Management of pediatric volar plate avulsion fractures of the proximal interphalangeal joint: A systematic review

ABSTRACT

Background: Sudden, forced hyperextension injuries to the proximal interphalangeal joint leading to volar plate avulsion fractures are common hand injuries in children. Suboptimal management of these fractures can lead to the development of long-term complications such as stiffness and flexion contracture.

Methods: MEDLINE (PubMed), Scopus, Embase, Google Scholar and Cochrane CENTRAL databases were systematically searched, and additional studies were found through reference of papers up to 15th June 2023. Identified articles were assessed using pre-determined inclusion/exclusion criteria.

Results: Twenty-five articles were included, involving 268 patients with ages from 3 to 17 years. Fractures with less than 30% joint involvement, classified as Eaton Type I or II, or designated as 'Stable' in the Keifhaber-Stern classification, were treated through non-surgical means. Surgical interventions, encompassing open reduction and internal fixation, were reserved for fractures with over 30% joint involvement and/or meeting criteria such as Eaton Type IIIa or IIIb and Keifhaber-Stern "Tenuous" or "Unstable". Positive outcomes were seen in 99.5% of patients receiving non-surgical treatment, compared with 85.7% in the surgical cohort.

Conclusions: The literature demonstrated positive outcomes for fractures presenting with less than 30% joint involvement that were managed non-surgically. In fractures with more than 30% joint involvement, surgical interventions yielded positive results. To further substantiate these findings, larger prospective studies with uniform measures are needed to validate the results of this study.

Keywords: volar plate avulsion fractures; palmar plate avulsion fracture; children; management; proximal interphalangeal joint

INTRODUCTION

Hand trauma affecting the phalanges is one of the most common injuries in children.[1] Household activity is responsible for the majority of these injuries in younger children whereas sports activities is known to be the common causative agent in older children.[2] Abrupt hyperextension injuries to the proximal interphalangeal joint (PIPJ) constitute a considerable proportion of injuries to the hand, leading to volar plate avulsion fractures.[3,4]

Despite a relatively high frequency of this injury in children, existing data on the management of volar plate avulsion fractures is scarce and is predominantly focused on the adult population.[5-7] As a result, recommendations on the management of these fractures in the pediatric population are often guided by clinical experience. The Keifhaber-Stern and Eaton classification[4,6] are the most widely accepted classifications for volar plate avulsion injuries that may offer assistance in the management of pediatric fractures, particularly on the indications for non-surgical and surgical management. For fractures defined as ‘Stable’ or ‘Tenuous’ under the Keifhaber-Stern classification or Type I to IIIa under Eaton’s classification, conservative extension block splinting and early mobilization is advocated.[4,7,8] ‘Unstable’ fractures under the Keifhaber-Stern classification or Eaton Type IIIb are deemed irreducible and require surgical treatment.[4]

Although the rate of complication is rare, the development of joint stiffness and flexion can cause serious long-term aesthetic and functional implications for the patient.[4,9] Patients who experience mismanagement or delayed treatment may also experience compromised PIPJ motion, late joint dislocation and joint deformity.[2,4,10,11]

In this way, presence of complications may also be associated with how such fractures are classified and subsequently treated, thus a closer inspection of the relationship between these factors particularly in the pediatric population is required[2,4,9-11].

This systematic review aims to understand the outcomes of both non-surgical and surgical management of volar plate avulsion fractures of the PIPJ in children and explore any factors that might affect these outcomes. We hope to provide recommendations on management of these fractures in this patient population depending on the presentation.

METHODOLOGY

MATERIALS AND METHODS

This systematic review complied with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines and is registered with PROSPERO.

Search strategy

MEDLINE (PubMed), Scopus, Embase, Google Scholar and Cochrane CENTRAL databases were comprehensively searched from database inception to 15th June 2023. The main concepts of the review included volar plate avulsion fractures of the PIPJ in the pediatric population, which was found via medical subject headings (MeSH) terms and keywords. Terms such as “hyperextension injury”, “volar subluxation”, “checkrein ligament injury”, “PIPJ dislocation/subluxation” were used. Four reviewers independently conducted the searches for relevant articles and duplicates were removed via Rayyan screening software. All authors screened the titles and abstracts for eligibility, retrieved full texts of the eligible articles and completed full text screening. Disagreements of eligibility were resolved between all authors through discussion. Additional sources were identified through searching references of papers and through grey literature search.

Selection Criteria and Outcome Measures

The Patient, Intervention, Comparison, Outcome (PICO) selection criteria included: (1) human pediatric patients (<18years); (2) acute or chronic volar plate avulsion fractures of the PIPJ; (3) reporting non-surgical and surgical outcomes or complications; (4) in retrospective, prospective studies or randomized control trials (RCTs). Exclusion criteria included dorsal fractures, adult population (>18 years), conference abstracts, article reviews, literature reviews, and animal studies. Only papers published in English were included. There was no date of publication restriction.

An acute fracture was defined as a fracture which was treated within four weeks of the injury; a chronic fracture was defined as a fracture which was treated more than four weeks after the injury.[12] An avulsion fracture was defined as a failure of bone in which a bone fragment is pulled away from its main body by soft tissue that is attached to it.[13] A pediatric patient was defined as an individual aged 17 years or younger.[14]

A positive outcome was defined as an outcome where the patient was satisfied with the results of the intervention (e.g., using the visual analogue scale (VAS[15])), experienced no pain, had full range of motion, no degenerative changes on X-ray, no clinical deformity, no infection, no functional disability, no hyperextension deformity or when no complications were reported following intervention (e.g., from results of Gaine's assessment[8], modified Incavo scoring system[3] and Catalano classification[16]).

A negative outcome was recorded if there was any reduced range of motion, pain, swelling, or deformity following intervention (e.g., including poor outcomes from the modified Incavo scoring system[3]).

Methodological Quality Assessment

Quality of the included studies was assessed by all authors depending on the type of study. Non-randomized studies were assessed using the Risk of Bias in Non-randomized Studies – of Interventions (ROBINS-I) tool,[17] and randomized studies were assessed using the Cochrane risk of bias (RoB 2) tool.[18] Results were presented in robvis visualization tool format.[19]

Data Extraction and Analysis

A bespoke data extraction form was used to extract data regarding demographics of each patient (e.g., age, gender), characteristics of each injury (e.g., presenting symptoms, etiology, fracture displacement, mechanism of injury, time since injury and time to treatment), investigations (e.g., X-ray, CT, MRI), intervention (e.g., splinting, strapping, hand therapy, open reduction and internal fixation (ORIF), arthroplasty, closed reduction, excision), intervention follow up, outcomes (positive or negative) and complications of non-surgical and surgical management for acute and chronic volar plate injuries of the PIPJ. All qualitative and quantitative data were downloaded onto an Excel spreadsheet and calculated through the Excel Formulas using various functions.

RESULTS

A total of 9,825 papers were identified. Following screening using the predetermined criteria, 25 studies were included into this systematic review (Figure 1).

Study Quality

Quality assessment for the singular RCT by Paschos *et al*[4] was determined to have 'Some Concerns' due to the lack of objective measurement tools which may have caused possible research bias (Supplemental Figure 1). Of the 24 non-RCT studies, 10 were deemed to have 'Moderate' risk of bias, mainly stemming from confounding factors within each study, and one study was deemed to have a serious risk of bias, also attributed to the presence of confounding factors. The risk of bias assessment for non-RCT studies is shown in Supplemental Figure 2.

Study Characteristics

Twenty-five studies were included in this review, with a publication date between June 1979 and June 2022. Only one study was a randomized control trial (RCT),[3] four were prospective studies,[5,6,20,21] nine were retrospective studies,[15,16,22-28] ten were case reports[11,28-36] and one was a case series.[8] A total of 268 pediatric participants were identified, with an average age of 11.09 years (Range: 3-17, Median: 16) and a male-to-female ratio of 2:1.

A larger proportion of the fractures were associated with dorsal displacement (35%), followed by undisplaced fractures (12.7%). When reported, the most common mechanism of injury was during sports activities (56/268 patients). No injury mechanism was reported for 73% of cases. In studies reporting the timeline of injury, 144 patients (53.74%) had an acute (<4 weeks) presentation and 6 patients (2.24%) presented chronically (>4 weeks). Almost half of the patients (48.1%) sought medical attention within one week, with 7.8% of them presenting on the same day, and 44% of participants gave no indication of when the patients presented to the clinician.

The most prevalent presenting complaint was pain and swelling observed in 38.8% and 44.4% of cases respectively. There were no treatment delays in 36.6% of cases, while in 15.3% of cases, there was a delay in ‘time to treatment’, where patients were treated between 2-7 days after presentation. The ‘time to treatment’ was not recorded in 119 cases.

Radiograph X-ray was the primary diagnostic modality used for 173 patients (64.5%). One study employed magnetic resonance imaging for one patient, and four studies opted for computed tomography. However, no specific imaging was described for the remaining 92 participants. Table 1 presents the demographic data of the included studies.

Outcomes

Positive outcomes were observed in 99.5% of non-surgical treatments across 198 participants, while 85.7% of positive outcomes were recorded in patients treated with surgical methods. Table 2 provides an overview of the studies.

Non-surgical management for acute presentations

In the acute non-surgical treatment group, six papers were included, comprising a total of 122 patients.[3,5,6,11,29,37] Two primary modalities were utilized: splinting and strapping.

In the acute non-surgical group, 73 patients (59.8% of the cohort) underwent treatment with aluminum splints,[3,6,37] while 46 patients (37.7%) received strapping.[3,5,6] Additionally, three cases (2.5%) utilized a combination of neighbor/buddy strapping and splinting.[11,29]

During the follow-up period, which ranged from three months to three years, almost 10% of participants (n=12) were not subjected to a particular type of immobilization technique.[5,11,29] In contrast, over 88% patients (n=108) were encouraged to engage in immediate unprotected weight-bearing mobilisation.[3,6] Additionally, a small percentage of participants, specifically 1.6% (n=2), received an aluminum splint for mobilization purposes.

Overall, positive outcomes were achieved in 121 patients (99.2%) with only one patient having persistent pain, swelling, deformity, and loss of function.[3]

Non-surgical management with unknown time frame

Furthermore, two papers including 76 patients reported non-surgical management with an unknown time scale.[22,23] Out of these, 75 patients received hand therapy,[23] while one patient underwent splinting.[22] Both studies reported positive outcomes in all cases. However, information regarding the immobilization technique, intervention follow-up, duration of the intervention, and time to treatment were not provided in these studies.

Surgical management for acute presentations

In the acute surgical treatment group, 22 patients received various types of interventions.[8,15,24,28,30-35] ORIF was the most frequently employed method, accounting for 16 cases. The management duration varied from 10 days to five weeks, while the follow-up period ranged from two months to 67 months. Only one negative outcome was reported, where mild synovitis was observed.

Surgical management for chronic presentations

The chronic surgical treatment group consisted of four studies with a total of 10 participants. Among the interventions employed in this group, the predominant approach involved ORIF using Kirschner wires (K-wires), with a follow up period varying between seven months to seven years.[20,21] Various suture techniques were also employed, including pull out sutures (n=2),[16] anchor suture with tendon graft (n=1),[16] and the use of monofilament polydioxanone suture (n=1).[36] There were three negative outcomes,[21] where two cases of distal interphalangeal joint lag and one case of joint erosion were observed.

Surgical management with unknown time frame

In four studies with a total of 38 patients,[23,25-27] surgical intervention was opted as a method of management without reports of a timescale. Within this group, the most frequently employed intervention was ORIF and K-wire (14 patients), with 11 patients receiving ORIF and 23-gauge needles,[25] and six patients being treated with osteoclasis.[25]

Out of the total 38 patients, 32 patients observed positive outcomes following the various interventions. However, six patients encountered negative outcomes, which included mild buttonhole deformity (n=1), volar angular deformity (n=1), and callous overgrowth and PIPJ swelling (n=4).[25]

Factors affecting outcomes

Classification

A shown in Tables 3 and 4, for non-surgical management, 43 patients (21.7%) were classified as Eaton Type I,[3,5,6,11] and only 3 patients (1.52%) as Eaton Type II,[3,37] with no cases of Eaton Type IIIa or IIIb identified. Keifhaber-Stern classification revealed 88 patients (44.4%) with a 'Stable' type.[1,3,5,37] In the surgical management group, there were seven cases of Type I,[8,20,28,33] 14 cases of Type II,[8,15,21,32,36] 10 cases of Type IIIa[27,30,34] and one case of Type IIIb[35] based on the Eaton classification. Keifhaber-Stern classification identified 20 cases as 'Stable'[8,20,21,27,28,30,32,33] and two cases as

'Tenuous'.[8,34] Notably, there were no cases classified as 'Unstable' in either group. However, a significant number of cases in both groups lacked sufficient data for further categorization.

Displacement

Of particular interest is a study by Lee et al.,[27] which extended the investigation by quantifying displacement and rotation of fragments within a specific subgroup of five patients. Five patients initially underwent non-surgical treatment (finger splint) due to not meeting surgical criteria. However, as these patients reported pain during end-range motion or restricted motion after three to six weeks, surgical interventions were subsequently performed with positive outcomes.

Other associations such as age and mechanism of injury with non-surgical/surgical outcomes could not be made due to scarcity of data in literature.

Comparison of outcomes between acute and chronic presentations

In acute presentations,[3,5,6,8,11,15,24,28-35,37] where treatment was initiated within four weeks of the injury, a substantial 99.5% of patients, constituting 144 individuals, experienced positive outcomes. This cohort demonstrated a high rate of successful recoveries, irrespective of whether the chosen approach was surgical or non-surgical. In contrast, among the 10 chronic cases,[16,20,21,36] the incidence of negative outcomes escalated. Approximately 30% of chronic cases[21] reported negative outcomes, including complications such as deformities and joint erosion. Unfortunately, a significant portion of the participants, accounting for 42.5% (n=114), had an unknown time scale of injury presentation.[22,23,25-27]

DISCUSSION

Hyperextension injuries leading to volar plate avulsion fractures are common in the pediatric population with severe implications if left untreated.[3-5,9] Despite high prevalence of these injuries, the standard of care of volar plate avulsion fracture in the pediatric population has not been well established in the literature. It is on this basis that this study was conducted to understand the outcomes of both non-surgical and surgical management and to explore any factors that might affect the outcomes.

From the included papers, the data suggests that in stable fractures with less than 30% joint involvement, non-surgical management is appropriate, as shown in Table 3 and 4. This is in line with the recommendations provided by the Eaton classification[20] and Keifhaber-Stern classification,[4] which recommend non-surgical management for injuries with less than 40% and 30% PIPJ surface involvement respectively.[4] Less severe injuries (<30% articular surface damage) appear to be better managed non-surgically with minimal complications as these are likely to heal rapidly without the need for invasive procedures.[20] In this review, only one poor outcome was reported for non-surgical management, where a patient experienced pain and swelling following intervention.[3] Traditionally, non-surgical treatment involves aluminum orthosis,[3] neighbor strapping,[5] and extension block splinting.[6] In line with this, the use of various non-surgical methods was reported although it was difficult to compare the effectiveness of each technique due to the positive outcomes observed in the majority of the applied non-surgical interventions. The preference of the senior authors of this review is to use a removable and soft Bedford splint for 2-3 weeks, which provides edema control in addition to relative immobilization. All the patients in this subgroup of patients presented within four weeks of injury, and the corresponding data for chronic counterparts (>4 weeks of injury) were not available.

According to Eaton Type IIIb and Keifhaber-Stern ‘Unstable’ classification, surgery is warranted for fractures involving greater than 40% articular base. However, from the identified literature in this study, patients commonly underwent surgical intervention when there was more than 30% joint involvement and displacement. One exception to this was seen in a study by Ikeda et al,[8] where fractures were treated surgically, despite articular involvement being less than 30% (26% and 27%). This was due to the presence of displacement and rotation. Several surgical techniques have been reported for the fixation of volar plate avulsion fractures, which include ORIF with plate and screws, K-wire fixation, volar plate arthroplasty,[20] volar plate reattachment.[15] No mention of the application of surgical techniques on an open/closed physis was made in the included studies. These surgical techniques may have variations depending on the types of devices used and practitioners’ techniques for fixation. Positive outcomes were seen in most cases (n=22).[8,15,24,27,28,31-33,35] However, complications such as joint erosion, deformities and swelling were observed in three out of 10 chronic cases where there were delays of seeking treatment for more than four weeks.[21,25] From this analysis, it is evident that patients must seek treatment immediately to avoid potential negative consequences. Regardless of the method of management, early commencement (<4 weeks) of management appeared to be linked to the optimal outcomes with minimal complications. This highlights the importance of immediate start to treatment, especially as fractures unite quickly in children and can lead to malunion.[38]

Most of the patients in our study (n=173) were evaluated with radiograph imaging. To clearly assess the severity and determine the optimal management of volar plate injury, anteroposterior and lateral view radiographs are required, as emphasized in four studies.[3,6,21,25] However, a different choice of imaging modality was seen in one of the studies. Ikeda et al.[8] pre-operatively evaluated the injury using three-dimensional CTs for volar plate avulsion fractures. High resolution 360-degree views and soft tissue visualization are offered by computed tomography, yet the question of cost-effectiveness and practicality of its use over X-ray imaging for every volar plate fracture persists.[39] This suggests that X-ray imaging currently provides the optimal mode of investigations for management. Figure 2 illustrates a suggested guideline for the management of volar plate fractures based on current literature.

Our study was limited by a small overall sample size, due to the scarcity of research on children. Having fewer numbers presents a selection bias as it may not be representative of the whole population, especially for evaluating surgical management. Additionally, although this review considered the data taking account of the age, it was unclear whether the pediatric populations reported in the literature were skeletally mature, which may potentially influence the outcomes of the patients. In addition, only one RCT was included with others being the retrospective studies, prospective studies, and case reports. Analyzing studies at the lower hierarchy of evidence, although supported by the RoB and ROBINS-I quality of assessment results, may impact the reliability of results. Finally, there were highly variable outcome parameters and heterogeneity in measurements, such as the methods and questionnaires (modification of Incavo scoring system,[3] Gaine's assessment,[8] DASH scores[10] and VAS[15]) used for determining positive and negative outcomes. For this reason, there was a degree of subjectivity and disparity between studies in defining positive and negative outcomes. Future studies should attempt to record information with more standardized measurements before and after the intervention, along with the information on skeletal maturation, to allow comparison and better understanding of the outcomes.

CONCLUSION

This review suggests that non-surgical intervention is indicated for fractures with less than 30% joint involvement, whereas surgical management may be indicated in fractures with more than 30% joint involvement. In addition, the literature strongly suggests that positive outcomes are linked to the early commencement of treatment (<4 weeks). The management of volar plate avulsion fracture in the pediatric population should integrate a comprehensive history, clinical examination, and investigation, including anteroposterior and lateral views of plain film radiograph to assess the severity of injury, after which the decision on the management technique can be made. Finally, larger prospective studies in younger children are required to direct and refine appropriate management for this age group.

STATEMENTS

Conflicts of Interest Statement:

The Authors declare there is no conflicts of interest.

Statement of Informed Consent:

Informed consent was obtained from all individual participants included in the study.

Statement of Human and Animal Rights:

This article does not contain any studies with human or animal subjects.

Statement of Funding:

None to Declare

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FIGURE LEGEND

Figure 1. PRISMA Flowchart of Study Selection

Figure 2. Suggested guideline for management of acute volar plate avulsion fractures in children.

TABLE LEGEND

Table 1. Injury characteristics

Table 2. Outcomes of management of acute volar plate avulsion fractures of the proximal interphalangeal joint in children.

Table 3. Keifhaber-Stern classification of volar plate injuries in both non-surgical and surgical groups.

Table 4. Eaton classification of volar plate injuries in both non-surgical and surgical groups.

Injury characteristics	n	%
Aetiology of injury		
Index finger	7	2.61
Middle finger	9	3.36
Ring finger	4	1.49
Little finger	16	5.97
Unknown	232	86.57
Fracture displacement		
Dorsal	95	35.45
Volar	20	7.46
Undisplaced	34	12.69
Both	26	9.70
Unknown	93	34.70
Mechanism of injury		
Sporting	56	20.90
Accidents	15	5.6
-Fight	1	0.37
-Slipping and falling	2	0.75
-Crushing	7	2.61
-Door slam	4	1.49
-Bicycle accident	1	0.37
Unknown	197	73.51
Investigations		
X-ray	173	64.55
-AP	105	39.18
-Lateral	105	39.18
-Type unmentioned	68	25.37
3D CT	4	1.49
MRI	1	0.37
Unknown	92	34.33
Presenting symptoms		
Pain / Tenderness	104	38.81
Swelling	119	44.40
Deformity	11	4.10
Reduced movement	13	4.85
Unknown	122	45.52
Time since injury		
Same day	21	7.84
< 1w	108	40.30
1 – 2w	6	2.24
2 – 4w	9	3.36
> 4w	6	2.24

Unknown	118	44.03
Time to treatment		
Immediate	98	36.57
2 – 7d	41	15.30
8d – 1m	2	0.75
> 4w	8	2.99
Unknown	119	44.4

Table 1. Injury characteristics

n: number of patients, %: percentage, d: day, w: week, m: month, AP: anteroposterior, D: dimensional, CT: computer tomography, MRI: magnetic resonance imaging

Author, Publication date	Eaton classification	Keifhaber-Stern classification	Start of Treatment	Technique used (n)	Equipment used (n)	Mobilization technique (n)	Intervention follow up	Outcome Positive or Negative (n)	Complications (n)
Non-surgical treatment (n=198)									
Acute (n=122)									
Lo and Richard[11] (01/06/1995)	Type I (1) Type II (1)	Stable (2)	0d, 3w	Splinting and Buddy strapping (2)	-	-	12w	Positive (2)	-
Murashige et al.[37] (01/08/2002)	Type II (2)	Stable (2)	0d	Splint (2)	Aluminum splint (2)	Aluminum splint	3y	Positive (2)	-
Rimmer and Burke[5] (01/01/2009)	Type I	Stable	1d	Strapping (9)	Neighbor strapping (9)	-	4m	Positive (9)	-
Weber et al.[6] (09/01/2009)	Type I	Stable and Tenuous	5d	Splint (33) - Extension block splint	Monodigital padded dorsal aluminum	Unprotected mobilization (33) - Fully flex and	12w	Positive (33)	-

					extension block splint (33)	extend fingers TDS; removed splint 10d after			
Paschos et al.[3] (01/02/2014)	Type I and Type II	Stable	0d	Group A - Strapping (37) Group B - Splinting (38)	Group A - Neighbor strapping (37) Group B - Aluminum orthosis (38)	Unprotected mobilization (75)	12m	Positive (74) Negative (1)	Pain (1) Swelling (1) Deformity (1) Loss of function (1)
Mehta et al.[29] (01/03/2021)	-	-	0d	Strapping and splinting (1)	Neighbor strapping (1) Dorsal extension block splinting	-	12w	Positive (1)	-
Unknown time scale (n=76)									
Nakago et al.[22] (05/04/1999)	-	-	-	Splint (1)	-	-	-	Positive (1)	-

Plonczak et al.[23] (12/2017)	-	-	-	Hand therapy (75)	-	-	-	Positive (75)	-
Surgical Treatment (n=70)									
Acute (n=22)									
Zook et al.[30] (01/06/1979)	Type IIIa	Stable	0d	Suture (3) Splint (3)	Ethilon suture (3) Stainless steel wire (1)	Splint (3)	2m (1), 3m (2)	Positive (3)	-
Stern et al.[28] (05/1985)	Type I	Stable	5 hours	Wires and suture (1)	Kirschner pin (1)	Kirschner wire with dorsal extension block splint	7m	Negative (1)	Mild synovitis (1)
Green et al.[31] (05/1992)	-	-	5d	Screws (1)	-	Splint	1y	Positive (1)	-
Takami et al.[32] (01/07/1997)	Type II	Stable	0d	ORIF (2)	Kirschner wire (2)	Kirschner wire (2)	2y	Positive (2)	-

Dionysian et al.[24] (11/02/2000)	-	-	17d	Arthroplasty (1)	-	-	15y	Positive (1)	-
Sano et al.[33] (01/11/2005)	Type I	Stable	6d	ORIF - Volar incision (1)	Kirschner wire (1)	Kirschner wire (1)	3m	Positive (1)	-
Otani et al.[34] (01/04/2007)	Type IIIa	Tenuous	0d	ORIF Kirschner wire, Pull out wire (1)	Kirschner wire, Pull out wire (1)	Kirschner wire	12w	Positive (1)	-
Ikeda et al.[8] (1/1/2009)	Type I (1) Type II (1) Type III (1)	Stable (2) Tenuous (1)	Mean: 3.3d	ORIF (3)	Kirschner wire (3)	Aluminum splint (3)	Mean: 16m (Range: 14-18m)	Positive (3)	-
Gengler et al.[35] (01/09/2018)	Type IIIb	-	2d	ORIF (1) - Kirschner wire and incision; volar bruner type incision	Kirschner wires and screws, suture (1), mini plate	-	4m	Positive (1)	-

Kim et al.[15] (01/09/2018)	Type II	-	1.75d	ORIF (8)	Mi-tek bone anchoring or PDS bone suturing (8)	-	Mean: 41.6m (Range: 12-67m)	Positive (8)	-
Chronic (n=10)									
Eaton et al.[20] (01/05/1980)	Type I	Stable	2m	Volar plate arthroplasty (1)	Kirschner wire (1)	Kirschner wire, Splint	7y	Positive (1)	-
Peimer et al.[21] (01/01/1984)	Type I (3) Type II (2)	Stable	Range: 1-52w	Wires and Suture (5)	Kirschner wire (5)	Splint	Mean: 22.4m (Range: 7-49m)	Positive (2) Negative (3)	DIP lag (2), Joint erosion (1)
Kaneshiro et al.[16] (01/10/2014)	-	-	12m, 21m, 6y	Pull out suture (2) Anchor suture with tendon graft (1)	-	Kirschner wire with dorsal splinting (1) Extension block with dorsal splinting (2)	Mean: 14.7m (Range: 9-23m)	Positive (3)	-

Garcia Bernal et al.[36] (23/06/2022)	Type II	-	19m	ORIF (1) - Volar bruner type incision. Reattachment suture	Mi-tek bone anchoring or PDS bone suturing (1) - monofilament PDS suture	Dorsal splinting	27m	Positive (1)	-
Unknown time scale (n=38)									
Kang et al.[25] (31/08/2005)	-	-	Mean: 18d (Range: 2d-2m)	Cross-Cross fixation (14) Surgical Kirschner wire fixation (10) Osteoclasis (6)	ORIF - Kirschner wire (8) 23-gauge needles (11) Pull out steel wire and Kirschner wire (1)	Splint	-	Positive (18) Negative (6)	Mild buttonhole deformity (1), Volar angular deformity (1), callous overgrowth and PIP joint swelling (4)

Hamilton et al.[26] (10/2006)	-	-	Mean: 17d (Range: 7-42d)	ORIF (1)	-	-	47m	Positive (1)	-
Lee et al.[27] (28/07/2013)	Type IIIa	Stable	Mean: 24.4d (Range: 7-56d)	Excision and reattachment (1) Excision only (1) ORIF + screws (2) ORIF + suture (1)	Suture (1) Screws (2)	-	-	Positive (5)	-
Plonczak et al.[23] (30/12/2017)	-	-	-	Kirschner (6) ORIF (2)	-	-	-	Positive (8)	-

Table 2. Outcomes of management of acute volar plate avulsion fractures of the proximal interphalangeal joint in children.
d: Day, w: Week, m: Month, y: Year, ORIF: Open reduction and internal fixation, TDS: Three times daily, DIP: Distal interphalangeal, PIP: proximal interphalangeal, n: number of patients, PDS: polydioxanone

Classification type	Description	Non-surgical		Surgical	
		n	%	n	%
Stable	Involving <30% articular base of the middle phalanx	88	44.4	20	28.6
Tenuous	Involving 30-50% of the articular base the middle phalanx; reduces with <30° of flexion	-	-	2	2.86
Unstable	Involving <50% articular base of the middle phalanx but requires >30% flexion to maintain reduction	-	-	-	-
Unknown		110	55.6	48	68.6

Table 3. Keifhaber-Stern classification of volar plate injuries in both non-surgical and surgical groups.
n: number of patients, %: percentage

Classification type	Description	Non-surgical		Surgical	
		n	%	n	%
Eaton Type I	Avulsion of the volar plate without a fracture dislocation	43	21.7	7	10
Eaton Type II	Dorsal dislocation of the PIP joint with avulsion of the volar plate; complete tear of the collateral ligament	3	1.52	14	20
Eaton Type IIIa	Fracture dislocation with <40% articular surface with dorsal aspect of the collateral ligament remaining attached to the middle phalanx	-	-	10	14.3
Eaton Type IIIb	Fracture dislocation with >40% articular surface without the collateral ligament remaining attached to the middle phalanx	-	-	1	1.43
Unknown		152	76.8	38	54.3

Table 4. Eaton classification of volar plate injuries in both non-surgical and surgical groups.
n: number, %: percentage, PIP: proximal interphalangeal