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# Prospective analysis of injury demographics, distribution, severity and risk factors in adolescent climbers

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## ABSTRACT

**Objective** This study aims to prospectively analyse current demographics, distribution and severity of climbing injuries in adolescents. We hypothesised that the injury distribution of adolescent climbers would differ from adults, as presented in the literature and that primary periphyseal stress injuries of the finger (PPSI) will be very common and correlate with training hours and climbing level.

**Methods** We performed a prospective single-centre injury surveillance of all adolescent (<18 years of age) climbers who presented between 2017 and 2020. A standard questionnaire, including questions for medical history, injury and training data and an examination protocol, was conducted in all patients. Injuries were graded, and risk factors, anthropometric specifics and stages of development were analysed. Injury epidemiology of adolescents was then compared with adults as presented in the literature.

**Results** 137 independent climbing-related injuries were found in 95 patients. Injury onset was acute in 67 (48.9%) and chronic in 70 (51.8%). Forty-one injuries (29.9%) occurred during bouldering, 18 (13.1%) during lead climbing, 2 (1.5%) in speed climbing and 1 (0.7%) while training on the campus board. Average International Climbing and Mountaineering Federation injury score was 1.5±0.5 (range 0–3). Females had more training hours (p=0.004), more campus board use (p=0.004) and more acute injuries than males (p<0.001). 82% of the injuries affected the upper extremity and the most frequent injury was PPSI (45.3% of all injuries). Finger injuries were significantly more common in males than in females (p<0.05). The injury distribution in adolescent climbers differed significantly from adults (p<0.001).

**Conclusions** Injured adolescent climbers had mostly chronic injuries affecting the upper extremity, with almost half of the injuries being PPSIs of the fingers. Further preventive measures targeting this type of injury need to be identified. Reducing the use of the finger crimp grip, monitoring the load, ensuring adequate recovery and targeted education appear to be crucial.

### WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Chronic overstrain injuries onto the upper extremity are the most frequent sport-specific injuries in climbers. Is this true in adolescent climbers as well?

### WHAT THIS STUDY ADDS

⇒ Overstrain injuries onto the upper extremity are the most frequent injuries in adolescent climbers. Climbers who are younger than 16 years mostly have primary periphyseal stress injuries of the fingers. Injuries in adolescent climbers differ significantly from those of adults.

### HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ As chronic overload is the main cause for injuries in young climbers, medical monitoring and recording of the overall training load are crucial for injury prophylaxis. Targeted prevention is especially important in boys to raise awareness of the injury and to seek medical attention.

## INTRODUCTION

Climbing developed into a modern trend sport, both at a leisure and at a highly competitive level. As a weight-sensitive sport (gravity sport), especially adolescents benefit from their high relative 'strength to bodyweight ratio'.[1–13] Thus, it is a logical consequence that adolescent climbers perform well in competitions and can often be found in the finals.[14 15] Even before climbing debuted at the 2021 Olympic Games in Tokyo, it was already presented as a new sport at the 2018 Youth Olympic Games in Rio de Janeiro.[16] Injury analysis of this event showed a low injury incidence in competition climbing, a trend which was also later found in the Olympic Games in Tokyo.[17] So far, many studies on climbing injuries in adults have been conducted in recent years,[3 8 18–33] but less work has specifically looked at adolescent climbers (<18 years).[4 10–14 16 34–50] In adult climbers, most frequent acute traumatic injuries are strains and sprains from falls onto the ankle, while the most frequent sport-specific injuries are onto the hand and fingers, involving pulley injuries, tenosynovitis and capsulitis of the small finger joints.[3 8 18–33] Most studies on youth and

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adolescent climbers specifically look into periphyseal growth plate fractures (primary periphyseal stress injuries (PPSIs)), an almost climbing-specific pathology in adolescents.[11 13 14 35 39–43 45–47 51–57] Since the first reported case in 1997, more than 200 of these fractures have been reported in the literature.[11 35 39 42 45 52 58 59] Recent reports showed an increase in their incidence.[35 46] This rise is expected to continue with sport climbing's inclusion into the Olympic programme and the ongoing increase in training intensity and load.[8 45] Other studies on youth climbing athletes focused onto a possible early onset of osteoarthritis in the fingers,[15 60 61] self-reported injury patterns in competitive youth climbers[10] or the effect of early specialisation and past injury.[38] Nevertheless, all studies looking into the injury distribution of adolescent climbers were cross sectional retrospectively with self-analysis of the injury by the study participants only, while a prospective evaluation of medically confirmed diagnosis is lacking.[10 35 37 38 62] Thus, we now aimed to prospectively record climbing injuries medically diagnosed in outpatient sports medicine clinic with focus on climbing medicine and analyse their epidemiology, grading and risk factors as well as the anthropometric specifics, stages of development and gender differences in adolescent climbers. We hypothesised that the injury distribution of adolescent climbers would differ from that of adult climbers and that PPSI will be very common and correlate with training hours and climbing level.

## METHODS

We performed a prospective single-centre injury surveillance of all adolescent (<18 years of age) climbers who presented between 2017 and 2020. Our outpatient sports medicine clinic with a focus on climbing medicine serves as a national and international referral centre for climbing injuries. Diagnoses were made based on clinical investigation and radiological findings by three experienced orthopaedic surgeons with expertise in climbing medicine (MS, CL, and VRS) and one radiologist (TB) specialised in the field of climbing-related injuries. All final diagnoses were reviewed and confirmed by the first author (VRS). The study was part of an evaluation of all adolescent climbing injuries and their risk factors as well as an evaluation of an algorithm for epiphysial growth plate fractures[40] and was approved by the ethical board of the Friedrich-Alexander University Erlangen-Nuremberg, FRG (No. 64_17B). All patients and/or their legal guardian provided informed consent. Study information and informed consent forms were age adapted and presented in three various age-related adopted texts, which were also approved by the ethical board.

Only adolescents (<18 years) suffering from pain during or after climbing were included in the study. Participation was voluntary. Climbing was defined as all climbing subdisciplines: sport climbing, bouldering, outdoor rock climbing, trad climbing and alpine climbing. Ice-climbing and mountaineering were not included. Injuries caused by climbing activities were defined as medical conditions forcing the athlete to rest from his sport due to pain or dysfunction and the necessity to seek help from a physician.[8]

A standard questionnaire, including questions for pre-existing medical conditions, medical history, demographics, adolescent development stage and an examination protocol, was conducted in all patients.[8] A differentiation was performed regarding onset of injury (acute or chronic) and overstrain (yes or no). Acute injuries were defined as injuries with a sudden onset during climbing or bouldering without any history of symptoms, while overuse injuries were defined as chronic injuries without an explicit event or a specific trauma during the sport.[8] However, while periphyseal growth plate fractures may have an acute onset, they are still considered a chronic injury by their pathophysiology.[35 39–41 45 51 53] This is also seen in the following other climbing-specific finger injuries: tenosynovitis, capsulitis and ganglion cysts.[35 51]

The *Union Internationale des Associations d'Alpinisme* (UIAA) metric scale was used for evaluation of climbing levels and the V-scale (Verm scale) was used for evaluation of bouldering levels.[8 63] The Orchard Sports Injury Classification System 10 (OSICS 10) scale was used to categorise the injury distribution.[63 64] In the event that more than one independent injury has been detected in an individual, we analysed the patient individual data at the date of injury in accordance to each individual injury.

To compare the injury distribution of adolescents to adults without a selection bias, we performed a statistical comparison to the studies from the literature[8 46 65] in which the same selection methods in a population were used.

Microsoft Excel (Microsoft) was used for data collection. Statistical analyses were performed with IBM SPSS Statistics V.28 (IBM Corp.) including descriptive statistics for continuous and categorical variables. Categorical variables were collated in cross tables to perform either Fisher's exact tests or $\chi^2$ tests. For continuous variables, normal distribution was analysed with the Shapiro-Wilk test. Groups with normally distributed, continuous values were compared using unpaired Student's t test, while for non-normally distributed data the comparison was performed with the Mann-Whitney U test. P values <0.05 were considered as statistically significant. If not stated otherwise, all data are presented as mean±SD and median (min, max).

## RESULTS

95 adolescent climbing patients were identified and further investigated. Overall, a total number of 137 independent climbing injuries was detected. 31 athletes presented with several independent climbing injuries (up to 4 injuries). The cohort consisted of 38 female (56 injuries) and 57 male climbers (81 injuries). The mean age was 15.1±1.5 years, mean height 171.2±9.2 cm, mean body weight 60.3±10.1 kg and mean body mass index 20.4±2.2 kg/m$^2$ (table 1). Climbing level averaged 9.1, ranging from almost beginners with 6 to expert level with

**Table 1** Patient demographics

| | All patients | Female | Male | P value |
|---|---|---|---|---|
| Number of patients | 95 | 38 | 57 | |
| Number of injuries | 137 | 56 | 81 | |
| Age (years) | 15.1±1.5 | 15.1±1.5 | 15.0±1.5 | 0.653 (U test) |
| Range | 9–17 | 11–17 | 9–17 | |
| Age at first recorded injury (years) | 15.1±1.5<br>9–17 | 14.8±1.5<br>11–17 | 15.0±1.6<br>9–17 | 0.524 (U test) |
| Height (cm) | 171.2±9.2<br>130–189 | 166.0±5.5<br>154–173 | 174.9±9.5<br>130–189 | **< 0.001 (U test)** |
| Weight (kg) | 60.3±10.1<br>28.0–80.0 | 55.5±6.2<br>38.0–63.9 | 63.7±11.0<br>28.0–80.0 | **< 0.001 (U test)** |
| Body mass index (kg/m²) | 20.4±2.2<br>15.2–25.4 | 20.1±1.8<br>15.6–23.4 | 20.7±2.4<br>15.2–25.4 | 0.209 (T test) |
| Climbing level (UIAA scale) | 9.1±1.1 | 9.3±0.6 | 8.9±1.3 | 0.414 (U test) |
| Range | 6–11 | 8–11 | 6–11 | |
| Bouldering level (Vermin scale) | 8.3±2.5<br>1–13 | 8.2±1.8<br>5–13 | 8.4±3.0<br>1–13 | 0.536 (U test) |
| Climbing years | 7.7±3.4<br>0.5–16 | 8.2±3.7<br>0.5–16 | 7.4±3.2<br>2–16 | 0.234 (T test) |
| Bouldering years | 7.1±3.3<br>0.5–16 | 7.6±3.9<br>0.5–16 | 6.8±2.7<br>2–11 | 0.427 (U test) |
| Climbing time spent per discipline: | | | | |
| Sport climbing | 36.9±17.5% | 36.0±14.8 | 37.6±19.3 | 0.859 (U test) |
| Bouldering | 47.5±17.7% | 47.4±17.7 | 47.7±17.9 | 0.572 (U test) |
| Other* | 19.9±13.0% | 17.9±11.2 | 21.3±14.1 | 0.211 (U test) |
| Competition participation | | | | 0.091 ($\chi^2$) |
| Yes | 60.6% (83/137) | 71.4% (40/56) | 53.1% (43/81) | |
| No | 8.8% (12/137) | 5.4% (3/56) | 11.1% (9/81) | |
| No answer | 30.7% (42/137) | 23.2% (13/56) | 35.8% (29/81) | |
| Warm up before climbing | | | | 0.060 ($\chi^2$) |
| Yes | 62% (85/137) | 71.4% (40/56) | 55.6% (45/81) | |
| No | 0 | 0 | 0 | |
| No answer | 38% (52/137) | 28.6% (16/56) | 44.4% (36/81) | |
| Climbing training hours/week | 11.9±4.8 | 13.3±4.2 | 10.7±5.0 | **0.004 (U test)** |
| Range | 1.5–25 | 1.5–25 | 2–20 | |
| Additional strength training | | | | 0.138 ($\chi^2$ square) |
| Yes | 59.9% (82/137) | 69.6% (39/56) | 53.1% (43/81) | |
| No | 3.6% (5/137) | 3.6% (2/56) | 3.7% (3/81) | |
| No answer | 36.5% (50/137) | 26.8% (15/56) | 43.2% (35/81) | |
| If, average hours per week | 3.2±1.7 | 3.6±2.0 | 2.9±1.4 | 0.375 (U test) |
| Campus board training | | | | **0.004** ($\chi^2$) |
| Yes | 40.9% (56/137) | 57.1% (32/56) | 29.6% (24/81) | |
| No | 21.2% (29/137) | 12.5% (7/56) | 27.2% (22/81) | |
| No answer | 38.0% (52/137) | 30.4% (17/56) | 43.2% (35/81) | |
| If, average hours per week | 1.1±0.7 | 1.0±0.5 | 1.3±0.8 | 0.130 (U test) |
| Training with additional weights | | | | 0.123 ($\chi^2$) |
| Yes | 29.2% (40/137) | 30.4% (17/56) | 53.1% (23/81) | |
| No | 32.8% (45/137) | 41.1% (23/56) | 28.4% (22/81) | |
| No answer | 38.0% (52/137) | 28.6% (16/56) | 44.4% (36/81) | |

Continued

**Table 1** Continued

| | All patients | Female | Male | P value |
|---|---|---|---|---|
| If, average hours per week | 1.1±0.7 | 1.2±0.4 | 1.0±0.8 | 0.312 (U test) |
| Compensatory training | | | | 0.335 ($\chi^2$) |
| Yes | 53.3% (73/137) | 60.7% (34/56) | 48.1% (39/81) | |
| No | 13.9% (19/137) | 10.7% (6/56) | 16.0% (13/81) | |
| No answer | 32.8% (45/137) | 28.6% (16/56) | 35.8% (29/81) | |
| If, average hours per week | 1.9±1.1 | 1.9±0.9 | 1.9±1.2 | 0.954 (T test) |
| Preferred finger grip position: | | | | **0.032** ($\chi^2$) |
| Hanging grip | 35.0% (48/137) | 39.3% (22/56) | 32.1% (26/81) | |
| Crimping grip | 19.7% (27/137) | 28.6% (16/56) | 13.6% (11/81) | |
| Sloper | 8.8% (12/137) | 3.6% (2/56) | 12.3% (10/81) | |
| No answer | 36.5% (50/137) | 28.6% (16/56) | 42.0% (34/81) | |

Bold typeface indicates significance.
*Other climbing disciplines include speed climbing, trad climbing and alpine climbing.

grade 11. In accordance with the injury grading scale of the International Rock Climbing Research Association, a UIAA lead climbing level of 9.1 is an elite level for women and an advanced level for men.[66] Bouldering level averaged Vermin 8.3 and ranged from 1 to 13 (table 1). A bouldering level of 8.3 on the Vermin scale reflects an elite level in women and an advanced level in men.[66] The climbing level was higher in females than males, while the bouldering level in males was higher (not significant). Injured climbers had been in average climbing since 7.7 and bouldering for 7.1 years. Of those 83 injured competing athletes, 45 (54%) did local competitions, 65 (78.3%) regional, 67 (81.7%) national level, 50 (60.2%) international (youth) level competitions and 12 (14.5%) regular senior World Cups. Training hours ranged up to 25 hours per week in females and 20 in males. Most of the climbers (62%) warmed up with a regular routine using stretching, rope jumping, rubber band or soft ball exercises (or similar devices for warming up the fingers), running and climbing easy routes. No climber reported about no warm-up, but 38% did not answer to this question. Additional strength training with either free weights or body weight exercises was performed by 59.9%, with an average of 3.3 hours per week. Female athletes (57.1%) trained significantly more frequently at the campus board than males (29.6%) (p=0.004) but had less overall training hours per week (0.96 vs 1.3) (p=0.130). A total of 29.2% of the athletes trained with additional weights to increase the load during hanging exercises (30.4% women, 53.1% men). Compensatory training was reported by 53.3% of the cohort only with an average of 1.8 hours per week. 35.8% did not answer to this matter. The preferred hand position was a 'hanging' position in 38%. Typical compensatory training consisted of stretching, running, antagonist training, yoga, rubber band exercises and cycling. Patient demographic, anthropometric and climbing-specific data are shown in table 1.

## Injuries

Overall 137 injuries in 95 climbers were recorded. Injury onset was acute in 67 (48.9%) and chronic in 70 (51.8%). Females had more acute injuries than males (p<0.001). Of the 137 injuries, 41 (29.9%) occurred during bouldering, 19 (13.9%) during lead climbing, 2 (1.5%) in speed climbing and 1 (0.7%) while training on the campus board. In 74 (54%), the climbing activity during which the injury occurred was not specified. Pain was reported overall since 131.9±193.9 days (females since 91.5±160 and males since 163.4±219.5 days (p=0.03)). All injuries were presented to a physician. The time to see a doctor was significantly longer in males than in females (p=0.004). Next to the physical examination, the MRI was the most frequent diagnostic tool (163.4±219.5), followed by X-ray 73 (56.6%) and ultrasound 64 (49.6%). Males were significantly more likely to receive a CT scan than female climbers (p=0.002). 74% reported about a break from climbing with an average of 60.4 days and a range of 5–365 days. Climbing break was significantly longer in males than females (p=0.01). The average UIAA injury score was 1.5±0.5 (range 0–3). 75.2% of the injuries were chronic overstrain. In 11 injuries, a surgical treatment was necessary, in three of them as inpatients. Females were more frequently hospitalised, which almost was statistically significant (p=0.066). Injury data are presented in table 2.

The injury distribution shows most injuries onto the upper extremity (81.8%). According to the OSICS classification, we found 84 P (finger), 13 W (wrist), nine A (ankle), seven K (knee), six S (shoulder), six E (elbow), three F (foot/toe), three D (thoracic spine), two B (lumbar spine) injuries, and one H (head) injury (table 3).

Finger injuries were significantly more common in males than in females (p<0.05), but preferred finger grip positions (crimping, hanging, and sloper) did not

**Table 2** Injuries

| | All injuries | Female | Male | |
|---|---|---|---|---|
| Number of patients | 95 | 38 | 57 | |
| Number of injuries | 137 | 56 | 81 | |
| Injury cause: | | | | 0.154 ($\chi^2$) |
| Bouldering | 41 (29.9%) | 14 (25%) | 27 (33.3%) | |
| Lead climbing | 18 (13.1%) | 11 (19.6%) | 7 (8.6%) | |
| Speed | 2 (1.5%) | – | 2 (2.5%) | |
| Campus board | 1 (0.7%) | 1 (1.8%) | – | |
| Not specified | 75 (54.7%) | 30 (53.6%) | 45 (55.6%) | |
| Injury onset | | | | **< 0.001 (Fisher's exact test)** |
| Acute | 67 (48.9%) | 37 (66.1%) | 30 (37.0%) | |
| Chronic | 70 (51.1%) | 19 (33.9%) | 51 (63.0%) | |
| Pain duration (days) | 141.9±190.9 | 104.4±160.8 | 173.6±209.6 | **0.032 (U test)** |
| Diagnostics: | n=127 | n=52 | n=75 | Fisher's exact test: |
| X-ray | 75 (59.1%) | 28 (53.8%) | 47 (62.7%) | 0.362 |
| Ultrasound | 67 (52.8%) | 23 (44.2%) | 44 (58.7%) | 0.148 |
| MRI | 89 (70.1%) | 39 (75.0%) | 50 (66.7%) | 0.333 |
| CT | 16 (12.6%) | 1 (1.9%) | 15 (20.0%) | **0.002** |
| Climbing break | n=127 | n=54 | n=73 | 1.000 (Fisher's exact test) **0.010 (U test)** |
| Yes | 93 (73.2%) | 40 (74.1%) | 53 (72.6%) | |
| No | 34 (26.8%) | 14 (25.9%) | 20 (27.4%) | |
| Days | 61.0±73.1 | 38.4±29.2 | 76.8±89.1 | |
| Range (d) | 5–365 | 5–150 | 7–365 | |
| Consultation with physician (%) | 100 | 100 | 100 | |
| Consultation after how many days: | 20.0±27.0 | 11.6±22.8 | 26.5±28.5 | **0.004 (U test)** |
| Range (d) | 0–120 | 0–120 | 0–120 | |
| UIAA injury score | 1.5±0.5 | 1.5±0.5 | 1.5±0.5 | 0.811 (U test) |
| Range | 0–3 | 0–3 | 0–3 | |
| Overstrain: | | | | 0.232 (Fisher's exact test) |
| Yes | 103 (75.2%) | 39 (69.6%) | 64 (79%) | |
| No | 34 (24.8%) | 17 (30.4%) | 17 (21.0%) | |
| Hospitalised | 3 (2.2%) | 3 (5.4%) | 0 | 0.066 (Fisher's exact test) |
| Surgical treatment | 11 (8.0%) | 4 (7.1%) | 7 (8.6%) | 1.000 (Fisher's exact test) |

Bold typeface indicates significance.
UIAA, Union Internationale des Associations d'Alpinisme.

significantly affect finger injuries. The most frequent injury was a PPSI of the fingers, which accounted to 45.3% of all injuries. 15 (24.2%) of the 62 PPSIs were only stress reactions with sometimes oedema in the MRI but without the detection of a fracture. Other frequent injuries were finger joint capsulitis (5.1%), wrist strains and sprains (5.1%) and ankle sprains (5.1%). Looking at different age groups (up to 15 years or 16 years and older), age did not significantly influence the onset of PPSI (fractures and overstrain). Gender significantly influenced the onset of PPSI overall (p=0.005) and specifically PPSI fractures (p=0.009) with male athletes having significantly more of these finger injuries. Gender did not influence PPSI overstrain. Preferred grip position did not significantly influence PPSI (fractures and strains). Training on the campus board, additional strength training and training with additional weight did not significantly influence the incidence of PPSI. Also, training hours per week and climbing years did not significantly influence the incidence of PPSI. The lead climbing grade showed an almost significant adverse influence onto the incidence of PPSIs (p=0.06) and reached significance if looking at the younger injured climbers with PPSIs (<16 years). In this group, athletes who climbed in lower UIAA

**Table 3** Injury distribution in OSICS classification[2]

| | All injuries | Female | Male | |
|---|---|---|---|---|
| | 137 | 56 | 81 | |
| Number of patients | 95 | 38 | 57 | |
| Injury location | | | | 0.052 ($\chi^2$) |
| Hand/finger/thumb | 84 (61.3%) | **24 (42.9%)** | **60 (74.1%)** | |
| Wrist | 16 (11.7%) | 10 (17.9%) | 6 (7.4%) | |
| Spine | 5 (3.6%) | 3 (5.4%) | 2 (2.5%) | |
| Knee | 8 (5.8%) | 5 (8.9%) | 3 (3.7%) | |
| Elbow | 6 (4.4%) | 3 (5.4%) | 3 (3.7%) | |
| Foot | 4 (2.9%) | 2 (3.6%) | 2 (2.5%) | |
| Ankle | 7 (5.1%) | 5 (8.9%) | 2 (2.5%) | |
| Shoulder | 6 (4.4%) | 3 (5.4%) | 3 (3.7%) | |
| Head | 1 (0.7%) | 1 (1.8%) | 0 (0.0%) | |

Bold typeface indicates significance.
OSICS, Orchard Sports Injury Classification System.

grades (7.9±1.3) had a significantly higher risk for PPSI than those climbing in higher grades (9.2±0.9). Type of climbing did not significantly influence the onset of PPSIs. All medical diagnoses of the various injuries are given in box 1.

### Comparison to studies with a similar patient selection

To answer the second part of our hypothesis, the results of the present study were statistically compared with two studies of adults with a similar selection bias. After weighting the values, the frequencies were compared using the $\chi^2$ test. This showed that the distribution of injuries was significantly different between children and adults (p<0.001). Bonferroni's post hoc test showed significant differences between children and adults for finger/hand, shoulder and other (p<0.05). The other sites did not differ significantly in frequency (table 4).

## DISCUSSION

The main findings of the present study were that the injury distribution of adolescent climbers differed significantly from that of adults and that PPSI was the most common specific injury in young athletes. Therefore, these hypotheses were proved to be correct. We further hypothesised that PPSI correlates with training hours and climbing or bouldering levels. However, this hypothesis was only partially proven to be correct since no correlation with training hours or bouldering level was found. Lead climbing level (UIAA), however, did influence the occurrence of PPSIs significantly in athletes<16 years, which is the risk group for this injury.

So far, many studies on climbing injuries in adults have been conducted in recent years,[3 8 18–33] but less work has specifically looked at adolescent climbers.[4 10–14 16 34–49] Cohorts of young climbers were mostly only analysed via cross-sectional questionnaires[10 12 13] or as part of general climbing injuries reporting.[8 18 21 25–28 32 35 41 46 67–70] The present study is the only one verifying the diagnosis

**Box 1 Medical diagnoses (n=137)**

Primary periphyseal stress injury of the fingers (PPSI) 62*
Capsulitis finger 7
Wrist strain/sprain 7
Ankle Sprain 7
Back sprain (including overstrain bone marrow oedema) 5
Knee contusion/sprain 4
Epicondylitis/brachialis tendonitis 4
Tenosynovitis finger/hand 4
Lumbrical strain 4
SLAP/Andrews or Bankart lesion 3
Finger joint capsular injury 3
Bone marrow oedema (carpus) 2
Finger flexor tendon strain 2
Ganglion wrist 2
AC joint inflammation 2
Wrist fracture 2
Finger pulley injury 2 (only sprain)
Ankle fracture 2
Plantar fasciitis
Meniscus Injury
Collateral ligament injury elbow joint
Tendonitis knee
Forearm fracture
Finger joint capsule sprain
Osgood Schlatter knee
Morbus Panner elbow
LBS tendonitis
Hallux valgus
Finger fracture
Cerebral concussion
Bone bruise talus

*15 of the 62 PPSI were only stress reaction, but no fracture was detected.
AC, acromioclavicular; LBS, long biceps tendon; SLAP, superior labrum anterior to posterior tear.

through medical examination and not only self-reporting. As the prior studies showed that the most common climbing injury in adolescents differs from that one in adults a specific youth injury analysis is important. Also, with the progression of the sport, these youngsters will be the Olympic champions in the near future and load monitoring and injury prevention are of upmost importance.[2 7] While the mean age of our adolescents was around 15 years, they were already climbing up to the highest levels with UIAA grade 11. Training time ranged up to 25 hours per week, being here on almost even levels to top-level athletes.[8 46] Since these adolescents still need to manage time attending school and are not full professionals, this is quite a high number. BMI was within a normal range and in average around 20. While this is a 'hot topic' in the climbing community, considering the cases of relative energy deficiency syndrome (REDs),[5 9 48 71–74] we found no case of suspected REDs in our cohort. It is surprising that the female climbers of our study trained significantly more hours; nevertheless, also their climbing level and years were higher (not significant) and this may be just a random finding. Overall, the top level in climbing does not differ much anymore in between both genders.[75]

**Table 4** Injury distribution according to body area as presented previously (data of trunk, spine and pelvis merged)

| Body area | Present study (n=137) | 2017–2018 (n=633) | 2009–2012 (n=911) | 1998–2001 (n=604) |
|---|---|---|---|---|
| Finger/hand | **100 (73%)†** | **310 (48.9%)** | **593 (65.1%)** | **294** (48.7%) |
| Shoulder | 6 (4.4%) | 128 (20.2%) | 157 (17.2%) | 30 (5%) |
| Forearm and elbow | 6 (4.4%) | 49 (7.7%) | 83 (9.1%) | 81 (13.4%) |
| Lower leg/foot | 12 (8.7) | 67 (10.6%) | 35 (3.8%) | 55 (9.1%) |
| Knee | 7 (5.1%) | 45 (7.1%) | 19 (2.1%) | 22 (3.6%) |
| Trunk, spine, pelvis | 5 (3.6 %) | 34 (5.4%) | 21 (2.3%) | 43 (7.1%) |
| Other | **1 (0.7%)** | – | **3 (0.3%)** | – |

Values are n (%).[1 3 4]
Bold typeface indicates significance.

Many climbers reported on a warm-up routine, additional strength training and additional compensatory training. Especially for shoulder injuries, compensatory training as, for example, the 'Adjunct Compensatory Training for rock climbers' programme (www.act.clinic) has shown its value in treating unspecific shoulder pain.[76] Nevertheless, potential injuries through a failure (tearing apart) of older exercise resistance bands (elastic bands) and whiplash injuries should be considered.[77] It is quite surprising that the females reported a much higher preference of the crimp grip than the male athletes (females 39.3% and males 13.6%), as well as a significantly higher preference of training at the campus board. While it is widely accepted that the crimp grip poses a high risk to the cartilage and is a risk factor for PPSI[39–42 55 78–80] even in the present study, we had only 16/62 cases of PPSI in girls (25.8%). Also, in these girls with a PPSI, we found an almost even distribution of grip preference between hanging and crimping. The most frequent diagnostic tool was the MRI followed by normal X-ray. This is probably[40 81] attributed to the high proportion of PPSI in the injuries and goes along with the latest algorithms on diagnostics of PPSI.[40 41] An early MRI diagnostic is reportedly important to detect early-stage PPSI in adolescent climbers.[37 54 55 62] Males did receive more CT scans than females which probably was due to the fact of a higher number of long-time PPSI in this group. In long-time complaints in a PPSI, CT scans are recommended to detect a possible sclerosis of the former fracture zone, which would then indicate a surgical procedure, as otherwise long-time non-union is to be expected.

The injury score overall was for all injuries in between UIAA grade 1–3 and thus within the same range as described in prior studies and in adults.[3 4 8 10–14 16 18–49 67–70] Also, the number of chronic injuries was high in the present study and higher than in adults in a similar setup.[8 46] The high number of chronic injuries is certainly based partially on a selection bias. As our department serves as a reference centre for climbing injuries, we see many patients for second or third opinions as well as patients from various regional, state and national teams. Acute injuries are likewise treated closely to the place of injury in a local hospital or ER and thus this number is underrepresented in our setup. This also explains why, for example, Müller *et al*,[26] Buzzacott *et al*[21] or Sabbagh *et al*[18] do see mostly lower extremity injuries due to falls and thus acute trauma. This was already previously discussed but needs to be considered when discussing these data.[8 35 37 46 62] The same bias applies if one compares our findings with those of Pirrucio *et al*[34] who recently used the NEISS data to examine the difference in between climbing injuries in adults versus adolescents and found for adolescents mainly head, neck and upper extremity injuries. These NEISS data are emergency room reporting in the US and will very likely miss minor finger injuries as PPSI.[21 67 70 82–84] While injury onset was almost evenly distributed between acute and chronic onset, it is interesting that in females injury onset was much more acute than chronic. Overall, boys had more overstrain injuries, which may go along with the fact that their boulder level was higher but in contradiction to the analysis of the overall time spent training. This overall time was higher in the girls in our study. Woollings *et al*[37] found that of self-reported injuries in adolescent climbers, repetitive overuse had the highest incidence rate of injury at 1.13 injuries per 1000 athlete-exposure hours, while falls accounted for 0.88 injuries per 1000 hours, and strenuous moves caused 0.56 injuries per 1000 hours. Barille *et al*[10] performed a retrospective, cross-sectional study to estimate the current frequency and impact of injuries sustained by competitive youth climbers. Fifty-two respondents aged 7–18 years completed all mandatory portions of the survey. 34 climbers reported an injury (acute or chronic). Hand/Finger injuries represented the most common type of injuries reported (36%). 91% of reported acute injuries occurred during bouldering which goes along with our findings, as we also had most acute injuries in bouldering.

Also, Chen *et al*[38] examined injury distribution in a study on early sport-specific specialisation and its possible influence on injury patterns. They found 49% of the injuries onto the upper extremity. In contradiction, Carraro *et al* report about a high prevalence (74.4% of the sample group) of lower back pain in young climbers (age 13–19 years).[50] This high number is not reflected in any of the other studies presented

**Table 5** Injury location (Orchard Sports Injury Classification System (OSICS)) or body parts

| | OSICS | Present study | Schöffl *et al*[46] 2015 | Schöffl *et al*[65] 2003 | Woollings *et al* 2015 | Barille *et al*[10] 2022 | Chen *et al*[38] 2022 | Nelson *et al*[67] 2009 |
|---|---|---|---|---|---|---|---|---|
| n (injuries) | | 137 | 26 | 54 | 142 | 56* | 67 | 243 |
| Specific injury location | | | | | | | | |
| Hand/finger/thumb | P | 84 (61%) | 17 (65%) | 25 (46%) | 30 (21%) | 20 (36%) | 16 (24%) | |
| Wrist | W | 16 (12%) | 3 (12%) | 1 (2%) | 11 (8%) | 7 (13%) (including forearm) | 4 (6%) | |
| Shoulder | S | 6 (4%) | 2 (8%) | 6 (11%) | 22 (15%) | 3 (5%) | 7 (10%) | |
| Knee | K | 8 (6%) | 1 (4%) | 8 (15%) | 13 (9%) | 1 (2%) | 5 (7%) | |
| Foot/toe | F | 4 (3%) | 1 (4%) | – | 4 (3%) | 2 (4%) | 2 (3%) | |
| Forearm | R | | 1 (4%) | 2 (4%) | 3 (2%) | see wrist | 4 (6%) | |
| Back | B/D | 5 (4%) | – | 8 (15%) | 14 (10%) | | 7 (10%) | |
| Elbow | E | 6 (4%) | 1 (4%) | 4 (7%) | 9 (6%) | 7 (13%) | 2 (3%) | |
| Ankle | A | 7 (5%) | | | 13 (9%) | 3 (5%) including lower leg | 15 (22%) | |
| Neck/cervical spine | N | | | | 5 (4%) | 2 (4%) | 1 (1%) | |
| Upper arm | U | | | | 5 (4%) | | | |
| Lower leg/Achilles tendon | Q, A | | | | 4 (3%) | | | |
| Head/face | H | 1 (1%) | | | 3 (2%) | 4 (8%) | | |
| Hip/groin | G | | | | 3 (2%) | 3 (5%) | 2 (3%) | |
| Thigh/upper leg | T | | | | 3 (2%) | 1 (2%) | | |
| Skin | | | | | | | 2 (3%) | |
| Body parts | | | | | | | | |
| | | | | | | | | |
| Upper extremity | | 112 (82%) | 24 (92%) | 38 (70%) | 80 (56%) | 37/53* (70%) | 33 (49%) | 33% |
| Lower extremity | | 19/14%) | 2 (8%) | 8 (15%) | 40 (28%) | 10/53* (19%) | 24 (36%) | 41% |
| Head and neck | | 1 (1%) | – | – | 3 (2%) | 6/53* (11%) | 1 (1%) | 16% |
| Trunk | | 5 (4%) | – | 8 (15%) | 14 (10%) | | 7 (10%) | 9% |
| Unspecified | | | | | | | 2 (3%) | |

*Number adds up only to 53 in paper.

yet.[12 35 37 62] Unfortunately, their study is specifically only focusing on the incidence of lower back pain in adolescent climbers; no reporting of other injuries is given. Table 5 shows the comparison of the injury distribution of our current study to those on adolescent climbers given in the literature.

Considering the injury distribution, the best way to exclude a selection bias in the current paper is to compare it with studies[8 46 65] who used the same selection methods in a population containing adult and junior rock climbers (table 5). This comparison is quite interesting. While there is a strong trend in adults to a higher portion of shoulder injuries, this is not found in adolescents. Shoulder injuries do apparently only play a minor role in adolescents. One cause would be likely the fact that a lot of these shoulder injuries in climbers, such as for example SLAP and rotator cuff injuries, have a degenerative and chronic onset and thus need many years of exposure.[85–90]

## Injury types

Almost half the injuries in our study group were PPSI, which is, even since we serve as a reference centre for climbing-specific injuries a high number. PPSIs typically present during periods of accelerated growth velocity, around 13–15 years of age, predominantly affecting males, and most commonly affecting the middle and ring fingers.[35 40 45 54 55] Unfortunately, comparison to other studies on youth climbers is difficult as, for example, Barille *et al*[10] do not give numbers of PPSI at all. They report about three cases of fractures but don't specify if these were PPSI or standard fractures from falls or contact to the wall. Schöffl *et al*[46] analysed 911 climbing injuries, and of these 26 were to adolescents (<18 years). 50% (13/26) of these were PPSI while the other injuries were a wide distribution onto the whole body. Chen *et al*[38] performed a survey on adolescent climbers and reported that hand and ankle injuries occurred most often. Only 12 growth plate injuries were reported, four of which involved the fingers.[38] This makes the number of PPSI in this study of four out of 67 as little as 6% and quite different to other studies on adolescent climbers. Other growth plate injuries in the Chen *et al*[38] study involved the ankle (n=5), wrist (n=2) and knee (n=1), but were most likely acute growth plate fractures and not chronic overstrain injuries as which the PPSI in the fingers are considered.[35 39 53 55] Three out of the 4 (75%) climbers who reported PPSI in the study of Chen *et al*[38] also reported a consistent (at least once a week) use of campus board training. This risk factor was already described by Schöffl *et al*.[15] In our present study also, 21 of 31 (67.7%) adolescent climbers who answered the question on campus board training and having a PPSI reported on using the campus board but we did not find a significant correlation. It is noteworthy that boys were more frequently diagnosed with PPSI, even though girls reported more frequent use of the crimp grip and more time spent on the campus board. We cannot provide a clear explanation for this from our study, but hypothesise that boys climb more strength oriented and therefore put more stress on their fingers. They may also be more likely to ignore pain and injury than girls, which may explain why, once they finally admitted to an injury, the climbing break was significantly longer and they had a longer duration of pain.

## CONCLUSION

In our study of injuries in adolescent climbers, we found a significantly different distribution of injuries compared with adults. PPSIs are the most common injury, with a high proportion of these injuries occurring in male climbers. Overall, boys have significantly more finger injuries, more chronic injuries, longer duration of pain and longer time away from climbing than girls. They also wait significantly longer to seek medical attention. Girls reported more frequent use of the crimp grip and a higher preference for campus board training. Specific injury prevention measures as well as targeted educational programmes are needed to prevent injuries among adolescent climbers.

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## REFERENCES

1 Strand M. Attitudes towards disordered eating in the rock climbing community: a digital ethnography. *J Eat Disord* 2022;10:1–14.
2 Schöffl I, Lutter C, Schöffl V. What to Examine in Youth Climbing Athletes: Yearly Examination of the German Climbing Team and its Consequences. *Sportverletz Sportschaden* 2019;33:212–5.
3 Lutter C, Tischer T, Schöffl VR. Olympic competition climbing: the beginning of a new era-a narrative review. *Br J Sports Med* 2021;55:857–64.

4 Morrison AB, Schöffl VR. Physiological responses to rock climbing in young climbers. *Br J Sports Med* 2007;41:852–61.
5 Watts PB, Joubert LM, Lish AK, *et al*. Anthropometry of young competitive sport rock climbers. *Br J Sports Med* 2003;37:420–4.
6 Ginszt M, Saito M, Zięba E, *et al*. Body Composition, Anthropometric Parameters, and Strength-Endurance Characteristics of Sport Climbers: A Systematic Review. *J Strength Cond Res* 2023;37:1339–48.
7 Lutter C, El-Sheikh Y, Schöffl I, *et al*. Sport climbing: medical considerations for this new Olympic discipline. *Br J Sports Med* 2017;51:2–3.
8 Lutter C, Tischer T, Hotfield 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 Ligaments and Tendons J* 2020;10:201.
9 Joubert L, Warme A, Larson A, *et al*. Prevalence of amenorrhea in elite female competitive climbers. *Front Sports Act Living* 2022;4:895588.
10 Barrile AM, Feng S-Y, Nesiama J-A, *et al*. Injury Rates, Patterns, Mechanisms, and Risk Factors Among Competitive Youth Climbers in the United States. *Wilderness Environ Med* 2022;33:25–32.
11 Meyers RN, Schöffl VR, Mei-Dan O, *et al*. Returning to Climb after Epiphyseal Finger Stress Fracture. *Curr Sports Med Rep* 2020;19:457–62.
12 Meyers RN, Hobbs SL, Howell DR, *et al*. Are Adolescent Climbers Aware of the Most Common Youth Climbing Injury and Safe Training Practices? *Int J Environ Res Public Health* 2020;17:812–22.
13 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;31:394–9.
14 Schöffl I, Schöffl V. Pediatric aspects in young rock climbers. In: Schöffl V, Schöffl I, Lutter C, *et al*., eds. *Climbing Medicine: A Practical Guide*. Cham: Springer International Publishing, 2022: 201–6.
15 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;6:2325967118792847.
16 Steffen K, Soligard T, Mountjoy M, *et al*. How do the new Olympic sports compare with the traditional Olympic sports? Injury and illness at the 2018 Youth Olympic Summer Games in Buenos Aires, Argentina. *Br J Sports Med* 2020;54:168–75.
17 Soligard T, Palmer D, Steffen K, *et al*. New sports, COVID-19 and the heat: sports injuries and illnesses in the Tokyo 2020 Summer Olympics. *Br J Sports Med* 2022:bjsports-2022-106155.
18 Sabbagh RS, Hoge CG, Kanhere AP, *et al*. The epidemiology of indoor and outdoor rock climbing injuries presenting to USA emergency departments. *J Sports Med Phys Fitness* 2022;62:1095–102.
19 Identeg F, Orava E, Sansone M, *et al*. Patterns of traumatic outdoor rock-climbing injuries in Sweden between 2008 and 2019. *J Exp Orthop* 2021;8:89.
20 Cole KP, Uhl RL, Rosenbaum AJ. Comprehensive Review of Rock Climbing Injuries. *J Am Acad Orthop Surg* 2020;28:e501–9.
21 Buzzacott P, Schöffl I, Chimiak J, *et al*. Rock Climbing Injuries Treated in US Emergency Departments, 2008-2016. *Wilderness Environ Med* 2019;30:121–8.
22 Lutter C, Hotfiel T, Tischer T, *et al*. Evaluation of Rock Climbing Related Injuries in Older Athletes. *Wilderness Environ Med* 2019;30:362–8.
23 Grønhaug G, Norberg M. First overview on chronic injuries in sport climbing: proposal for a change in reporting of injuries in climbing. *BMJ Open Sport Exerc Med* 2016;2:e000083.
24 Schöffl VR, Hoffmann G, Küpper T. Acute injury risk and severity in indoor climbing-a prospective analysis of 515,337 indoor climbing wall visits in 5 years. *Wilderness Environ Med* 2013;24:187–94.
25 Schöffl V, Burtscher E, Coscia F. Injuries and medical incidences during the IFSC 2012 Climbing World Cup Series. *Med Sport* 2013;17:168–70.
26 Müller M, Heck J, Pflüger P, *et al*. Characteristics of bouldering injuries based on 430 patients presented to an urban emergency department. *Injury* 2022;53:1394–400.
27 Leung J, Petrin Z, Southern W. Self-Reported Injuries in Indoor Gym-Based Rock Climbers: A Retrospective Study of Predictors of Prolonged Injury and Seeking Medical Care. *Wilderness Environ Med* 2023;34:311–7.
28 von Essen D, Schöffl VR. Acute and Chronic Injury Patterns in Competitive Paraclimbing Sports. *Am J Phys Med Rehabil* 2023.
29 Simon M, Geffel L, Lutter C, *et al*. Functional and Sport-Specific Outcome Following Traumatic First-Time Shoulder Dislocation and Arthroscopic Surgical Repair in Rock Climbers. *Wilderness Environ Med* 2023;34:303–10.
30 Schöffl V, von Schroeder H, Lisse J, *et al*. Wrist Injuries in Climbers. *Am J Sports Med* 2023;51:3416–25.
31 Artiaco S, Bosco F, Lusso A, *et al*. Flexor Tendon Pulley Injuries: A Systematic Review of the Literature and Current Treatment Options. *J Hand Microsurg* 2023;15:247–52.
32 Sims LA. Upper Extremity Injuries in Rock Climbers: Diagnosis and Management. *J Hand Surg Am* 2022;47:662–72.
33 Kovářová M, Pyszko P, Kikalová K. Analyzing Injury Patterns in Climbing: A Comprehensive Study of Risk Factors. *Sports (Basel)* 2024;12:61.
34 Pirruccio K, Shin M, Ganley TJ, *et al*. Rock climbing confers distinct injury risk in pediatric versus adult populations: an analysis of twenty-year national trends. *Phys Sportsmed* 2022;50:343–8.
35 Schöffl V, Lutter C, Woollings K, *et al*. Pediatric and adolescent injury in rock climbing. *Res Sports Med* 2018;26:91–113.
36 McDonald JW, Henrie AM, Teramoto M, *et al*. Descriptive Epidemiology, Medical Evaluation, and Outcomes of Rock Climbing Injuries. *Wilderness Environ Med* 2017;28:185–96.
37 Woollings KY, McKay CD, Kang J, *et al*. Incidence, mechanism and risk factors for injury in youth rock climbers. *Br J Sports Med* 2015;49:44–50.
38 Chen DL, Meyers RN, Provance AJ, *et al*. Early Sport Specialization and Past Injury in Competitive Youth Rock Climbers. *Wilderness Environ Med* 2022;33:179–86.
39 Caine D, Meyers R, Nguyen J, *et al*. Primary Periphyseal Stress Injuries in Young Athletes: A Systematic Review. *Sports Med* 2022;52:741–72.
40 Schöffl V, Schöffl I, Flohé S, *et al*. Evaluation of a Diagnostic-Therapeutic Algorithm for Finger Epiphyseal Growth Plate Stress Injuries in Adolescent Climbers. *Am J Sports Med* 2022;50:229–37.
41 Jones G, Johnson R, Schöffl V, *et al*. Primary Periphyseal Stress Injuries of the Fingers in Adolescent Climbers: A Critical Review. *Curr Sports Med Rep* 2022;21:436–42.
42 Bärtschi N, Scheibler A, Schweizer A. Symptomatic epiphyseal sprains and stress fractures of the finger phalanges in adolescent sport climbers. *Hand Surg Rehabil* 2019;38:251–6.
43 Halsey T, Johnson MI, Jones G. Epiphyseal Stress Fractures of the Fingers in an Adolescent Climber: A Potential "Maslow's Hammer" in Terms of Clinical Reasoning. *Curr Sports Med Rep* 2019;18:431–3.
44 Desaldeleer AS, Le Nen D. Bilateral fracture of the base of the middle phalanx in a climber: Literature review and a case report. *Orthop Traumatol Surg Res* 2016;102:409–11.
45 Schöffl I, Schöffl V. Epiphyseal stress fractures in the fingers of adolescents: Biomechanics, Pathomechanism, and Risk factors. *European Journal of Sports Medicine* 2015;3:27–37.
46 Schöffl V, Popp D, Küpper T, *et al*. Injury trends in rock climbers: evaluation of a case series of 911 injuries between 2009 and 2012. *Wilderness Environ Med* 2015;26:62–7.
47 Bayer T, Schöffl VR, Lenhart M, *et al*. Epiphyseal stress fractures of finger phalanges in adolescent climbing athletes: a 3.0-Tesla magnetic resonance imaging evaluation. *Skeletal Radiol* 2013;42:1521–5.
48 Schöffl I, Schöffl V, Dötsch J, *et al*. Correlations between high level sport-climbing and the development of adolescents. *Pediatr Exerc Sci* 2011;23:477–86.
49 Jüngert J, Hochholzer T, Schöffl V. Ultrasound evaluation of the finger flexor tendon pulley system in adolescent rock climbers and there comparison to radiographic findings [In Preparation]. 2005.
50 Carraro A, Gilic B, Bertolo R, *et al*. Lower back pain in young climbers: a retrospective cross-sectional study. *Front Sports Act Living* 2023;5:1328811.
51 Schöffl VR, Schöffl I. Finger pain in rock climbers: reaching the right differential diagnosis and therapy. *J Sports Med Phys Fitness* 2007;47:70–8.
52 Hochholzer T, Schöffl VR. Epiphyseal fractures of the finger middle joints in young sport climbers. *Wilderness Environ Med* 2005;16:139–42.
53 Caine D, Maffulli N, Meyers RN, *et al*. Inconsistencies and Imprecision in the Nomenclature Used to Describe Primary Periphyseal Stress Injuries: Towards a Better Understanding. *Sports Med* 2022;52:685–707.
54 Miro P, Schöffl VR. Prevention of primary periphyseal stress injuries in skeletally immature climbers. *Br J Sports Med* 2024;58:883–4.
55 Schöffl V, Iruretagoiena X. Physeal stress injuries of the hand and fingers. In: Caine D, Nguyen J, Grady M, eds. *Physeal stress injuries Physeal Stress Injuries in Young Athletes: Diagnosis, Treatment and Prevention. Contemporary Pediatric and Adolescent Sports Medicine*. Springer, 2024.

56 Miro P, Crawford A, Mills MK, *et al*. Imaging of primary periphyseal finger stress injuries in climbers. *Skeletal Radiol* 2024.
57 Schöffl V, Moser O, Küpper T. Stress fractures of the growth plates in the fingers of adolescent rock climbers. *Unfallchirurgie (Heidelb)* 2024;127:824–31.
58 Hochholzer T, Schöffl V, Krause R. Finger-Epiphysenverletzungen jugendlicher Sportkletterer. *Sport Ortho Trauma* 1997;13:100–3.
59 Chell J, Stevens K, Preston B, *et al*. Bilateral fractures of the middle phalanx of the middle finger in an adolescent climber. *Am J Sports Med* 1999;27:817–9.
60 Schöffl VR, Hochholzer T, Imhoff AB, *et al*. Radiographic adaptations to the stress of high-level rock climbing in junior athletes: a 5-year longitudinal study of the German Junior National Team and a group of recreational climbers. *Am J Sports Med* 2007;35:86–92.
61 Schöffl V, Hochholzer T, Imhoff A. Radiographic changes in the hands and fingers of young, high-level climbers. *Am J Sports Med* 2004;32:1688–94.
62 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;49:1094–9.
63 Schöffl V, Morrison A, Hefti U, *et al*. The UIAA Medical Commission Injury Classification for Mountaineering and Climbing Sports. *Wilderness Environ Med* 2011;22:46–51.
64 Orchard J. Orchard Sports Injury Classification System (OSICS). *Sport Health* 1993;11:39–41.
65 Schöffl V, Hochholzer T, Winkelmann HP, *et al*. Pulley injuries in rock climbers. *Wilderness Environ Med* 2003;14:94–100.
66 Draper N, Giles D, Schöffl V, *et al*. Comparative grading scales, statistical analyses, climber descriptors and ability grouping: International Rock Climbing Research Association position statement. *Sports Technology* 2015;8:88–94.
67 Nelson NG, McKenzie LB. Rock climbing injuries treated in emergency departments in the U.S., 1990-2007. *Am J Prev Med* 2009;37:195–200.
68 Auer J, Schöffl VR, Achenbach L, *et al*. Indoor Bouldering-A Prospective Injury Evaluation. *Wilderness Environ Med* 2021;32:160–7.
69 Jones G, Schöffl V, Johnson MI. Incidence, Diagnosis, and Management of Injury in Sport Climbing and Bouldering: A Critical Review. *Curr Sports Med Rep* 2018;17:396–401.
70 Schöffl V, Morrison A, Schöffl I, *et al*. The epidemiology of injury in mountaineering, rock and ice climbing. *Med Sport Sci* 2012;58:17–43.
71 Mountjoy M, Ackerman KE, Bailey DM, *et al*. 2023 International Olympic Committee's (IOC) consensus statement on Relative Energy Deficiency in Sport (REDs). *Br J Sports Med* 2023;57:1073–97.
72 Smith EJ, Storey R, Ranchordas MK. Nutritional Considerations for Bouldering. *Int J Sport Nutr Exerc Metab* 2017;27:314–24.
73 Kemmler W, Roloff I, Baumann H, *et al*. Effect of exercise, body composition, and nutritional intake on bone parameters in male elite rock climbers. *Int J Sports Med* 2006;27:653–9.
74 Grønhaug G. Lean and mean? Associations of level of performance, chronic injuries and BMI in sport climbing. *BMJ Open Sport Exerc Med* 2019;5:e000437.
75 Carroll C. Female excellence in rock climbing likely has an evolutionary origin. *Curr Res Physiol* 2021;4:39–46.
76 Grohnert LS, Bonato M, Schöffl V. Evaluation of a four-week Adjunct Compensatory Training for the treatment of climbing-specific overstrain syndromes of the shoulder. *Sportverletz Sportschaden* 2022;36:138–44.
77 Heyn J, Strohm P, Schöffl V. Exercise Resistance Band induced injuries during Covid 19 Pandemic Lockdown Training. *Sportverletz Sportschaden* 2023;37:96–9.
78 Bärtschi N, Scheibler AG, Schweizer A. Palmar Shift of the Proximal Interphalangeal Joint in Different Grip Positions as a Potential Risk Factor for Periphyseal Injuries in Adolescent Climbers. *Wilderness Environ Med* 2023;34:451–6.
79 Schöffl I, Oppelt K, Jüngert J, *et al*. The influence of the crimp and slope grip position on the finger pulley system. *J Biomech* 2009;42:2183–7.
80 Roloff I. [Biomechanical modelling of the climbers hand: estimation of the mechanical constrains applied on the finger flexor tendon pulleys] modélisation biomécanique de la main du grimpeur: estimation des contraintes mécaniques exercées sur les poulies digitalis [master thesis]. Grenoble Université Joseph Fourier Grenoble 1; 2004.
81 El-Sheikh Y, Lutter C, Schoeffl I, *et al*. Surgical Management of Proximal Interphalangeal Joint Repetitive Stress Epiphyseal Fracture Nonunion in Elite Sport Climbers. *J Hand Surg Am* 2018;43:572.
82 Chou DW, Kshirsagar R, Liang J. Head and Neck Injuries from Rock Climbing: A Query of the National Electronic Injury Surveillance System. *Ann Otol Rhinol Laryngol* 2021;130:18–23.
83 Backe S, Ericson L, Janson S, *et al*. Rock climbing injury rates and associated risk factors in a general climbing population. *Scand J Med Sci Sports* 2009;19:850–6.
84 Schöffl V, Morrison AB, Schwarz U, *et al*. Evaluation of Injury and Fatality Risk in Rock and Ice Climbing. *Sports Med* 2010;40:657–79.
85 Simon M, Popp D, Lutter C, *et al*. Functional and Sports-Specific Outcome After Surgical Repair of Rotator Cuff Tears in Rock Climbers. *Wilderness Environ Med* 2017;28:342–7.
86 Popp D, Schöffl V. Superior labral anterior posterior lesions of the shoulder: Current diagnostic and therapeutic standards. *World J Orthop* 2015;6:660–71.
87 Popp D, Schöffl V. Shoulder SLAP and biceps tendon repair. *Minerva Ortop Traumatol* 2013;64:247–63.
88 Schöffl V, Popp D, Dickschass J, *et al*. Superior labral anterior-posterior lesions in rock climbers—primary double tenodesis? *Clin J Sport Med* 2011;21:261–3.
89 Boileau P, Parratte S, Chuinard C, *et al*. Arthroscopic treatment of isolated type II SLAP lesions: biceps tenodesis as an alternative to reinsertion. *Am J Sports Med* 2009;37:929–36.
90 Ott B, Popp D, Schöffl I, *et al*. Primary long biceps tenodesis as treatment for high grade SLAP lesions: Clinical evaluation in rock climbers. *European Journal of Sports Medicine* 2016;4:51–63.