Dynamic External Fixation in the Management of Dorsal Fracture-dislocations of the Proximal Interphalangeal (PIP) Joint

Dr. Ajeesh Sankaran
MS (Ortho); FNB (Hand & Microsurgery)
Hand Surgery Fellowship at Kleinert Institute, Louisville, USA
Consultant Hand Surgeon at KIMS Al-Shifa Hospital, Perintalmanna, Kerala

ISSH ACADEMICS

"Motion is life" – Robert Salter

Dorsal fracture dislocations of the proximal interphalangeal [PIP] joint are often missed serious injuries of the finger. Controversy arises from a lack of high-quality evidence regarding the management of these injuries. Techniques continue to be described for treating them, including a myriad number of devices for external fixation. Commonly utilized frames also allow varying degrees of movement to prevent stiffness, while maintaining an acceptable reduction of the joint surfaces. This article reviews the basic science of PIP joint stability and dynamic traction, along with the indications, techniques and evidence for the use of dynamic external fixation in PIP dorsal fracture dislocations.

BASIC PRINCIPLES

i] <u>PIP joint stability</u> – The PIP joint is critically dependent on non-osseous structures for its stability. The joint capsule is reinforced on the radial and ulnar sides by the collateral ligaments. On each side, the Proper Collateral Ligament [PCL] passes from a tubercle on the proximal phalangeal head to the middle phalangeal base. The Accessory Collateral Ligament [ACL] is volar to the PCL and attaches to the volar plate and the flexor sheath. The Volar Plate [VP] is a fibrocartilaginous structure attached to the lip of the volar middle phalanx base, proximally held by the *checkrein ligaments* that attach to the periosteum and A2 pulley on either side. In addition, the central slip and flexor digitorum superficialis (FDS) insertion are also stabilizers of the PIP joint. The PCL, ACL, VP and the central slip collectively form a *ligamentous box* all around the PIP joint that affords stability in the dorso-palmar plane, the radio-ulnar plane and the rotational plane {Fig 1}.

**Anatomy of the PIP joint is discussed in further detail in an earlier ISSH Academics article by Dr. Mithun Pai.*

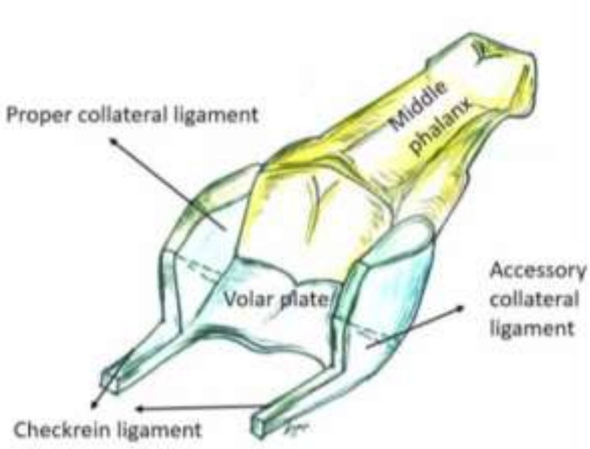

Figure 1. PIP joint anatomy – demonstrating the ligamentous box concept

Fractures of the palmar lip of the middle phalanx base remove the VP, along with the ACL, as a stabilizing component. The PCL by virtue of its broad insertion on the middle phalanx is variably involved in such fractures. It is often considered that if most of the PCL attachment to the middle phalanx base is retained the joint should stay stable. In a cadaveric study, Caravaggi *et al* concluded that instability resulted only if the collateral ligaments, the volar plate and 30% of the middle phalanx base lip were *all* removed.[1] Injury to the collateral ligaments or the volar plate alone would be unlikely to cause any instability. Tyser *et al* considered bony defects alone of the middle phalanx base in their cadaveric study by creating defects of 20%, 40%, 60% and 80% of the middle phalanx base. They concluded that 20% defects were stable. 60% and 80% defects were unstable in flexion, whereas 40% defects were variably unstable. They indicated 40% middle phalanx base defect to be a possible threshold for stability.[2]

ii] Traction and Ligamentotaxis – Fracture reduction, almost anywhere in the body, most often involves longitudinal traction. In PIP fracture dislocations, traction applied to the finger directly counteracts the proximal pull of the central slip insertion. Apart from this obviation of the tendency of fractures to compression, traction also effects fragments to fall in place by tensing the surrounding soft tissue. This effect, termed *Ligamentotaxis*, was introduced by Vidal *et al* and is commonly applied in the external fixation of distal radius fractures.[3] In the finger, the flexor tendons and the extensor expansion induce reduction of the fracture fragments when stretched by traction.

iii] Motion and Cartilage Regeneration – Until a few decades ago, rest and immobilization were considered the time honoured methods for healing of joint injuries. Through a series of classic experiments, Robert Salter and his team conclusively proved the beneficial effect of movement on joint cartilage regeneration.[4] Specifically, they showed better short term and long-term cartilage healing in rabbit knee intra-articular fractures with continuous passive motion [CPM] than with immobilization. In related studies, full thickness cartilage defects also healed better with CPM. While CPM devices have been tried in the hand, they have not achieved popularity for being cumbersome and expensive. However, the deleterious effects of immobilization are now well accepted and early mobilization is recommended for nearly all hand conditions. In PIP fracture dislocations, this would require either stable internal fixation or dynamic traction methods to be employed.

DYNAMIC EXTERNAL FIXATION

i] Rationale and Biomechanics – The goal of dynamic external fixation in PIP fracture dislocations would be to ensure joint reduction throughout a functional range of joint mobilization. As already mentioned, longitudinal traction along the finger counteracts the proximal pull of the central slip. The dorsal dislocating pull of the extensor is countered indirectly by ligamentotaxis, mostly by tension in the FDS insertion {Fig 2}. Traction also brings the extensor and flexor systems closer to one another, which tends to hold the middle phalanx in place. Shortening of the collateral ligaments is also prevented by adequate traction. Some techniques, like the Suzuki system, include the use of a pin placed in the middle phalanx that acts as a 'stop' to dorsal dislocation.

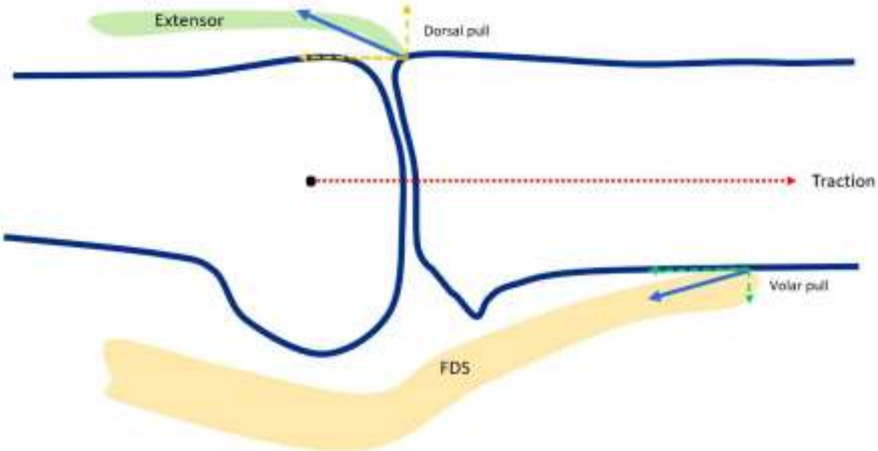

Figure 2. Forces acting on a PIP fracture dislocation.

ii] <u>Techniques</u> – The first systems for hand traction came to be widely used from experience gained in the Second World War. Probably the first external fixation device specifically intended for PIP fracture dislocations was described by Robertson et al in 1946, which was based on a Banjo splint and multiple wires that allowed traction to be applied in different directions.[5] But this design did not allow for proper mobilization through a functional range. However, in the very next year Quigley and Urist described a system that allowed PIP motion.[6] Their design was intended for use in hand fractures, especially open injuries, but they emphasized the need for mobilizing the fingers while they heal. Schenck described a system based on the Banjo splint and used early passive motion for these injuries.[7] Other systems include the Agee force couple splint[8], the Stockport Serpentine Spring System ['S Quattro'][9], the Inanami rhomboid fixator[10] and, arguably the most used, the pins and rubber traction system [PRTS][11] {Fig 3}.

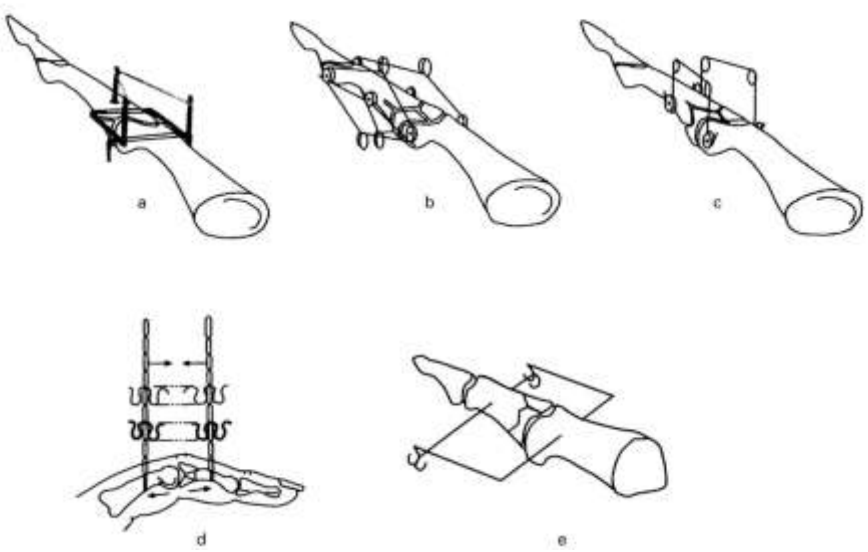

Figure 3. Different external fixation systems described

a) Agee force couple splint, b) Inanami Rhomboid fixator, c) Allison system, d) S Quattro system, e) Hynes- Giddins fixator

The PRTS is commonly attributed to Suzuki, but it was also described by Slade at around the same time.[12] Compared to other systems, the PRTS is simpler to apply and maintain while being less cumbersome for the patient to manage with. Since it uses no more than K wires and elastic bands, it can be used easily in resource constrained or other austere practice environments.

iii] Data and Evidence – No study has directly demonstrated the efficacy of dynamic external fixation over other modalities in a comparative study. A review of data from some studies is presented in Table 1. These studies indicate that a PIP joint active range of about 80^{o} is achievable by dynamic distraction methods, with minimal complications. However, studies do not wholly agree on the indications for use of dynamic external fixation in these injuries. More stable injuries may require only splinting or extension block pinning while more severe injuries require more invasive procedures.

Authors	No. of Cases	PIP ROM		DIP ROM	
		ROM	F/E	ROM	F/E
Schenk, 1986[7]	10	87	92/5	50	60/10
Suzuki, 1994[11]	4	82.5	92.5/10		
Majumder, 2003[13]	13	74		48.5	
Duteille, 2003[14]	16	85.9	92.2/6.3		
Deshmukh,2004[15]	13	85		48	
Keramidas, 2007[16]	11	84.54	91.36/6.82		
Slade, 2008[12]	34	88	93/5	60	
Richter, 2008[17]	13	85			
Debus, 2010[18]	15	56.6	NA/9.6	39.6	NA/7.3
Finsen, 2010[19]	18	72	83/9		
Nanno, 2019[20]	39	74.6		45.4	
*Hynes,2001[21]**	8	76	88/12		
*Mansha, 2013[22]**	12	74	87/13		
Korting, 2009 [23]#	15	56.4	76.3/19.9		
Damert, 2013 [24]#	10	60	73/13		

Table 1: Summary of results of studies on dynamic external fixation systems.

F/E – Flexion/ Extension; * used Hynes- Giddins system; # used Ligamentotaxor system iv] Indications and Contra-Indications –

High quality evidence is not available regarding the indications of dynamic external fixation, primarily due to a lack of comparative studies between techniques. The allure of this method lies in its near universal applicability for a PIP fracture-dislocation. However, in certain situations use of other techniques is more appropriate than dynamic external fixation. Injuries that are stable after reduction, usually with fractures involving no more than 30% of the articular surface, require only dorsal block splinting or pinning. Fracture-dislocations that are unstable (at >30^{o} of PIP flexion) constitute the classic indication for use of dynamic fixation. It is most often recommended for injuries involving 30% - 50% of the articular surface with multiple fragments.[25] While dynamic traction can be employed for acute injuries with even greater articular surface involvement, HHRA is generally recommended for injuries with >50% joint surface involvement when internal fixation of the fracture fragment is not possible.[26] Chronic injuries with bone resorption of the volar lip are more definite indications for HHRA/ VPA. Injuries greater than 6 weeks old are considered chronic where closed reduction may not be successful and, hence, open procedures need to be considered. However, dynamic external fixation has been combined with limited open reduction for delayed presentations also (notably even in the original description by Suzuki *et al*).[11,12] It can be used for open injuries or in combination with other techniques like VPA to achieve early stable mobilization.[12] Middle phalanx base pilon fractures can also be treated by dynamic traction, but a displaced central slip avulsion fracture fragment would require to be addressed separately. In general, the simplicity of execution and reliability in obtaining reasonable results of dynamic external fixation makes it an option in a wide variety of injuries. Severe injury to other digits is a relative contra-indication due to the difficulty in managing the frame and early mobilization. Patients who would not be able to co-operate with the post-operative care, like children, multiply injured, altered sensorium etc., can also be considered contra-indications.

SURGICAL TECHNIQUE [from Suzuki, 1994] {Fig 4}[11]

- Local anaesthesia, in the form of a digital block, is preferred for intra-operative active ROM examination.
- The first pin [P1 or **axial traction pin**] is a long (9") 1.2mm K wire, which is drilled transversely through the centre of rotation of the proximal phalanx head.

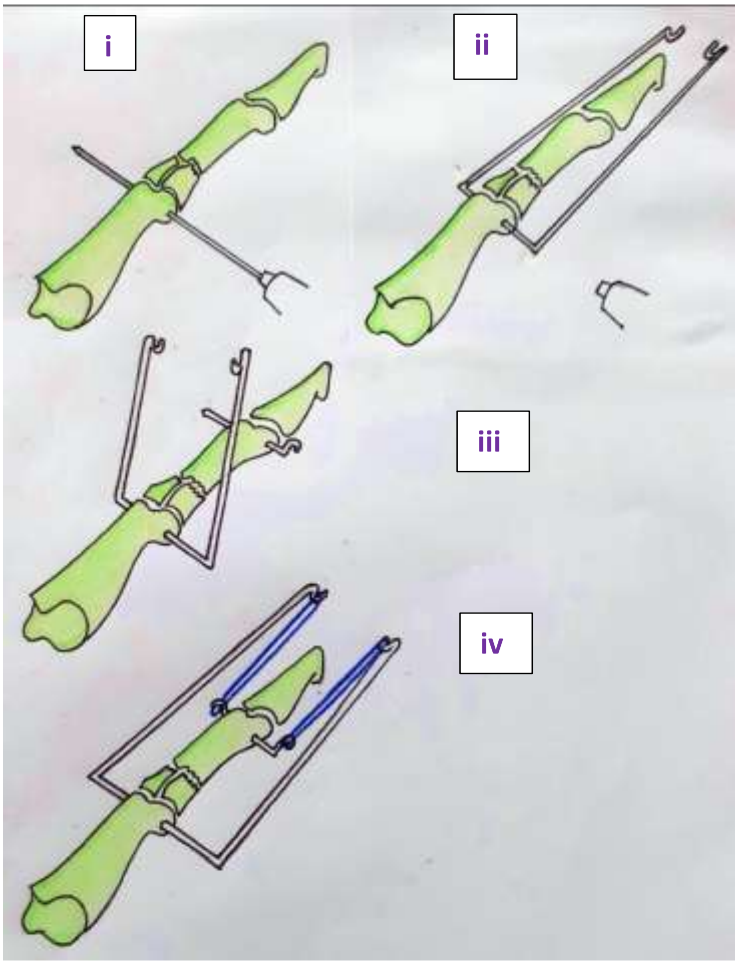

Figure 4. Steps of PRTS application [adapted from Suzuki et al, 1994].[11]

- Intra-op imaging is used to confirm that the pin lies exactly perpendicular to the phalangeal axis and is centered on a lateral view.

- P1 is bent 90^{o} towards the fingertip close to the skin on both sides of the finger. On each side, at least 3cm wire length distal to the fingertip is ensured. At this level the wires are again bent to create a hook *facing distally*. A useful technique is to then rotate this pin dorsally so that it stays out of the way for further steps.

- The next pin [P2 or **hook pin**] used is a 1mm or 1.2mm K wire of standard length (6"). This is drilled through the distal middle phalanx, ensuring that it is exactly perpendicular to the phalangeal axis. This pin too is bent 90^o similar to the first pin. It is further bent to make a hook *facing proximally*.
- Rubber bands are then placed between the hooks. The traction is adjusted by the length and number of bands used. Adequate traction is confirmed by imaging – 1mm joint space visible on an AP view is considered sufficient.
- For fracture- dislocations, a third pin is added [P3 or **reduction pin**] to prevent dorsal subluxation. P3 is placed in the base of the middle phalanx distal to the fracture and slightly dorsal to level of insertion of the P1 and P2 {Fig 5}.

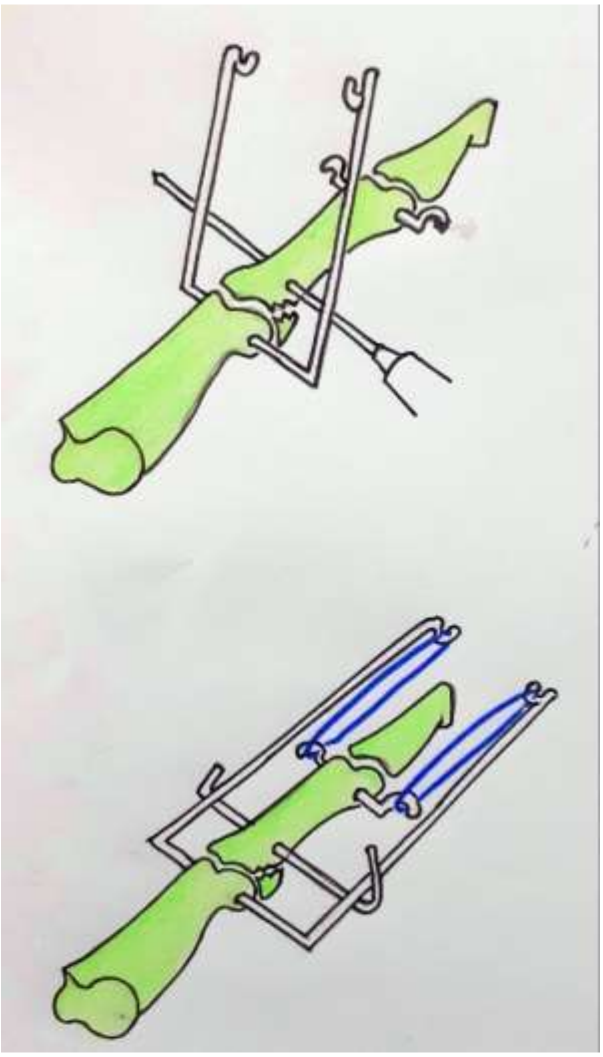

Figure 5. Use of 'reduction pin' in dorsal fracture – dislocations [adapted from Suzuki et al, 1994].[11]

- When rubber bands are applied, P3 is pushed volar to the bent P1 {Fig 6}. After confirmation of reduction, P3 is then bent to hook around the P1.
- Intra-operative fluoroscopy can be used to confirm maintenance of traction and reduction during active flexion.

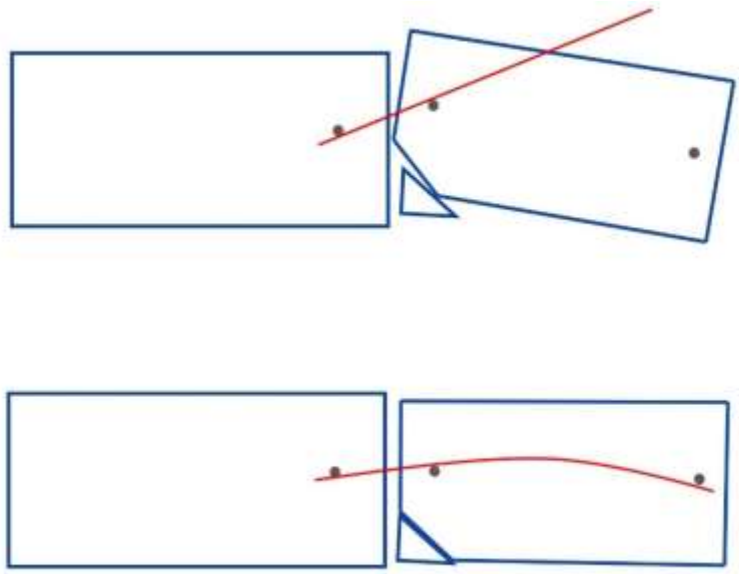

Figure 6. Principle of lever assisted reduction with use of a third pin [modified from Ruland et al, 2008].[12]

Post operatively, the frame is usually maintained for 4 weeks. Weekly follow ups are necessary for radiography and pin tract care. Impending or mild infections can be managed by local care and oral antibiotics. Care is also needed to replace any broken rubber bands, especially imbalance between the traction applied to either side of the finger. This imbalance can lead to a radial or ulnar deviation), if not identified and corrected early. Some patients also benefit from digital block at their follow up visits to encourage them to mobilize more.

Figure 7 shows a 10 days old fracture dislocation of the PIP joint managed by Suzuki frame. We achieved good reduction was distraction itself so; the reduction wire was not applied for this case. Patient was started on immediate mobilization. The frame was removed at 4 weeks. He achieved almost full range of movements at the PIP and the DIP joints at three months post-surgery (Figure 7).

Figure 7: 10 days old injury in a 21/years/male. Frame applied under digital block and started on immediate mobilization. Frame was removed at 4 weeks. He attained almost full range of motion at 3 months follow up.

<u>Modifications:</u> The frame can be modified for other fractures as well, like proximal phalangeal head fractures. A useful modification by Deshmukh allows for a premade frame, which is hooked around the P1 {Fig 8}.[15] Rubber bands are then applied between P2 and this frame. This design reduces operative time and has the additional advantage of decreasing movement at the pin-bone and pin-skin interfaces which can decrease pin tract complications. Adjustments to traction are also easier in the post-operative period.

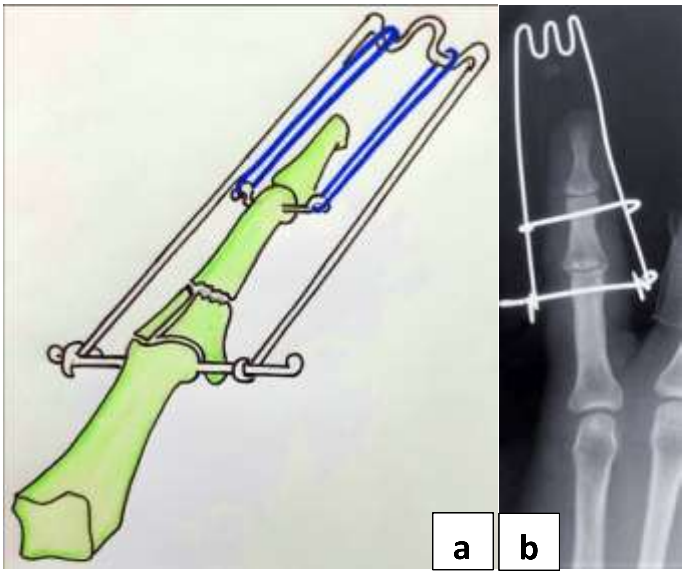

Figure 8 [a &b]. a & b) Deshmukh frame [adapted from Deshmukh et al, 2004].[15]

When rubber bands are not available, they can be substituted with pieces cut off from a rubber catheter or the ends of IV infusion sets. Alternatively, dental bands can be used which are available colour coded according to elasticity.

SUMMARY

- The *ligamentous box* around the base of the middle phalanx is critically important for PIP stability. Dynamic external fixation marries the concepts of *ligamentotaxis* and early motion for cartilage regeneration.
- While many such systems are known, their results are similar and the PRTS is probably the most commonly used due to its simplicity. Delayed presentations and large volar bone loss are often managed by other modalities.
- Functional PIP ROM can be achieved with these systems – about 80^{o} flexion with minimal extension lag.

****

REFERENCES:

1. Caravaggi P, Shamian B, Uko L, Chen L, Melamed E, Capo JT. In vitro kinematics of the proximal interphalangeal joint in the finger after progressive disruption of the main supporting structures. Hand (N Y). 2015 Sep;10(3):425-32. doi: 10.1007/s11552-015-9739-x. PMID: 26330773; PMCID: PMC4551636.
2. Tyser AR, Tsai MA, Parks BG, Means KR Jr. Stability of acute dorsal fracture dislocations of the proximal interphalangeal joint: a biomechanical study. J Hand Surg Am. 2014 Jan;39(1):13-8. doi: 10.1016/j.jhsa.2013.09.025. Epub 2013 Nov 6. PMID: 24211175.
3. Vidal J, Buscayret C, Connes H. Treatment of articular fractures by ''ligamentotaxis'' with external fixation. In: Brooker AF Jr, Edwards CC, editors. External fixation: the current state of the art. Baltimore: Williams and Wilkins; 1979. p. 75–81.
4. Salter RB. History of rest and motion and the scientific basis for early continuous passive motion. Hand Clin. 1996 Feb;12(1):1-11. PMID: 8655611.
5. Robertson RC, Cawley JJ Jr, Faris AM. Treatment of fracture-dislocation of the interphalangeal joints of the hand. J Bone Joint Surg Am. 1946 Jan;28:68-70. PMID: 21008075.
6. Quigley TB, Urist MR. Interphalangeal joints; a method of digital skeletal traction which permits active motion. Am J Surg. 1947 Feb;73(2):175-83. doi: 10.1016/0002-9610(47)90310-3. PMID: 20282202.
7. Schenck RR. Dynamic traction and early passive movement for fractures of the proximal interphalangeal joint. J Hand Surg Am. 1986 Nov;11(6):850-8. doi: 10.1016/s0363-5023(86)80236-2. PMID: 3794242.
8. Agee JM. Unstable fracture dislocations of the proximal interphalangeal joint. Treatment with the force couple splint. Clin Orthop Relat Res. 1987 Jan;(214):101-12. PMID: 3791731.
9. Fahmy NR. The Stockport Serpentine Spring System for the treatment of displaced comminuted intra-articular phalangeal fractures. J Hand Surg Br. 1990 Aug;15(3):303-11. doi: 10.1016/0266-7681(90)90009-s. PMID: 2230496.

10. Inanami H, Ninomiya S, Okutsu I, Tarui T. Dynamic external finger fixator for fracture dislocation of the proximal interphalangeal joint. J Hand Surg Am. 1993 Jan;18(1):160-4. doi: 10.1016/0363-5023(93)90265-5. PMID: 8423305.
11. Suzuki Y, Matsunaga T, Sato S, Yokoi T. The pins and rubbers traction system for treatment of comminuted intraarticular fractures and fracture-dislocations in the hand. J Hand Surg Br. 1994 Feb;19(1):98-107. doi: 10.1016/0266-7681(94)90059-0. Erratum in: J Hand Surg [Br] 1994 Jun;19(3):408. PMID: 8169490.
12. Ruland RT, Hogan CJ, Cannon DL, Slade JF. Use of dynamic distraction external fixation for unstable fracture-dislocations of the proximal interphalangeal joint. J Hand Surg Am. 2008 Jan;33(1):19-25. doi: 10.1016/j.jhsa.2007.07.018. PMID: 18261660.
13. Majumder S, Peck F, Watson JS, Lees VC. Lessons learned from the management of complex intra-articular fractures at the base of the middle phalanges of fingers. J Hand Surg Br. 2003 Dec;28(6):559-65. doi: 10.1016/s0266-7681(03)00139-6. PMID: 14599828.
14. Duteille F, Pasquier P, Lim A, Dautel G. Treatment of complex interphalangeal joint fractures with dynamic external traction: a series of 20 cases. Plast Reconstr Surg. 2003 Apr 15;111(5):1623-9. doi: 10.1097/01.PRS.0000054160.46502.D0. PMID: 12655207.
15. Deshmukh SC, Kumar D, Mathur K, Thomas B. Complex fracture-dislocation of the proximal interphalangeal joint of the hand. Results of a modified pins and rubbers traction system. J Bone Joint Surg Br. 2004 Apr;86(3):406-12. doi: 10.1302/0301-620x.86b3.14350. PMID: 15125130.
16. Keramidas E, Solomos M, Page RE, Miller G. The Suzuki frame for complex intra-articular fractures of the proximal interphalangeal joint of the fingers. Ann Plast Surg. 2007 May;58(5):484-8. doi: 10.1097/01.sap.0000244975.89885.c7. PMID: 17452830.
17. Richter M, Brüser P. [Long-term follow-up of fracture dislocations and comminuted fractures of the PIP joint treated with Suzuki's pin and rubber traction system]. Handchir Mikrochir Plast Chir. 2008 Oct;40(5):330-5. German. doi: 10.1055/s-2008-1038450. Epub 2008 Jul 16. PMID: 18633885.
18. Debus G, Courvoisier A, Wimsey S, Pradel P, Moutet F. Pins and rubber traction system for intra-articular proximal interphalangeal joint fractures revisited. J Hand

Surg Eur Vol. 2010 Jun;35(5):396-401. doi: 10.1177/1753193409359493. Epub 2010 Feb 11. PMID: 20150391.

19. Finsen V. Suzuki's pins and rubber traction for fractures of the base of the middle phalanx. J Plast Surg Hand Surg. 2010 Nov;44(4-5):209-13. doi: 10.3109/02844311.2010.494416. PMID: 21446818.
20. Nanno M, Kodera N, Tomori Y, Takai S. Pins and rubbers traction system for fractures of the proximal interphalangeal joint. J Orthop Surg (Hong Kong). 2019 May-Aug;27(2):2309499019840771. doi: 10.1177/2309499019840771. PMID: 30987517.
21. Hynes MC, Giddins GE. Dynamic external fixation for pilon fractures of the interphalangeal joints. J Hand Surg Br. 2001 Apr;26(2):122-4. doi: 10.1054/jhsb.2000.0521. PMID: 11281662.
22. Mansha M, Miranda S. Early results of a simple distraction dynamic external fixator in management of comminuted intra-articular fractures of base of middle phalanx. J Hand Microsurg. 2013 Dec;5(2):63-7. doi: 10.1007/s12593-013-0099-x. Epub 2013 Jun 19. PMID: 24426677; PMCID: PMC3827646.
23. Körting O, Facca S, Diaconu M, Liverneaux P. Treatment of complex proximal interphalangeal joint fractures using a new dynamic external fixator: 15 cases. Chir Main. 2009 Jun;28(3):153-7. doi: 10.1016/j.main.2009.03.001. Epub 2009 Mar 25. PMID: 19362033.
24. Damert HG, Altmann S, Kraus A, Infanger M, Sattler D. Treatment of intraarticular middle phalanx fractures using the Ligamentotaxor®. Hand (N Y). 2013 Dec;8(4):460-3. doi: 10.1007/s11552-013-9553-2. PMID: 24426967; PMCID: PMC3840757.
25. Merrell G, Slade JF (2011). Dislocations and ligament injuries in the digits. In *Green's Operative Hand Surgery* (6th edition, pp 291–332). Philadelphia, PA: Elsevier.
26. Calfee RP, Kiefhaber TR, Sommerkamp TG, Stern PJ. Hemi-hamate arthroplasty provides functional reconstruction of acute and chronic proximal interphalangeal fracture-dislocations. J Hand Surg Am. 2009 Sep;34(7):1232-41. doi: 10.1016/j.jhsa.2009.04.027. PMID: 19700071.