude of studies have demonstrated the merit of ligamentotaxis in maintaining skeletal length during fracture healing[8,14,15,22,30,48,49]. Although many commerical devices that utilize longitudinal traction are available, clinical[5,19,33,50] and cadaveric[5] observations have revealed that they are often unable to restore joint congruity and normal palmar tilt of the distal radial articular surface.

Biomechancis of Multiplanar Ligamentotaxis

Inherent to the design of any external fixator that allows restoration of joint congruity and palmar tilt to a fractured distal radius is a detailed understanding of the biomechanical principles of multiplanar ligamentotaxis. Multiplanar ligamentotaxis extends the principle of uniplanar ligamentotaxis to include translation of the hand to bring the distal fragment(s) of a fractured radius into alignment. Not only does the design of the fixator allow longitudinal ligamentotaxis, it also integrates the capacity to utilize ligamentotaxis independently in the dorsal-palmar and radial-ulnar planes. This technologically advanced design, which is based on the sound biomechanical principles defined below, allows the surgeon to improve the quality of fracture reduction by permitting fracture reduction in several planes[1].

Biomechanics of Longitudinal Ligamentotaxis

A typical Colles' type fracture is depicted in Figure 1A. Note the displacement of the dorsal fragment. Application

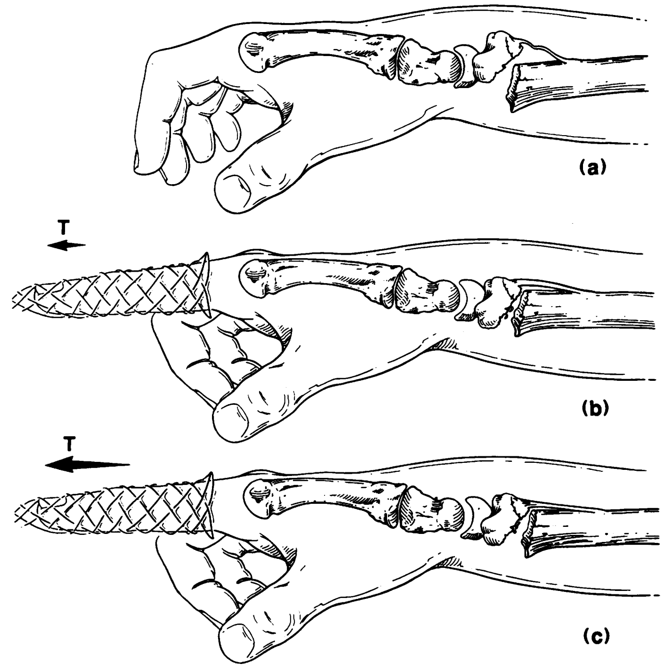
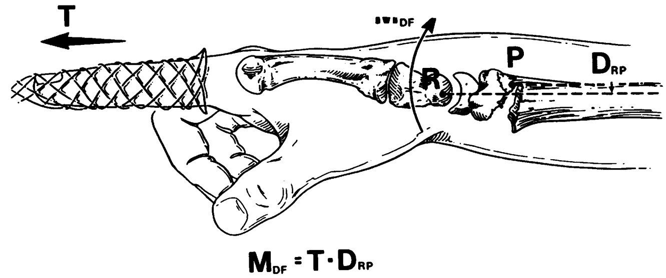


Figure 1
A. Typical displaced Colles' type fracture. B. Restoration of skeletal length by longitudinal traction. C. Increased dorsal tilt resulting from excessive longitudinal traction. (Courtesy of Hand Biomechanics Lab, Inc., Sacramento, CA.)

of longitudinal traction, shown in Figure 1B, initially tilts the dorsal fragment palmarly and restores skeletal length. However, if excessive traction is applied (Figure 1C), dorsal tilt may actually be increased as the distal fragment pivots on the intact dorsal soft tissue hinge. The biomechanical forces responsible for the adverse effects of excessive longitudinal traction on dorsal tilt are shown in Figure 2. The dorsal tilting force on the distal fragment (MDF) is a product of the traction force (T) and a moment arm (DRP) created by the distance between the line of transmission of the force down the shaft of the radius (R) and the pivot point (P) defined by the dorsal hinge.

An external fixator using the principle of longitudinal ligamentotaxis is shown in Figure 3. Skeletal length is restored using skeletal traction with the wrist in a neutral position. The fingers extend as skeletal length is restored.



$$M_{DF} = T \cdot D_{RP}$$

Figure 2
Dorsal tilt of the distal fragment resulting from excessive traction. (Courtesy of Hand Biomechanics Lab, Inc., Sacramento, CA)

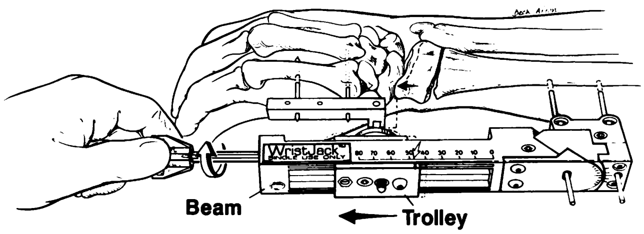


Figure 3
External fixator restoration of skeletal length using the principle of longitudinal ligamentotaxis. (From Agee, J.M.: Agee-Wrist Jack Surgeon's Manual. Sacramento, CA. Hand Biomechanics Lab, Inc., 1993, p.25; with permission.)

This extension reflects the wrist distraction and increased carpal height required for ligamentotaxis to pull the fragments into position. Metacarpophalangeal (MP) joint extension and extrinsic finger extensor tendon tightness are useful indicators of skeletal length. Excessive distraction force applied in increments is accompanied by concomitant degrees of finger MP joint extension. Progressive separation of the carpal bones with each degree of extension can be demonstrated radiographically.

Biomechanics of Dorsal-Palmar Ligamentotaxis

Clinically, longitudinal traction is combined with thumb pressure and wrist flexion to restore palmar tilt. However, it is only when the dorsal ligaments tighten, as the limits of wrist flexion are approached, that palmar tilt will be effectively restored. Persistent advanced wrist flexion is necessary to maintain palmar tilt, but this position cannot be used safely during fracture healing due to subsequent adverse effects on hand function[4,10,23].

Two types of ligamentotaxis used for reduction of distal fractures are shown in Figure 4. Longitudinal traction, as discussed above, restores skeletal length. Palmar translation of the hand on the forearm produces forces that act to sublux the midcarpal joint, creating a force that is transmitted through the proximal carpal row to the distal radial fragment, which tilts its articular surface palmarly. As forces are transmitted from the third metacarpal and capitate distally to the lunate and distal radius proximally, a volar intercalated segmental deformity of the carpus is created that is not unlike the volar wrist collapse described by Linscheid et al[32]. The capitate impinges on the lip of the lunate to create the rotatory force necessary to tilt the lunate and distal radial fragments palmarly. The mechanical link for the ligamentotaxis that restores palmar tilt is provided by the capsular ligaments common to the carpus and distal radius. In the operating room, reduction is achieved as follows. While the wrist is held in neutral position and longitudinal traction is used to maintain skeletal length, a translating force is used to displace the hand palmarly. Palmar translation rotates the distal fragment and palmar tilt is restored as the tightened dorsal periosteal hinge impinges on the shaft fragment. Use of excessive force to restore palmar tilt must be avoided as it can tear the soft tissue hinge and convert the Colles' fracture into a palmarly displaced Smith's fracture[50].

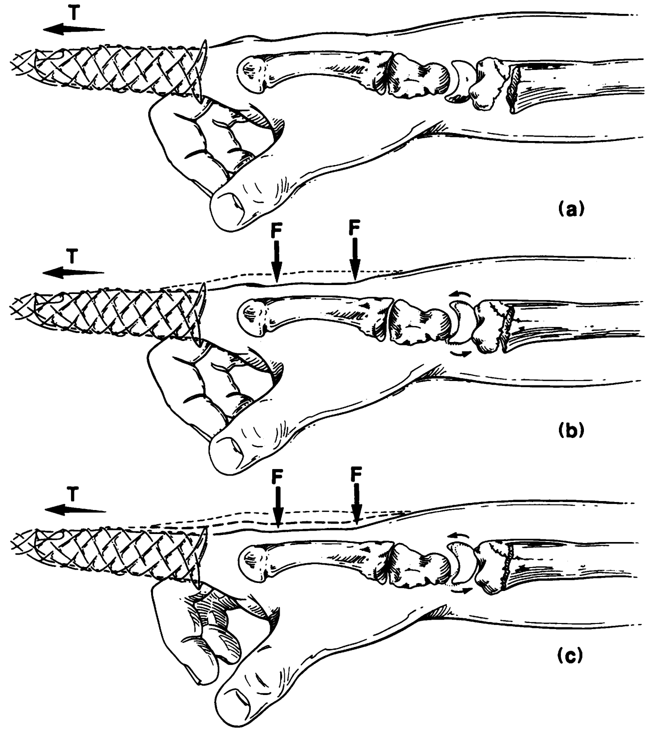


Figure 4 A.
Biomechanics of ligamentotaxis obtained by longitudinal traction to restore skeletal length.
Figure 4 B,C.
A palmar translating force(F) tilts the distal radius articular surface palmarly. (Courtesy of Hand Biomechanics Lab, Inc., Sacramento, CA.)

After restoration of skeletal length following fracture of the distal radius, an adjustment is made to the multiplanar external fixator to decrease any excessive longitudinal traction. This adjustment prevents a dorsal tilting moment on the distal fragment that would prevent palmar translation of the hand from restoring palmar tilt to the distal fragment (Figure 5). A worm gear adjustment on the fixator carries the hand, wrist and distal radius fragment through an arc centered on one of the radial shaft pins. Distracting forces combine with an intact dorsal periosteum to tilt and displace the distal fragment(s) dorsally (Figure 5A). The fragment(s) aligns dorsally as the periosteum is reapposed (Figure 5B), and additional palmar translation rotates the distal fragment(s) and tilts its articular surface palmarly (Figure 5C).

Biomechanics of Radial-Ulnar Ligamentotaxis

The hand can also be translated on the forearm in a third geometric plane; i.e., in a radioulnar plane. With ulnar translation, the first and second extensor compartment

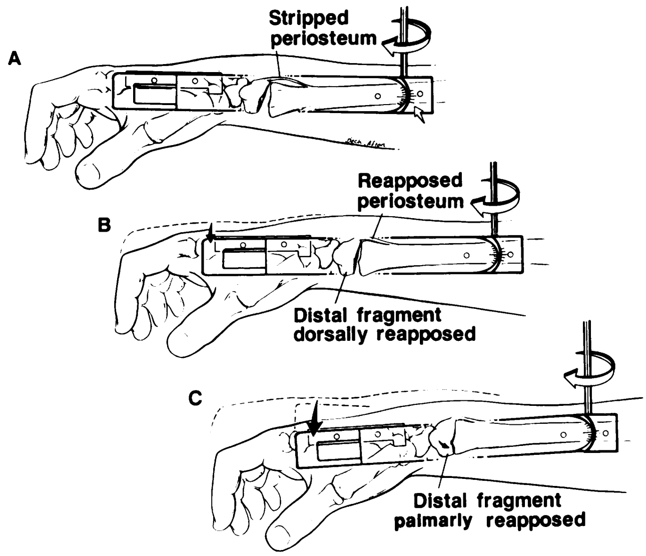


Figure 5
External fixator restoration of palmar tilt using the principle of dorsal-palmar ligamentotaxis (From Agee, J.M.: Agee-WristJack Surgeon's Manual. Sacramento, CA. Hand Biomechanical Lab, Inc., 1993, p. 29; with permission.)

tendons and their associated retinaculum create a radial soft tissue hinge. This forms the basis of the mechanism for the ligamentotaxis of ulnar translation to restore ulnar tilt.

If the fracture is malaligned in the radial-ulnar plane, further selective fracture reduction is accomplished using the radial-ulnar gear adjustment of the external fixator as ligamentotaxis is used to obtain optimal alignment of the distal fragment. Although this is an infrequently used adjustment of the fixator, it can be used to improve appositional alignment of the fracture fragments when the fractures extend to involve the distal radioulnar joint.

Excessive Distraction and Wrist Position During Fracture Healing

An understanding of the biomechanics of the hand related to distraction forces and wrist position during fracture healing is absolutely essential to prevent the external fixator-induced complication known as claw hand.

External skeletal fixators for distal radius fractures are most frequently applied with pins inserted proximally into the radial shaft and distally into the index and long finger metacarpals[2,3,11,15,44,47]. The applied traction forces pass dorsal to the axis of rotation of the wrist, producing fixator-induced wrist flexion and reciprocal MP joint extension. When excessive distraction is applied and maintained during fracture healing, the carpal bones remain distracted and there is increased skeletal length (Figure 6). The increased length transmits tension forces into the extrinsic digital muscles, producing clinically evident clawing of the fingers. Thus the "claw hand" produced by

Figure 6
Excessive distraction induced by an external fixator leads to clinically evident clawing of the fingers. (Courtesy of Hand Biomechanics Lab, Inc., Sacramento, CA.)

external fixation results from fixator-induced wrist flexion and excessive distraction.

Research on the biomechanics of external fixation led to the design of a fixator[1] that permits wrist flexion and extension about an axis that projects through the center of rotation of the wrist[56]. When the wrist is in extension, tension on the finger extensor tendons is relatively relaxed so as to prevent contractures of MP joint extension. MP joint flexion facilitates active finger range-of-motion exercises and hand use during fracture healing. This fixator, that has evolved from the basic biomechanical studies, permits the wrist to be flexed and extended without loss of fracture reduction. These positions can be independently adjusted to restore palmar tilt and to select a "wrist-extended" position to avoid hand stiffness.

DISCUSSION

Colles' fractures are frequently treated inadequately[4,13,14]. Complications that occur during and following treatment can be osteoarticular[14], associated with the soft tissues[14,45] or both[14]. As discussed by Semel[57], an increased complication rate is correlated with inadequate reduction.

Charnley[10] emphasized that the classical method of treating Colles' fractures with plaster violates two basic principles of fracture treatment: 1) the plaster slab is not mechanically sound, and 2) the position of flexion of the wrist is not optimal for function of the hand. Gupta[23] found that for distal radius fracture patients treated with plaster, the best functional results, including the least finger stiffness, occurred in those patients with their wrists immobilized in an extended rather than a neutral or flexed position.

External fixation of a fractured distal radius allows the surgeon to place the wrist in an extended position during healing while maintaining reduction. In a study of 20 Frykman Type V to VIII fractures[1], a "wrist-extended" position (average, 8.4 degrees) was used without any loss of reduction when an external fixator designed to maintain only longitudinal ligamentotaxis was used. Subsequent to this study, the design of the fixator was enhanced to create a multiplanar fracture reduction system. This design extended the principle of ligamentotaxis obtained by traction in one plane[3,5] to ligamentotaxis in two additional planes in which both appositional and rotational (tilting) alignment in dorsal-palmar and radial-ulnar planes are achieved. Beckenbaugh et al.[6] used this new system to treat 20 Colles' fracture patients. They found that the average postreduction measurement of palmar tilt was 5.4 degrees and ulnar inclination was 22.6 degrees. They reported that in addition to maintaining fracture reduction, the fixator accurately restored both radial length and palmar tilt to the distal radius with only minimal or no wrist distraction. Their study using a fracture reduction system based upon the principle of multiplanar ligamentotaxis has provided the best clinical evidence to date of the value of palmar translation to restore palmar tilt. The ability of this system to restore palmar tilt in laboratory-created fractures has also been reported[36].

The best functional results following fracture of a distal radius are obtained when the radius is restored to its original anatomy[12,15,18,22,26,42,49]. The quality of fracture reduction is measured objectively by palmar tilt, radial length, ulnar inclination (radial tilt), radial shift and dorsal shift[51]. The multiplanar fracture reduction system allows the surgeon not only to perform the initial fracture reduction and fragment alignment, but it permits additional adjustments to be made early during postoperative care if follow-up radiographs indicate the necessity.

A similar approach to the design of external fixators has been reported by others[43,44]. By using multiplanar ligamentotaxis external fixators the need for immobilization of adjacent joints is eliminated, allowing for early mobilization and an earlier return to function. The basic purpose of external fixation is to maintain distraction forces during fracture healing. Fixators that maintain excessive traction produce delayed fracture healing and clawing of the fingers with associated hand stiffness. Although initial overdistraction of the fracture may be necessary to disimpact and align the fragments, continued use of excessive distraction is detrimental to the functional outcome[28]. The clinically recognizable clawing of the hand, an "intrinsic minus position," is actually an "extrinsic extensor plus" position of the fingers. The degree of this deforming force can be estimated by passively flexing the finger tips to the distal palmar crease, with the index finger being the most sensitive indicator of this biomechanical imbalance. While some distraction is required for an external fixator to maintain skeletal length, the detrimental effects can be lessened by placing the wrist in a neutral or extended position. The lowest carpal tunnel pressures occur with the wrist in a neutral position[20,21]. Based upon this finding, it seems that placement of the wrist in extension in excess of 20 degrees may improve hand tendon mechanics and decrease the risk of finger stiffness at the risk of increased carpal tunnel pressures on the median nerve.

Although the treatment of Colles' fractures has been significantly improved through application of multiplanar ligamentotaxis via dorsal-palmar and radial-ulnar translation, severe fragment displacement and the absence of soft tissue attachment often require additional treatment. When displaced fragments cannot be reduced with external fixation alone[26,30], external fixation with percutaneous pin manipulation of key fragments or open reduction and internal fixation may be the option of choice. Bone grafting may be of benefit when voids created by crushed metaphyseal bone are evident[26,34]. In those injuries that extend to involve the distal radioulnar joint, a long arm splint may be of benefit if forearm supination improves reduction and stability of that joint.

BIBLIOGRAPHY

1. Agee, J.M.: External Fixation: Technical Advances Based upon Multiplanar Ligamentotaxis. Orthop. Clin. North America, 24:265-74, 1993.

2. Agee, J.M.; Szabo, R.M.; Chidgey, L.K.; King, F.C. and Kerfoot, C.: Treatment of Comminuted Distal Radial Fractures: An Approach Based on Pathomechanics. Orthopaedics, (In Press).

3. Anderson, R. and O'Neil, G.: Comminuted Fractures of the Distal End of the Radius. Surg. Gynecol. Obstet., 78:434-40, 1944.

4. Bacorn, R.W. and Kurtzke, J.F.: Colles' Fracture: A Study of Two Thousand Cases from the New York State Workman's Compensation Board. J. Bone and Joint Surg., 35A:643-64, 1953.

5. Bartosh, R.A. and Saldana, M.J.: Intraarticular Fractures of the Distal Radius: A Cadaveric Study to Determine if Ligamentotaxis Restores Radiopalmar Tilt. J. Hand Surg., 15A:18-21, 1990.

6. Beckenbaugh, R.D.; Berger, R.A.; Amadio, P.C. and Cooney, W.P. III: Preliminary Experience with the Agee

"Wrist Jack" External Fixator. SS-81, American Society for Surgery of the Hand, 46th Annual Meeting, Orlando, FL, October 2-5, 1991.

7. Böhler, L.: The Treatment of Fractures. New York, Grune and Stratton, 1929.

8. Chapman, D.R.; Bennett, J.B.; Bryan, W.J. and Tullos, H.S.: Complications of Distal Radial Fractures: Pins and Plaster Treatment. J. Hand Surg., 7:509-12, 1982.

9. Charnley, J.: Compression Arthrodesis of the Ankle and Shoulder. J. Bone and Joint Surg., 33B:180-91, 1951.

10. Charnley, J.: The Closed Treatment of Common Fractures, ed. 2. Baltimore, Williams & Wilkins, 1957.

11. Clyburn, T.A.: Dynamic External Fixation for Comminuted Intra-Articular Fractures of the Distal End of the Radius. J. Bone and Joint Surg., 69A:248-54, 1987.

12. Cole, J.M. and Obletz, B.E.: Comminuted Fractures of the Distal End of the Radius Treated by Skeletal Transfixion in Plaster Cast. J. Bone and Joint Surg., 48A:931-45, 1966.

13. Colles, A.: On the Fracture of the Carpal Extremity of the Radius. Edinb. Med. Surg. J., 10:182-86, 1814.

14. Cooney, W.P.III; Dobyns, J.H. and Linscheid, R.L.: Complications of Colles' Fractures. J. Bone and Joint Surg., 62A:613-19, 1980.

15. Cooney, W.P., III; Linscheid, R.L. and Dobyns, J.H.: External Pin Fixation for Unstable Colles' Fractures. J. Bone and Joint Surg., 61A:840, 1979.

16. DePalma, A.F.: Comminuted Fractures of the Distal End of the Radius Treated by Ulnar Pinning. J. Bone and Joint Surg., 34A:651-62, 1952.

17. Dobyns, J.H. and Linscheid, R.L.: Fractures and Dislocations of the Wrist. In: Rockwood, C.A., Jr. and Green, D.P. eds. Fractures in Adults, Volume 1. Philadelphia: J.B. Lippincott, 411, 1984.

18. Frykman, G.: Fracture of the Distal Radius Including Sequelae - Shoulder-Hand-Finger Syndrome, Disturbance in the Distal Radio-Ulnar Joint and Impairment of Nerve Function. Acta Orthop. Scand. (Suppl.), 108:1, 1967.

19. Gartland, J.J., Jr. and Werley, C.W.: Evaluation of Healed Colles' Fractures. J. Bone and Joint Surg., 33A:895-907, 1951.

20. Gelberman, R.H.; Hergenroeder, P.T.; Hargens, A.R.; Lundborg, G.N. and Akeson, W.H.: The Carpal Tunnel Syndrome. A Study of Carpal Canal Pressures. J. Bone and Joint Surg., 63A:380-3, 1981.

21. Gelberman, R.H.; Szabo, R.M. and Mortensen, W.W.: Carpal Tunnel Pressures and Wrist Position in Patients with Colles' Fractures. J. Trauma, 24:747-49, 1984.

22. Green, D.P.: Pins and Plaster Treatment of Comminuted Fractures of the Distal End of the Radius. J. Bone and Joint Surg., 57A:304-10, 1975.

23. Gupta, A.: The Treatment of Colles" Fracture: Immobilization with the Wrist Dorsiflexed. J. Bone and Joint Surg., 73B:312-15, 1991.

24. Hoffman, R.: Osteotaxis, Osteosyntheses Externe par Fiches et Rotules. Acta Chir. Scand., 107:72-88, 1954.

25. Ilizarov, L.: Results of Clinical Tests and Experience Obtained from the Clinical Use of the Set Ilizarov Compression-Distraction Apparatus. Med. Export, Moscow, 1976.

26. Isani, A. and Melone, C.P., Jr.: Classification and Management of Intra-articular Fractures of the Distal Radius. Hand Clin., 4:349-60, 1988.

27. Judet, R. and Judet, J.: Remarque a Propos des Fixateurs Externs dans le Traitement des Fractures Ouvertes de Jambe. Mem. Acad. Chir., 84:288, 1958.

28. Kaempffe, F.A.; Wheeler, D.R.; Peimer, C.A.; Hvisdak, K.S.; Ceravolo, J. and Senall, J.: Severe Fractures of the Distal Radius: Effect of Amount and Duration of External Fixator Distraction on Outcome. H. Hand Surg., 18A:33-41, 1993.

29. Kain, T., III; Mandel, R.J.; Snedden, H.E.; Stewart, W.G., Jr. and Adams, D.J.: Comminuted Distal Radius Fractures: Two Methods of Treatment. Clin. Orthop. Rel. Res. (Abstr.), 128:369, 1977.

30. Knirk, J.L. and Jupiter, J.B.: Intra-Articular Fractures of the Distal End of the Radius in Young Adults. J. Bone and Joint Surg., 68A:647-59, 1986.

31. Lidström, A.: Fractures of the Distal End of the Radius: A Clinical and Statistical Study of the End-Results. Acta Orthop. Scand. (Suppl.), 41:1-118, 1959.

32. Linscheid, R.L.; Dobyns, J.H.; Beabout, J.W. and Bryan, R.S.: Traumatic Instability of the Wrist: Diagnosis, Classification and Pathomechanics. J. Bone and Joint Surg., 54A:1612-32, 1972.

33. Melone, C.P., Jr.: Articular Fractures of the Distal Radius. Orthop. Clin. North. Am., 15:217-36, 1984.

34. Melone, C.P., Jr.: Open Treatment for Displaced Articular Fractures of the Distal Radius. Clin. Orthop. Rel. Res., 202:103-11, 1986.

35. Mohanti, R.C. and Kar, N.: Study of Triangular Fibrocartilage of the Wrist Joint in Colles' Fracture. Injury, 11:321-24, 1980.

36. Moran, J.P.: The Use of Multi-Planar Ligamentotaxis in the Treatment of Distal Radius Fractures. M.S. Thesis, California State University, Sacramento, CA, 1992.

37. Müller, M.E.; Nazarian, S. and Koch, P.: Classification AO des Fractures, Berlin: Les os Longs, Springer, 1987.

38. Nissen-Lie, H.S.: Fractura Radii Typica. Nordisk Medicin., 1:293-303, 1939.

39. Older, T.L.; Stabler, E.V. and Cassebaum, W.H.: Colles Fracture: Evaluation and Selection of Therapy. Trauma, 5:469-76, 1965.

40. Putnam, M.D. and Seitz, W.H., Jr.: Advances in Fracture Management in the Hand and Distal Radius. Hand Clin., 5:455-70, 1989.
41. Sarmiento, A.; Pratt, G.W.; Berry, N.C. and Sinclair, W.F.: Colles' Fractures: Functional Bracing in Supination. J. Bone and Joint Surg., 57A:311-17, 1975.
42. Scheck, M.: Long-term Follow-up of Treatment of Comminuted Fractures of the Distal End of the Radius by Transfixation with Kirschner Wires and Cast. J. Bone and Joint Surg., 44A:337-51, 1962.
43. Seitz, W.H., Jr.; Froimson, A.I. and Leb, R.B.: Reduction of Treatment-Related Complications in the External Fixation of Complex Distal Radius Fractures. Orthop. Rev., 20:169-77, 1991.
44. Seitz, W.H., Jr.; Putman, M.D. and Dick, H.M.: Limited Open Surgical Approach for External Fixation of Distal Radius Fractures. J. Hand Surg., 15A:288-93, 1990.
45. Stern, P.J. and Der, R.G.: Non-osseous Complications Following Distal Radius Fractures. Iowa J. Orthop. J., 13:63-9, 1993.
46. Suman, R.K.: Unstable Fractures of the Distal End of the Radius (Transfixion Pins and a Cast). Injury, 15:206-11, 1983.
47. Szabo, R.M.: Fractures of the Distal Radius. In: Chapman, M.W. and Madison, M. eds. Operative Orthopaedics, Volume 2. Philadelphia: J.B. Lippincott Co., 1279-89, 1988.
48. Szabo, R.M.: Comminuted Distal Radius Fractures. Orthop. Clin. North America, 23:1-6, 1992.
49. Szabo, R.M. and Weber, S.C.: Comminuted Intraarticular Fractures of the Distal Radius. Clin. Orthop. Rel. Res., 230:39-48, 1988.
50. Thomas, F.B.: Reduction of Smith's Fracture. J. Bone and Joint Surg., 39B:463-70, 1957.
51. Van der Linden, W. and Ericson, R.: Colles' Fracture: How Should Its Displacement Be Measured and How Should It Be Immobilized? J. Bone and Joint Surg., 63A:1285-88, 1981.
52. Vidal, J.; Buscayret, C. and Connes, H.: Treatment of Articular Fractures by "Ligamentotaxis" with External Fixation. In: Brooker, A.F., Jr. and Edwards, C.C. eds. External Fixation, The Current State of the Art. Baltimore:Williams & Wilkins, 75-81, 1979.
53. Vidal, J.; Buscayret, C.; Paran, M. and Mulka, J.: Ligamentotaxis. In: Mears, D.C., ed. External Skeletal Fixation. Baltimore:Williams & Wilkins, 493-96, 1983.
54. Wagner, H.: Operative Lengthening of the Femur. Clin. Orthop. Rel. Res., 136:125-42, 1978.
55. Weber, S.C. and Szabo, R.M.: Severely Comminuted Distal Radial Fracture as an Unsolved Problem: Complications Associated with External Fixation and Pins and Plaster Techniques. J. Hand Surg., 11A:157-65, 1986.
56. Youm, Y.; McMurtry, R.Y.; Flatt, A.E. and Gillespie, T.E.: Kinematics of the Wrist. I. An Experimental Study of Radial-Ulnar Deviation and Flexion-Extension. J. Bone and Joint Surg., 60A:423-31, 1978.
57. Zemel, N.P.: The Prevention and Treatment of Complications from Fractures to the Distal Radius and Ulna. Hand Clin., 3:1-11, 1987.