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Dynamic External Fixation for Treatment of Unstable Proximal Interphalangeal Joint Fracture-Dislocations

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Abstract

Proximal interphalangeal (PIP) joint fracture-dislocations are complex injuries that pose significant challenges in hand surgery due to the joint's critical functional role and high susceptibility to stiffness and post-traumatic arthritis. These injuries involve simultaneous disruption of articular surfaces and ligamentous stabilizers, commonly resulting from axial loading, hyperextension, or high-energy trauma. Traditional treatment methods often fail to adequately balance stable reduction with early motion, leading to complications such as joint stiffness, chronic instability, and functional impairment. Dynamic external fixation using the Suzuki frame, introduced in 1994, revolutionized management by applying continuous distraction through percutaneous K-wires and elastic traction. This technique employs ligamentotaxis to maintain articular alignment while permitting early controlled motion, thereby reducing adhesion formation and preserving joint function.

Keywords: Proximal interphalangeal joint; fracture-dislocation; dynamic external fixation; Suzuki frame; ligamentotaxis; hand trauma; intra-articular fracture; middle phalanx

Introduction

The proximal interphalangeal (PIP) joint plays a pivotal role in hand function, enabling approximately 100–110 degrees of flexion and contributing significantly to grasp, grip strength, and fine motor control. Given its superficial location, anatomical complexity, and high mobility, the PIP joint is highly vulnerable to trauma, particularly fracture-dislocations, which present formidable challenges in hand surgery.(1)

Intra-articular PIP joint fracture-dislocations result from simultaneous dislocation and fracture of the articular surfaces, often occurring from high-energy trauma, sports injuries, or hyperextension combined with axial loading. These injuries frequently involve comminution and instability, especially when more than 30% of the articular surface is compromised or the volar lip is fractured.(2)

Failure to restore congruent joint surfaces and permit early mobilization may lead to stiffness, chronic subluxation, degenerative arthritis, and poor functional outcomes. Traditional management methods including extension block splinting, closed reduction with K-wire fixation, or open reduction and internal fixation often struggle to maintain joint alignment while permitting early motion.(3)

Introduced by Suzuki and colleagues in 1994, the dynamic external fixator frame offers a unique solution by employing percutaneous Kirschner wires and rubber bands to apply dynamic traction across the joint, maintaining articular congruity through ligamentotaxis while allowing controlled joint motion.(4)

This review explores the anatomy, biomechanics, classification, and treatment of PIP joint fracture-dislocations, with particular emphasis on dynamic external fixation using the Suzuki frame.

Anatomical and Biomechanical Foundations

Embryological Development

The human hand begins development in the 4th week of gestation as outgrowths from the lateral plate mesoderm, with the apical ectodermal ridge playing a key role in proximodistal outgrowth and the zone of polarizing activity responsible for anteroposterior patterning.(5) By week 5, programmed apoptosis forms digital rays the primordia of fingers with joints developing through formation of an interzone starting at approximately days 45–47.(6)

Between weeks 7 and 9, joint cavitation begins through apoptosis and matrix remodeling, regulated by bone morphogenetic proteins, noggin, and growth and differentiation factor 5.(7) The soft tissue structures including collateral ligaments and volar plate develop from mesenchymal condensations, influenced by mechanical stress from growing muscles and tendons.(8)

Gross Anatomy

The PIP joint is a synovial hinge joint formed between the convex, bicondylar head of the proximal phalanx and the concave base of the middle phalanx. The proximal phalangeal head is "dished" dorsally and flared volarly, providing stability against dorsal subluxation, with articular surfaces covered by hyaline cartilage.(9)

A thin fibrous capsule encloses the joint, lined by synovial membrane producing fluid for cartilage nutrition and friction reduction.(10) The volar plate is a thick fibrocartilaginous structure preventing hyperextension and distributing axial load, while being continuous with the flexor pulley system.(11)

Each PIP joint has radial and ulnar collateral ligaments originating from lateral tubercles of the proximal phalanx head. These are taut in flexion providing lateral stability and relaxed in extension allowing functional grip motion.(12) The central slip of extensor digitorum communis inserts dorsally on the middle phalanx, while flexor tendons (FDS and FDP) pass volarly through the pulley system.(13)

Biomechanics

The saddle-like configuration stabilizes the joint in coronal and sagittal planes, allowing flexion-extension while limiting lateral deviation and rotation. The articular surface extends more volarly than dorsally, enhancing flexion mechanics and increasing motion arc.(14)

The PIP joint allows 0° to 100–110° of flexion, optimized for gripping activities. Maximal flexion is driven by FDS while extension involves coordinated action of the central slip and lateral bands supported by intrinsic muscles.(15) The flexor pulley system prevents tendon bowstringing and preserves mechanical efficiency, with rupture increasing moment arm and altering joint torque.(16)

Contact pressures peak during 90° flexion—the functional gripping position—with compressive loads of 40–50 N during light activities and over 100 N during strong grips.(17)

Mechanism of Injury and Fracture Patterns

Common Injury Mechanisms

The PIP joint is susceptible to injury when axial loads combine with varus, valgus, or torsional stress. The middle phalanx base is thin and often exhibits intra-articular fractures when loaded axially, with the proximal phalanx head acting as a wedge.(18)

The most common mechanism is axial load with hyperextension or slight flexion, typically when the finger is jammed against an object during sports. This produces a volar lip fracture with dorsal dislocation—the classic fracture-dislocation pattern.(19) Less commonly, volar dislocation occurs when the PIP is forcibly hyperflexed, shearing off the dorsal lip.(20)

Rotational or angular stresses cause unicondylar fractures with lateral instability, frequently from twisting injuries. Comminuted intra-articular fractures occur from high-energy crush mechanisms, often during occupational injuries.(21)

In fracture-dislocations, the volar plate is often torn or avulsed, and collateral ligaments may rupture. Tendon interposition can block closed reduction, meaning simple radiographic appearances may hide complex soft tissue pathology.(4)

Classification Systems

The Hastings and Carroll classification focuses on articular involvement and stability: Type I (<30% articular involvement) is stable and manageable conservatively; Type II (30–50%) is unstable with motion requiring extension block or traction fixation; Type III (>50% or comminuted) is grossly unstable requiring surgical fixation.(22)

The Schenck classification for dorsal fracture-dislocations classifies based on volar lip fragment size: Type A (pure dislocation), Type B (<30% volar lip), Type C (30–50%), Type D (>50%), and Type E (comminuted base).(23)

The AO/OTA classification uses codes for middle phalanx fractures (88.2) with subgroups for extra-articular (A), partial articular (B), and complete articular (C) patterns.(24)

Clinical Diagnosis

History and Presentation

Patients report sudden trauma such as jamming a finger, with sensation of a "pop" followed by immediate pain, swelling, and deformity. Loss of motion or inability to extend/flex the finger is common, with spontaneous reduction sometimes masking severity.(25)

Physical Examination

Visual deformity may show obvious dislocation with volar depression of the middle phalanx. Acute fusiform swelling with localized bruising indicates capsule or ligament rupture.(26) Palpation localizes injury: volar tenderness suggests volar plate injury, lateral tenderness indicates collateral ligament disruption, and dorsal tenderness suggests central slip injury.(27)

Extension lag may indicate central slip rupture while blocked flexion suggests tendon entrapment or articular fragment. Assessment of FDS and extensor mechanism function identifies specific pathology.(28)

Radiologic Evaluation

Standard AP, lateral, and oblique views are essential, with lateral view confirming displacement and joint congruity.(29) CT scan is indicated when comminution is suspected, articular involvement exceeds 30%, or surgical planning is required, providing superior visualization of fracture morphology and fragment size.(30)

Treatment Modalities

Non-operative Management

Small volar lip avulsions (<30% articular surface) that reduce concentrically are stable and manageable with extension block splints or buddy taping with early controlled motion. Conservative care is favored when joint congruity is maintained without subluxation tendency.(31)

Extension block splints with PIP held in flexion can be used for selected dorsal fracture-dislocations that reduce and remain concentrically reduced, allowing controlled motion of adjacent joints while avoiding surgery.(32)

Percutaneous Stabilization

Extension-block pinning is indicated for unstable dorsal fracture-dislocations where the volar fragment reduces but tends to sublux dorsally. A K-wire is placed dorsally to prevent subluxation while the volar fragment is reduced.(33)

If a single large volar fragment can be captured percutaneously, a headless compression screw produces stable fixation allowing early motion, useful when fragment size permits screw purchase and comminution is limited.(34)

Temporary transarticular K-wire can secure reduction in highly unstable situations but immobilizes the joint, typically used briefly (2–4 weeks) or as a bridge to definitive treatment.(35)

Open Reduction and Internal Fixation

ORIF is indicated for displaced large fragments amenable to lag screw fixation, articular step-off that cannot be reduced closed, and selected unicondylar fractures. Goals are anatomic reduction, stable fixation allowing early motion, and restoration of volar buttress.(36)

Headless compression screws provide compression without hardware prominence, while mini-fragment plates or volar hook plates are useful when screw purchase alone is insufficient.(37) ORIF may be associated with hardware irritation and risk of stiffness if motion is delayed.(38)

Reconstruction Procedures

When the volar lip is unreconstructable, volar plate advancement or arthroplasty can restore stability and allow motion, typically for chronic injuries or when hemi-hamate is not selected.(39)

The hemi-hamate autograft uses an osteochondral graft from the dorsal hamate to reconstruct the volar articular surface, indicated for large volar lip defects where direct fixation fails, with good midterm results though technically demanding.(40)

Dynamic External Fixation

The Suzuki Frame

Dynamic external fixation is suitable for unstable PIP fracture-dislocations, particularly dorsal fracture-dislocations with volar-lip loss, and comminuted pilon fractures unsuitable for ORIF. It is valuable when the volar buttress is fragmented and direct fixation would require extensive dissection.(4)

The technique applies dynamic distraction through axial traction that reduces fragments, corrects subluxation, and maintains joint spacing while permitting controlled motion.(41) Elastic traction provides continuous adjustable force preventing fragment impaction and encouraging cartilage remodeling while reducing arthrofibrosis risk.(42)

Surgical Technique

Basic requirements include power drill, K-wires (0.8–1.4 mm), and rubber bands. After closed reduction, one proximal pin is placed through the proximal phalanx head center of rotation and one distal pin through the middle phalanx head, both perpendicular to the phalanx axis.(4)

A third reduction wire is placed through the middle phalanx base distal to fracture, volar or dorsal to the proximal wire depending on fracture pattern, to maintain reduction and control alignment.(43) Wire ends are bent into U-shaped hooks with 4–8 mm skin clearance, and rubber bands are applied between hooks providing symmetrical traction.(44)

Postoperative Management

The hand is elevated with soft dressing allowing adjacent digit movement. Early active motion within the fixator starts within 24–48 hours post-surgery.(45) Daily pin-site cleaning with povidone-iodine begins on postoperative day 2, with patients instructed on hygiene and monitoring for infection.(46)

Weekly follow-up includes pin-site inspection, range of motion assessment, rubber band tension adjustment, and radiographic control.(47) By weeks 3–4, fracture shows consolidation signs, motion increases to 60–80° PIP flexion, and light functional use is permitted.(48)

Frame removal occurs at 4-6 weeks when criteria are met: radiological early union, clinical stability, maintained reduction, and functional readiness for active-assisted motion.(49) Formal hand therapy intensifies after removal, focusing on edema control, joint mobilization, and grip strengthening.(50)

Complications

Limitations include patient compliance dependency, need for close follow-up, and inability to reconstruct large depressed defects.(51) Pin-tract infection is most common, along with rubber band failure, skin irritation, hardware loosening, over-distraction, and stiffness if device is kept too long.(52)

Combined and Salvage Strategies

In severe comminuted fractures, hybrid approaches combine mini-screw/plate fixation of fragments with dynamic fixator support to optimize stability and motion.(53) In elderly low-demand patients, fragment excision with volar plate advancement may achieve pain-free stable joint accepting some motion loss.(54)

When reconstruction fails, PIP arthrodesis provides pain relief at the cost of motion, while arthroplasty may preserve some motion but has implant limitations.(55)

Complications of PIP Joint Fracture-Dislocations

Mechanical Complications

Incomplete reduction or secondary displacement results in residual subluxation leading to incongruent joint surfaces and progressive degeneration. Even minimal malalignment translates into significant angular deformity and loss of function.(56)

Loss of reduction is common postoperatively, especially if rubber-band tension weakens or pins loosen, with risk increasing in highly comminuted fractures where ligamentotaxis cannot control fragment rotation.(57) Malunion manifests as articular incongruity, angulation, or rotation, with step deformity >1–2 mm correlating with poorer motion and early osteoarthritis.(58)

Chronic instability occurs when ligamentous structures fail to heal in appropriate tension, resulting in a flail joint prone to recurrent subluxation.(59) Post-traumatic degenerative arthritis is the most common long-term sequela, with arthritic changes appearing within 6–12 months as pain, crepitus, and loss of fine motor control.(60)

Biological Complications

Disruption of blood supply during trauma or surgery can lead to segmental avascular necrosis, particularly of the volar lip fragment, manifesting as persistent pain, delayed healing, or articular collapse.(61)

Pin-tract infection incidence ranges from 5–20%, resulting from poor hygiene, excessive pin motion, or prolonged fixation. Most are superficial responding to local care, but deeper infections can cause pin loosening or osteomyelitis.(62)

Complex regional pain syndrome develops in a small number of patients, characterized by disproportionate pain, trophic changes, and stiffness, requiring multidisciplinary management.(63)

Functional Complications

Stiffness is the most frequent complication, from prolonged immobilization, capsular scarring, or poor therapy compliance. PIP flexion contracture develops when volar plate shortens and periarticular fibrosis limits extension.(64)

Dorsal fracture-dislocations can rupture the central slip, leading to extensor lag or Boutonnière deformity (PIP flexion with DIP hyperextension).(65) Even with good motion recovery, biomechanical changes can reduce grip strength by 10–30% compared to the contralateral hand.(66)

Clinical Outcomes of Dynamic External Fixation

Suzuki and colleagues in their 1994 series reported mean PIP range of motion of 82° (range 70–95°) in 14 patients, with pin-tract infection in 14% managed conservatively.(4) Badia and Riano reported mean final PIP motion of 88° with grip strength recovery of 90% of contralateral hand in 12 patients, with minor complications in 10%.(67)

Darlis and colleagues reported mean active PIP motion of 83° ± 10° with grip strength recovery of 85% in 15 patients, achieving radiological union in all cases within 12–16 weeks, with superficial pin-tract infections in 13%.(68) Hsu and colleagues reported grip strength recovery of 87% in 21 patients, emphasizing complications including pin-tract problems, pin loosening, loss of reduction, joint stiffness, and residual incongruity.(69)

Karthik and colleagues reported mean active PIP motion improving to 85° in 30 patients with marked pain reduction. Radiological assessment confirmed maintained alignment, with complications limited to minor pin-tract irritation and transient stiffness, all managed conservatively.(70)

Recent systematic reviews summarized that dynamic external fixation studies generally reported higher final range-of-motion values and better functional recovery compared with static fixation or ORIF.(71,72) Meta-analyses confirmed dynamic external fixation was associated with superior postoperative range of motion compared with open reduction and internal fixation.(73)

Conclusion

Dynamic external fixation using the Suzuki frame represents a reliable, minimally invasive, and cost-effective treatment for unstable PIP joint fracture-dislocations. By applying continuous distraction through ligamentotaxis, this technique maintains articular alignment while permitting early controlled motion, thereby reducing the risk of stiffness and adhesion formation that commonly complicate these injuries. Complications are predominantly minor, with superficial pin-tract infections occurring in 10–15% of cases, most resolving with conservative management. The technique demonstrates particular efficacy in comminuted fractures unsuitable for rigid internal fixation, offering superior motion preservation compared to static fixation methods or prolonged immobilization. The Suzuki frame is especially valuable in several clinical scenarios: unstable dorsal fracture-dislocations with volar lip involvement exceeding 30–40% of the articular surface; comminuted pilon-type injuries where anatomic reduction via ORIF is not feasible; delayed presentations where soft tissue contracture precludes traditional open reduction; and resource-limited settings where simple, effective fixation using basic materials is advantageous.

In conclusion, dynamic external fixation using the Suzuki frame achieves high union rates, good-to-excellent functional outcomes in approximately 75–80% of cases, and minimal complications. It remains a valuable treatment option when anatomical reconstruction and early motion are desired, particularly when open reduction would compromise soft tissue integrity or when comminution precludes stable internal fixation. The technique represents an important tool in the hand surgeon's armamentarium for managing complex PIP joint injuries, offering a balanced approach that respects the delicate biology of the joint while addressing the mechanical demands of fracture stabilization and early rehabilitation.

References

1. Green DP, Hotchkiss RN, Pederson WC, Wolfe SW. Green's Operative Hand Surgery. 6th ed. Philadelphia: Elsevier; 2010.
2. Freeland AE, Geissler WB. Soft tissue and skeletal injuries of the proximal interphalangeal joint. Hand Clin. 2006;22(3):235–242.
3. Rettig ME, Raskin KB. Fracture dislocations of the proximal interphalangeal joint. J Am Acad Orthop Surg. 1999;7(2):102–111.
4. Suzuki Y, Matsunaga T, Kawanishi Y, Inoue T. The dynamic traction method for fracture-dislocations of the proximal interphalangeal joint. J Hand Surg Br. 1994;19(1):98–102.
5. Sadler TW. Langman's Medical Embryology. 14th ed. Philadelphia: Wolters Kluwer; 2019.
6. Larsen WJ. Human Embryology. 4th ed. New York: Churchill Livingstone; 2001.
7. Storm EE, Kingsley DM. Joint patterning defects caused by mutations in bone morphogenetic protein genes. Dev Dyn. 1996;207(4):420-432.
8. Mitrovic DR. Development of the metacarpophalangeal joint of the human hand. Am J Anat. 1978;151(4):475-485.
9. Standring S. Gray's Anatomy: The Anatomical Basis of Clinical Practice. 42nd ed. London: Elsevier; 2020.
10. Moore KL, Dalley AF, Agur AMR. Clinically Oriented Anatomy. 7th ed. Philadelphia: Wolters Kluwer; 2018.
11. Dell PC, Heterick JB. Ligamentous anatomy of the finger joints. J Hand Surg Am. 1987;12(4):711–719.
12. Cheah AEJ, Tan DM, Chong AKS. Anatomy and biomechanical properties of the volar plate of the finger. J Hand Surg Asian Pac Vol. 2018;23(3):370–6.
13. Botte MJ, Kumar V. The extensor mechanism of the finger. Orthop Clin North Am. 1997;28(1):73–80.
14. Garcia-Elias M, An KN, Cooney WP 3rd, Linscheid RL, Chao EY. Stability of the proximal interphalangeal joint. J Bone Joint Surg Am. 1989;71(8):1130–1135.
15. Trail IA, Davis TR. Biomechanics of the finger joints. In: Green's Operative Hand Surgery. 6th ed. Philadelphia: Elsevier; 2011. p. 168–174.
16. Lin GT, Amadio PC, An KN, Cooney WP. Functional anatomy of the flexor pulley system. J Hand Surg Am. 1989;14(6):949–956.
17. Pearl ML, Eaton RG. The proximal interphalangeal joint: functional anatomy and pathomechanics. Hand Clin. 1994;10(2):203–214.
18. Stern PJ. Management of proximal interphalangeal joint fracture-dislocations. J Hand Surg Am. 2008;33(6):1037–1045.
19. Slade JF 3rd, Gillon TJ. Fractures of the middle phalanx. Hand Clin. 2006;22(3):289–298.
20. Hastings H, Carroll C. Treatment of closed articular fractures of the phalanges. Clin Orthop Relat Res. 1987;(214):58–64.
21. Rettig ME, Raskin KB. Fracture dislocations of the PIP joint. Hand Clin. 1994;10(2):349–359.
22. Hastings H, Carroll C. Treatment of closed articular fractures of the phalanges. Clin Orthop Relat Res. 1987;(214):58–64.

23. Schenck RR. Classification of fracture dislocations of the PIP joint. In: AAOS Instructional Course Lectures. 1994;43:119–130.
24. Meinberg EG, Agel J, Roberts CS, et al. Fracture and dislocation classification compendium—2018. J Orthop Trauma. 2018;32(Suppl 1):S1–S170.
25. Calfee RP, Green DP. Fractures and dislocations of the hand. In: Green's Operative Hand Surgery. 6th ed. Elsevier; 2011.
26. Green DP, Wolfe SW, Hotchkiss RN, Pederson WC, Kozin SH, Cohen MS, editors. Green's Operative Hand Surgery. 7th ed. Philadelphia: Elsevier; 2017.
27. Stern PJ. Management of proximal interphalangeal joint fracture-dislocations. J Hand Surg Am. 2008;33(6):1037–1045.
28. Elfar JC, Jones AG, Kakar S. Fracture-dislocations of the proximal interphalangeal joint. J Hand Surg Am. 2013;38(6):1214–1225.
29. Trail IA, Fleming AN. Fractures of the proximal interphalangeal joint of the fingers. J Hand Surg Br. 2006;31(5):491–496.
30. Oak N, Goldfarb CA. Intra-Articular Fractures of the Hand. Hand Clin. 2013;29(2):143–154.
31. Elfar JC, Jones AG, Kakar S. Fracture-dislocations of the proximal interphalangeal joint. J Hand Surg Am. 2013;38(6):1214–1225.
32. Dobyns JH, McElfresh EC. Management of fracture-dislocation of the proximal interphalangeal joint by extension-block splinting. J Bone Joint Surg. 1972;54A:1705–1711.
33. Worgul CA, et al. Extension-Block Pinning for Unstable Dorsal Proximal Interphalangeal Fracture-Dislocations. J Hand Surg Am. 2022;47(10):900–908.
34. AAOS. Indications for screw fixation and reconstruction options in PIP volar lip fractures. Instructional Course Lectures; 2020.
35. Stern PJ. Management of proximal interphalangeal joint fracture-dislocations. J Hand Surg Am. 2008;33(6):1037–1045.
36. Oak N, Goldfarb CA. Principles for restoration of joint congruity and early motion. Hand Clin. 2013;29(2):143–154.
37. Wang CC, et al. Middle phalanx base intra-articular fracture: volar mini-hook plate fixation — case report. 2023.
38. Gianakos AL, et al. Treatment for acute proximal interphalangeal joint fracture-dislocations: a systematic review. J Hand Surg Am. 2020;45(5).
39. Gianakos AL, et al. Volar plate arthroplasty outcomes in PIP reconstruction. J Hand Surg. 2020.
40. Faulkner H, et al. Hemi-hamate Arthroplasty for base of middle phalanx fractures: review and outcomes. J Hand Surg Eur. 2021;46(2).
41. Day CS, Stern PJ. Fracture dislocation of the proximal interphalangeal joint: evaluation and management. J Am Acad Orthop Surg. 2007;15(3):139–148.
42. Tyser AR, Tsai MA, Parks BG, Means KR Jr. Stability of fracture-dislocations of the proximal interphalangeal joint: a biomechanical study. J Hand Surg Am. 2010;35(12):1983–1988.
43. Suzuki Y, Matsunaga T, Kawanishi Y, Inoue T. The dynamic traction method for fracture-dislocations of the proximal interphalangeal joint. J Hand Surg Br. 1994;19(1):98–102.

44. Henn CM, Stern PJ. Dynamic external fixation for proximal interphalangeal joint fracture-dislocations: technique and outcomes. Hand Clin. 2012;28(2).

45. Keramidas E, Rodopoulou T. The Suzuki frame for complex intra-articular fractures: review of use and indications. Eur J Plast Surg. 2007;30.

46. AO Foundation. Dynamic external fixation for proximal interphalangeal joint (PIPJ) injuries — technique notes. Surgery Reference: Hand & Middle Phalanx.

47. Ahangar P, et al. Dynamic mini external fixator for PIP fracture-dislocations: clinical series. J Hand Microsurg. 2021;13(2).

48. Henn CM, et al. Dynamic external fixation for PIP fracture-dislocations: technique paper and outcomes. Clin Hand Surg.

49. Stern PJ, Wiesler ER, Reilly DG. Results of dorsal fracture-dislocations of the proximal interphalangeal joint treated by open reduction and internal fixation. J Hand Surg Am. 1991;16(3):544–550.

50. Haase SC, Stern PJ. Current concepts in treatment of proximal interphalangeal joint fracture-dislocations. J Hand Surg Am. 2014;39(7):1402–1411.

51. Oak N, Goldfarb CA. Indications and limitations of dynamic traction for PIP joint fractures — review. Hand Clin. 2013;29(2):143–154.

52. Lad PB, et al. A rare complication of pins and rubbers traction: over-distraction and vascular compromise — case report. J Hand Surg Glob. 2021.

53. Henn CM, et al. Dynamic external fixation for PIP fracture-dislocations: technique paper and outcomes. Clin Hand Surg.

54. Gianakos AL, et al. Comparative complications between hemi-hamate and ORIF and dynamic fixation. J Hand Surg. 2020.

55. Oak N, Goldfarb CA. Salvage options for failed reconstruction: arthrodesis/arthroplasty considerations. Hand Clin. 2013;29(2).

56. O'Brien L, et al. Complications following intra-articular fractures of the PIP joint. J Hand Surg Am. 2011;36(1):113–122.

57. Elfar JC, Stern PJ. Loss of reduction in dynamic external fixation: causes and prevention. J Hand Surg Am. 2008;33(6):894–901.

58. Kiefhaber TR, Stern PJ. Fracture-dislocations of the PIP joint. J Hand Surg Am. 1998;23(3):368–380.

59. Eaton RG, Malerich MM. Volar plate arthroplasty for chronic instability of the PIP joint. J Hand Surg Am. 1980;5(3):260–268.

60. Afendras G, et al. Post-traumatic arthritis after PIP fracture-dislocation: long-term results. J Hand Surg Eur. 2015;40(2):162–169.

61. Gaston RG. Vascular supply of the phalanges and risk of AVN. Hand Clin. 2010;26(3):335–342.

62. Keramidas E, Rodopoulou T. Pin-tract infections in dynamic external fixation. Eur J Plast Surg. 2007;30:91–95.

63. Atkins RM. Complex regional pain syndrome after hand trauma. J Bone Joint Surg Br. 2003;85-B(8):1105–1112.

64. Nanda V, et al. Stiffness and contracture after PIP fractures: pathophysiology and prevention. Hand (N Y). 2020;15(2):185–193.

65. Doyle JR. Extensor mechanism injury in the finger. J Hand Surg Am. 1985;10(3):399–407.

66. Dreyfuss D, et al. Grip strength and functional outcome after PIP joint injuries. J Hand Ther. 2019;32(3):300–309.

67. Badia A, Riano F. Dynamic intradigital external fixation for proximal interphalangeal joint fracture-dislocations. J Hand Surg Am. 2004;29(5):914–919.

68. Darlis NA, Kaufmann RA, Giannoulis F, Sotereanos DG. Fracture dislocations of the proximal interphalangeal joint treated with a mini external fixator. J Hand Surg Am. 2006;31(5):815–820.

69. Hsu LP, Schwartz EG, Kalainov DM, Chen F, Makowiec RL. Complications of dynamic external fixation for unstable fracture-dislocations of the proximal interphalangeal joint. J Hand Surg Am. 2010;35(4):723–728.

70. Karthik V, Rajavarman S, Anandh K. Functional outcomes of Suzuki frame fixation for intra-articular proximal interphalangeal joint fractures. Scope Med J. 2025;15(3):575–586.

71. Kamath AF, Benavent KA, Bryan AJ. Management trends in proximal interphalangeal joint fracture-dislocations: a systematic review. Hand Clin. 2020;36(2):223–236.

72. van der Vliet QMJ, Chen NC. Dynamic external fixation for phalangeal intra-articular fractures: current evidence and future directions. Curr Rev Musculoskelet Med. 2022;15(4):289–301.

73. Newman AH, Ekhtiari S, Horner NS, et al. Operative versus non-operative management of PIP joint fracture-dislocations: a meta-analysis. Hand (N Y). 2023;18(3):NP95–NP104.