RISK FACTORS FOR INJURY IN SPORT CLIMBING AND BOULDERING: A SYSTEMATIC REVIEW OF THE LITERATURE

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Keywords: athletic injuries, risk factors, epidemiology, rock climbing, prevention

Word count (excluding title page, abstract, references, figures, and tables): 4500

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ABSTRACT

Background: Rock climbing is an increasingly popular sport worldwide, as both a recreational activity and a competitive sport. Several disciplines including sport climbing and bouldering have developed, each employing specific movements and techniques, leading to specific injuries.

Objective: To examine risk factors and prevention measures for injury in sport climbing and bouldering, and assess the methodological quality of existing studies.

Methods: Twelve electronic databases and several other sources were searched systematically using predetermined inclusion and exclusion criteria. Eligible articles were peer-reviewed, based on primary research using original data; outcome measures included injury, morbidity or mortality in rock climbing, and included one or more potential risk factor or injury prevention strategy. Two independent reviewers assessed the methodology of research in each study using the Downs and Black Quality Index. The data extracted is summarized, and appraisals of the articles are presented with respect to the quality of evidence presented.

Results: Nineteen studies met the inclusion criteria, and introduced 35 possible risk factors or injury prevention measures in climbing. Age, increasing years of climbing experience, highest climbing grade achieved (skill level), high Climbing Intensity Score (CIS), and participating in lead climbing are potential risk factors. Results regarding injury prevention measures remain inconclusive.

Discussion: This field is relatively new and as such, the data are not as robust as for more established sports with a larger research foundation. The key need is establishing modifiable risk factors using prospective studies and high quality methodology, such that injury prevention strategies can be developed. The climbing intensity score (CIS) may be a useful measure in this field of research.

New Findings:

- Risk factors for acute and overuse injury in climbers may include age, increasing years of climbing experience, skill level, and participating in lead climbing.
- Injury prevention strategies targeting modifiable risk factors should be developed, including controlling climbing volume and intensity.
- The climbing intensity score (CIS) measures the degree of exposure to “climbing stress” of an individual. CIS scores have been introduced and used only in two studies to date, but both have indicated that participants who scored higher in CIS to be at a higher injury risk. This will be a measure to further examine and use in future research.

INTRODUCTION

Rock climbing is a popular sport worldwide, both as a recreational activity and as a competitive sport. Several disciplines of the sport exist, including traditional climbing, sport climbing, and bouldering.[1,2] Sport climbing and bouldering, the newest disciplines, are performed on artificial surfaces and on natural rock. Sport climbing routes are typically up to 30 metres high. The climber is attached to a rope clipped into permanent bolts using "quickdraws," spaced intermittently from the bottom up (lead climbing), or the rope is anchored at the top of the climb (top roping), to allow climbers to incur frequent falls safely. Bouldering uses crash mats instead of ropes to protect climbers from falls. "Boulder problems" are usually short and low to the ground.

As sport climbing and bouldering employ specific movements and techniques, these two climbing disciplines lead to specific injuries. Previous research, involving primarily adult populations, suggests that upper extremity overuse injuries and acute flexor tendon pulley strains of the fingers are the most common injuries sustained by rock climbers in varying disciplines, though ankle injuries are also common due to falls .[3–9] There have been no reviews examining specific risk factors for injury in sport climbing and bouldering. By identifying potentially modifiable risk factors for these injuries, it may be possible to develop and evaluate injury prevention strategies. We systematically reviewed intrinsic and extrinsic risk factors and prevention strategies for injury in sport climbing and bouldering.

METHODS

Information Sources

Twelve electronic databases were searched systematically for relevant documents during November 2012, and the search was updated in December 2014: PubMed (1960–present), MEDLINE (OVID) (1946–present), SPORTDiscus (1960–present), BIOSIS Previews (1980–present), CINAHL Plus (1960–present), Academic Search Complete (EBSCO) (1960–present), PsychInfo (1967–present), ScienceDirect (Elsevier) (1960–present), Health STAR (1980–present), EMBASE (1974–present), SafetyLit (www.safetylit.org), and Statistics Canada (http://statcan.summon.serialssolutions.com). Four websites were searched for additional relevant publications: the UIAA (www.theuiaa.org), the International Federation of Sport Climbing (IFSC) (www.ifsc-climbing.org), the Alpine Club of Canada (ACC) (http://www.alpineclubofcanada.ca) and *The Alpine Journal* (a flagship publication of the ACC). Articles were also obtained from a comprehensive collection provided at the annual 2012 Banff Climbing Conference. Bibliographies of selected articles were searched for additional relevant publications. The terms used for article extraction are found in Table 1.

Table 1. Medical subject headings and text words used for article extraction

Medical subject headings (MeSH) (also used as text words in each search)	Text words (tw)
1. "Mountaineering" 2. "Wounds and injuries" 3. "Athletic injuries" 4. "Risk factors"	5. "Climb" [Boolean climb*] 6. "Boulder" [Boolean boulder*] 7. "Injury" 8. "Sport injury" 9. "Prevention" 10. "Intervention" 11. "Safety"

Search Strategy

Climbing search terms: 1 OR 5 OR 6

Injury search terms: 2 OR 3 OR 7 OR 8

Risk factors: 4

Injury prevention search terms: 9 OR 10 OR 11

A. climbing and injury: A AND B

B. climbing and risk factors for injury: E AND C

C. climbing and injury prevention: E AND D

D. climbing, risk factors for injury, and prevention: F AND D

Search terms for climbing, injury, risk factors, and injury prevention were not searched individually as they each yielded a high number of articles that were not specific to the topic of interest. Strategies A to D were used to search each electronic database. If fewer than 300 articles were obtained, titles were screened, abstracts reviewed to retrieve relevant articles, and duplicates removed. Finally, the full texts of the remaining articles were reviewed to assess eligibility based on the inclusion and exclusion criteria.

Eligibility Criteria

Study inclusion criteria were: articles based on primary research using original data; outcome measure included injury, morbidity or mortality in rock climbing (indoor or outdoor); included one or more potential risk factor or injury prevention strategy; designs included randomized controlled trials, quasi-experimental, cohort, cross-sectional, case-control, longitudinal, and case series studies; peer reviewed, and published in English. Review articles and case studies were excluded; however, reference lists of review articles were reviewed for additional relevant articles.

Two independent reviewers completed the review of selected articles during December 2012, and again in December 2014 for the additional articles. Each reviewer screened the full text articles to determine whether all inclusion criteria were met. Disagreements were resolved by discussion and subsequent consensus.

Data Collection Process

Descriptive data were extracted from studies that met all inclusion criteria. Study design, population, definition of injury, injury incidence, risk factor(s) examined, and results were extracted (Table 2). Risk factors and prevention measures for sport climbing were considered separately from those examined for bouldering, though not all articles specified, and thus discipline could not always be isolated. Injury incidence was examined to give context to the risk factor analysis (Table 3).

Two independent reviewers assessed each study using the Downs and Black criteria for methodological quality. Downs and Black includes a 27-item checklist for both randomized and non-randomized study designs. It aids in evaluating the quality of reporting, external validity, internal validity, and power.[10] The reviewers reached consensus for each article. The Oxford Centre for Evidence-Based Medicine Levels of Evidence were also determined for each study.[11]

Data Synthesis

Due to the diversity of objectives, methodology, and statistical analyses in these studies, meta-analyses to calculate injury rates or to quantitatively establish risk factors and prevention measures were not appropriate to carry out for this review. Therefore extracted data are descriptive. Relevant data are summarized, and appraisals of the articles are presented with respect to the quality of evidence presented.

RESULTS

Study Selection

Titles and abstracts from database searches (n=149) and other sources (i.e., websites, conference, bibliographies) (n=54) were screened for inclusion and duplicates removed. The full texts of 49 articles were reviewed to assess each for eligibility; 19 studies met the inclusion criteria. Figure 1 summarizes the study selection process.

Methodological Quality Assessment

Study appraisal based on the Downs and Black criteria produced scores ranging from six to 15 out of 32 possible points (Table 2). Overall quality was low as the majority of the studies were cross-sectional (n=16). Furthermore, though the disciplines of sport climbing and bouldering were the focus of this review, results were included from studies that did not specify the type of climbing examined, as it was likely that they included sport climbing and bouldering, among others. Often, all "rock climbers" willing to participate were included in a study, and some samples may therefore have been less representative of the target population being examined for this review. The authors thought it better to include rather than exclude these studies and risk overlooking potential risk factors. Age ranges varied, and there was sex disparity in most studies, with samples composed of approximately 60-100% males.[2,12] Several studies failed to adjust for confounding variables, introducing potential bias in the results. Study quality scores and the Oxford Centre for Evidence-Based Medicine Levels of Evidence are summarized in Table 2.

Table 2. Characteristics and results of studies examining risk factors for injury in sport climbing and bouldering

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Backe *et al.* (2008) [13]	Cross-sectional	Swedish Climbing Association members n=355 (70% male, 30% female) Ages 9-67 years	4	15	Sport climbing and bouldering	"Injuries that occurred while participating in a climbing activity indoors or outdoors and that resulted in an injury treatment intervention (medical treatment, hospitalization and/or discontinuation and rest from climbing)." Traumatic injuries defined as acute onset, overuse injuries defined as repeated microtrauma without a single identifiable event.	Primary risk factor analysis for climbing injury: • Body mass index (BMI): p<0.015 • Bouldering: p<0.047 Risk factor analysis for re-injury (re-injury risk factors were used as a proxy for injury risk factors in the analysis): • Time climbing per year: p=0.439 • BMI: p=0.121 • Sex (male): p=0.019 • Age group (20-45 vs. <20 yrs.): p=0.003 • Age group (46+ vs. <20 yrs.): p<0.001 • Bouldering: p=0.122 • Sport climbing: p=0.719 • Years climbing experience (5-9 vs. 0–4 yrs.): p=0.775 • Years climbing experience (10+ vs. 0–4 yrs.): p=0.060)
Carmeli *et al.* (2002) [14]	Cross-sectional	Sport climbing club in Tel Aviv, Israel n=19 (67% male, 33% female) Ages 9-34 years	4	11	Sport climbing	Injuries sustained during sport climbing were self-reported soft tissue injury to the hands and fingers, classified by functional diagnoses (tendons and ligaments), and medical diagnoses	• Sex (male): p<0.05 • Age (19-34 vs. 9-18 yrs.): significant (p<0.05) • Frequency: p<0.05 (practicing 4-5x per week reported more diverse wrist and finger injuries) • Grip strength: p<0.05 "mild to moderate correlation: r=0.26 and r=0.41"

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Gerdes *et al.* (2006) [15]	Cross-sectional	Rock climbers of any age, ability, or experience, primarily male, advanced or intermediate n=1887 (87% male, 13% female) Ages 10-66 years	4	9	All types of "rock climbing"	Subjects identified three most significant injuries. Data was collected on injured body part, type of injury, type of climbing, medical care sought, and recovery time.	• Climbing discipline: more injuries in climbers participating in traditional climbing (mean 2.53 vs. 1.92; p<0.001) or free solo climbing (mean 3.30 vs. 2.09; p<0.001) *(traditional and free solo climbing are outside the scope of this systematic review)* • Indoors vs. outdoors: 47.7% and 52.3% of injuries (no test of hypothesis) • Familiar location versus unfamiliar/new area: 79.2% and 20.8% of injuries (no test of hypothesis) ○ 4.3% (95% Confidence Interval [CI]; 3.6, 5.2) injuries sustained by 'beginner' climbers ○ 28.3% (95% CI; 26.6, 30.1) by 'intermediate' group ○ 46.3% (95% CI; 44.4, 48.3) by 'advanced' group ○ 21.2% (95% CI; 19.6, 22.9) by 'expert' group • Use of illicit substances (while climbing): p<0.008
Hasler *et al.* (2012) [16]	Case-control	Indoor and outdoor climbers in Switzerland n=113 (76% of patients, 67% of controls male, 24% of patients, 33% of controls female) Ages 16-64 years	3b	13	All types of "rock climbing"	Acute injury from indoor or outdoor climbing where the climber was admitted to an emergency department. (Chronic overuse syndromes, intracranial bleeding, skull fractures, Glasgow Coma Score [GCS] of greater than 14 or persistent retrograde amnesia were excluded.)	• Sex: p>0.05 • Age: p>0.05 • Level of difficulty of the climbing route: p>0.05 • Duration of warm-up: p>0.05 • Readiness for risk: p>0.05 • Abstinence from alcohol and drugs: p>0.05 • >10 yrs. climbing experience (vs. <1 yr.): p>0.05 • 1–10 yrs. climbing experience (vs. <1 yr.): p=0.006, Odds ratio (OR)=5.34, (95%CI; 1.61; 17.76) • No previous experiences on the climbing route: OR=2.72 (95%CI; 1.15, 6.39), p=0.022

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Jones *et al.* (2008) [3]	Cross-sectional	British rock climbers n=201 (81% male, 19% female) Ages 16-62 years	4	11	All types of "rock climbing"	Injuries requiring medical attention or withdrawal from sport participation for more than one day	• Age: p>0.05 • Sex (male): p>0.05 • Years climbing experience: p>0.05 • Soloing frequency: p<0.05 for overuse injury, OR=1.79 (95% CI; 1.14, 2.83) • Soloing grade: p>0.05 • Traditional lead frequency: p>0.05 • Traditional lead grade: p<0.05 for overuse injury, OR=1.25 (95% CI; 1.07, 1.46) *(traditional and free solo climbing are outside the scope of this systematic review)* • Sport lead frequency: p<0.05 for overuse injury, OR=1.49 (95% CI; 1.05, 2.13) • Sport lead grade: p<0.05 for falls, OR=1.47 (95% CI; 1.04, 2.09); p<0.05 for overuse injury, OR=1.28 (95% CI; 1.05, 1.56) • Indoor lead frequency: p<0.05 for overuse injury, OR=1.21 (95% CI; 1.03, 1.42) • Indoor lead grade: p<0.05 for overuse injury, OR=1.42 (95% CI; 1.17, 1.71) • Bouldering frequency: p<0.05 for overuse injury, OR=1.24 (95% CI; 1.07, 1.43) • Bouldering grade: p<0.05 for overuse injury, OR=1.42 (95% CI; 1.16, 1.73) and strenuous moves, OR=1.24 (95% CI; 1.02, 1.50)

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Josephsen *et al.* (2007) [2]	Cross-sectional with a prospective cohort component	Boulderers in two cohorts: primarily indoor climbers and primarily outdoor climbers n=152 (60% male, 40% female) Mean age 25±5 years (range not reported)	2b	12	Bouldering	Not defined, divided by anatomical location and mechanism of injury	Risk factor examination: For finger injuries (analyzed since it was the most common climbing injury, as opposed to falling): • Outdoor vs. indoor bouldering: higher outdoor (19 (61%) vs. 6 (27%); 95% CI for risk difference: -10, -3) • Previous history of finger injury: p=0.03, OR=4.0 (95% CI; 1.2, 13.6) • Sex: p>0.05 • Years climbing experience: p>0.05 • Body mass index (BMI): p>0.05 • Weight: p>0.05 • Climbing ability: p>0.05 For fall injuries: • Outdoor vs. indoor bouldering: higher indoor (7 (23%) vs. 11 (50%); 95% CI for risk difference: 2, -53) • Presence of spotters: p>0.05 • Number of spotters: p>0.05 • Height of average boulder: p>0.05 • Height of tallest boulder climbed: p>0.05 • Use of pads: p>0.05 • Years climbing experience: p>0.05 • BMI: p>0.05 • Weight: p>0.05 • Ability level: p>0.05 Prevention measure examination: • Warm-up (5, 10, and >10 mins. examined): p>0.05 • Stretching: p>0.05 • Regular yoga practice: p>0.05

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Josephsen *et al.* (2007) *continued*							• Finger taping: $p>0.05$ • Wrist taping: $p<0.05$ (protective effect) • Glucosamine: $p>0.05$ • Other supplement use: $p>0.05$ • Heating hands prior to climbing: $p>0.05$ • Taking time off to prevent injuries: $p>0.05$ • Use of corticosteroid injections: $p>0.05$ • Weight training: $p<0.05$ (protective effect) • Presence of spotters: $p>0.05$ • Use of bouldering pads: $p>0.05$
Limb (1995) [17]	Cross-sectional	Climbing facilities in England, Scotland, and Wales n=56 facilities (sex and ages of injured climbers not reported)	4	6	Indoor climbing (likely sport climbing and bouldering)	"Significant injuries": requiring the injured party to be transported to a local casualty department for emergency treatment	Risk factor examination: • Climbing styles had a relation to injury rates • Wall height had no relation to injury rates • Walls allowing soloing had no relation to injury rates Prevention measure examination: • Walls which instituted safety regulations had no relation to injury rates • Safety features had a relation to injury rates • Safety mats: $p>0.05$ for injury rate ($p<0.05$, $X^2=4.57$ upper limb injuries occurring on walls which provided fixed safety mats (11/14=78.57%)
Logan *et al.* (2004) [9]	Cross-sectional	Members of the Climber's Club of Great Britain n=545 (91% male, 9% female)	4	10	All types of "rock climbing"	Wrist or hand injury by type and severity	• Climbing intensity score (CIS): $p=0.01$

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Logan *et al.* (2004) *continued*		Ages 23-93 years					
Nelson *et al.* (2009) [18]	Cross-sectional	Rock climbers in the US n=40 282 (70% male, 30% female) Ages 2-74 years	4	9	All types of "rock climbing"	Injuries presenting to a hospital emergency department in the United States.	• Sex: Males more likely to sustain lacerations (OR=1.65; 95% CI; 1.03, 2.67) and fractures (OR=1.54; 95% CI; 1.10, 2.17) • Women more likely to sustain sprains/strains (OR=1.68; 95% CI; 1.13, 2.51)
Neuhof *et al.* (2011) [4]	Cross-sectional	Sport climbers n=1962 (81% male, 19% female) Ages13-60 years	4	12	Sport climbing	Acute injury only, sustained in sport climbing	• Sex: $p>0.05$ • Age: $p>0.05$ • BMI: $p>0.05$ • Difficulty level: $p<0.01$ • Climbing experience: $p<0.01$ • Climbing time per week during summer months: $p<0.01$ • Climbing time per week during winter months: $p<0.01$
Paige *et al.* (1998) [1]	Cross-sectional	Traditional and sport climbers n=398 (86% male, 14% female) Ages 11-63 years	4	7	Traditional and sport climbing	Injuries occurring outdoors during either traditional or sport rock climbing (Only sport climbing injuries were used for the purpose of this review)	Of 48 sport climbing injuries: • 38 (79%) were leading, • 8 (17%) were top roping, • 2 (4%) were belaying

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Pieber *et al.* (2012) [19]	Cross-sectional	Sport climbers and boulderers in Austria n=193 (69% male, 31% female) Mean age of females 29.4±5.6 years, mean age of males 31.2±8.6 years (range not reported)	4	12	Sport climbing and bouldering	Injuries and overuse syndromes, classified by anatomical location, cause, diagnosis if known. Minor abrasions were excluded.	• Sex (male): p=0.032 • Age group (~29.5 yrs. vs.~23 yrs.): p=0.021 (injury higher in older group) • Age group (~39.7 yrs. vs. ~29.5 yrs.): non-significant (p>0.05) • Climbing intensity score (CIS) groups: p=0.000 (injury higher in higher intensity groups)
Rohrbough *et al.* (2000) [5]	Cross-sectional	Elite competitive climbers in the U.S. n=42 (83% male, 17% female) Ages 13-40 years	4	12	Elite competitive climbing (likely sport climbing)	Upper extremity injuries only. Recorded by location of pain, type and difficulty of move that caused injury, duration and intensity of pain. Injuries sustained in a fall were not included.	• Age: significant for A2 pulley pain only (p=0.004) • Years of climbing experience: significant for history of medial epicondylitis only (p<0.0005) • Difficulty level climbing: non-significant (authors did not report a test statistic) • Years climbing at an elite level: non-significant • Gender: non-significant
Schlegel *et al.* (2002) [20]	Cross-sectional	Adolescent, nationally-ranked sport climbers n=29	4	13	Sport climbing (elite level)	Climbers were divided into two groups: one with current finger pain, one asymptomatic.	• Age: p>0.05 • Height: p>0.05 • Body weight: p>0.05 • Percentage of body fat: p>0.05 • Laxity score (0-9): p>0.05 • Start of regular climbing training (age): p>0.05

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Schlegel *et al.* (2002) *continued*		(sex distribution not reported) Ages 10-17 years					• Increase in climbing difficulties (highest grade and increase in grade per year): p>0.05 • Climbing training volume during the last season (hours/week): p>0.05 • General physical training volume during the last season (hours/week): p>0.05 • Climbing techniques such as position of the fingers while climbing on small grips: p>0.05 • One finger climbing: p>0.05 • Grip strength: p>0.05 • Use of initial warm-up: p>0.05
Schöffl *et al.* (2013) [21]	Cross-sectional	2012 World Cup Series competitors n=unknown (5 injury events, 40% male, 60% female) Ages not reported	4	7	Indoor competitive bouldering, sport climbing, and speed climbing	Injury events and medical incidences reported to the doctor in charge.	• Sex: incidence rate = 0.54/1000h in males, 0.97/1000h in females • Climbing type: incidence rate = 0.29/1000h for lead climbing, 1.47/1000h for bouldering, zero for speed climbing
Schöffl *et al.* (2013) [22]	Prospective cohort	Climbers at one indoor facility n=515, 337 visits (64% male, 36% female) Ages 8-80 years	2b	6	Indoor bouldering and sport climbing	Injuries requiring immediate medical attention, through either paramedic or doctor on site (ambulance was called)	• Sex: Acute injury rates were equal in males and females (0.2/1000 hrs.)

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Shahram *et al.* (2007) [12]	Cross-sectional	Male climbers from western provinces of Iran n=50 (100% male) Ages not reported	4	7	Sport climbing	Injury determined by clinical examination, (clinical signs: topical pain, weakness, tenderness, decreased range of motion, topical deformity, and physical tests)	• Maximum climbing grade: p=0.000 • Type of climbing: non-significant (authors did not report a test statistic)
Tomczak *et al.* (1989) [23]	Cross-sectional	Rock climbers in Peru, U.S., U.K., Canada, Australia n=460 (95% male, 5% female) Mean age 31 years (range not reported)	4	7	All types of "rock climbing"	Injuries were classified as either fall injuries or overuse injuries. Location of each injury was determined.	• Stretching prior to climbing: 'P' value of 0.9763
Wright *et al.* (2001) [8]	Cross-sectional	Climbers participating at indoor facilities n=295 (sex not reported) Ages <20-35+ years	4	11	Indoor climbing (likely sport climbing and bouldering)	Overuse injury sustained indoors, defined in an introductory paragraph and reiterated verbally.	• Sex: p=0.009 • Preferred activity • Bouldering vs. top roping: p=0.001 • Leading vs. top roping: p>0.05 • Bouldering/leading (together) vs. top roping: p<0.0005 • Lead grade: p<0.0005 • Bouldering: p<0.0005 • Age group: p=0.576 • Years experience: p=0.006 • Visits per annum: p=0.016

Injury Incidence

Reported proportions and rates of injury in rock climbing are not easily compared due to varied injury definitions, methodologies, reporting characteristics, and contexts of each study (Table 3). Backe *et al.* estimated the injury incidence rate to be 4.2 injuries/1000 participation hours in climbing.[13] The career incidence of injury ranges from 1.52 injuries/subject to 4.24 injuries/subject for a general population of rock climbers.[23,24]

Table 3. Reported injury incidence proportions or incidence rates for all reviewed studies

Study (year)	Injury incidence proportion (IP) or incidence rate (IR) (95% Confidence Interval)
Tomczak *et al.* (1989) [23]	Career incidence proportion (IP): 428 injuries (409, 447)/100 participants
Limb (1995) [17]	Injury incidence rate (IR): 53.87 injuries (40.58, 70.12)/1 million visits
Paige *et al.* (1998) [1]	Not examined.
Rohrbough *et al.* (2000) [5]	Career IP: 300 injuries (250, 357)/100 participants
Wright *et al.* (2001) [8]	Not examined.
Carmeli *et al.* (2002) [14]	Not examined.
Schlegel *et al.* (2002) [20]	Not examined.
Logan *et al.* (2004) [9]	Career IP: 152 injuries (133, 172)/100 participants
Gerdes *et al.* (2006) [15]	Career IP: 131 injuries (126, 136)/100 participants (Authors allowed 3 injury reports maximum)
Josephsen *et al.* (2007) [2]	IP of outdoor bouldering injuries: 103 injuries (71, 146)/100 participants/year IP of indoor bouldering injuries: 127 injuries (85, 184)/100 participants/year
Shahram *et al.* (2007) [12]	Not examined.
Backe *et al.* (2008) [13]	IR: 4.2 injuries (3.61, 4.77)/1000 climbing hours (14 traumatic and 194 overuse injuries in 49,986 climbing hours)
Jones *et al.* (2008) [3]	IP: 137 injuries (121, 154)/100 participants/year
Nelson *et al.* (2009) [18]	Not examined.
Neuhof *et al.* (2011) [4]	IR: 0.2 injuries (0.02, 0.72)/1000 climbing hours (acute injury only)
Hasler *et al.* (2012) [16]	Not examined.
Pieber *et al.* (2012) [19]	Career IP: 194 injuries (175, 214)/100 participants
Schöffl *et al.* (2013) [21]	IR: 0.74 injuries (0.24, 1.73)/1000 competition hours -acute injury only
Schöffl *et al.* (2013) [22]	IR: 0.02 injuries (0.01, 0.03)/1000 climbing hours (acute injury only)

Risk Factors

The 19 studies introduced 35 possible risk factors or injury prevention measures, though 19 of these were examined uniquely in single studies.

Intrinsic Risk Factors

Sex

Twelve studies examined sex as a potential risk factor for injury in sport climbing, bouldering, or both. Results were conflicting; six studies found no difference in injury risk between sexes,[2–5,16,22] while four found that males were at greater risk than females.[8,13,14,19] Schöffl *et al.* conversely found that the incidence rate of injury was 0.54 per 1000 competition hours for males, and 0.97 per 1000 competition hours for females.[21] Nelson *et al.* found that females were at higher risk of sprain and strain injuries, while males were at higher risk of lacerations and fractures.[18] Study quality scores were similar for all studies, however Backe *et al.*, scored highest at 15/32 for their cross-sectional study, and had the second largest sample size with 355 participants.[13] Neuhof *et al.*, who, conversely, found no difference between sexes, had the largest sample size at 1962, and scored 12/32.[4]

Age

Age was investigated as a possible risk factor in nine studies. Five reported that injury risk was not associated with age.[3,4,8,16,20] However, most of these studies covered a broad age range, with Downs and Black methodological quality scores between 11-13/32. Sample sizes ranged from 29-1962 participants. Carmeli *et al.* reported finding significantly more hand and finger injuries ($p<0.05$) and a higher incidence of tendonitis in the long flexor tendons of the second and third fingers for those 19–34 years versus those 9–18 years, though their study only included 19 participants.[14] However, Pieber *et al.*, whose sample size numbered 193, found that similarly, their two older age groups (29.5±1.7 years and 39.7±5.6 years) sustained significantly more injuries ($p=0.021$) than the younger climbers (23±2.4 years),[19] and Rohrbough *et al.* found that, of 42 climbers, those suffering from A2 pulley pain were significantly older (30.7±8.2 years versus 22.6±5.9 years, $p=0.004$).[5] Conversely, Backe *et al.*, who again scored highest on methodological quality at 15/32 and used a sample of 355 participants, found that the risk of re-injury increased for the adolescent age group, as opposed to older climbers ($p=0.003$ for 20–45 year-olds, and $p<0.001$ for +46-year-olds compared with <20-year-olds). However, their sample in this study was predominantly between 22 and 45 years.[13]

Years of Experience

Total years of climbing experience were examined as a risk factor in seven studies. Three found the number of years of climbing participation to have no significant impact on the risk of injury,[2,3,13] while four found this factor to be a significant predictor of injury.[4,5,8,16] Wright *et al.* found higher injury rates in climbers with over 10 years of experience ($p=0.006$), as did Hasler *et al.* ($p=0.006$), though both of these studies analyzed prevalence only.[8,16] Similarly, Neuhof *et al.* found higher injury rates for climbers with over five years of experience ($p<0.01$).[4] Finally, Rohrbough *et al.* found that history of medial epicondylitis increased with increasing experience ($p<0.0005$), though these authors found no impact by experience on any other injuries.[5]

Difficulty (Skill) Level

Eight studies investigated the highest difficulty level at which the subject could climb, a measure of skill level, as a risk factor for injury. Three studies found no significant impact on injury,[2,5,20] with study quality scores between 11-12/32 and sample sizes ranging from 29-152 participants. Five studies found a difference, though Gerdes *et al.* did not analyze this statistically.[3,4,8,12,15] Though the latter studies differed in their populations, all found that in general, participants that climbed at higher grades reported more injuries. Sample sizes varied between 201-1962 participants, though study quality scores, ranged from 7-12/32.

Body Mass Index (BMI)

BMI was examined in three studies. Josephsen *et al.* and Neuhof *et al.* reported no significant difference in injury risk associated with this factor.[2,4] However, Backe *et al.*, who scored higher on methodological quality than either of the other studies (15/32 versus 12/32 for both of the former studies), found that higher BMI was significantly associated with a higher risk of injury ($p<0.015$), and of re-injury ($p=0.121$).[13]

Body Weight

Only two studies examined weight as a risk factor, and neither found any significant association with injury.[2,20] However, because these studies examined different populations (Schlegel *et al.*'s study included only young, elite rock climbers, and Josephsen *et al.*'s, active boulderers), it is difficult to hypothesize the effect of body weight on injury.

Grip Strength

Grip strength in relation to injury risk has only been examined in two climbing-specific studies to date; Schlegel *et al.* (Downs and Black score: 13/32) measured grip strength at 90˚ of elbow flexion in 29 climbers, and found that it did not significantly affect the risk of injury ($p>0.05$),[20] though Carmeli *et al*. (Downs and Black score: 11/32), who measured at 90˚ of shoulder flexion with a straight elbow in 19 climbers, found a "mild to moderate correlation" ($p<0.05$).[14]

Extrinsic Risk Factors

Lead Climbing and Top roping

Lead (sport) climbing was investigated in five studies.[1,4,8,12,15] Most of these articles compared it to top roping, though two also compared it to bouldering, and a third included bouldering, traditional climbing, and free soloing (free soloing is a type of climbing where no ropes, harnesses or any other protective gear are used, and therefore falls would likely be fatal). Four of these studies suggested that lead climbing was a risk factor for injury.[1,4,8,15] Though they did not conduct a statistical comparison, Schöffl *et al.*, who did not conduct a statistical comparison, noted the injury incidence rate for lead climbing to be 0.29 injuries per 1000 hours, versus 1.47 per 1000 hours for bouldering (and 0 for speed climbing, a third competitive discipline). Methodological scores ranged from 7-12/32 for these studies, though sample sizes were large, Gerdes *et al.*, for example, with 1887,[15] and Neuhof *et al.* with 1962 participants.[4] Shahram *et al.* were the only authors who found that lead climbing was not associated with injury, though this conclusion was based on prevalence proportions, as incidence and risk were not captured in their study.[12] Methodological quality was also low for this study (7/32), and the sample size comprised 50 climbers.

Climbing Volume

The amount of time spent climbing (per week or per year) was examined in three studies.[4,13,20] Backe *et al.*, who scored highest on methodological quality at 15/32, found that the total climbing time each year did not have a significant effect on injury for their 355 participants, though the authors did control for exposure hours in their injury incidence rate (IR).[13] Schlegel *et al.*, whose study scored 13/32, found the same results when examining injury and hours per week spent climbing, though they included only 29 participants.[20] Conversely, the study by Neuhof *et al.* found that climbing volume per week did significantly increase the risk of injury for their 1962 participants during both summer ($p<0.01$) and winter months ($p<0.01$), though they did not indicate whether indoor climbing, outdoor climbing, or both were examined (Downs and Black score: 12/32).[4] Similarly, Jones *et al.* investigated the frequency of climbing (times per year) for each subject, and also found that as the frequency per year of outdoor (lead) sport climbing, indoor (lead) sport climbing, and bouldering increased, so did the incidence of overuse injury.[3]

Climbing Intensity Score (CIS)

A climbing intensity score (CIS) was used in two studies to examine degree of exposure to "climbing stress" as a risk factor.[9,19] CIS scores, introduced by Logan *et al.,* and used again by Pieber *et al.,* indicate both climbing intensity and volume by multiplying the average grade of climbing by the mean number of climbing days per year.[9,19] Both studies found participants who scored higher in climbing intensity to be at a higher injury risk. Logan *et al.* (Downs and Black score: 10/32) compared an injury group to a non-injury group and found the mean CIS scores in the injury group to be significantly higher ($p=0.01$).[9] Pieber *et al.* (Downs and Black score: 12/32) split CIS into tertiles (CIS 1: 398±232 points; CIS 2: 1526±461 points; CIS 3: 5088±2701 points) with 56 subjects per group, and found groups two and three to be significantly different from group one, which scored lower on the CIS ($p<0.001$).[19]

Indoor Versus Outdoor Climbing

Two studies investigated outdoor climbing compared to indoor climbing as a predictor for injury. Josephsen *et al.* (Downs and Black score: 12/32), who examined bouldering specifically in 152 participants, suggest a significantly higher risk of finger injuries outdoors, but a higher risk of fall-related injury indoors.[2] Gerdes *et al.* (Downs and Black score: 9/32), who examined sport climbing, traditional climbing, bouldering, and free soloing, observed an approximately even distribution of injuries indoors and outdoors in their 1887 participants.[15] However, traditional climbing is rarely performed indoors and free soloing is performed exclusively outdoors, thus introducing a potential bias. It is likely that outdoor injuries would be overrepresented for the purposes of this systematic review, since the focus here is on sport climbing and bouldering.

Influence of Drugs/Alcohol

Only two articles studied the influence of drugs or alcohol on climbing injury, and these yielded different results. Gerdes *et al.* (Downs and Black score: 9/32) found that substance use significantly increased the potential for injury in their 1887 participants, while Hasler *et al.* (Downs and Black score: 13/32) found no significant increase in risk in their 113 subjects.[15,16]

Other Risk Factors

A number of different risk factors were examined uniquely in single studies (Table 2): wall height,[17] average boulder height,[2] maximum boulder height,[2] previous history of injury,[2] on-sighting (climbing a route for the first time),[16] self-reported readiness for risk,[16] lean body mass,[20] increase in climbing difficulty per year,[20] start age (of climbing),[20] performing regular one-finger climbing,[20] capsular thickening of finger joints,[20] radio-ulnar instability of finger joints,[20] Beighton score,[20] number of years climbing at the elite level,[5] handedness,[12] and climbing in a familiar versus new location.[15]

Prevention Measures

The self-reported use of a warm-up and different lengths of warm-up were investigated in three studies, and no significant difference in injury was found between groups.[2,17,23] Stretching prior to climbing was reported to be significantly associated with overuse injury by Tomczak *et al.* (Downs and Black score: 7/32) However, their claim that their "'P' value of 0.9763 [meant] that 97% of all people who reported stretching prior to climbing reported an overuse injury of some type" is incorrect.[23] It is possible that a value of 0.9763 is instead a correlation coefficient, in which case this would suggest a strong association between stretching and overuse injuries. Conversely, Josephsen *et al.*, who scored higher on methodological quality (12/32), found no significant difference in injury risk between those climbers who stretched versus those who did not. These authors also examined regular participation in yoga as a preventative measure and found the same results.[2] Imposing strict regulations regarding equipment use and instructor presence were not found to significantly decrease the risk of injury in sport climbing or bouldering, nor were the presence or number of safety mats used, nor the number of spotters.[2,17] Josephsen *et al.* also investigated the taping of fingers and wrists, taking glucosamine and other supplements, heating hands prior to climbing, taking time off to prevent injuries, the use of corticosteroid injections, and weight training as potential preventive measures. Of these strategies, only taping wrists and weight training were found to be significantly associated with a decreased rate of injury.[2]

DISCUSSION

In previous studies, older age, a higher number of years of climbing experience, higher climbing skill level, higher climbing intensity score (CIS), and lead climbing are risk factors. However, the reviewed studies differ in injury definitions, study populations, and methodological quality, resulting in variability in injury rates and making conclusions regarding risk factors difficult. Nevertheless, modifiable potential risk factors may be relevant for future interventions.

Many studies examining sport injury in general have identified age, sex, and BMI as significant risk factors for injury in youth, but there are conflicting results in the literature as to whether these specific factors affect injury risk in rock climbers in this, or any other age group.[2,3,13,25–27] Results regarding sex as a risk factor for injury in climbing are conflicting. The majority of the studies examined samples that were predominantly male, and Wright *et al.,* who found a significantly higher risk of injury in males, failed to report sex distribution.[8] The studies that reported no difference between sexes included samples ranging from 59.9%-83.3% male.[2–5,16] It is therefore difficult to know the validity of these conclusions, as overall methodological quality was low.

Results suggest that older age may be a risk factor for injury in sport climbing and bouldering, though conclusions are difficult to draw, as reviewed studies used convenience samples with heterogeneous age groups. Authors have also suggested that there are differences in the types of injury sustained by younger and older climbers, such as epiphyseal fractures of the fingers from repeated stress on the bone in children and adolescents.[28] Based on this research, the International Climbing and Mountaineering Federation (UIAA) has set the minimum age for international bouldering competition participation to 16 years old. This guideline was established to minimize the risk of epiphyseal fractures, as bouldering training often involves dynamic movements that should be avoided in children whose bones have not yet matured sufficiently.[28] It would follow that if the types of injury differ between adults and children, the risk of injury may differ as well. Similar conclusions have been made previously with regards to resistance training in young children and adolescents, though past claims that such training is unsafe and poses a risk of injury are now being refuted. Current research indicates that age-appropriate resistance training can be safe.[29] Future studies are needed to explore this possibility in young climbers. An additional consideration when examining age as a risk factor is that multicollinearity may exist with factors such as years of experience and difficulty level. Analyses involving these individual factors must therefore be adjusted for age.

The literature suggests that increasing years of climbing experience may increase the risk of injury. More research is needed to confirm these findings and to explore whether this factor is associated with other variables (e.g., age, height, weight, skill level). The same is true for the highest difficulty or skill level at which individuals climb. A multitude of different rating scales were used to grade the technical difficulty of climbs, as different countries and different disciplines often use different scales. However, the UIAA Medical Commission recently established a metric rating system into which all countries' scales can be converted, standardizing reporting for research purposes in particular.[30,31] With this scale, reporting will become more standardized, and it will become easier to compare studies and make conclusions about skill level as a risk factor.[31]

Though there is a paucity of valid research about BMI as a risk factor for injury in climbing, the results reported by Backe *et al.* that higher BMI was significantly associated with a higher risk of injury and re-injury appear to be valid, as this study was of higher methodological quality. As well, their study sample approached a normal population distribution for BMI, making their results more generalizable.[13] Previous research involving other sports has also indicated that BMI is a potentially modifiable risk factor.[26] As such, it may gain attention for injury prevention strategies in climbing. Similarly, body weight merits further investigation, though care must be taken when analyzing BMI and body weight together, considering multicollinearity between these two measures.

When compared to top roping (and in two cases bouldering), the examination of lead climbing suggests that it is a potential risk factor for injury. As a modifiable risk factor, limiting the amount of "leading" that a climber does may reduce injury.

Results are conflicting with regards to climbing volume as a predictor for injury in climbing. Backe *et al.* and Schlegel *et al.* did not find that higher climbing volumes increased the risk of injury.[13,20] Two studies, however, combined climbing volume with climbing grade to calculate CIS, both showing a significant correlation between higher CIS and injury. Neither study sample however, was representative of their population, and neither adequately adjusted for confounding.[9,19] While more research examining climbing volume and intensity is required, CIS may be a measure to use in future studies. Both climbing volume and CIS are potentially modifiable risk factors and knowing the healthy limit may aid in injury prevention.

Research involving general youth populations has shown that behaviours like alcohol consumption and smoking tobacco are risk factors for sport injury.[32] Although findings by Gerdes *et al.* and Hasler *et al.* are conflicting, it follows that these behaviours would increase the risk of injury in youth climbers.[15,16] These behaviours are modifiable and therefore merit further investigation.

Finally, muscular strength has been suggested as a possible factor influencing musculoskeletal injury.[33] Results from the two studies examining this factor are difficult to ascertain conclusions from, but as low grip strength may be another modifiable risk factor, research is warranted in this area.

Few studies have investigated prevention strategies for climbing. Stretching is often used for injury prevention, though Josephsen *et al.*[2] found no association, and Tomczak *et al.*[23] suggested a positive relationship between climbing injury and the use of stretching. However, a high proportion of the subjects in Tomczak *et al.*'s study reported stretching prior to climbing (73%), and the association found by the authors does not necessarily imply causation. This is likely a spurious correlation.[23] Though there is presently no evidence that warming up affects injury risk in climbing and the use of stretching remains inconclusive, this may yet be an avenue for future research as these are both easily modifiable factors that many climbers perform nonetheless.

Limitations

Several factors limit our ability to draw valid conclusions based on the data available for this systematic review, including the multidisciplinary nature of climbing, the multitude of injury definitions, injury rate reporting, and methodologies, and the heterogeneous nature of the study populations. The majority of studies were retrospective surveys and were therefore subject to the biases associated with cross-sectional studies. Recall bias and an overestimation of the most traumatic injuries may have resulted, as well as uncertainty of temporal relationships and causation. Selection bias is also a limitation of convenience samples, as injured climbers may not be included in the sample if they were not present during recruitment. Finally, publication bias may have influenced the results.

CONCLUSIONS & PERSPECTIVES

Intrinsic and extrinsic risk factors for injury specific to sport climbing and bouldering have not previously been the subject of reviews. Twelve electronic databases and several other sources were searched systematically to examine risk factors and prevention strategies for injury in these disciplines, and to assess the methodological quality of existing studies. The injury incidence proportions and rates are inconsistent throughout the literature, emphasizing the need for standardized injury reporting in climbing research. Overall methodological quality of reviewed studies was low according to the Downs and Black Quality Index. However, several potential risk factors for injury in sport climbing and bouldering were highlighted, including age, increasing years of climbing experience, higher skill (difficulty) level, a high CIS, and lead climbing. Several potential risk factors are worth further investigation, namely those that are modifiable, such as BMI, taping, weight training, and the use of stretching. Results regarding injury prevention measures remain inconclusive. Future avenues for research in climbing should include previous injury, as it has been shown to be a significant predictor for subsequent injury in other sports,[6] as well as examining the use of correct climbing technique, and the growing issue of "climber's back." [34] As climbing continues to gain popularity, understanding the healthcare burden presented by this sport is essential. Developing injury prevention measures will reduce the strain on healthcare resources, and disseminating knowledge about the main types, mechanisms, and risk factors for injury will be important to reduce these injuries through awareness, for both climbers and healthcare providers. It will be important for future research to involve youth, such that young climbers, their parents, and coaches will be able to learn safe development and training for climbing.

Acknowledgments: The Sport Injury Prevention Research Centre is one of 9 International Research Centres for Prevention of Injury and Protection of Athlete Health supported by the International Olympic Committee. We acknowledge and thank the participants in this study, their parents, and the climbing facilities that helped facilitate this research.

Competing Interests: None.

Funding: We acknowledge the funding provided by Alberta Innovates Health Solutions and the Alberta Children's Hospital Research Institute for Child & Maternal Health through the Talisman Energy Research Fund in Healthy Living and Optimizing Health Outcomes. Dr. Emery is supported by a Population Health Investigator Award from Alberta Innovates Health Solutions and a Professorship in Pediatric Rehabilitation in the Faculty of Medicine, University of Calgary (Alberta Children's Hospital Foundation).

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5 Multiple choice questions:

Which is not a piece of injury prevention equipment used regularly while sport climbing or bouldering?

a) Ropes
b) Crash mats
c) Quickdraws
d) Helmets
e) Gloves

Which of the following is a modifiable potential risk factor for climbing injury?

a) Sex
b) Height
c) Body Mass Index (BMI)
d) Age

Which of the following has NOT been shown to be a potential risk factor for injury in the studies reviewed here?

a) Lead climbing
b) Top-roping
c) High climbing volume
d) High skill level
e) High Climbing Intensity Score

Which study design gives the least reliable evidence in a systematic review?

a) Case-control
b) Case-study
c) Randomized controlled trial
d) Cross-sectional
e) Quasi-experimental design

Which of the following is *not* true of the Climbing Intensity Score (CIS)?

a) CIS incorporates climbing volume (number of climbing days/year)

b) CIS incorporates climbing speed (metres/second)

c) CIS incorporates climbing intensity (average grade of climbing)

d) Higher CIS has been shown to be predictive of higher injury risk in two studies.

Multiple choice answer key:

Which is not a piece of injury prevention equipment used regularly while sport climbing or bouldering?

f) Ropes

g) Crash mats

h) Quickdraws

i) Helmets

j) Gloves – gloves are not worn by climbers while sport climbing and bouldering, though some people choose to wear gloves if they are belaying.

Which of the following is a modifiable potential risk factor for climbing injury?

e) Sex

f) Height

g) Body Mass Index (BMI) – BMI is potentially modifiable, in that the weight of a person is variable and changeable, whereas the sex, age, and height are non-modifiable.

h) Age

Which of the following has NOT been shown to be a potential risk factor for injury in the studies reviewed here?

f) Lead climbing

g) Top-roping – top-roping has not been shown to be a risk factor for injury. It has sometimes been compared to lead-climbing, which *has* been shown in some studies to increase injury risk.

h) High climbing volume

i) High skill level

j) High Climbing Intensity Score

Which study design gives the least reliable evidence in a systematic review?

f) Case-control

g) Case-study – a case study is based on the description of a single case and therefore represents a weak level of evidence.

h) Randomized controlled trial

i) Cross-sectional

j) Quasi-experimental design

Which of the following is *not* true of the Climbing Intensity Score (CIS)?

e) CIS incorporates climbing volume (number of climbing days/year)

f) CIS incorporates climbing speed (metres/second) – The CIS does not incorporate speed. It represents both climbing intensity and volume by multiplying the average grade of climbing by the mean number of climbing days per year.

g) CIS incorporates climbing intensity (average grade of climbing)

h) Higher CIS has been shown to be predictive of higher injury risk in two studies.