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*The Journal of Sports Medicine and Physical Fitness 2018 Jun 07*

DOI: 10.23736/S0022-4707.18.08579-1

Article type: Review Article

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Article first published online: Jun 07, 2018

Manuscript accepted: May 22, 2018

Manuscript revised: April 18, 2018

Manuscript received: January 17, 2018

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## **A systematic review on posterior circumflex humeral artery pathology: sports and professions at risk and associated risk factors**

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### **ABSTRACT**

**INTRODUCTION:** Posterior circumflex humeral artery (PCHA) aneurysm formation and thrombosis as overuse injury in the dominant shoulder can result in ischemia of the forearm, hand and digits due to arterial embolisms. Increased awareness among physicians is necessary as PCHA pathology (PCHAP) might be underdiagnosed. Knowledge of sports and professions at risk and risk-factors for obtaining PCHAP is essential for the development of future preventive measures. This study aims to identify sports and professions at risk as well as risk factors for PCHAP.

**EVIDENCE ACQUISITION:** The databases of MEDLINE, EMBASE, BIOSIS, CINAHL and SPORTDiscus were systematically searched.

**EVIDENCE SYNTHESIS:** Twenty-seven papers fulfilled the inclusion criteria and described 67 patients with PCHAP involved in seven sports and three professions. The sports (number of cases) were volleyball (41), baseball (13), swimming (1), tennis (3), American football (2), canoeing (1) and yoga (1) (2 unknown). The professions included a baseball coach, a circus trapeze artist and a mechanic. Apart from expert opinions, no studies have identified risk

factors for PCHAP. An anatomic variation of the PCHA origin is suggested to be protective for PCHAP.

**CONCLUSIONS:** PCHAP is reported in seven overhead sports and three professions. No risk factors for PCHAP were identified. An anatomic variant of the PCHA origin was found to be a potential protective factor for PCHAP. Physicians should be cautious for distal embolization as a result of PCHAP in athletes and workers, both adult and adolescent, involved in repetitive powerful overhead movements.

**Key words:** vascular system injuries / digital ischemia / athletes / shoulder injuries / overhead sports / embolism and thrombosis

## INTRODUCTION

The posterior circumflex humeral artery (PCHA) is an arterial branch originating from the distal third of the axillary artery.<sup>1, 2</sup> After its origin the artery runs through the quadrilateral space (QS), which is bounded by the subscapularis, teres minor and teres major muscles, the medial cortex of the surgical neck of the humerus, and the long head of the triceps muscle.<sup>3-6</sup> The PCHA winds around the surgical neck of the humerus, where it takes care of a major part of the blood supply of the glenohumeral joint and deltoid, teres major, minor muscles and the long head of the triceps muscle.<sup>1, 5, 6</sup>

Vascular abnormalities of the PCHA have mainly been described in overhead athletes (e.g. baseball and volleyball players).<sup>2, 6-11</sup> Traumatic stretching and compression of the PCHA during repetitive powerful overhead motion may result in aneurysm formation, occlusion and thrombosis of the PCHA.<sup>8, 11-14</sup> Athletes with PCHAP are at risk for digital ischemia induced by embolization of the distal arterial circulation. Compression of a thrombus located in the PCHA by the humeral head squeezes small embolisms retrograde into the axillary artery leading to occlusion of the arterial circulation in the arm, hand and fingers.<sup>2, 3, 5, 8, 11</sup>

Symptoms of digital ischemia, which are closely related to PCHA pathology (PCHAP), are frequently reported by elite indoor- and beach-volleyball players, 35% and 38% respectively.<sup>15, 16</sup> The prevalence of PCHA related symptoms in other sports is unknown, however it is presumed that PCHAP is often underdiagnosed<sup>6, 14, 17-20</sup>, since it is relatively unknown and symptoms are regularly attributed to (sub)acute musculoskeletal injuries.<sup>3, 5, 11, 21</sup>

PCHAP may be career-threatening as it hinders performance in healthy and young athletes often in the prime of their career.<sup>3, 5, 11, 18, 20-22</sup> Awareness for sports- and professions-at risk as well as risk factors for PCHAP is essential, as quick treatment and accurate diagnosis are eminent to prevent ischemic complications.<sup>6, 14, 17-20</sup> Therefore, the aim of this systematic review of the literature is to identify sports- and professions- at risk as well as risk factors for PCHAP.

## EVIDENCE ACQUISITION

### Search strategy

A comprehensive literature search regarding PCHAP in overhead athletes or professions was conducted from inception until June 20<sup>th</sup>, 2017 in MEDLINE (including in-process & other non-indexed citations) and EMBASE and until July 1<sup>st</sup>, 2015 in BIOSIS, CINAHL and

SPORTDiscus. The search strategy was created in line with the PRISMA statement<sup>23</sup> with the assistance of an experienced library database specialist. Key components used in the search were; 1) Athletes, 2) Specific anatomy of the PCHA, 3) Arterial disorders (e.g. thrombosis, aneurysm, ischemia, embolism)', 4) Broad anatomy of the shoulder region. Animal studies were excluded with the search. A validation set of 24 articles was created and used for optimization of the search strategy. This resulted in the following search; component 2 OR (component 1 AND 3 AND 4). The complete search is enclosed in Appendix 1

In addition, the WHO-ICTRP (International Clinical Trials Registry Platform) search portal was used to identify potentially relevant trials. A scoping search in Cochrane CENTRAL was performed to determine whether the Cochrane Library should be systematically searched.

### **Study selection**

All studies were imported in Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia) after duplicate records were removed using Endnote (Clarivate Analytics, Philadelphia, PA, USA). First, each study was screened by 2 authors based on title and abstract using the following inclusion criteria;

Study population consisted of patients with all of the following four criteria:

- 1) Patient with the following arterial injury; thrombosis, aneurysm, ischemia, embolism, thromboembolism, occlusion, stenosis or blood supply disorder(s)
- 2) Arterial injury which was unrelated to acute injury or trauma
- 3) The injury was located in the shoulder, quadrilateral space, axilla, forearm, hand or digits
- 4) Association between the arterial injury and sports, work or other activities was described

Study designs containing original data were included. Language of published articles was restricted to English, French, German or Dutch. No restrictions regarding year of publication or sample size were used.

Consensus on eligibility had to be reached by the two screening authors. After screening on title and abstract, full text of the included articles was searched. Authors of unavailable full text articles were contacted. If full text remained unavailable articles were either retrieved via the journal or excluded from the study. Each full text was again screened by two authors using the aforementioned inclusion criteria with the following additions regarding study population;

- 1) The arterial injury was described as PCHAP (aneurysm, occlusion or thrombosis)
- 2) PCHAP was diagnosed by a physician.

Subsequent to the full-text selection, the reference lists of the included articles were screened manually for relevant articles. Additionally, all included articles were entered in Google Scholar to check for relevant citations after publication.

### **Data extraction**

Data was extracted and verified by two authors using a predefined data-extraction form in Microsoft Excel. Data extracted from the included studies included date of publication, study design, study population, data collection method, demographic data of patients, type and level of sports or profession, symptoms, physical examination, diagnostic information, co-morbidity, diagnosis, and associated risk factors. If two studies used data of the same patients only the study with the most recent publication date was used.

### **Quality assessment**

If cohort- or randomized studies were identified a quality assessment would be performed. For case reports or case series no quality assessment was done.

### **Data Analysis**

Data analysis focused on the study characteristics (study design, language and country of origin), study population, type of PCHAP, clinical information (symptoms, physical examination and diagnostic tests), type of sports and professions, and mentioned risk factors. The mean size of the study population, male-female ratio, average age of the patients was described. Descriptive statistics were used to illustrate percentage of occurred symptoms, most frequently used diagnostic tests and type of sports and professions. The variants of PCHAP in the affected limbs of athletes and workers were arranged into the categories aneurysm, thrombosis and occlusion. Risk factors mentioned in included articles were described.

## **EVIDENCE SYNTHESIS**

### **Study selection**

The literature search identified 9866 results, leading to the inclusion of 26 articles containing original data of patients with PCHAP described in association with sports or professions (see figure 1). One additional article was included after checking the references of the included studies, resulting in a total of 27 studies. Reasons for exclusion based on full text were as follows; sixty-two articles did not meet our full-text inclusion criteria, seven articles were not available in full-text version and four articles had overlapping data with other included articles.<sup>7, 24-26</sup> The patient data in the study of McIntosh et al.<sup>7</sup> was excluded because it described the same patients as Brown et al.<sup>3</sup>, however risk factors mentioned in the article

were included in our review. The WHO ICTRP search portal did not reveal any relevant trails and CENTRAL did not yield relevant hits after a scoping search. Extracted data is presented in table 1 and table 2. 2, 3, 5-11, 14, 17, 18, 20, 22, 27-40

### **Study characteristics**

The study designs of the 27 included studies consisted of 17 case reports, 5 case series, 2 case studies combined with a review of literature, a letter with cases, a cross-sectional study focused on ultrasound and a case combined with a cross-sectional study on prevalence of symptoms. The studies were conducted in the USA (14), the Netherlands (6), Switzerland (2), France (1), Greece (1), Belgium (1), Canada (1) and Japan (1). Total patients with PCHAP differed from 1 to 17 between the studies. The studies were all published between 1990 and 2017, with 13 of the 27 studies published in the last 10 years.

### **Study population**

The 27 articles reported 67 patients with PCHAP. Fifty-six were male (84%), 7 were female (10%), and in 4 cases sex was not reported. Two males showed bilateral PCHAP. The age of the patients varied between 15 and 64 years with an average of 27.1 years. In 12 cases age was not reported. Forty-nine percent of the patients in whom age was reported were 25 years old or younger.

### **Sports and professions**

The included articles described 64 athletes and 3 workers. The athletes participated in 7 different sports; volleyball, baseball, swimming, tennis, American football, canoeing and yoga. In two athletes practiced sport was not reported. Cases of PCHAP among female athletes consisted of 6 volleyball players and a swimmer.

The majority of PCHAP cases were described in volleyball players (41 cases; 61%), active at different levels: 32 professional, two collegiate, two amateur and three well-trained. In 2 cases level was not described. The second largest group was formed by baseball players (13 cases, 19%); all professional.

The remaining cases involved three tennis players (1 professional, 1 amateur and 1 athlete competing in the national finals of the US tennis association), one high-school swimmer, two American football players (one division 1-collegiate quarterback and one high school quarterback), one amateur canoer, and a patient who practiced no other sports than yoga.

The 3 cases of work-related PCHAP reported in the included articles consisted of a baseball coach, a circus trapeze artist and a mechanic. In the latter two cases PCHAP was described bilateral.

## **Clinical findings**

In 48 PCHAP cases symptoms were described in the article. Despite the localization of the PCHA in the shoulder, most symptoms were located in the hand or forearm of the dominant arm. Most reported symptoms included coolness of the hand or digits (58% of the cases), pain of the forearm, hand or digits (40%), loss of power, accuracy or endurance of the arm (31%) or cold intolerance (14%). Color changes of the hand or digits (paleness and/or cyanosis) and neurologic symptoms (numbness, paresthesia and/or dysesthesia) were both reported in 24 cases (50%). An overview of clinical findings can be found in table 3.

Reported abnormalities in arterial pulsation involved absent arterial pulsation of the ulnar artery (7 cases) or absence of both radial and ulnar artery (7 cases). In 15 cases normal arterial pulsation of the radial and ulnar artery were reported. In 19 cases evaluation of arterial pulsations was not mentioned. Signs of distal artery occlusion were present in 8 patients (necrosis of the fingers in 4 cases and splinter hemorrhage in 4 cases). Capillary refill test was performed in 4 cases and delayed in 3 of these 4 cases. Allen's test was positive in 5 of the 6 cases in which the test was performed.

## **Imaging**

In all 67 cases imaging was used to confirm the PCHA injury. Digital subtraction angiography (DSA) was performed in 47 cases, ultrasound in 31 cases, CT-angiography in 4 cases and MR-angiography in one case. Final diagnosis of PCHAP was based on DSA in 46 cases (68.7%), on ultrasound in 18 cases (26.9%), on CT-angiography, MR-angiography and combined CT-angiography with DSA each in one case. In 13 cases both DSA and ultrasound were performed. In all these cases both modalities were able to detect a PCHA abnormality. Embolization of the distal circulation was identified in 42 of the 50 cases (84%) in which imaging of the distal circulation was described. In 6 cases distal embolisms were not reported. 2 studies described the presence of increased collaterals implying the presence of past embolisms. In 17 cases the distal arterial circulation was not imaged.

## **PCHA Pathology**

Several types of PCHAP were reported: aneurysm, occlusion and thrombosis. Aneurysm was most frequently reported (38 cases), occlusion/thrombosis was described in 24 cases, 2 dissections and 3 dilatations were described. PCHAP was reported in the dominant shoulder in 53 of the 67 cases and in both shoulders in two of these cases. In the remaining cases, the affected arm was not described.

## **Risk factors**

None of the included articles presented risk factors based on statistical computations. Five studies presented information on risk factors based on expert opinions. Two studies hypothesized an association between an anatomical variation of the PCHA with the presence of PCHAP. The first study reported two athletes with an anatomic variation in which the posterior and anterior circumflex humeral artery arose as a common trunk from the axillary artery.<sup>38</sup> The other study considered an association between PCHAP and anatomic variation as all 13 cases of PCHA aneurysms occurred in patients with a PCHA originating directly from the axillary artery, despite various anatomical variations in the study population. The authors suggested that an anatomical variant of the PCHA might be protective for obtaining PCHAP.<sup>2</sup>

One of the included articles stated that PCHAP was possibly associated with time of exposure to overhead movements.<sup>7</sup> This hypothesis was based on the fewer cases reported in amateur volleyball players compared to professional volleyball players. A sex based risk-factor was theorized because PCHAP occurred mainly in men, showing a male-female ratio of 7:1 in both vascular and neural quadrilateral space syndrome.<sup>3</sup>

Finally the importance of identifying risk factors for the prevention of PCHAP was underlined in an article that divided potential risk factors into personal (e.g. anatomic variation of the PCHA origin), sports-related (e.g. training per week, position in the field and number of spikes in a training session) and work-related risk factors (e.g. the performance of repetitive overhead activities during daily working activities). However, the study did not provide numbers to validate this categorization.<sup>8</sup>

## DISCUSSION

Twenty-seven articles were identified which described 67 patients with PCHAP. Sixty-two patients were athletes, and 3 cases were work-related. In two athletes practiced sport was not reported. The large majority of the athletes were involved in overhead sports such as volleyball and baseball. Work-related PCHAP was reported in 3 professions: a baseball coach, a trapeze artist and a mechanic. One study identified a potential protective factor for PCHAP, namely an anatomic variant of the PCHA origin. Five studies provided expert opinions on risk factors for obtaining PCHAP without statistical basis. Mentioned risk factors included sex and duration of exposure to repetitive overhead motion.

### Sports and professions

The occurrence of PCHAP in athletes has been documented before, however magnitude of the problem has never been established through a systematic approach.<sup>3, 33</sup> PCHAP cases in

athletes identified in this review are almost exclusively reported in athletes participating in sports involving repetitive powerful overhead movements of the shoulder. This underlines the suggested relation between these types of movements and PCHAP.

In addition, two of the three patients with work-related cases of PCHAP reported to be exposed to repetitive overhead movements: the professional baseball coach had daily pitching responsibilities and the circus trapeze artist was exposed to repetitive overhead movements with extreme shoulder angles. In the third case, the mechanic who presented with bilateral PCHAP, the extent of overhead motions during daily work was not reported.<sup>11</sup>

Vascular injuries in the shoulder similar to PCHAP (such as thoracic outlet syndrome and axillary artery aneurysms) are associated with repetitive overhead movements as well. Similar to PCHAP, these injuries are attributed to cumulative damage to the vascular structures due to repetitive vascular compression and traction in overhead athletes.<sup>19, 41</sup> Reviews focusing on these injuries have described cases in athletes participating in water polo, rowing, wrestling, synchronized swimming, diving and weightlifting.<sup>19, 21, 41-50</sup> Despite the absence of cases reported in literature, it is likely that PCHAP might be prevalent in these sports and other possibly risk full overhead sports (e.g. basketball, gymnastics, badminton and javelin throwing) or professions (e.g. painters, plasterers, meat cutters and window cleaners) as well. The absence of literature on PCHAP in these sports and professions might be due to the fact that the PCHA is not prone to injury because of specific differences in biomechanics of overhead movements and the exposure to repetitive overhead motion.

Future epidemiologic studies (e.g. cross-sectional studies using ultrasound or angiography for diagnosing of PCHAP in sports involving overhead movements, similar to the study of van de Pol et al.<sup>2</sup>) are essential to determine the specific sports- and profession-related risk for obtaining PCHAP.

### **Risk factors**

Risk factors mentioned in the included articles are anatomic variation of the PCHA origin, male sex and exposure time to overhead movements.

Todd et al. described a common trunk of the posterior- and anterior-circumflex humeral artery in two athletes.<sup>38</sup> Among the other PCHAP cases in this review, no anatomical variation of the PCHA was described. Using ultrasound as a diagnostic device among 280 elite volleyball players, Van de Pol et al. identified PCHAP solely in athletes with a PCHA originated directly from the axillary artery, while in 19% of the athletes a different origin of the PCHA was identified. Due to the absence of identified cases of PCHAP among the

athletes with an anatomical variation of the PCHA, an anatomic variant of the origin of the PCHA was suggested to be protective for obtaining PCHAP.<sup>2</sup> Future studies focusing on detailed description of the PCHA anatomy in cases with and without PCHAP have to confirm this hypothesis.

Male sex has been mentioned as an expert opinion based risk factor for obtaining PCHAP.<sup>3</sup> This review identified 56 cases of PCHAP in male athletes and 7 cases in female athletes. In 4 cases sex was not described. In contrast, van de Pol et al. found an incidence of PCHAP of 5.7% in professional female volleyball players and 4.5% in professional male volleyball players using ultrasound.<sup>2</sup> In addition, no sex-related differences between elite volleyball players with or without ultrasound confirmed PCHAP were reported.<sup>16</sup> The same research group described that more female beach volleyball players reported complaints of digital ischemia than male players: OR 5.8 (90% CI 1.5-22.2).<sup>15</sup> This latter study however assessed self-reported complaints of digital ischemia (possibly related to PCHAP) and not diagnosed PCHAP.

Among comparable arterial injury of the upper extremity, such as thoracic outlet syndrome, women seem to be equally or more effected than male.<sup>41, 50, 51</sup> Reeser et al. described sex distribution to be approximately equal in overhead athletes as well.<sup>19</sup> Based on the current information, it is unclear if sex is a risk factor for PCHAP. As sex distribution in our review is based on mainly case reports, it may not be a valid representation of patients with PCHAP.

The last mentioned risk factor in the identified studies was amount of exposure to repetitive overhead movements. McIntosh et al. indicated that more practice hours per day might be a possible sports-related risk factor.<sup>7</sup> The cumulative effect of training may result in more frequent overhead movements with increased power (due to muscle hypertrophy) resulting in a higher risk of damage to the PCHA in combination with less time for tissue recovery. Durham et al. suggested that stretch and tension on the PCHA is increased in well trained athletes due to humeral head hypertrophy.<sup>11</sup> Several other studies hypothesize compression of the PCHA may be more severe by narrowing of the quadrilateral space by muscle hypertrophy, which may be related to amount of training hours.<sup>30, 33, 34</sup> The majority of PCHAP cases in this review were found among professional volleyball players. This might support the assumption that exposure time to repetitive powerful overhead movements is a risk factor for PCHAP.

In addition, Van de Pol et al. found that the total length of the volleyball career among Dutch elite volleyball players was associated with the reporting of ischemic complaints in the

dominant hand; a volleyball career duration of more than 17 years resulted in an increased risk OR of 6.7 (95% CI 1.1–29.5) compared to a career duration of up to 10 years.<sup>52</sup> Lastly, a study focusing on symptoms of PCHAP in world-class beach volleyball players reported a significant difference in volleyball career duration between athletes with and without symptoms of PCHAP.<sup>15</sup> However, and again, these two studies evaluated self-reported complaints of digital ischemia and did not assess the PCHA using imaging techniques.

Recently, a study screening 280 elite volleyball players to identify possible risk factors for PCHAP was reported. Athletes were assessed using 1) a questionnaire for symptoms of digital ischemia (SPI-Questionnaire) and 2) ultrasound aimed at visualizing PCHAP (SPI-US protocol). In this study PCHAP was significantly associated with career duration and age. Volleyball career duration (OR 1.1; 95%CI 1.1-1.2) and age (OR 1.2; 95%CI 1.1-1.3) were dose-response related risk factors: a volleyball career of  $\geq 17$  years and age of  $\geq 27$  years were associated with a 9-fold and 14-fold increased risk of PCHAP, respectively.<sup>16</sup>

Although career duration of overhead athletes may be associated with increased risk for PCHAP, physicians should be aware of PCHAP in young athletes as well, as this review showed that 49% of reported cases in medical literature is 25 years or younger.

### **Strengths and limitations**

The literature search was extensive and developed in collaboration with an experienced library database specialist and findings were reported following the PRISMA statement.<sup>23</sup> In addition, a broad and sensitive search in seven databases and worked with a validation set to optimize the literature search. However, additional articles might have been found if no language restriction on articles was used. Another possible limitation to the results of this study is that merely case reports and case series have been identified and that some information on risk-factors is based on an unpublished paper in a PhD-thesis.

### **Implications for research and practice**

Timely diagnosis of PCHAP is essential as distal embolization can cause digital ischemia and irreversible damage tissue damage. Therefore, sports physicians, physiotherapists and other (para)medical professionals should be cautious of PCHAP in overhead athletes and workers, both adult and adolescent.

The cases identified by the review demonstrated that distal embolization originated from the PCHA typically causes coolness of the hand and digits and discoloration, possibly accompanied by numbness, pain, fingertip ulceration and splinter hemorrhage. In athletes or

workers with abnormal clinical findings of the hand and fingers clinicians should be aware that symptoms may originate from the shoulder. Follow-up should be discussed with a vascular surgeon, especially if onset of symptoms is acute.<sup>16, 28</sup>

In case PCHAP is suspected, brachial and finger pressure measurement and digital photoplethysmography are valuable to evaluate the vitality of the arterial blood supply in the upper extremity. If imaging is required, ultrasound of the PCHA (using the standardized and reliable SPI-US protocol) can be a valuable (noninvasive) first step in the diagnostic workup of PCHAP.<sup>16, 53, 54</sup> Invasive techniques as DSA and magnetic resonance angiography can provide additional information as these techniques are able to evaluate the PCHA and the presence of distal embolisms at once.<sup>22</sup>

## CONCLUSION

In the medical literature, PCHAP is reported in seven overhead sports and three professions. No risk factors for PCHAP were identified. An anatomic variant of the PCHA origin was assumed to be a potential protective factor for PCHAP. Physicians should be cautious for distal embolization as a result of PCHAP in athletes, both adult and adolescent, and workers involved in repetitive powerful overhead movements who report seemingly innocuous symptoms like coolness and discoloration of the hand. Better understanding of risk factors and clinical consequences of asymptomatic PCHAP is essential for the development of future preventive measures.

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**Authors' contributions** - RBK, LB, DvdP, JD, MM and PK all contributed to the paper. JD designed the search strategy. RBK, LB, DvdP and PK performed the study selection and composed the manuscript. All authors critically revised it and approved the final version of the article. PK is the guarantor of the paper.

**Funding** - This research did not receive any specific grants from funding agencies in the public, commercial, or not-for profit sectors.

**Conflicts of interest** - The authors declare that there is no conflict of interest regarding the publication of this article.

## **TITLES OF TABLES**

Table 1 - Overview of 27 included articles

Table 2 - Overview of sports and professions practised by cases with PCHA pathology

Table 3 - Overview of clinical findings in cases with PCHA pathology

## **TITLES OF FIGURES**

Figure 1 - PRISMA flow diagram

**Table 1** Overview of included articles after full text selection and reference check (N.D. = Not described)

Study information	Study population with PCHA pathology				Outcomes	
	Author (Year) Country. Design.	Patients (F/M)	Mean age (range)	Sport or profession (cases)	Dominant/ Non-Dominant arm.	PCHA aneurysm/thrombosis/occlusion. Diagnosis
Arko (2003) U.S.A. Case-series <sup>a 18</sup>	4 (4 M, 0 F)	25.7 (19-32)	Baseball (3) (1 = N.D.)	N.D. (4)	PCHA aneurysm (4)	N.D.
Atema (2012) The Netherlands. Case report <sup>d 14</sup>	3 (3 M, 0 F)	27.7 (22-32)	Volleyball (3)	Dominant (3)	PCHA thrombosis (2), with distal emboli (1 of 2), PCHA occlusion with distal ischemia and emboli (1)	N.D.
Baumgarten (2007) U.S.A. Case report <sup>27</sup>	1 (1 M, 0 F)	29	Baseball (1)	Dominant (1)	PCHA occlusion with axillary artery aneurysm and thrombosis with distal embolization (1)	N.D.
Brown (2015) U.S.A. Case report/literature review <sup>3</sup>	3 (0 M, 3 F)	23.3 (20-26)	Volleyball (3)	Dominant (3)	PCHA aneurysm with occlusion in abduction and distal embolization (1), PCHA thrombosis with distal embolization (2)	Male sex (almost exclusive male population for vQSS)
Durham (1995) U.S.A. Case-series <sup>11</sup>	4 (3 M, 1 F)	22.8 (15-27)	Swimmer (1), baseball (2), mechanic (1)	Dominant (3), bilateral (1)	PCHA aneurysm (1), PCHA occlusion (2) with embolic occlusion (1), Bilateral PCHA occlusion (1)	N.D.
Duwayri (2011) U.S.A. Case-series <sup>b 28</sup>	2 (2 M, 0 F)	34 (31-37)	Baseball (2)	Dominant (2)	PCHA occlusion and thrombosis with embolic occlusion (2)	N.D.
Gelabert (1997) U.S.A. Case-series <sup>29</sup>	1 (1 M, 0 F)	19	Volleyball (1)	N.D. (1)	PCHA aneurysm with distal embolization (1)	N.D.
Ikezawa (2000) Japan. Case-report <sup>5</sup>	2 (2 M, 0 F)	18.5 (17-20)	Tennis (1), volleyball (1)	Dominant (2)	PCHA Aneurysm with digital embolism (1), thrombotic occlusion with digital embolism (1)	N.D.
Kane (2013) U.S.A. Case-report <sup>10</sup>	1 (1 M, 0 F)	23	Baseball (1)	Dominant (1)	Aneurysmal PCHA, with echogenicity suggestive of thrombus and distal occlusion (1)	N.D.

Kee (1995) U.S.A. Case-report <sup>17</sup>	1 (1 M, 0 F)	25	Baseball (1)	Dominant (1)	PCHA occlusion with an aneurysm containing thrombus, with distal embolization (1)	N.D.
Lee (2012) U.S.A. Case-report <sup>20</sup>	2 (2 M, 0 F)	37 (17-57)	Tennis (1) American football (1)	N.D. (2)	PCHA aneurysm with subsequent thrombosis and embolism to the hand and wrist (1)	N.D.
Maas (2004) the Netherlands. Case-report <sup>9</sup>	2 (2 M, 0 F)	29.5 (21-38)	Volleyball (1), tennis (1)	Dominant (1), N.D. (1)	Unilateral PCHA aneurysm with distal embolization (2)	N.D.
McIntosh (2006) U.S.A. Case-report <sup>e 7</sup>						Extreme hours of practice (4 to 8 hours/day)
Nuber (1990) U.S.A. Case-series <sup>c 30</sup>	1 (1 M, 0 F)	(18-34)	Baseball (1)	Dominant (1)	Occlusion and thrombosis of the PCHA with embolization of the digit(s) (1)	N.D.
Reekers (1993) The Netherlands. Case report <sup>6</sup>	3 (3 M, 0 F)	27.7 (23-35)	Volleyball (3)	Dominant (3)	PCHA aneurysm with distal occlusion (2), occlusion of the proximal PCHA with distal occlusion (1)	N.D.
Reekers (1998) The Netherlands. Letter with case <sup>31</sup>	4 (4 M, 0 F)	N.D.	Volleyball (3) Circus trapeze artist (1)	Bilateral (1), N.D. (3)	PCHA aneurysm with distal embolization (1) PCHA occlusion with distal embolization (2). Right PCHA aneurysm and left PCHA occlusion, embolization in both hands (1)	N.D.
Reutter (2010) Switzerland. Case-report <sup>32</sup>	1 (1 M, 0 F)	64	Yoga (1)	N.D. (1)	PCHA aneurysm with brachial artery occlusion and emboli (1)	N.D.
Rollo (2017) U.S.A., Case report <sup>22</sup>	3 (3 M)	17.7 (17-19)	Volleyball (2), American football(1)	Dominant (3)	Thrombosis of the PCHA with occlusion of radial and ulnar arteries (1), dissection of the PCHA with distal embolization (1), dissection of the PCHA with thrombotic disease of the right radial artery (1)	N.D.
Schneider, K. (1999) U.S.A. Case report/ review literature <sup>33</sup>	1 (1 M, 0 F)	25	Baseball (1)	Dominant (1)	Aneurysm of the axillary artery an its branches, including the common origin of the humeral circumflex arteries (1)	N.D.

Schneider, D.B. (2002) U.S.A. Case-report <sup>34</sup>	1 (1 M, 0 F)	30	Baseball (1)	Dominant (1)	Unilateral PCHA thrombosis with distal embolization (1)	N.D.
Seinturier (2008) France. Case-report <sup>35</sup>	1 (1 M, 0 F)	48	Canoeing (1)	N.D. (1)	Unilateral PCHA aneurysm with thrombosis and distal embolization (1)	N.D.
Stänz (2001) Switzerland. Case-report <sup>36</sup>	1 (1 M, 0 F)	25	Volleyball (1)	Dominant (1)	Unilateral PCHA aneurysm with occlusion with distal embolization (1)	N.D.
Tao (2016) Canada. Case-report <sup>37</sup>	1 (1 F)	20	Volleyball (1)	Dominant (1)	Unilateral thrombosis of the PCHA with distal embolic occlusions (1)	N.D.
Todd (1998) U.S.A. Case-report <sup>38</sup>	2 (2 M, 0 F)	30 (27-33)	Baseball (2)	Dominant (2)	Unilateral: PCHA aneurysm with distal embolization (2)	An anatomic variation; PCHA and ACHA with a common trunk from the axillary artery
Van de Pol (2012) The Netherlands. Case-report/ cross-sectional <sup>d 8</sup>	3 (3 M, 0 F)	24.7 (22- 27)	Volleyball (3)	Dominant (3)	Unilateral PCHA aneurysm and thrombosis with distal occlusion with digital emboli (3)	N.D.
Van de Pol (2017) The Netherlands. Cross-sectional <sup>2</sup>	17 (15 M, 2 F)	28.3 (19-34)	Volleyball (1)	Dominant (17)	Unilateral aneurysm of the PCHA (13), occlusion of the PCHA (1) and dilatation of the PCHA (3).	PCHA with its origin directly from the axillary artery
Vlychou (2001) Greece. Case-report <sup>39</sup>	1 (1 M, 0 F)	19	Volleyball (1)	Dominant (1)	Unilateral PCHA aneurysm with distal embolization (1)	N.D.
Volckaert (2014) Belgium. Case-report <sup>40</sup>	1 (1 M, 0 F)	24	Volleyball (1)	Dominant (1)	Unilateral occlusion and thrombosis of the PCHA with distal embolization (1)	N.D.
<b>Total</b>	<b>67</b> <b>(56 M, 7 F)</b>	<b>27.1</b> <b>(15-57)</b>		<b>Dominant</b> <b>(53), Bilateral</b> <b>(2), N.D. (12)</b>		

a Arko et al. (2001) is excluded based on overlapping data with Arko et al. (2003),<sup>18</sup> b Duwayri et al. (2010) is excluded based on overlapping data with Duwayri et al. (2011),<sup>28</sup> c McCarthy et al. (1989) is excluded based on overlapping data with Nuber et al. (1990)<sup>30</sup>; d 3 professional volleyball players of Van de Pol et al. (2012)<sup>8</sup> were excluded based on overlapping data with Atema, et al. (2012)<sup>14</sup>; e Patient data from McIntosh et al.<sup>7</sup> is excluded based on overlapping data with Brown et al.<sup>3</sup> Risk-factor mentioned in the article is included in the review.

**Table 2** Overview of sports and professions practised by cases with PCHA pathology

	Sport							Profession		
	Volleyball	Baseball	Tennis	Swimming	American football	Yoga	Canoeing	Trapeze artist	Baseball coach	Mechanic
<i>Number of cases</i>	41 (63.1%)	13 (20.0%)	3 (4.6%)	1 (1.5%)	2 (3.1%)	1 (1.5%)	1 (1.5%)	1 (1.5%)	1 (1.5%)	1 (1.5%)
<i>Sex</i>	6 F, 35 M	0 F, 13 M	0 F, 3 M	1 F, 0 M	0 F, 2 M	0 F, 1 M	0 F, 1 M	0 F, 1 M	0 F, 1 M	0 F, 1 M
<i>Level of sport/ profession (n)</i>	Professional (32), Collegiate (2) Amateur (2) Well-trained (3), N.D. (2)	Professional (13)	Professional (1), US tennis association national finals (1), Amateur (1)	High school (1)	Division 1 collegiate (1), High-school (1)	Amateur (1)	Amateur (1)	Professional (1)	Professional (1)	N.D.
<i>Speciality of sport / profession (n)</i>	Outside hitters (2) N.D. (39)	Relief pitcher (4) Pitcher (9)	N.D.	N.D.	Starting quarter-back (1)	N.D.	N.D.	Hanging and flying (1)	Batting and pitching (1)	N.D.

\* Two cases of Arko et al. 2003 were not included in this table, sport was unclear. (N.D. =Not described)

**Table 3** Overview of clinical findings in cases with PCHA pathology in cases where symptoms were described in the article (n=48)

Symptom	Number of cases reporting the symptom	% of cases with reported symptoms
Coolness of the hand or digits	28	58%
Paleness and/or cyanosis of the hand or digits	24	50%
Neurologic symptoms	24	50%
Pain of the forearm, hand or digits	19	40%
Loss of power, accuracy or endurance of the arm	15	31%
Cold intolerance	7	14%

## Appendix 1 Search strategy

Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations and Ovid MEDLINE(R) 1946 to Present via Ovid interface. Search date: June 20th 2017		
#	Searches	Results
1	baseball/ or basketball/ or "cricket (sport)"/ or exp racquet sport/ or swimming/ or volleyball/	31403
2	(handball or basketball or baseball or swimming or racquet sport? or tennis or volleyball or cricket or javelin).ab,kw,ti.	41782
3	or/1-2 [rel. sports]	49846
4	"prevention and control"/ or prevention/ or primary prevention/	445461
5	prevent*.ab,kw,ti.	1546001
6	(Manage training programs or (training adj3 (duration or intensity or recovery)) or (match adj5 frequen*) or season duration or Symptom monitoring system or medical help or Intensity monitoring or pitch velocity or Throwing technique or curveballs or Preseason supraspinatus strengthening or Dedicated warm-ups or Pitch-count or rest period).ab,kw,ti.	13911
7	or/4-6 [prevention]	1689368
8	(injur* adj15 (handball or basketball or baseball or swimming or racquet sport? or tennis or volleyball or cricket or javelin)).ab,kw,ti.	2326
9	injur*.hw.	1286887
10	(handball or basketball or baseball or swimming or racquet sport? or tennis or volleyball or cricket or javelin).ab,kw,ti.	41782
11	9 and 10	5321
12	or/8,11 [rel. sport injuries]	5538
13	shoulder pain/ or exp cumulative trauma disorder/ or stress fracture/	37385
14	(shoulder pain or (shoulder? adj5 (complaint? or disorder? or exertion or flexion or repetitive)) or rotator cuff syndrome or cumulative trauma disorder? or little league or humeral epiphysi* or apophysi* or capitellum or capitellar or stress fracture? or gymnast wrist or Distal Radial Epiphysitis).ab,kw,ti.	17570
15	or/13-14 [known injuries]	44512
16	risk factor/	915573
17	(risk adj3 factor?).ab,hw,kw,ti.	1063111
18	or/13,16-17 [injury risk]	1097756
19	exp upper limb/ or exp rotator cuff/ or exp epiphysis/ or epiphysis plate/ or epiphysis injury/	346666
20	(axilla or upper extremit* or upper limb? or arm? or forearm? or shoulder? or wrist? or elbow? or rotator cuff or epiphys* or growth plate?).ab,kw,ti.	467439
21	or/19-20 [anatomy]	556101
22	age/ or exp childhood/ or exp adolescence/ or exp child/	3164349
23	(kid? or pubescen* or prepube* or puberty or teen* or adolescen* or young* or youth? or juvenile or minors or under ag* or school? or girl? or boy? or preadolesc* or young adult* or adolescen* or highschool or junior).ab,kw,ti.	1564368
24	or/22-23 [children   young adults]	3983790
25	3 and (7 or 18) and 21	2297
26	sport injury/	27284

27	((injur* adj5 (sport? or athlet*)) or overuse injur*).ab,kw,ti.	14670
28	or/26-27 [athletic injuries]	33267
29	and/21,24,28	1572
30	((young or junior or pe?diatric or school? or highschool or child* or adolescen* or puberty) adj7 (sport? or athlet* or handball or basketball or baseball or swimming or racquet sport? or tennis or volleyball or cricket or javelin) adj7 (risk factor? or injur*)).ab,kw,ti.	1896
31	or/29-30 [athletic injuries in children   young adults]	3074
32	25 or 31	5147
33	remove duplicates from 32	4983

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<b>Embase Classic+Embase 1947 to 2015 June 30 via Ovid interface. Search date: June 20th 2017</b>		
<b>#</b>	<b>Searches</b>	<b>Results</b>
1	exp racquet sport/ or volleyball/ or basketball/ or swimming/	19239
2	(handball or basketball or baseball or swimming or racquet sport? or tennis or volleyball or cricket or javelin).ab,kf,ti.	34827
3	or/1-2 [rel. sports]	42323
4	prevention control.fs. or prevent*.ab,kf,ti.	1981452
5	(Manage training programs or (training adj3 (duration or intensity or recovery)) or (match adj5 frequen*) or season duration or Symptom monitoring system or medical help or Intensity monitoring or pitch velocity or Throwing technique or curveballs or Preseason supraspinatus strengthening or Dedicated warm-ups or Pitch-count or rest period).ab,kf,ti.	10797
6	or/4-5 [prevention]	1991111
7	(injur* adj15 (handball or basketball or baseball or swimming or racquet sport? or tennis or volleyball or cricket or javelin)).ab,kf,ti.	1990
8	injur*.hw.	499383
9	(handball or basketball or baseball or swimming or racquet sport? or tennis or volleyball or cricket or javelin).ab,kf,ti.	34827
10	8 and 9	2597
11	or/7,10 [rel. sport injuries]	3434
12	shoulder pain/ or exp cumulative trauma disorders/ or fractures, stress/	18619
13	(shoulder pain or (shoulder? adj5 (complaint? or disorder? or exertion or flexion or repetitive)) or rotator cuff syndrome or cumulative trauma disorder? or little league or humeral epiphysi* or apophysi* or capitellum or capitellar or stress fracture? or gymnast wrist or Distal Radial Epiphysitis).ab,kf,ti.	13391
14	or/12-13 [known injuries]	27708
15	(risk adj3 factor?).ab,hw,kf,ti.	910888
16	or/11,14-15 [injury risk]	938585
17	exp upper extremity/ or exp hand joints/ or elbow joint/ or shoulder joint/ or rotator cuff/ or exp epiphyses/	193510
18	(axilla or upper extremit* or upper limb? or arm? or forearm? or shoulder? or wrist? or elbow? or rotator cuff or epiphys* or growth plate?).ab,kf,ti.	334789
19	or/17-18 [anatomy]	434005
20	age factors/ or child/ or adolescent/	2740522
21	(kid? or pubescen* or prepube* or puberty or teen* or adolescen* or young* or youth? or juvenile or minors or under ag* or school? or girl? or boy? or preadolesc* or young adult* or adolescen* or highschool or junior).ab,kf,ti.	1182964
22	or/20-21 [children   young adults]	3344117
23	3 and (6 or 16) and 19	1782
24	athletic injuries/	23291

25	((injur* adj5 (sport? or athlet*)) or overuse injur*).ab,kf,ti.	12216
26	or/24-25 [athletic injuries]	29234
27	and/19,22,26	2194
28	((young or junior or pe?diatric or school? or highschool or child* or adolescen* or puberty) adj7 (sport? or athlet* or handball or basketball or baseball or swimming or racquet sport? or tennis or volleyball or cricket or javelin) adj7 (risk factor? or injur*)).ab,kf,ti.	1614
29	or/27-28 [athletic injuries in children   young adults]	3478
30	23 or 29	4835
31	remove duplicates from 30	4757

<b>BIOSIS Previews 1993 to 2014, via Ovid interface. Search date: 1 July 2015</b>		
#	Searches	Results
1	((athlet* or sport) adj1 (injur* or trauma)) or Vascular System Injuries).ab,mi,ti. [related injuries]	436
2	athlet*.ab,mi,ti.	19038
3	(tennis or korfbal or squash or judo or swimming or weight lifting or pole vault or waterpolo or kayak or handball or basketball or softball or javelin throw or baseball or volleyball or sport*).ab,mi,ti. [sports]	53318
4	or/1-3 [athletes]	65334
5	(humeral circumflex arter* or posterior circumflex arter* or circumflex humeral arter* or (axillar* adj4 arter*) or quadrangular space or quadrilateral space or quadrangular area or quadrilateral area).ab,mi,ti. [specific anatomy]	502
6	(thromb* or aneurysm? or occlusion or stenosis or stenoses or ischemi? or embol* or thromboembol* or quadrilateral or vascularization or blood supply or blood flow).ab,mi,ti.	525193
7	"14508".cc. [blood vessel pathology]	916217
8	6 or 7 [disorders]	1160742
9	"11309".cc. [shoulder]	2257
10	"11318".cc. [extremities]	33736
11	(axilla or upper extremit* or arm? or forearm? or shoulder?).ab,mi,ti.	120039
12	or/9-11 [anatomy]	150193
13	5 or (4 and 8 and 12)	732
14	limit 13 to human	653
15	remove duplicates from 14	627

<b>CINAHL via Ebscohost. Search date: 1 July 2015</b>		
<b>#</b>	<b>Query</b>	<b>Resultaten</b>
S1	(MH "Athletic Injuries+")	15,318
S2	TI ( (((athlet* or sport) N1 (injur* or trauma)) or Vascular System Injuries) ) OR AB ( (((athlet* or sport) N1 (injur* or trauma)) or Vascular System Injuries) ) OR SU ( (((athlet* or sport) N1 (injur* or trauma)) or Vascular System Injuries) )	13,849
S3	S1 OR S2	15,754
S4	(MH "Athletes+")	15,599
S5	TI athlet* OR AB athlet* OR SU athlet*	40,582
S6	S4 OR S5	40,582
S7	(MH "Sports+")	49,699
S8	TI ( (tennis or korfbal or squash or judo or swimming or weight lifting or pole vault or waterpolo or kayak or handball or basketball or softball or javelin throw or baseball or volleyball or sport*) ) OR AB ( (tennis or korfbal or squash or judo or swimming or weight lifting or pole vault or waterpolo or kayak or handball or basketball or softball or javelin throw or baseball or volleyball or sport*) ) OR SU ( (tennis or korfbal or squash or judo or swimming or weight lifting or pole vault or waterpolo or kayak or handball or basketball or softball or javelin throw or baseball or volleyball or sport*) )	44,77
S9	S7 OR S8	66,414
S10	S3 OR S6 OR S9	78,139
S11	(MH "Axillary Artery")	166
S12	TI ( (humeral circumflex arter* or posterior circumflex arter* or circumflex humeral arter* or (axillar* adj4 arter*) or quadrangular space or quadrilateral space or quadrangular area or quadrilateral area) ) OR AB ( (humeral circumflex arter* or posterior circumflex arter* or circumflex humeral arter* or (axillar* adj4 arter*) or quadrangular space or quadrilateral space or quadrangular area or quadrilateral area) ) OR SU ( (humeral circumflex arter* or posterior circumflex arter* or circumflex humeral arter* or (axillar* adj4 arter*) or quadrangular space or quadrilateral space or quadrangular area or quadrilateral area) )	40
S13	S11 OR S12	203
S14	(MH "Thrombosis+") OR (MH "Aneurysm") OR (MH "Ischemia") OR (MH "Embolism") OR (MH "Thromboembolism") OR (MH "Arterial Occlusive Diseases")	33,002
S15	TI ( (thromb* or aneurysm? or occlusion or stenosis or stenoses or ischemi? or embol* or thromboembol* or quadrilateral or vascularization or blood supply or blood flow) ) OR AB ( (thromb* or aneurysm? or occlusion or stenosis or stenoses or ischemi? or embol* or thromboembol* or quadrilateral or vascularization or blood supply or blood flow) ) OR SU ( (thromb* or aneurysm? or occlusion or stenosis or stenoses or ischemi? or embol* or thromboembol* or quadrilateral or vascularization or blood supply or blood flow) )	125,382
S16	S14 OR S15	127,764
S17	(MH "Arm") OR (MH "Axilla") OR (MH "Forearm") OR (MH "Shoulder")	11,246
S18	TI ( (axilla or upper extremit* or arm? or forearm? or shoulder?) ) OR AB ( (axilla or upper extremit* or arm? or forearm? or shoulder?) ) OR SU ( (axilla or upper extremit* or arm? or forearm? or shoulder?) )	19,346
S19	S17 OR S18	27,451
S20	(S10 AND S16 AND S19) OR S13	271

<b>SPORTDiscus, Ebsco Host, 20150701</b>		
<b>#</b>	<b>Query</b>	<b>Results</b>
S13	( S5 AND S9 AND S12 ) OR S6	53
S12	S10 OR S11	22,339
S11	TI ( (axilla or upper extremit* or arm? or forearm? or shoulder?) ) OR AB ( (axilla or upper extremit* or arm? or forearm? or shoulder?) ) OR KW ( (axilla or upper extremit* or arm? or forearm? or shoulder?) )	12,922
S10	(DE "ARM" OR DE "ELBOW" OR DE "FOREARM") OR (DE "SHOULDER" OR DE "ACROMIOCLAVICULAR joint" OR DE "CLAVICLE" OR DE "SHOULDER joint" OR DE "TERES major" OR DE "TERES minor")	11,716
S9	S7 OR S8	12,19
S8	(((((DE "THROMBOSIS") OR (DE "ANEURYSMS")) AND (DE "ARTERIAL occlusions" OR DE "ARTERIOSCLEROSIS" OR DE "EMBOLISMS" OR DE "ARTERIES -- Dilatation" OR DE "TRANSLUMINAL angioplasty")) OR (DE "STENOSIS" OR DE "AORTIC stenosis" OR DE "SPINAL stenosis")) OR (DE "ISCHEMIA" OR DE "COMPARTMENT syndrome")) OR (DE "EMBOLISMS" OR DE "CEREBRAL embolism & thrombosis" OR DE "GAS embolism" OR DE "PULMONARY embolism")	2,169
S7	TI ( (thromb* or aneurysm? or occlusion or stenosis or stenoses or ischemi? or embol* or thromboembol* or quadrilateral or vascularization or blood supply or blood flow) ) OR AB ( (thromb* or aneurysm? or occlusion or stenosis or stenoses or ischemi? or embol* or thromboembol* or quadrilateral or vascularization or blood supply or blood flow) ) OR KW ( (thromb* or aneurysm? or occlusion or stenosis or stenoses or ischemi? or embol* or thromboembol* or quadrilateral or vascularization or blood supply or blood flow) )	11,307
S6	TI ( (humeral circumflex arter* or posterior circumflex arter* or circumflex humeral arter* or (axillar* adj4 arter*) or quadrangular space or quadrilateral space or quadrangular area or quadrilateral area) ) OR AB ( (humeral circumflex arter* or posterior circumflex arter* or circumflex humeral arter* or (axillar* adj4 arter*) or quadrangular space or quadrilateral space or quadrangular area or quadrilateral area) ) OR KW ( (humeral circumflex arter* or posterior circumflex arter* or circumflex humeral arter* or (axillar* adj4 arter*) or quadrangular space or quadrilateral space or quadrangular area or quadrilateral area) )	27
S5	S1 OR S2 OR S3 OR S4	207,238
S4	DE "SPORTS" OR DE "AMATEUR sports" OR DE "BALL games" OR DE "BASEBALL" OR DE "DISC golf" OR DE "GYMNASTICS" OR DE "OLYMPIC Games" OR DE "PROFESSIONAL sports" OR DE "RACKET games" OR DE "SOFTBALL"	157,2
S3	DE "SPORTS injuries" OR DE "BASEBALL injuries" OR DE "BASKETBALL injuries" OR DE "GYMNASTICS injuries" OR DE "JUDO injuries" OR DE "KARATE injuries" OR DE "MARTIAL arts injuries" OR DE "RACKET game injuries" OR DE "TENNIS injuries" OR DE "VOLLEYBALL injuries" OR DE "WEIGHT training injuries"	8,481
S2	TI ( (((athlet* or sport) N1 (injur* or trauma)) or Vascular System Injuries) ) OR AB ( (((athlet* or sport) N1 (injur* or trauma)) or Vascular System Injuries) ) OR KW ( (((athlet* or sport) N1 (injur* or trauma)) or Vascular System Injuries) )	7,435
S1	DE "AMATEUR athletes" OR DE "BASEBALL players" OR DE "BASKETBALL players" OR DE "BLACK athletes" OR DE "MALE athletes" OR DE "OLYMPIC athletes" OR DE "ROWERS" OR DE "SOFTBALL players" OR DE "SQUASH players" OR DE "SWIMMERS" OR DE "TENNIS players" OR DE "VOLLEYBALL players" OR DE "WOMEN athletes"	46,497

**PRISMA Flow Diagram**

