Evaluation of a Diagnostic-Therapeutic Algorithm for Finger Epiphyseal Growth Plate Stress Injuries in Adolescent Climbers

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Background: Finger epiphyseal growth plate stress injuries are the most frequent sport-specific injuries in adolescent climbers. Definitive diagnostic and therapeutic guidelines are pending.

Purpose: To evaluate a diagnostic-therapeutic algorithm for finger epiphyseal growth plate stress injuries in adolescent climbers.

Study Design: Case series; Level of evidence, 4.

Methods: On the basis of previous work on diagnostics and treatment of finger epiphyseal growth plate stress injuries (EGPIs) in adolescent climbers, we developed a new algorithm for management of these injuries, which was implemented into our clinical work. During a 4-year period, we performed a prospective multicentered analysis of our patients treated according to the algorithm. Climbing-specific background was evaluated (training years, climbing level, training methods, etc); injuries were analyzed (Salter-Harris classification and UIAA MedCom score [Union Internationale des Associations d'Alpinisme]); and treatments and outcomes were recorded: union, time to return to climbing, VAS (visual analog scale), QuickDASH (shortened version of the Disabilities of the Arm, Shoulder, and Hand), and a climbing-specific outcome score.

Results: Within the observation period, 27 patients with 37 independent EGPIs of the fingers were recorded (mean ± SD age, 14.7 ± 1.5 years; 19 male, 8 female; 66.7% competitive athletes). Regarding maturity at time of injury, the mean age at injury did not differ by sex. Average UIAA climbing level was 9.5 ± 0.8, with 6 ± 4.6 years of climbing or bouldering and 14 ± 9.1 hours of weekly climbing-specific training volume. Among the 37 injuries there were 7 epiphyseal strains, 2 Salter-Harris I fractures, and 28 Salter-Harris III fractures (UIAA 1, n = 7; UIAA 2, n = 30). Thirty-six injuries developed through repetitive stress, while 1 had an acute onset. Twenty-eight injuries were treated nonoperatively and 9 surgically. Osseous union was achieved in all cases, and there were no recurrences. The time between the start of treatment and the return to sport was 40.1 ± 65.2 days. The climbing-specific outcome score was excellent in 34 patients and good in 3. VAS decreased from 2.3 ± 0.6 to 0.1 ± 0.4 after treatment and QuickDASH from 48.1 ± 7.9 to 28.5 ± 3.3.

Conclusion: The proposed management algorithm led to osseous union in all cases. Effective treatment of EGPIs of the fingers may include nonsurgical or surgical intervention, depending on the time course and severity of the injury. Further awareness of EGPI is important to help prevent these injuries in the future.

Keywords: growth plate injuries; periphyseal injuries; rock climbing; finger; epiphyseal injuries

Injuries to the hand and fingers are the most sport-specific injuries in rock climbers.[9,20,30] While there are >20 differential diagnoses of hand injuries to be considered in adult climbers,[46] there is primarily only 1 in adolescent climbers, which is almost exclusive to this sport: the finger epiphyseal growth plate stress fracture.[38,50] Since the first reported case in 1997, >100 of these fractures have been cited in the literature.[1,7,8,13,14,26,34,38] Recent reports show an increase in incidence.[38,42] This trend is expected to continue with sport climbing's inclusion into the Olympic program and the ongoing increase in training intensity and load in elite and recreational athletes.[20,34] Most recently, these injuries have been related to an increase in speed climbing training.[24] Patients are typically between 13 and 15 years of age and in the phase of the pubertal growth spurt.[1,2,7,11,14,29,34,38,47] The middle and ring fingers are most commonly affected, and these fractures are believed to be caused by repetitive stress and microtrauma rather than from a single acute event.[1,7,34,38] Because these injuries can present as acute fractures or repetitive stress apophysitis,[1] we refer to this clinical entity as *epiphyseal growth plate stress injuries* (*EGPIs*).

In climbing, the frequently used "crimp grip position" (ie, hyperextended distal interphalangeal joint and highly

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flexed proximal interphalangeal joint) causes high pressure at the dorsal aspect of the middle phalanx base growth plate.[1,34] In addition, the pulling force of the extensor tendon central slip attaches at the dorsal aspect of the growth plate[2,11,14] and pulls it out of its place. Bärtschi et al[1] reported a translatory shift of the fingers' middle phalanx base on the proximal phalanx head as a possible additional cause. During the crimp grip position, the pulling force of the flexor tendons forces the physis dorsally, while the pressure acting on the fingertip does the same.[34]

In the clinical presentation, the climber reports dorsal proximal interphalangeal (PIP) joint pain, mostly at the base of the middle phalanx. There is palpable tenderness in the respective area, sometimes accompanied by minor swelling and a palpable protruding bone fragment.[34] The fracture pattern is usually Salter-Harris type III (81%)[1,34,38,47] and mostly affects the middle finger but sometimes the ring finger.[1,34,38,47,49] Also, finger epiphyseal strains are reported.[1,34] These injuries cannot be classified by the Salter-Harris classification[32] or any other given classification. An epiphyseal strain injury is a precursor to an epiphyseal fracture.[1] It can either heal without consequences or, if neglected, progress to an epiphyseal fracture.

Until today, treatment mostly consisted of nonoperative therapy[14] and a stepwise return to climbing.[25] In some cases, when a nonoperative therapy did not lead to a osseous fusion, a surgical spot-drilling epiphysiodesis treatment has been described.[11,34] To date, guidelines for the decision making regarding the treatment of this injury are lacking, especially for how long a nonoperative therapy is possible and when a secondary surgical procedure should be performed. Also, no clear recommendations exist if and when a primary surgical intervention should be performed and for how long after the initial diagnosis a resting period is necessary. Most therapeutic decisions are empirical and not guideline based. Thus, after our multicenter experiences with >50 clinical cases, we developed a diagnostic-therapeutic algorithm for the management of finger EGPIs in adolescent climbers, which was implemented in our clinical work and has not been described before. For this study we performed a prospective multicentered analysis of our patients treated according to this new algorithm over a 4-year period. The primary aim of the study was to identify if the algorithm is useful, while the secondary aim was to determine the outcomes of these finger EGPIs. The hypothesis was that by first using this new algorithm, a delayed fracture healing, as seen in previous nonoperative cases,[11] could be avoided.

METHODS

Patients

All adolescent climbers with EGPIs treated in 3 specialized outpatient sports medicine clinics between 2017 and 2020 were included. The medical centers represent referral centers for climbing-related injuries (eg, German Alpine Club). The study was part of an evaluation of all pediatric and adolescent climbing injuries and was approved by the ethical board of the Friedrich-Alexander University Erlangen-Nuremberg.

Therapeutic-Diagnostic Algorithm

The algorithm consists of a preclinical part, which is based on a consensus recommendation by the British Mountaineering Counsil,[4] and a clinical part, which is our proposal (Figure 1).

All patients with suspected EGPIs were examined clinically and their injury histories analyzed, and each received an ultrasound examination to exclude any soft tissue injury (eg, tenosynovitis, pulley injury).[3,18,23,46] All patients received magnetic resonance imaging (MRI) after the ultrasound. A standard questionnaire and examination protocol was additionally conducted. The nonoperative therapy consisted of splint immobilization if the injury was acute. Otherwise, functional therapy with stress restriction and a break from climbing was recommended. All hand-related sports or labor activities were prohibited. The surgical cases received a percutaneous spot-drilling epiphysiodesis procedure, as described elsewhere.[11]

Classification and Scores

The UIAA metric scale (Union Internationale des Associations d'Alpinisme) was used for evaluation of climbing levels and the Vermont scale for evaluation of bouldering levels, as previously published.[39] For injury grading, the Salter-Harris classification[32] and the UIAA MedCom score were used.[39] A finger epiphyseal strain was defined as visible periphyseal edema on MRI but with an absence of

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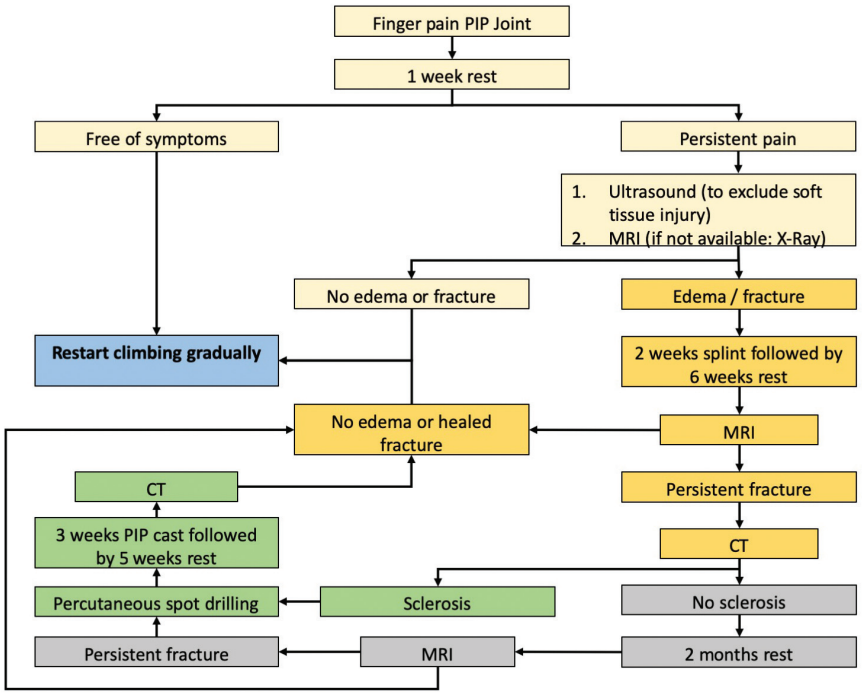

Figure 1. Diagnostic-therapeutic algorithm. CT, computed tomography; MRI, magnetic resonance imaging; PIP, proximal interphalangeal.

fracture.[7] Visual analog scale (VAS) for pain, QuickDASH (shortened version of the Disabilities of the Arm, Shoulder, and Hand), and a climbing-specific outcome score were used for outcome analysis.[15,19,37]

Outcome

All patients were seen for follow-up evaluations in accordance with the algorithm after the initial consultation and after 1 year. The VAS scores were collected at the initial visit and after 1 year. QuickDASH and climbing-specific outcome scores were recorded at 1 year. All patients self-reported preinjury conditions (Table 1).

Statistical Analysis

Microsoft Excel was used for data collection; statistical analyses were performed using SigmaStat software (Systat Software Inc). Values were checked for normality with the Shapiro-Wilk test. To determine correlations between groups, a Spearman or Pearson correlation test was used depending on normal distribution. Unless stated otherwise, data were expressed as mean, standard deviation, and range, as appropriate. P values $<.05$ were considered as statistically significant.

RESULTS

During the 4-year period, we treated 27 patients (19 male, 8 female; 66.7% competitive athletes) with 37 finger EGPIs. The mean age was 14.7 ± 1.5 years, and age at injury did not differ by sex. Twenty-five patients were White, with 1 Indian and 1 Chinese Canadian. The mean height was 172 ± 8.2 cm; weight, 60.1 ± 9.9 kg; and body mass index, 20.1 ± 2.5. None of the patients had a medical condition or took medications regularly. The average UIAA lead climbing level was 9.5 ± 0.8, and the average bouldering level was 9.1 ± 2.2 (Vermont scale), with a mean 6 ± 4.6 years of climbing/bouldering and 14 ± 9.1 hours of weekly sport-specific training volume. In accordance with the injury grading scale of the International Rock Climbing Research Association, a UIAA leading climbing level of 9.5 is an elite level for women and in between elite and advanced for men.[10] A bouldering level of 9.1 on the Vermont scale reflects an elite level in women and men. Overall climbing time was split: bouldering, 53.3%; sport climbing, 34.4%; alpine climbing, 7.1%; and competition climbing, 16.9%. Most of the investigated athletes (66.7%, 18/27) participated in climbing competitions. Of these, 63% (17/27) were involved in national competitions, 26% (7/27) in international youth competitions, and 15% (4/27) in World Cups. Additional strength training was performed by 63% (17/27) of the climbers for an average of 3 ± 1.4 hours per week. Campus board training, which is a specialized finger power training method for climbers, was performed by 44.4% (12/27) and training with additional weights by 29.6% (8/27). Of 27 climbers, 16 (59.3%) reported having a coach. The preferred hand gripping position was the hanging position in 13 of 27, the sloper in 7, and crimping in 17 (Figure 2). The majority of the climbers (85.2%) warmed up with a regular routine,

TABLE 1
Patient Characteristics

	Mean ± SD or % (No.)[a]
Age, y	14.7 ± 1.5
Height, cm	172 ± 8.2
Weight, kg	60.1 ± 9.9
Body mass index	20.1. ± 2.5
Level	
Climbing	9.5 ± 0.8
Bouldering	9.1 ± 2.2
Climbing/bouldering, y	6 ± 4.6
Climbing time spent, %	
Sport	34.4 ± 18.9
Bouldering	53.3 ± 22.9
Alpine	7.1 ± 7.4
Competition	16.9 ± 11.3
Competing athlete	66.7 (18)
Competitions	
"Fun"	33.3 (9)
Regional	52 (14)
National	63 (17)
International youth	26 (7)
World cups	15 (4)
Training	
Climbing, h/wk	14 ± 9.1
Additional strength	63 (17)
Campus board	44.4 (12)
With additional weights	29.6 (8)
Warm-up routine	85.2 (23)
Compensatory	63 (12)
Preferred hand-hold position	
Hanging	48.1 (13)
Sloper	25.9 (7)
Crimping	63 (17)

[a]Percentages are based on 27 patients (19 men, 8 women) with 37 injuries.

using stretching, rope jumping, rubber band, or softball exercises (or similar devices for warming up the fingers), including running and climbing easy routes. Compensatory training was reported by 63% (12/27), with an average of 1.0 ± 0.9 hours per week. Typical compensatory training consisted of stretching, running, antagonist training, yoga, rubber band exercises, and bicycling.

Injuries

Thirty-seven injuries were diagnosed in 27 climbers, as 10 climbers had injuries on 2 fingers at different time points. The right and left hands were equally affected (19 injuries on the right vs 18 on the left) (Table 2). The most common finger to be injured was the middle finger (91.9%, 34/37), followed by the ring finger (8.1%, 3/37). Of the 37 injuries, 7 were classified as epiphyseal strains, 2 as Salter-Harris I fractures, and 28 as Salter-Harris III fractures (Figure 3).

The average UIAA injury score was 1.8 ± 0.4 (UIAA 1, n = 7; UIAA 2, n = 30). Thirty-six injuries developed chronically over time, and only 1 had an acute onset. Twenty-seven injuries occurred during bouldering, 1 during lead

Figure 2. (1) The hanging position, (2) the sloper, and (3) the crimping position. Photo: Kilian Reil.

TABLE 2
Description of Injuries[a]

	% (No.)[b]
No. of patients	27
Finger	
Middle	91.9 (34)
Ring	8.1 (3)
Injury type/grade	
Epiphyseal strain	18.9 (7)
Salter-Harris I	5.4 (2)
Salter-Harris III	75.7 (28)
UIAA 1	18.9 (7)
UIAA 2	81.1 (30)
Condition	
Chronic	97.3 (36)
Acute	2.7 (1)
Treatment	
Nonoperative	75.7 (28)
Surgical	24.3 (9)

[a]UIAA, Union Internationale des Associations d'Alpinisme.
[b]Percentages are based on 37 injuries (19 right, 18 left) among 27 patients.

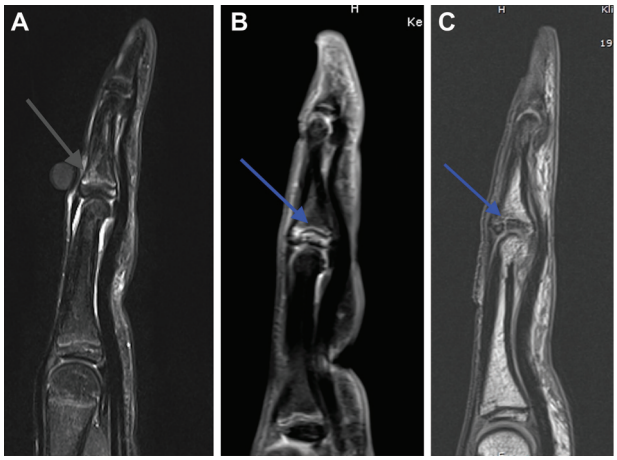

Figure 3. (A) Epiphyseal strain with intraosseous edema. (B) Salter-Harris I fracture. (C) Salter-Harris III fracture.

TABLE 3
Outcome According to Injury Grading and Therapy of Finger EGPI in Adolescent Climbers[a]

	All Injuries	Epiphyseal Strain	Salter-Harris I	Salter-Harris III (Nonoperative)	Salter-Harris III (Surgical)
Cases	37[b]	7	2	19	9
UIAA score	1.8 ± 0.4	1	2	2	2
Climbing break after therapy start, d	82.1 ± 65.9	37 ± 18.4	105 ± 21.2	92.3 ± 92.4	91.7 ± 16.0
Clinical outcome					
No persisting damage	64.9 (24)	100 (7)	100 (2)	52.6 (10)	55.6 (5)
Dorsal thickened cortical bone	24.3 (9)			36.8 (7)	22.2 (2)
Dorsal thickened cortical bone and extension deficit PIP joint	10.8 (4)			10.5 (2)	22.2 (2)
Pain[c]					
No pain	91.9 (34)	100 (7)	100 (2)	94.7 (18)	77.8 (7)
Occasional pain	8.1 (3)			5.3 (1)	22.2 (2)
Climbing score					
Excellent	91.9 (34)	100 (7)	100 (2)	94.7 (18)	77.8 (7)
Good	8.1 (3)			5.3 (1)	22.2 (2)
Visual analog scale					
Before	2.3 ± 0.6	1.9 ± 0.7	2.5 ± 0.7	2.2 ± 0.5	2.5 ± 0.6
After	0.1 ± 0.4	0	0	0.05 ± 0.2	0.6 ± 0.9
QuickDASH					
Before	48.1 ± 7.9	39.7 ± 3.7	45 ± 0	48.8 ± 6.7	52.5 ± 9.9
After	28.5 ± 3.3	27.5 ± 0	27.5 ± 0	28.0 ± 2.3	31.7 ± 6.7

[a]Values are presented as mean ± SD or % (No.). Blank cells indicate *not applicable.* EGPI, epiphyseal growth plate stress injury; PIP, proximal interphalangeal; QuickDASH, shortened version of the Disabilities of the Arm, Shoulder, and Hand; UIAA, Union Internationale des Associations d'Alpinisme.
[b]All injuries achieved osseous healing.
[c]Always pain, n = 0; pain decreases climbing ability, n = 0.

climbing, and in 9 cases the underlying climbing-specific subdiscipline could not be identified. The patients reported that 85 ± 95 days (range, 2-300) passed until initial medical consultation, and they were finally seen in our centers after 127 ± 112 days. All received ultrasound, radiograph, MRI, and, if indicated, a CT scan in accordance with the algorithm.

The period of rest from climbing before any medical consultation was 40.1 ± 65.2 days (in the patients who rested); 11 of 37 did not rest before seeking medical attention. Nonoperative treatment was used for 28 injuries, and 9 were treated surgically.

Outcome

Osseous healing was achieved in all cases without recurrences. Most patients (64.9%, 24/37) had no persisting damage to the joint, whereas 24.3% (9/37) showed a dorsal thickened cortical bone at the level of the finger middle phalanx base and 10.8% (4/37) an extension deficit in the PIP joint of 3° to 5°. Most climbers (34/37) reported no pain in the formerly injured finger. There were no reports about permanent pain, and the occasional pain reported by some patients (8.1%) did not influence climbing activity. The break from climbing after the start of treatment was 82.1 ± 65.9 days. The climbing score after healing was excellent in 91.9% (34/37) and good in 8.1% (3/37). The VAS score decreased from 2.3 ± 0.6 at therapy start to 0.1 ± 0.4 and the QuickDASH from 48.1 ± 7.9 to 28.5 ± 3.3. For further analysis, all EGPIs were classified as epiphyseal strain, Salter-Harris I, Salter-Harris III treated nonoperatively, and Salter-Harris III treated surgically (Table 3).

Statistical Analysis

Statistical analysis was performed concerning delta VAS score as well as delta QuickDASH score before and after therapy in correlation with the interval between the onset of symptoms and medical consultation; no significance was found. Also, no correlation was found for the interval between the onset of symptoms and medical consultation to climbing break after start of treatment. Delta VAS and QuickDASH score did not correlate significantly with injury grading (sprain and Salter-Harris I, II, or III [nonoperative and surgical]).

DISCUSSION

This is the first study to systematically evaluate an algorithm-based approach for diagnosing and treating finger EGPIs. This is a first presentation of a new algorithm, which was adhered to in all our cases. We achieved fracture healing in all injuries. Thus, we were able to show that this algorithm is suitable for the treatment of EGPIs.

Furthermore, the outcome of all treated injuries was excellent. Using this algorithm, a delayed fracture healing could be avoided, as no cases with delayed fracture healing or secondary surgery occurred.

The mean age of our patients was 14.7 ± 1.5 years and is within the time frame of epiphyseal closure of the fingers[34] and is consistent with the literature.[1,14,25] The risk of finger EGPI correlates with puberty, which most often will occur at an age of 13 to 15 years but has large interindividual variability.[5,35,38] As a consequence of the different maturation of boys and girls, these injuries could also occur at different times. However, this effect was not found in the present collective.

We found more injuries in male than female adolescent climbers, a fact that has been observed in previous studies.[14,38] There are several possible explanations for this sex bias.[34] First, climbing is still a sport predominantly performed by males. In competition, the number of boys participating is approximately twice as high as the number of girls. However, the endocrine aspect of the adolescent growth spurt needs to be taken into account as well. The growth spurt is caused by stimulation of growth hormone production by low doses of estradiol.[31] As the doses of estradiol increase, the growth is increasingly inhibited up to the fusion of the physes.[28] The differences in estradiol levels during puberty may well explain the higher number of injuries in boys as compared with girls.[34]

Bilateral finger injuries were observed in 10 of 37 cases, a pathomechanism that has also previously been described.[8,34,48] The middle finger was most often affected (91.9%), followed by the ring finger (8.1%). This has already been described by Bärtschi et al[1] (middle finger, 58%; ring finger, 30%), as well as Schöffl and Schöffl[34] (95% middle finger), and is based on the fact that the middle finger is longer than the other fingers and thus subjected to the highest stress during crimping. Also, the growth plates of the middle fingers are the last to close.

Our patients had a relatively high climbing level of 9.5 ± 0.8 UIAA (metric[41]), and most of the athletes competed (66.7%) nationally (63%) or internationally (15%). Campus board training (feetless climbing hand over hand on small overhanging vertical rungs), which was reported as a risk factor for EGPI and osteoarthritis,[36,45] was performed by almost half of the athletes with EGPIs in this study. This study cannot ascertain a cause and effect between campus board training and EGPI, but campus boarding adds to the already highly intensive training load in these young climbers. The crimp grip, which is widely considered the underlying biomechanical cause for EGPI,[1,34,38] was the preferred finger position in this study (62.9%) and a previous one (71.4%).[34] Avoidance of the crimp grip through training in a half crimping technique is possible and may be an effective prevention (Figure 4).[44] In the half crimp the distal interphalangeal joints are not overextended, and the proximal interphalangeal joints are only partially bent. Consequently, the stress onto the dorsal part of the growth plate is decreased.

In general EGPIs are believed to be a consequence of repetitive trauma, in contrast to a single acute event leading to this injury,[34] which places them in the chronic injury group.[7,38] However, in many cases the athletes can describe 1 specific event when they first noticed the injury, suggesting an acute onset on top of a chronic condition.[8,14,34,46] Nevertheless, a single event does not represent a strong-enough trauma to lead to a fracture on its own. Therefore, distinguishing between acute and chronic onsets in the literature may well be misleading. While Hochholzer and Schöffl[14] found no case with an acute onset in their case series of 24 patients with EGPI (1994-2004), 50% of the athletes investigated in the study by Schöffl and Schöffl[34] reported a single incident during a boulder competition as the moment of injury. This was thought to be caused by the increasing number of competitions, especially in bouldering, challenging children and adolescents on an almost weekly basis.[38] Bouldering is known to place higher stress on the hand and fingers because it is more maximum strength orientated than lead climbing and involves more dynamic moves.[12,17,21,27] In our present study, only 1 EGPI was reported as an acute trauma, while all other cases were chronic but again reported mostly during bouldering (96.4% known cases).

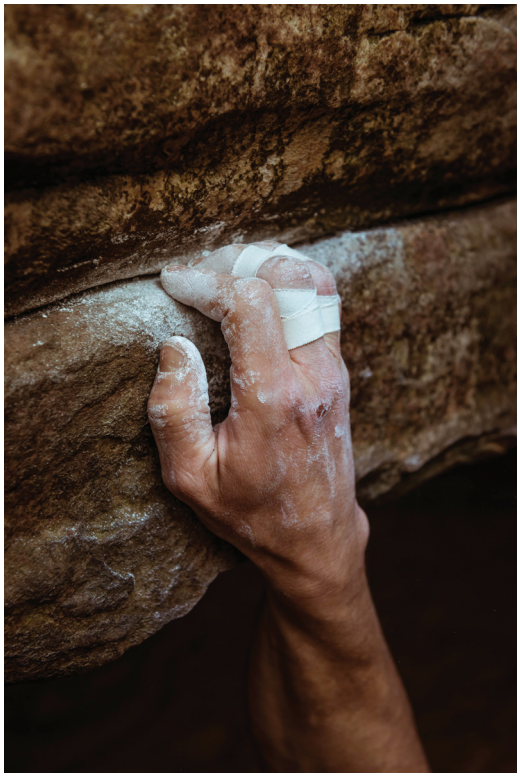

Figure 4. The half crimp. Note that in comparison with Figure 3, the distal interphalangeal joints are not overextended, and the proximal interphalangeal joints are only partially bent. Photo: Kilian Reil.

Fracture Types and Nomenclature

Other than the present study and the recent study of Bärtschi et al,[1] none of the previous studies reported epiphyseal strains. Only 7 of the 37 injuries in our study were finger

epiphyseal strains; all others were Salter-Harris I or III injuries. In the study by Bärtschi et al, 13 of 28 patients had an epiphyseal strain. These injuries cannot be classified by the Salter-Harris classification.[32] While Wen et al[48] described a case of bilateral EGPI as Osgood-Schlatter of the finger, a precise classification, including strain and the various types of fractures, is pending. The definition of these injuries as *epiphyseal* was recently questioned by Caine et al.[7] They proposed the term *periphyseal stress injuries* since the injury involves 1 or more constituents of the epiphyseal-physeal-metaphyseal complex.[5-7] Nevertheless, they also stated that periphyseal strain injuries are not represented within the given classifications and further work on a new classification is pending.[7]

Therapy

The time frame from the onset of symptoms to presentation for medical consultation in this study was comparably long and showed a wide range (85 ± 95 days). This is much longer than recommended in the preclinical part of our proposed algorithm. Nevertheless, the present evaluation could not influence that time frame, as the patients presented themselves to our centers after 127 ± 112 days (range, 2-360). This delay between the onset of symptoms and seeking medical advice is concerning. It has been observed that climbers often wait considerable amounts of time before seeking medical advice.[16,40,43] Therefore, education about this injury is essential in young climbers, trainers, and parents. Meyers et al[24] reported that only 29.2% of young climbers considered themselves to be sufficiently informed about finger growth plate injuries. This must be targeted in preventive measures.

While the entity of EGPI is well described in the climbing literature, studies detailing its management are still rare. Since El-Sheikh et al[11] reported on surgical management of epiphyseal fracture nonunion using spot-drilling epiphysiodesis, the question now is, which EGPIs should be treated surgically and which nonoperatively? This was the reason for developing the new algorithm. The present study shows a rather high proportion of injuries treated surgically (24.3%). This number likely does not reflect the rate of surgical treatment in EGPIs, as our centers are referral centers for climbing injuries and thus see a higher proportion of complicated or delayed-presentation EGPIs, which are more likely to require aggressive treatment.

The climbing break after start of therapy in our center was 82.1 ± 65.9 days. This number is difficult compare with other case series, as few give an exact time to return to sport. Bärtschi et al[1] reported a mean 35 weeks to radiological union but no time to return to climbing. Schöffl and Schöffl[34] noted a faster return to sport after treatment, with athletes climbing again after a mean 6.8 weeks and regaining their previous level of climbing within 3 months.

Outcome

By applying the algorithm presented in this report, we were able to achieve osseous union of all epiphyseal fractures, with only 4 patients developing a minor extension deficit in the injured finger. Most of the climbers reported no pain in the formerly injured finger, and only some noted occasional pain that did not influence the climbing activity afterward. The climbing score after healing was excellent in 91.9% of cases and good in 8.1%. Hochholzer and Schöffl[14] reported on 24 epiphyseal fractures (20 Salter-Harris III and 4 Salter-Harris II) with 56% of the injuries healing without resultant dysfunction, 31% with incongruency of the joint space, and 13% with angular deformity at the PIP joint. Unfortunately, this study did not indicate the climbing-specific outcome. Certainly, this rate of incongruency and deformities is higher than in the present study. The poorer outcomes of Hochholzer and Schöffl's patients may be explained by the fact that in 2005 early diagnosis using MRI was more difficult than nowadays. Also, the knowledge about these injuries within the climbing community was scarce, resulting in more delayed presentations. The fact that EGPI in an early stage is often misinterpreted as a pulley injury was recently shown by Meyers et al[24] and may complicate early diagnosis. The proposed algorithm mitigates this risk, as all patients get an ultrasound examination to exclude soft tissue injury.

In another study, Schöffl and Schöffl[34] reported that 70% of youth climbers with 22 epiphyseal fractures had good outcomes, whereas 23% were pending and 1 (4.5%) had permanent damage. An overall 22 were climbing again at the same level, and 1 patient was not. Unfortunately again, no climbing ability outcome score was used in this study. Bärtschi et al[1] reported that although most patients (20/28, 71%) had a positive outcome in their study, this injury can damage the growth plate when left untreated. This resulted in 8 of 28 cases having an articular surface incongruency with permanent impairment of the affected finger. Fifty percent of their patients stopped competing on a national or international level, 3 of whom stopped because of the injury. Most patients (75%) were still climbing on a regular basis and regained their preinjury climbing level. Two-thirds of the patients reported no pain during climbing, as opposed to rare (25%) and occasional (12.5%). In conclusion, we achieved in our patients a little better outcome, but these results are difficult to compare as no other study used an outcome score.

The number of undetected cases needs to be considered in our estimated incidence of epiphyseal fractures. In a survey of youth Swiss competition climbers, Schlegel et al[33] found that 5 of 29 (17%) showed healed epiphyseal fractures with radiographic abnormalities caused by fracture displacements. The number of epiphyseal fractures that healed without radiographic abnormalities could not be given, leaving the question of how many truly had this injury.

All these studies and the present one are lacking long-term follow-up to answer whether EGPI can lead to early osteoarthritis. Schöffl et al[45] reported long-term results of 2 cases after 11 years. Both had healed without consequences. A good outcome was also reported for patients with surgical spot-drilling epiphysiodesis.[11] Nevertheless, this series presented only 2 cases. In comparison with the published outcomes after epiphyseal fractures, the present

study showed a better outcome, especially when considering that Bärtschi et al[1] included more of the less severe epiphyseal strains (46% [13/28] vs 18.9% in our study).

The present study is the first to record validated outcome measures in this population, and we found that the outcome is mostly excellent, with generally full return of function after treatment and with only mild finger impairment remaining in a few climbers. Nevertheless, long-term outcomes are missing, and it is unclear to what extent the injury may lead to secondary conditions, such as osteoarthritis, extensor hood syndrome, or PIP capsulitis. Mafulli et al[22] showed that osteoarthritis may result from chondral damage at the time of growth plate injury, growth disturbance, articular incongruency, or joint malalignment. In a longitudinal study on competitive climbers, Schöffl et al[45] found that one-quarter who performed at a high level in their youth showed a mild form of osteoarthritis (Kellgren-Lawrence grade 2). Whether the remaining deformities after EGPI need to be considered as precursors to osteoarthritis in later life is unanswered.

Limitations

This study has several limitations. Our centers are referral centers for climbing injuries; thus, the number of complicated or delayed-healing finger EGPIs, as seen for a second opinion, lead to a selection bias. This was not a randomized controlled study, so direct implications cannot be deduced from the design. Also, ultrasound examination to exclude a soft tissue injury and the easy availability of MRI are one foundation of our algorithm and may not be possible in some clinical settings. If MRI is not possible, a standard radiograph may substitute and will detect Salter-Harris III injuries and most Salter-Harris I. Nevertheless, it cannot detect epiphyseal strains. If an epiphyseal strain is clinically suspected and the radiograph finding is normal, we recommend treating it as a suspected EGPI rather than risk long-term damage to the finger.

CONCLUSION

The use of the new algorithm helps to effectively treat finger EGPIs, and it produces good to very good outcomes. Delayed healing can be avoided through early surgical intervention (spot drilling) as outlined in the algorithm. As the time frame between the onset of the symptoms and medical diagnosis is very long, the most important intervention for preventing EGPIs are sports medical education and close sports medical surveillance of competitive adolescent climbers. Using the "half crimp" rather than a "full crimp" hand position during climbing may decrease stress on the finger's growth plate and can be a preventive measure. In symptomatic climbers, a stringent diagnostic evaluation involving early MRI and CT scan is to be performed in accordance with the proposed algorithm. Only MRI can detect finger epiphyseal strain injuries. As epiphyseal strains are not represented within the Salter-Harris classification, a revised classification system for EGPI should be considered in future studies.

REFERENCES

1. Bärtschi N, Scheibler A, Schweizer A. Symptomatic epiphyseal sprains and stress fractures of the finger phalanges in adolescent sport climbers. *Hand Surg Rehabil*. 2019;38(4):251-256.
2. Bayer T, Schöffl VR, Lenhart M, Herold T. Epiphyseal stress fractures of finger phalanges in adolescent climbing athletes: a 3.0-Tesla magnetic resonance imaging evaluation. *Skeletal Radiol*. 2013;42(11):1521-1525.
3. Bodner G, Rudisch A, Gabl M, et al. Diagnosis of digital flexor tendon annular pulley disruption: comparison of high frequency ultrasound and MRI. *Ultraschall Med*. 1999;20(4):131-136.
4. British Mountaineering Counsil. Growth plate stress fractures in teenage climbers. 2020. Accessed July 1, 2021. https://www.thebmc.co.uk/media/files/Comps/Development%20Squad/Growth%20Plate%20Stress%20Fractures%20in%20Teenage%20Climbers.pdf
5. Caine D, DiFiori J, Maffulli N. Physeal injuries in children's and youth sports: reasons for concern? *Br J Sports Med*. 2006;40(9):749-760.
6. Caine D, Howe W, Ross W. Does repetitive physical loading inhibit radial growth in female gymnasts? *Clin J Sport Med*. 1997;7:102-108.
7. Caine D, Meyers R, Nguyen J, Schöffl V, Maffulli N. Primary periphyseal stress injuries in young athletes: a systematic review. *Sports Med*. Published online August 9, 2021. doi:10.1007/s40279-021-01511-z
8. Chell J, Stevens K, Preston B, Davis TR. Bilateral fractures of the middle phalanx of the middle finger in an adolescent climber. *Am J Sports Med*. 1999;27(6):817-819.
9. Cole KP, Uhl RL, Rosenbaum AJ. Comprehensive review of rock climbing injuries. *J Am Acad Orthop Surg*. 2020;28(12):e501-e509.
10. Draper N, Gilles D, Schöffl V, et al. Comparative grading scales, statistical analyses, climber descriptors and ability grouping: International Rock Climbing Research Association position statement. *Sports Technology*. 2016;8(3-4):88-94.
11. El-Sheikh Y, Lutter C, Schöffl I, Schöffl V, Flohe S. Surgical management of proximal interphalangeal joint repetitive stress epiphyseal fracture nonunion in elite sport climbers. *J Hand Surg Am*. 2018;43(6):572.e571-572.e575.
12. Fanchini M, Violette F, Impellizzeri FM, Maffiuletti NA. Differences in climbing-specific strength between boulder and lead rock climbers. *J Strength Cond Res*. 2013;27(2):310-314.
13. Hochholzer T, Schöffl V, Krause R. Finger-Epiphysenverletzungen jugendlicher Sportkletterer. *Sport Ortho Trauma*. 1997;13(2):100-103.
14. Hochholzer T, Schöffl VR. Epiphyseal fractures of the finger middle joints in young sport climbers. *Wilderness Environ Med*. 2005;16(3):139-142.
15. Hudak PL, Amadio PC, Bombardier C; Upper Extremity Collaborative Group. Development of an upper extremity outcome measure: the DASH (Disabilities of the Arm, Shoulder, and Hand). *Am J Industrial Med*. 1996;29:602-608.
16. Jones G, Asghar A, Llewellyn DJ. The epidemiology of rock climbing injuries. *Br J Sports Med*. 2008;42(9):773-778.
17. Josephsen G, Shinneman S, Tamayo-Sarver J, et al. Injuries in bouldering: a prospective study. *Wilderness Environ Med*. 2007;18(4):271-280.
18. Klauser A, Frauscher F, Bodner G, et al. Value of high-resolution ultrasound in the evaluation of finger injuries in extreme sport climbers. Article in German. *Ultraschall Med*. 2000;21(2):73-78.
19. Lutter C, Tischer T, Cooper C, et al. Mechanisms of acute knee injuries in bouldering and rock climbing athletes. *Am J Sports Med*. 2020;48(3):730-738.
20. Lutter C, Tischer T, Hotfiel T, et al. Current trends in sport climbing injuries after the inclusion into the Olympic program: analysis of 633 injuries within the years 2017/18. *Muscle Tendons Ligament J*. 2020;10(2):201-210.

21. Lutter C, Tischer T, Schöffl VR. Olympic competition climbing: the beginning of a new era—a narrative review. *Br J Sports Med*. 2021;55(15):857-864. doi:10.1136/bjsports-2020-102035
22. Maffulli N, Longo UG, Gougoulias N, Loppini M, Denaro V. Long-term health outcomes of youth sports injuries. *Br J Sports Med*. 2010;44:21-25.
23. McGeorge DD, McGeorge S. Diagnostic medical ultrasound in the management of hand injuries. *J Hand Surg Br*. 1990;15:256-261.
24. Meyers RN, Hobbs SL, Howell DR, Provance AJ. Are adolescent climbers aware of the most common youth climbing injury and safe training practices? *Int J Environ Res Public Health*. 2020;167:812-822.
25. Meyers RN, Howell DR, Provance AJ. The association of finger growth plate injury history and speed climbing in youth competition climbers. *Wilderness Environ Med*. 2020;31(4):394-399.
26. Meyers RN, Schöffl VR, Mei-Dan O, Provance AJ. Returning to climb after epiphyseal finger stress fracture. *Curr Sports Med Rep*. 2020;19(11):457-462.
27. Michailov M, Mladenov L, Schöffl V. Anthropometric and strength characteristics of world-class boulderers. *Medicine Sportiva*. 2009;2009(13):231-238.
28. Parfitt AM. Misconceptions (1): epiphyseal fusion causes cessation of growth. *Bone*. 2002;20(2):337-339.
29. Pfeifer C, Messner K, Scherer R, Hochholzer T. Injury pattern and overuse stress syndrome in young sport climbers. Article in German. *Wien Klin Wochenschr*. 2000;112(22):965-972.
30. Pozzi A, Pivato G, Pegoli L. Hand injury in rock climbing: literature review. *J Hand Surg Asian Pac Vol*. 2016;21(1):13-17.
31. Ross JL, Cassorla FG, Skerda MC, et al. A preliminary study of the effect of estrogen dose on growth in Turner's syndrome. *N Engl J Med*. 1983;309(18):1104-1106.
32. Salter RB, Harris WR. Injuries involving the epiphyseal plate. *J Bone Joint Surg Am*. 1963;45(3):587-622.
33. Schlegel C, Buechler U, Kriemler S. Finger injuries of young elite rock climbers. *Schweizerische Zeitschrift für Sportmedizin und Sporttraumatologie*. 2012;50(1):7-10.
34. Schöffl I, Schöffl V. Epiphyseal stress fractures in the fingers of adolescents: biomechanics, pathomechanism, and risk factors. *Eur J Sports Med*. 2015;3(1):27-37.
35. Schöffl I, Schöffl V, Dotsch J, Dorr HG, Jungert J. Correlations between high level sport-climbing and the development of adolescents. *Pediatr Exerc Sci*. 2011;23(4):477-486.
36. Schöffl V, Hochholzer T, El-Sheikh Y, Lutter C. Hand and fingers. In: Schöffl V, Schöffl I, Hochholzer T, Lutter C, eds. *Climbing Medicine*. Vol 1. Springer; 2021.
37. Schöffl V, Küpper T, Hartmann J, Schöffl I. Surgical repair of multiple pulley injuries—evaluation of a new combined pulley repair. *J Hand Surg Am*. 2012;37(2):224-230.
38. Schöffl V, Lutter C, Woollings K, Schöffl I. Pediatric and adolescent injury in rock climbing. *Res Sports Med*. 2018;26(suppl 1):91-113.
39. Schöffl V, Morrison A, Hefti U, Ullrich S, Küpper T. The UIAA Medical Commission injury classification for mountaineering and climbing sports. *Wilderness Environ Med*. 2011;22(1):46-51.
40. Schöffl V, Morrison A, Schöffl I, Küpper T. Epidemiology of injury in mountainering, rock and iceclimbing. In: Caine D, Heggie T, eds. *Medicine and Sport Science—Epidemiology of Injury in Adventure and Extreme Sports*. Vol 58. Karger; 2012:17-43.
41. Schöffl V, Morrison AB, Hefti U, Schwarz U, Küpper T. The UIAA Medical Commission injury classification for mountaineering and climbing sports. *Wilderness Environ Med*. 2011;22(1):46-51.
42. Schöffl V, Popp D, Küpper T, Schöffl I. Injury distribution in rock climbers—a prospective evaluation of 911 injuries between 2009-2012. *Wilderness Environ Med*. 2015;26(1):62-67.
43. Schöffl V, Popp D, Küpper T, Schöffl I. Injury trends in rock climbers: evaluation of a case series of 911 injuries between 2009 and 2012. *Wilderness Environ Med*. 2015;26(1):62-67.
44. Schöffl V, Schöffl I. Anatomy and biomechnics of the hand. In: Schöffl V, Schöffl I, Hochholzer T, Lutter C, eds. *Climbing Medicine*. Vol 1. Springer; 2021.
45. Schöffl VR, Hoffmann PM, Imhoff A, et al. Long-term radiographic adaptations to stress of high-level and recreational rock climbing in former adolescent athletes: an 11-year prospective longitudinal study. *Orthop J Sports Med*. 2018;6(9):2325967118792847.
46. Schöffl VR, Schöffl I. Finger pain in rock climbers: reaching the right differential diagnosis and therapy. *J Sports Med Phys Fitness*. 2007;47(1):70-78.
47. Schweizer A, Göhner Schweizer K. Sport climbing, bouldering and associated injuries in childhood and adolescence. *Der Orthopade*. 2019;48:998-1004.
48. Wen J, Ting C, Jacomel T, Lindau TR, Oestreich K. ''Osgood Schlatter of the finger'': a case report of apophysitis of the proximal interphalangeal joint of the finger and review of injuries in adolescent climbers. *Actta Scientific Orthopedics*. 2020;3(1):137-142.
49. Woollings KY, McKay CD, Emery CA. Risk factors for injury in sport climbing and bouldering: a systematic review of the literature. *Br J Sports Med*. 2015;49(17):1094-1099.
50. Woollings KY, McKay CD, Kang J, Meeuwisse WH, Emery CA. Incidence, mechanism and risk factors for injury in youth rock climbers. *Br J Sports Med*. 2015;49(1):44-50.