













Diagnosis and management of finger injuries in sport climbers – narrative review with clinical and training implications

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Abstract

Introduction and Objective. The transformation of sport climbing into a high-performance Olympic discipline has increased exposure to extreme finger loading and a rise in overuse and acute structural injuries. The aim of the review is to synthesize clinical and biomechanical evidence to support accurate diagnosis, evidence-based treatment, and safe return-to-sport strategies after sustaining climbing-related finger injuries.

Review Methods. A structured narrative search of PubMed/MEDLINE, Scopus, and Web of Science prioritized peer-reviewed studies from 2017–2025 with key foundational literature. Clinical and biomechanical investigations involving climbers or climbing-specific grips were analyzed thematically across epidemiology, anatomy, imaging, treatment, and rehabilitation.

Brief description of the state of knowledge. Finger injuries are the most prevalent musculoskeletal condition in climbers, with flexor pulley lesions representing the dominant structural pathology. High-resolution ultrasonography is supported as the primary diagnostic modality. Evidence favours rigid pulley-protection splints over taping for Grade II–III injuries and progressive, load-based rehabilitation grounded in mechanotransduction. Injury patterns vary by age, discipline, and grip mechanics, requiring individualized clinical decisions.

Summary. Management integrates precise imaging, pathology-specific protection, and criteria-driven rehabilitation aligned with sport-specific training to reduce recurrence, optimize recovery, and sustain long-term performance.

Key words

finger injuries, tendon injuries, mountaineering, ultrasonography, cumulative trauma disorders

INTRODUCTION AND OBJECTIVE

The transformation of sport climbing from a niche outdoor pursuit into a globally recognized Olympic discipline has fundamentally altered the athlete profile and training demands [1, 2]. This evolution has been accompanied by a dramatic increase in training volume, movement complexity, and the specificity of finger loading. Consequently, finger injuries have emerged as the predominant musculoskeletal pathology, representing the leading cause of chronic dysfunction and performance decline across all skill levels [1]. The high prevalence of these injuries is intrinsic to the unique biomechanics of the sport. Modern climbing necessitates sustained isometric contractions and repetitive high-force gripping, particularly in the ‘crimp’ and ‘half-crimp’ positions. These maneuvers expose the finger flexor tendons, annular pulleys, and joint capsules to mechanical stresses that frequently exceed physiological thresholds [3, 4]. Biomechanical analyses indicate that such loading patterns predispose athletes to a spectrum of trauma ranging from acute structural failure to chronic overload syndromes [3]. The risk is further amplified by contemporary

training paradigms that emphasize maximal finger strength development through high-intensity hangboard protocols and dynamic campus board exercises. While finger strength remains a primary determinant of elite performance [5, 6], the fine line between adaptive stimulus and injurious overload presents a significant clinical challenge. Abrupt spikes in loading intensity or volume are strongly correlated with injury incidence [5, 7]. Clinically, this manifests as a broad spectrum of conditions, including flexor pulley ruptures (A2/A4), tenosynovitis, capsulitis, and lumbrical muscle tears [8–11]. Among these, injuries to the annular pulley system are of particular concern due to their critical role in maintaining tendon–bone congruency and the mechanical efficiency of the finger flexor unit [8, 9].

Despite the growing popularity of the sport, the literature regarding climbing-related finger injuries remains fragmented. Studies often focus on isolated biomechanical parameters or specific surgical techniques, limiting their direct translational value for the multidisciplinary team. Therefore, the aim of this narrative review is to synthesize current evidence on the epidemiology, diagnosis, and management of finger injuries. By integrating recent biomechanical insights with clinical protocols, the review seeks to provide a comprehensive framework for diagnosis, conservative and surgical management, and the crucial return-to-sport transition.

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MATERIALS AND METHOD

The study was designed as a comprehensive narrative review with a clinical focus, aimed at synthesizing current evidence regarding the diagnosis, management, and rehabilitation of finger injuries in sport climbers. To ensure a reproducible and rigorous selection of sources, a structured literature search was conducted across major electronic databases, including PubMed/MEDLINE, Scopus, and Web of Science. The search strategy utilized a combination of Medical Subject Headings (MeSH) and free-text key words related to the specific demands of the sport and anatomical structures involved. Key search terms included: 'sport climbing', 'rock climbing', 'finger injuries', 'flexor pulley rupture', 'flexor tendinopathy', 'lumbrical tears', 'capsulitis', and 'climbing biomechanics'. Boolean operators (AND, OR) were employed to refine the search results (e.g., 'climbing AND finger injury').

The scope of the review was primarily limited to peer-reviewed articles published within the last eight years (2017–2025) to ensure the inclusion of the most recent diagnostic algorithms and therapeutic protocols. Older seminal works were included only if they provided foundational knowledge or biomechanical data that remains currently valid. Inclusion criteria encompassed clinical trials, prospective and retrospective cohort studies, systematic reviews, case series, and biomechanical analyses published in the English language. Studies were eligible if they specifically addressed the adult or adolescent climbing population, or investigated loading mechanisms analogous to climbing-specific grips (e.g., the crimp grip).

Exclusion criteria were applied to remove studies focusing on non-climbing-related hand trauma, isolated animal models without direct clinical translation, and non-peer-reviewed sources, such as conference abstracts or opinion pieces lacking empirical data. The screening process involved an initial evaluation of titles and abstracts for relevance, followed by a full-text review of eligible articles. Data were extracted and synthesized thematically to cover epidemiology, functional anatomy, injury-specific diagnostics (ultrasonography and MRI), and therapeutic strategies ranging from conservative management to surgical intervention. This narrative approach allows for a holistic integration of clinical findings with training implications, addressing the specific gaps in standardized care for this athletic population.

DESCRIPTION OF THE STATE OF KNOWLEDGE

Epidemiology and injury patterns. Finger injuries consistently represent the predominant musculoskeletal pathology in sport climbing, accounting for the vast majority of training time lost. Contemporary clinical cohorts indicate that finger-related diagnoses constitute approximately 41% of all reported climbing injuries, with lesions to the flexor tendon pulley system forming the largest subgroup – roughly 30% of all finger injuries [8].

Systematic reviews confirm the upper extremity as the primary anatomical site of trauma, driven largely by overuse mechanisms rather than acute accidents [12]. The prevalence of these injuries correlates strongly with climbing intensity and volume; advanced climbers exhibit significantly higher injury rates compared to novices, a trend attributed to their

capacity to exert higher forces on smaller holds. Regarding anatomical distribution, the ring (4th) and middle (3rd) fingers are disproportionately affected [8, 9]. This localization pattern is biomechanically linked to the load distribution in the crimp grip, where the middle and ring fingers often function as the primary force transducers.

Age and discipline-specific patterns are also evident. In adolescent populations, finger injuries account for up to 45.3% of diagnoses, but frequently manifest as Primary Periphyseal Stress Injuries (PPSI), rather than the ligamentous ruptures seen in adults [2]. Discipline-wise, bouldering is associated with a higher incidence of upper-extremity injuries compared to lead climbing, reflecting the sport's emphasis on maximal power and dynamic movements [13]. Conversely, traditional and lead climbing present a broader injury spectrum, including acute trauma from falls, although finger overuse remains a constant baseline risk.

Functional anatomy and injury mechanisms. The literature underscores that sport climbing places unique and supramaximal demands on the finger flexor apparatus. Biomechanical analysis identifies grip configuration as the principal determinant of tissue stress. Of particular clinical relevance is the 'crimp' grip, characterized by flexion of the proximal interphalangeal (PIP) joint to 90–100° alongside hyperextension of the distal interphalangeal (DIP) joint [14]. In this closed-hand configuration, the flexor tendons exert a massive bowstringing force against the phalanges. The annular pulley system, specifically the A2 and A4 pulleys, must counteract this torque to maintain mechanical efficiency. Studies estimate that during a full 'crimp', the load on the A2 pulley can reach 380–700 N, which is three to four times the magnitude of the external force applied at the fingertip [4, 7]. This frequently exceeds the physiological failure threshold of the pulley ligaments. Conversely, 'open-hand' positions distribute force more uniformly across the kinetic chain, significantly attenuating the reaction forces at the pulley level.

Although elite climbers often exhibit structural adaptations – such as cortical thickening of the phalanges and hypertrophy of the flexor tendons – the disparity between muscular force production and the tensile limit of passive tissues remains the primary driver of pathology. Furthermore, modern training protocols involving high-intensity hangboard intervals often approach maximal voluntary contraction (MVC), leading to cumulative micro-trauma when recovery periods are insufficient to allow for collagen synthesis [5].

TYPES OF FINGER INJURIES

Flexor tendon pulley injuries. Injuries to the flexor tendon pulley system represent the quintessential climbing pathology. Mechanistically, these injuries are typically precipitated by eccentric loading events, such as a foot slip while maintaining an isometric crimp grip, which triggers an abrupt spike in force on the active system. Clinically, acute ruptures present with a pathognomonic audible 'pop', accompanied by immediate localized pain, swelling, and loss of range of motion. In severe cases (Grade III-IV), the mechanical failure of the retinacular system results in visible bowstringing of the flexor tendon during resisted flexion. While the A2 pulley is most frequently affected due to its

Table 1. Classification and management of flexor tendon pulley injuries

Grade	Structural Injury Definition	Clinical Presentation	Ultrasound Findings (TBD)	Therapeutic strategy
I	Pulley strain without structural rupture.	Pain on palpation and during crimping. No visible swelling or bowstringing.	TBD normal (< 2.0 mm). Possible mild oedema or thickening.	Conservative: rest/unloading (10–14 days), functional taping, gradual return to climbing.
II	Complete rupture of A4 OR partial rupture of A2/A3.	Localized pain, mild swelling. Audible 'pop' may be reported.	TBD increased but < 2.0 mm (or < 1 mm asymmetry vs contralateral). Full A4 rupture can be >2.0 mm	Conservative: rigid pulley protection splint (PPS) for 2–4 weeks to restore contact.
III	Complete rupture of A2 OR A3.	Significant pain, swelling, audible 'pop', functional impairment.	TBD > 2.0 mm (indicating bowstringing) at the affected phalanx.	Conservative: rigid PPS for 4–6 weeks. Strict cessation of crimping for 6–8 weeks.
IV	Multiple ruptures (e.g., A2+A3, A2+A4) or combined trauma (lumbrical/ligament).	Visible clinical bowstringing, haematoma, loss of full flexion range.	TBD significantly elevated, clear tendon lift-off from bone.	Surgical: reconstruction indicated to restore biomechanics; or direct repair in acute elite cases

TBD – Tendon-to-bone distance; PPS – Pulley protection splint.

Source: adapted from Schöffel et al. (2025) [2] and Miro et al. (2021) [1].

location at the apex of the bowstringing force, A4 ruptures are also common (Tab.1).

Lumbrical muscle tears. Lumbrical muscle tears constitute a specific injury pattern linked to the 'quadriga effect' observed in one- or two-finger pocket grips. The injury mechanism is shear-based: when a load is applied to a single extended finger (often the middle or ring finger) while the adjacent digits remain flexed into the palm, the divergent excursion of the flexor digitorum profundus (FDP) tendons generates excessive strain. Specifically, the FDP of the extended finger is pulled distally, while the FDPs of the flexed fingers are held proximally, tearing the bipennate origin of the III or IV lumbrical muscle located between them [10]. Diagnosis is confirmed by the 'lumbrical stress test', which reproduces pain upon independent extension of the affected digit against resistance (Tab. 2).

Tenosynovitis and joint pathologies. Unlike the acute and traumatic nature of pulley ruptures, flexor tenosynovitis manifests as an insidious overuse syndrome. It is characterized by chronic inflammation of the synovial sheath, presenting clinically with diffuse tenderness along the volar aspect of the digit, morning stiffness, and the ultrasonographic 'halo sign' representing fluid effusion [15]. Distinct from tendon pathology, joint capsulitis typically affects the dorsal aspect of the PIP joint. This condition results from repetitive capsular stress at extreme ranges of motion and must be differentiated from the osteophytic remodelling frequently observed in veteran climbers [16].

DIAGNOSTIC APPROACHES

Clinical and ultrasonographic assessment. A robust diagnostic algorithm integrates detailed clinical history with advanced imaging to navigate the complex differential diagnosis of finger pain. Physical examination serves as the essential initial filter; distinguishing an acute traumatic event – often heralded by an audible 'pop' from chronic, insidious pain – helps narrow the pathology. However, given the significant symptom-overlap between partial pulley tears, tenosynovitis, and collateral ligament strains, physical examination alone lacks the specificity required for accurate injury grading [4].

Consequently, high-resolution ultrasonography (US) has established itself as the diagnostic gold standard, offering superior spatial resolution to magnetic resonance imaging (MRI) for superficial structures [17]. US facilitates a dynamic assessment of the flexor mechanism under functional load. The critical metric for diagnosing pulley incompetence is the tendon-to-bone distance (TBD). Recent validation studies suggest that a TBD exceeding 2.0 mm (or a significant asymmetry compared to the contralateral digit) during forced flexion is highly indicative of a complete A2 or A4 rupture [18]. Furthermore, US is indispensable for differentiating mechanical ruptures from inflammatory conditions; in tenosynovitis, it visualizes the pathognomonic 'halo sign' of peritendinous fluid while confirming tendon integrity (Tab. 2).

Advanced imaging. Magnetic Resonance Imaging (MRI) plays a vital adjunctive role, particularly when ultrasound

Table 2. Differential diagnosis of climbing-related finger pathologies

Pathology	Primary Mechanism	Key Clinical Signs	Ultrasound Hallmarks
Pulley Rupture (A2/A4)	Acute eccentric load (e.g., foot slip in crimp grip).	Audible 'pop', immediate localized tenderness, potential bowstringing.	Increased Tendon-to-Bone Distance (TBD). Disruption of pulley continuity.
Flexor Tenosynovitis	Chronic volume overload (repetitive strain).	Diffuse volar pain, morning stiffness, crepitus along tendon sheath.	'Halo Sign': Anechoic fluid surrounding the tendon; tendon structure intact.
Lumbrical Muscle Tear	Shear force in 1- or 2-finger pockets (Quadriga Effect).	Pain in palm upon 'Lumbrical Stress Test' (independent finger extension).	Muscle oedema or fibre disruption at the bipennate origin (III/IV lumbrical).
Joint Capsulitis	Repetitive compression/torque at PIP joint.	Dorsal PIP joint pain, limited flexion, tenderness at joint line.	Synovial thickening at dorsal aspect; no bowstringing or tendon sheath fluid
Primary Periphyseal stress injury (PPSI)	Repetitive high-intensity loading in adolescents.	Pain at dorsal PIP joint, reduced crimp strength, chronic onset.	Epiphyseal widening or irregularity (requires correlation with X-ray/MRI).

TBD – Tendon-to-bone distance; PIP – Proximal interphalangeal joint; PPSI – Primary periphyseal stress injury.

Source: data compiled based on findings from Schöffel et al. (2025) [2], Miro et al. (2021) [1], Lutter et al. (2018) [10], Mohn et al. (2022) [15] and Bellomo et al. (2024) [18].

findings are equivocal or operator-dependent. Its superior soft-tissue contrast is essential for evaluating complex, deep-seated pathologies, such as isolated A3 pulley ruptures, combined multi-structure trauma, or deep lumbrical tears that may be obscured by the flexor tendons on ultrasound [7].

THERAPEUTIC STRATEGIES

Conservative management and orthotics. Conservative management is currently the consensus standard of care for Grade I–III pulley injuries and the majority of overuse conditions. However, the approach to external support has undergone significant revision based on biomechanical efficacy. While circumferential ‘H-taping’ remains ubiquitous in the climbing community, systematic reviews indicate that it reduces bowstringing by only 15–22%, rendering it mechanically ineffective for restoring the physiological tendon-to-bone distance [19, 22].

In stark contrast, clinical guidelines have shifted toward the use of rigid thermoplastic Pulley Protection Splints (PPS) for the acute management of Grade II–III injuries (Tab. 1). Quantitative biomechanical evidence supports this approach: application of a custom PPS significantly reduced pathological tendon–bone distance (TBD) in A2 pulley ruptures from 4.4 ± 1.0 mm to 2.3 ± 0.6 mm, effectively restoring anatomical congruency to near-intact levels. [20] Therefore, rigid splinting is recommended to facilitate optimal fibroblastic healing, while taping is relegated to a proprioceptive role during the later stages of rehabilitation.

Rehabilitation and surgical indications. The rehabilitation paradigm has evolved from strict immobilization toward mechanobiologically informed loading. Emerging evidence suggests that low-intensity, long-duration isometric loading (e.g., ‘density hangs’) is more effective than passive rest for stimulating collagen synthesis and preserving tendon stiffness during the remodeling phase [5]. Furthermore, rehabilitation must eventually progress from isometric to dynamic modalities to prepare the flexor unit for the eccentric demands of climbing [11].

Surgical intervention is largely reserved for Grade IV injuries (multiple ruptures), combined trauma involving ligaments or lumbricals, or cases that remain symptomatic despite a structured conservative course. Notably, recent advancements in direct repair techniques for acute ruptures

in elite climbers suggest potential for accelerated recovery (approximately six months) compared to traditional graft reconstructions [22].

Return to climbing. The decision to return to sport climbing must be criteria-driven rather than purely time-based to minimize the high risk of recurrence. A graduated progression is essential, typically initiating with open-hand loading on large holds and strictly prohibiting the full crimp until specific strength benchmarks are achieved. Recent protocols suggest that easy climbing is permissible once pain levels remain consistently low (<3/10 on the VAS) during daily activities [23]. This structured reintroduction of load is critical to bridging the gap between clinical recovery and performance (Tab. 3).

CONCLUSIONS

Finger injuries remain the most prevalent and performance-limiting musculoskeletal disorder in sport climbers, arising from the extreme and highly specific mechanical loads generated by modern training practices and intensive crimp gripping. The synthesis of current evidence demonstrates that effective management can no longer rely on generalized orthopedic paradigms; instead, it requires a pathology-specific, multidisciplinary model that integrates precise imaging, biomechanically appropriate protection, and mechanobiologically guided rehabilitation within the broader context of sport-specific load management.

At the diagnostic level, early and accurate differentiation of injury subtypes is fundamental. The predominance of overuse-related conditions supports routine use of high-resolution ultrasonography as a first-line modality capable of distinguishing structural pulley ruptures – requiring mechanical stabilization – from inflammatory entities such as tenosynovitis or capsulitis, which benefit from controlled mobilization. This precision underpins the broader conceptual shift away from uniform prescriptions of rest and taping toward targeted, tissue-appropriate intervention.

Conservative treatment strategies have undergone a parallel evolution. Despite their persistence in community practice, flexible taping methods are biomechanically insufficient to counteract the substantial forces generated during crimping. Rigid pulley protection splints therefore represent the contemporary standard for acute A2 and A4

Table 3. Criteria-driven return-to-sport (RTS) protocol

Phase	Timeline (Approximate)	Progression Criteria	Permitted Activities	Prohibited Activities
Inflammatory/ Protection	Weeks 0–2 (Grade I-II)	Pain at rest > 3/10 (VAS). Visible swelling.	Immobilization (Splint/Tape). Active Range of Motion (unloaded).	No climbing. No hanging. No heavy carrying.
	Weeks 0–4 (Grade III)			
Mobilization & Activation	Weeks 2–4 (Grade I-II)	Pain at rest < 3/10. Full Range of motion achieved.	Sponge squeezing, low-resistance putty. Easy hanging (feet on ground).	No climbing. No crimp grip loading.
	Weeks 4–6 (Grade III)			
Early Loading	Weeks 4–6 (Grade I)	Pain-free open-hand hang (body weight).	Easy climbing (jugs, vertical wall). Open-hand grip only.	No full crimp. No dynamic moves. No overhangs.
	Weeks 6–8 (Grade II-III)			
Sport-Specific Progression	Weeks 6–8+	>80% strength of uninjured hand (open-hand).	Increase intensity/volume. Introduce half-crimp on large edges.	Full crimp strictly monitored or prohibited.
Full Return	Weeks 10–12+	Pain-free full crimp. >90% strength symmetry.	Unrestricted climbing. Dynamic moves. Small edges.	Monitor for recurrence symptoms.

VAS – Visual Analog Scale (pain score 0–10).

Source: adapted from Popławska et al. (2024) [27] and Schöffel et al. (2025) [2].

pulley injuries, restoring functional tendon–bone congruency and providing stability unattainable with tape alone. Within this framework, taping assumes a secondary, proprioceptive role during graded return to climbing rather than serving as a primary structural support.

Rehabilitation, likewise, has transitioned from immobilization toward active, load-progressive recovery grounded in mechanotransduction. Early low-intensity isometric loading, including density-hang protocols, appears to promote collagen synthesis while limiting catabolic remodelling, contrasting with the stiffness and atrophy associated with prolonged rest. Restoration of climbing-specific capacity further requires systematic progression toward dynamic and eccentric loading to prepare the flexor apparatus for rapid force fluctuations. Adjunctive strategies, such as blood flow restriction training, may preserve muscle hypertrophy under reduced mechanical stress, narrowing the gap between biological healing and functional readiness. Crucially, treatment and prevention must be viewed as a continuum, with particular attention to load regulation in adolescents vulnerable to epiphyseal injury.

Surgical management remains indispensable for complex Grade IV injuries involving multiple pulley ruptures or combined trauma that compromise biomechanical integrity. Emerging evidence suggests that acute direct repair in elite climbers may enable faster recovery than traditional graft reconstruction, underscoring the importance of early high-resolution imaging to identify repairable lesions before fibrosis develops.

Irrespective of treatment modality, return-to-climbing decisions should progress from time-based conventions to standardized, criteria-driven clearance incorporating objective functional metrics and psychological readiness to reduce fear-mediated compensation and reinjury risk.

Future investigation should prioritize validation of sport-specific return-to-sport criteria, long-term outcomes of contemporary surgical repair, and deeper integration of clinical science with performance training. Bridging these domains is essential for reducing injury burden, and supporting sustainable athletic development in the rapidly evolving landscape of Olympic sport climbing.

Conflict of interest

The authors declare no conflicts of interest related to this study

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Ethical approval

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