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Shoulder Tendinopathies and Occupational Biomechanical Overload: A Critical Appraisal of Available Evidence

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Abstract

Background: *The aim of this study is to evaluate the association between occupational exposure to biomechanical risk factors and shoulder tendinopathies.* **Methods:** *We updated recent systematic reviews about specific shoulder disorders and work-related risk factors. MEDLINE was searched up to September 2022. Studies satisfying the following criteria were included: i) the diagnosis was based on physical examination plus imaging data (when available), and ii) the exposure assessment was based on video analysis and/or directly measured.* **Results:** *Five studies met the inclusion criteria: three cross-sectional studies identified from published systematic reviews and two cohort studies retrieved from the update. Two studies investigated shoulder tendinitis, one supraspinatus tendinitis, and the other two rotator cuff syndrome. The diagnosis was based on physical examination, not supported by imaging techniques for all the included studies. In four out of five studies, the exposure was assessed by experienced ergonomists with the support of video recordings. In two studies, the exposure assessment was further supplemented by force gauge measurements or direct measurements of upper arm elevation. Only the combined exposure of working with arms above shoulder level with forceful hand exertion appears to be associated with rotator cuff syndrome: i) a cohort study reported an HR=1.11 (95%CI 1.01-1.22) for each unit increase in forceful repetition rate when the upper arm is flexed ≥45° for ≥29% of the working time; and ii) a cross-sectional study showed an OR=2.43 (95%CI 1.04-5.68) for the combination of upper arm flexion ≥45° for more than 15% of the time with a duty cycle of forceful exertions more than 9% of the time.* **Conclusions:** *There is moderate evidence of a causal association between shoulder tendinopathy and combined exposures of working above shoulder level with forceful hand exertion. The evidence is insufficient for any single biomechanical exposure on its own. High-quality cohort studies with direct exposure measures and objective diagnostic criteria are needed. The occupational origin of shoulder tendinopathies is still an open question that must be properly answered.*

1. Introduction

Shoulder disorders are prevalent among men and women of the general population (7% and 9.1% in England and 6.8% and 9.0% in France, respectively) [1, 2]. However, the prevalence of shoulder pain varied considerably across studies and case definitions [3]. Rotator cuff syndrome is one of the

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most frequently reported shoulder disorders among the working population in both men and women, with an incidence of more than 2/100 person-years among subjects older than 44 years [4].

Rotator cuff disorders encompass a broad spectrum of conditions affecting tendons of rotator cuff muscles ranging from inflammation to tears or rupture [5]. There is no universally accepted way to label or define shoulder tendinopathies [6]. Shoulder disorders have been described in the literature under a variety of names including, but not limited to, rotator cuff disease, rotator cuff syndrome, rotator cuff tendinitis/tendinosis, subacromial impingement syndrome, subacromial shoulder disorders, subacromial bursitis, supraspinatus tendinitis/tendinosis, infraspinatus tendinitis/tendinosis, and bicipital tendinopathy.

The international classification of diseases 10th revision (ICD-10) covers the following shoulder lesions: M75.0 (adhesive capsulitis of shoulder), M75.1 (rotator cuff syndrome), M75.2 (bicipital tendinitis), M75.3 (calcific tendinitis of the shoulder), M75.4 (impingement syndrome of the shoulder), M75.5 (bursitis of the shoulder), M75.8 (other shoulder lesions), and M75.9 (shoulder lesion, unspecified). However, no international consensus has been reached about the diagnosis of "subacromial pain syndrome" suitable for epidemiological studies: only 34% of the panellists agreed that a case definition for epidemiological research could be based on symptoms only [7].

Biomechanical risk factors for shoulder disorders include repetitive upper arm movements, working above shoulder height, and shoulder efforts; non-occupational risk factors could be associated with shoulder pain among adults [4, 8].

We aimed to evaluate the association between shoulder tendinopathies and occupational exposure to biomechanical risk factors ranking the quality of evidence for establishing a causal relationship. However, to our knowledge, a critical appraisal focusing on objective criteria for both exposure assessment and diagnosis has yet to be performed.

2. METHODS

For the present review, we included shoulder tendinopathies defined as the following: i) rotator cuff syndrome/disease; ii) tendinitis/tendinosis of the rotator cuff muscles; iii) bicipital tendinitis/tendinopathy; iv) calcific tendinitis; and v) impingement syndrome. These diagnoses correspond to M75.1-M75.4 codes of ICD-10.

At first, we re-evaluated the studies already included in published systematic reviews about specific shoulder disorders and work-related risk factors [9-11]. These three systematic reviews are based on the same methodological approach, and each, in turn, constitutes an update of the previous one. We retrieved the list of included studies, and two authors (SC and SM) independently extracted the following data: first author, year of publication, systematic reviews identifying the included studies, study design, outcome assessment, and exposure assessment. For each included study, data about diagnosis and exposure assessment were retrieved and categorized according to predefined criteria [12]. Each combination of diagnosis and exposure was ranked for case definition and exposure assessment. The hypothetical combinations of case definition and exposure assessment and their evidence quality are reported in Supplementary Table 1.

The minimum criteria to be qualified as potentially eligible for the present study are as follows: i) the diagnosis is based on physical examination (symptoms plus clinical signs), and ii) the exposure assessment is based on video analysis or video-based observations. The best scenario is represented by studies whose case definition is based on physical examination plus imaging (e.g., Magnetic Resonance Imaging, MRI). Exposure is assessed using quantitative measures of biomechanical exposure like inclinometer measurements. Studies based on self-reported symptoms (e.g., shoulder pain) and/or an indirect assessment of biomechanical exposure (e.g., job titles, job exposure matrix, self-reports, or expert ratings) did not qualify for inclusion but were retained for descriptive purposes. Studies about a wide spectrum of shoulder pathologies were poorly rated and reported non-standardized and adequately described diagnostic criteria and/or exposure assessment. Of note, studies using imaging alone (without physical examination) do not allow a standardized medical diagnosis, precluding any ratings. Occupational exposure to vibration and psychosocial risk factors were not included as well.

In addition, we updated the search of the literature included in MEDLINE (through PubMed) from November 1, 2018, up to September 25, 2022. The search strategy is reported in Supplementary Table 2. Briefly, search terms related to shoulder tendinopathies were combined with the "more specific" PubMed search filter for occupational determinants of diseases [13], along with terms related to biomechanical risk factors. Such a search strategy was validated against the reference set of 34 citations included in the three selected systematic reviews [9-11]. The reference lists of included studies and other reviews about the topic of interest (if any) were checked for additional citations (including grey literature reports). No language restriction was applied. Case reports and case series were excluded.

Two authors (SC and SM) independently screened titles and abstracts to identify potentially relevant studies. The same two authors assessed whether each full article met the inclusion criteria. Disagreements were resolved by a third author (FSV). Multiple publications were detected, and valuable information was retained as appropriate. Two authors (SC and SM) independently extracted data from each eligible study. We collected information on the first author, year of publication, study design, outcome assessment, and exposure assessment. Data about diagnosis and exposure were then classified according to the quality of evidence [12].

The quality of included studies was evaluated according to predefined criteria [12]. Two authors (SC and SM) independently performed the quality assessment. Disagreements were resolved by consensus. The quality assessment covered the following topics: i) study design; ii) study population; iii) outcome assessment; iv) exposure assessment; and v) data analysis. The overall quality score ranges from 3 to 17. According to tertile distribution, studies were classified into three categories, namely: low-quality (3-7), medium-quality (8-12), and high-quality studies (13-17). To evaluate the causal relationship between shoulder tendinopathies and occupational exposure to biomechanical risk factors, a slightly modified version of the criteria developed by The Scientific Committee of the Danish Society of Occupational and Environmental Medicine was used [12, 14].

3. Results

The three published systematic reviews on specific shoulder disorders and work-related risk factors included 34 studies (excluding duplications) [9-11]. Of these, three studies met the inclusion criteria for the present study [15-17]. The update of the electronic search in MEDLINE retrieved 696 potentially relevant references, of which 20 were assessed in full text. Of these, one met the inclusion criteria [18]. Eight additional references were identified through other sources [19-21] and one study qualified for inclusion [22]. Overall, five studies were included in qualitative synthesis. The flow diagram is summarised in Figure 1.

Table 1 reported the list of studies included in three published systematic reviews classified according to quality of evidence. Overall, 34 studies were listed including 19 cross-sectional studies, 3 case-control studies and 12 cohort studies.

Most of these applied a case definition based on physical examination but performed an indirect assessment of biomechanical exposure. In one case, ultrasonography further supported the clinical diagnosis [23]. Of note, three other studies did not meet the minimum diagnostic requirements (i.e., imaging - MRI or ultrasonography - without physical examination was used) [24-26]. On the contrary, none of the studies was detected using a case definition based on self-reports and direct exposure measurements. In addition, 13 studies were poorly ranked according to case definition and exposure assessment criteria. The ranking for outcome/exposure combination by study design is reported in Table 2.

Altogether, five studies met the inclusion criteria for the present review: three cross-sectional studies were identified from the selected systematic reviews [15-17], and two cohort studies were retrieved from the update [18, 22] (Table 1). The main characteristics of the included studies are reported in Table 3.

Two studies investigated shoulder tendinitis [15, 22], another one supraspinatus tendinitis [16], and the last two rotator cuff syndromes [17, 18]. The case definition was based on physical examination

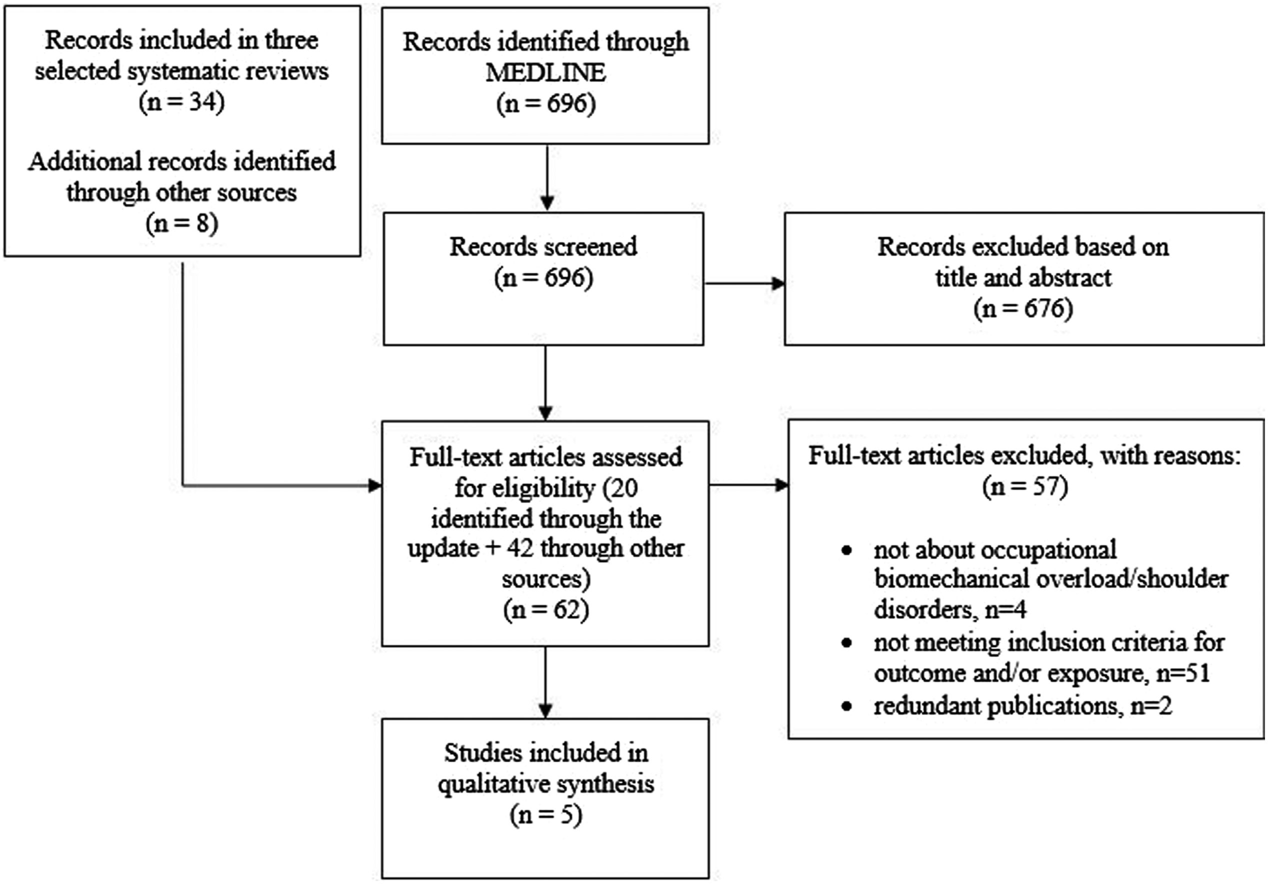

Figure 1. Flow-chart of included studies.

for all the included studies. In four out of five studies, the exposure was assessed by experienced ergonomists with video recordings combined with plant walkthrough and self-reported task distribution [15, 18, 22] or work history [17]. In one study, the exposure assessment was further supplemented by force gauge measurements of objects' weights and push/pull forces [17]. The other study was based on direct measurements of upper arm elevation above 30°, 60°, and 90° using an inclinometer which consisted of a sensor on each upper arm and a torque index combining posture and force along with the collection of individual occupational history [16].

In the study by Frost and colleagues, the risk of shoulder tendinitis was three times higher for workers performing repetitive tasks (adjusted Odds Ratio [OR] 3.12, 95% Confidence Interval [95%CI] 1.33-7.34) [15]. In particular, the high frequency of shoulder movements (i.e., 15-36 movements/min) was associated with an adjusted OR of 3.29 (95%CI 1.34-8.11) compared to non-repetitive work. The risk for high force demands (i.e., ≥10% of maximal voluntary contraction) was more than fourfold (adjusted OR 4.21, 95%CI 1.71-10.40) compared to the reference group, whereas performing 80% of cycle time without pauses reported an OR of 3.33 (95%CI 1.37-8.13). Combined exposures were found to be at risk as well [15]. Svendsen and colleagues reported that supraspinatus tendinitis was associated with current upper arm elevation above 90° for 6–9% of working hours (OR 4.70, 95%CI 2.07-10.68); however, no association was found for lifetime upper arm elevation above 90°, for both dominant and non-dominant shoulder [16]. The cohort study by Werner and colleagues did not report an association between shoulder tendonitis and abnormal hand activity threshold limit value (42.3% of incident cases vs. 40.6% of referent subjects, p=0.87

Table 1. List of studies included in published systematic reviews on specific disorders of the shoulder and work-related risk factors along with those included in the update categorised by quality of evidence.

Authors	Systematic reviews			Critical appraisal/update	Study Design	Outcome assessment	Exposure assessment	Ranking outcome/exposure
	van Rijn 2009	van der Molen 2017	Seidler 2020					
Luopajärvi 1979	X	X			Cross-sectional	Humeral tendinitis: self-reported symptoms plus physical examination	Job title (assembly-line packers vs shop assistants)	+/-
Herberts 1981	X				Cross-sectional	Supraspinatus tendinitis: self-reported symptoms plus physical examination	Job title (welders vs office clerks)	+/-
Park 1992	X	X			Nested case-control	Rotator cuff syndrome: medical insurance claims	Work history	-/-
Andersen 1993	X				Cross-sectional	Rotator cuff syndrome: self-reported symptoms plus physical examination	Job title (sewing machine operators vs control group) and years of employment as sewing machine operators	+/-
Ohlsson 1994	X				Cross-sectional	Supraspinatus tendinitis, infraspinatus tendinitis, bicipital tendinitis: self-reported symptoms plus physical examination	Job title (fish processing factories vs control group)	+/-
Frost 1999	X	X			Cross-sectional	Shoulder impingement syndrome: self-reported symptoms plus physical examination	Years of employment as slaughterhouse work	+/-
Nordander 1999	X	X			Cross-sectional	Supraspinatus tendinitis, infraspinatus tendinitis, bicipital tendinitis: self-reported symptoms plus physical examination	Job title (fish processing factories vs control group)	+/-
Kaergaard 2000	X	X			Cross-sectional	Rotator cuff tendinitis: self-reported symptoms plus physical examination	Duration of exposure as sewing machine operators	+/-
Frost 2002	X	X	X	X	Cross-sectional	Shoulder tendinitis: self-reported symptoms plus physical examination	Observations by plant walk-through, video recordings, and self-reported task distribution	+/+

(Continued)

Table 1. List of studies included in published systematic reviews on specific disorders of the shoulder and work-related risk factors along with those included in the update categorised by quality of evidence. (Continues)

Authors	Systematic reviews			Critical appraisal/update	Study Design	Outcome assessment	Exposure assessment	Ranking outcome/ exposure
	van Rijn 2009	van der Molen 2017	Seidler 2020					
Svendsen 2004a	X	X	X	X	Cross-sectional	Supraspinatus tendinitis: self-reported symptoms plus physical examination	Inclinometer measurements, torque index, and job title	+/++
Svendsen 2004b	X	X	X		Cross-sectional	Supraspinatus tendinopathy: MRI without physical examination	Inclinometer measurements, torque index, and job title	NA/++
Miranda 2005	X	X	X		Cross-sectional	Chronic rotator cuff tendinitis: self-reported symptoms plus physical examination	Cumulative exposure based on self-reported work-related physical loading	+/-
Wang 2005	X	X			Cross-sectional	Shoulder impingement syndrome: self-reported symptoms plus physical examination, and ultrasonography	Job title (culler group vs non-culler group)	++/-
Werner 2005				X	Cohort	Shoulder tendinitis: self-reported symptoms plus physical examination	Jobs rated according to the American Congress of Governmental Industrial Hygienists' (ACGIH) TLV® for hand activity and peak force	+/++
Melchior 2006	X	X			Cross-sectional	Rotator cuff syndrome: self-reported symptoms plus physical examination	Manual work and self-reported physical work exposure	+/-
Sutinen 2006	X	X	X		Cohort	Rotator cuff syndrome: self-reported symptoms plus physical examination	Lifetime vibration dose in chain saw use	+/++ (*)
Kaerlev 2008	X	X			Cohort	Rotator cuff syndrome: hospital register (ICD-10: M75.1)	Job title (fishermen vs seamen)	-/-

Silverstein 2008	X	X	X	X	Cross-sectional	Rotator cuff syndrome: self-reported symptoms plus physical examination	Observations by workplace walkthrough, video recordings, force gauges measurements, and work history	+/++
Nordander 2009		X			Cross-sectional (pooling 30 studies, including Ohlsson 1994 and Nordander 1999)	Supraspinatus, infraspinatus & bicipital tendinitis: self-reported symptoms plus examination (diagnostic criteria not standardized and adequately described)	Occupational groups (exposure assessment not standardized and adequately described)	-/-
Seidler 2011		X	X		Population-based case-control	Supraspinatus tendon lesions: MRI and self-reported symptoms	Job title and self-reported physical workload	NA/-
Bodin 2012		X	X		Cohort	Rotator cuff syndrome: self-reported symptoms plus physical examination	Work history and self-reported work-related factors	+/-
Grzywacz 2012		X			Cross-sectional	Rotator cuff syndrome: self-reported symptoms plus physical examination	Job title (poultry vs non-poultry manual workers) and self-reported work-related factors	+/-
Herin 2012		X	X		Cohort	Chronic shoulder pain: self-reported symptoms plus physical examination	Self-reported work-related factors	-/-
Bugajska 2013		X			Cohort	Rotator cuff tendinitis: self-reported symptoms plus physical examination	Self-reported physical working conditions	+/-
Chung 2013		X			Cohort	Rotator cuff syndrome: national health insurance database (ICD-9 CM code: 726.1)	Job title (nurses vs reference group)	-/-
Rosenbaum 2013		X			Cross-sectional	Rotator cuff syndrome: self-reported symptoms plus physical examination	Job title (poultry vs non-poultry manual workers) and self-reported work-related factors	+/-
Svendsen 2013		X			Cohort (including the population described by Svendsen 2004b)	Subacromial impingement syndrome: first-time surgery (medical register, ICD-10: M19, M75.1– M75.9)	Job exposure matrix, experts' ratings and self-reported occupational exposure	-/-
Dalbøge 2014		X	X		Cohort	Subacromial impingement syndrome: first-time surgery (medical register, ICD-10: M19, M75.1– M75.9)	Job exposure matrix, experts' ratings, and employment register	-/-

(Continued)

Table 1. List of studies included in published systematic reviews on specific disorders of the shoulder and work-related risk factors along with those included in the update categorised by quality of evidence. (Continues)

Authors	Systematic reviews			Critical appraisal/update				
	van Rijn 2009	van der Molen 2017	Seidler 2020		Study Design	Outcome assessment	Exposure assessment	Ranking outcome/ exposure
Møller 2018			X		Cohort (same population as Thygesen 2016)	Subacromial shoulder disorders: diagnosed or surgically treated (patient register, ICD-10: M75.1-M75.9)	Job title (baggage handlers vs unskilled workers), self-reported data on work tasks, and biomechanical modelling in experimental setting	-/-
Hsiao 2015		X			Cohort	Shoulder subacromial impingement: military medical register (ICD-9 CM code: 726.10)	Military rank and branch of military service (military register)	-/-
Sansone 2015		X			Cross-sectional	Calcific tendinopathy: self-reported symptoms and ultrasonography without physical examination	Job title (cashiers vs customers)	NA/-
Nordander 2016		X			Cross-sectional (pooling 16 studies, including Ohlsson 1994, Nordander 1999 and Nordander 2009)	Supraspinatus, infraspinatus, and bicipital tendinitis: self-reported symptoms plus physical examination (diagnostic criteria not standardized and adequately described)	Direct measurements of physical exposure (exposure assessment not standardized and adequately described)	-/-

Thygesen 2016	X		Cohort	Subacromial shoulder disorders: diagnosed or surgically treated (patient register, ICD-10: M75.1-M75.9)	Job title (baggage handlers vs unskilled workers) and cumulative years of employment	-/-
Dalbøge 2017	X		Case-control (nested within the cohort described by Dalbøge 2014)	Subacromial impingement syndrome: first-time surgery (medical register, ICD-10: M19, M75.1– M75.9)	Self-reported job title, job exposure matrix, and cumulative occupational mechanical exposure	-/-
Dalbøge 2018	X		Cohort (reanalysis of Dalbøge 2014)	Subacromial impingement syndrome: first-time surgery (medical register, ICD-10: M19, M75.1– M75.9)	Employment register, job exposure matrix, and cumulative occupational mechanical exposure	-/-
Meyers 2021		X	Cohort	Rotator cuff syndrome: self-reported symptoms plus physical examination	Task-level biomechanical exposure assessment including video recordings: repetition rates and duty cycle of total exertion and forceful exertions, vibration (yes/no), and upper arm postures	+/++

(*) Occupational exposure to vibration was excluded from the present study.
Notes: NA, not applicable. These studies did not meet minimum requirements for diagnosis. The references of excluded studies are reported in Supplementary Table 3.

Table 2. Ranking for outcome/exposure combination by study design.

	Ranking for outcome/exposure combination			
Study design	**Minimum criteria for eligibility from (+/+) to (++/++)**	**Objective diagnostic criteria and indirect exposure assessment from (+/-) to (++/-)**	**Case definition based on self-reported symptoms from (-/-) to (-/++)**	**Not meeting minimum requirements for diagnosis**
Cross-sectional	3	12	2	2
Case-control	0	0	2	1
Cohort	3 (*)	2	9	0
Overall	6 (*)	14	13	3

(*) Sutinen 2006 measured the cumulative exposure to hand-arm vibration (excluded from the present study).
Note: The ranking for outcome and exposure combination is reported in Supplementary Table 1.

Table 3. Summary characteristics of included studies by study design (chronological order).

Study design	Country	Participants	Outcome	Main results	Covariates
Cohort					
Meyers 2021	USA	485 workers from a cohort of manufacturing and healthcare workers were followed for two years	Rotator cuff syndrome	Multivariable analyses: i. no association between rotator cuff syndrome and any single biomechanical exposure; ii. HR 1.11 (95%CI 1.04-1.34) for each unit increase in total repetition rate when the upper arm is abducted 30° for 12-21% of the working time; iii. HR 1.18 (95%CI 1.04-1.34) for each unit increase in forceful repetition rate when the upper arm is abducted 30° for 12-21% of the working time; iv. HR 1.16 (95%CI 1.04-1.29) for each unit increase in forceful repetition rate when the upper arm is abducted ≥60° for 5% of the working time; v. HR 1.11 (95%CI 1.01-1.22) for each unit increase in forceful repetition rate when the upper arm is flexed ≥45° for ≥29% of the working time	Confounders controlled for in the analysis: age, gender, education, BMI, diabetes mellitus, biomechanical exposure, psychosocial factors Data on physical activities outside of work were recorded
Werner 2005	USA	501 workers from four industrial and three clerical work sites were followed for an average of 5.4 years	Shoulder tendinitis	Univariate analysis: The study did not report an association between shoulder tendinitis and abnormal hand activity TLV (42.3% of incident cases vs 40.6% of referent subjects, p=0.87) or hand peak force at the dominant side (2.96 in incident cases vs 2.96 in referent subjects, p=0.98)	Covariates explored in univariate analysis included: age, gender, BMI, smoking habits, exercise levels, medical history, biomechanical exposure, psychosocial factors

Cross-sectional					
Silverstein 2008	USA	733 workers from manufacturing and health care sites	Rotator cuff syndrome	Multivariable analyses: i. OR 2.02 (95%CI 1.01-4.07) for frequent forceful exertions (i.e., ≥5 times/min); ii. OR 1.01 (95%CI 0.43-2.38) for performing shoulder movements > 20 times/min; iii. OR 2.16 (95%CI 1.22-3.83) for upper arm flexion ≥45° maintained for more than 18% of the time; iv. Combination of upper arm flexion ≥45° for more than 15% of the time was associated with rotator cuff syndrome either with a duty cycle of forceful exertions more than 9% of the time (OR 2.43, 95%CI 1.04-5.68) or a forceful pinch more than 0% of the time (OR 2.66, 95%CI 1.26-5.59)	Confounders controlled for in the analysis: age, gender, BMI, and psychosocial factors (only for combined exposures) Hobbies or sports requiring: i. high hand force, or ii. high repetitive hand activities were recorded
Svendsen 2004a	Denmark	529 machinists, 599 car mechanics, 758 house painters from 29 machine shops, 110 garages for domestic cars, and 119 painters' workshops	Supraspinatus tendinitis	Multivariable analyses: The supraspinatus tendinitis was associated with current upper arm elevation above 90° for 6-9% of working hours (OR 4.70, 95%CI 2.07-10.68) No association was found for lifetime upper arm elevation above 90° for both dominant and non-dominant shoulder	Confounders controlled for in the analysis: age, smoking habits, psychosocial factors Shoulder intensive sports were recorded
Frost 2002	Denmark	2846 workers from: four food processing companies, three textile plants, four electronic plants, three cardboard industries, two postal sorting centers, one bank, and two supermarkets	Shoulder tendinitis	Multivariable analyses: i. OR 3.29 (95%CI 1.34-8.11) for high frequency of shoulder movements (i.e., 15-36 movements/min); ii. OR 4.21 (95%CI 1.71-10.40) for high force demands (i.e., ≥10% of maximal voluntary contraction); iii. OR 3.33 (95%CI 1.37-8.13) for performing 80% of cycle time without pause; iv. combined exposures were found to be at risk	Confounders controlled for in the analysis: age, gender, BMI, shoulder injury/surgery, physical activity during leisure time, overhead sport

Abbreviations: ACGIH=American Conference of Governmental Industrial Hygienists; CI=Confidence Interval; BMI=Body Mass Index; HR=Hazard Ratio; OR=Odds Ratio; TLV=Threshold Limit Value.

at the univariate analysis) or hand peak force at the dominant side (2.96 in incident cases vs. 2.96 in referent subjects, p=0.98 at the univariate analysis) [22].

The study by Silverstein and colleagues reported that frequent forceful exertions (i.e., ≥ five times/min) were associated with an increased risk of rotator cuff syndrome (adjusted OR 2.02, 95%CI 1.01-4.07); on the other hand, performing shoulder movements more than 20 times per minute was found not to be associated (adjusted OR 1.01, 95%CI 0.43-2.38) [17]. In addition, upper arm flexion ≥45° doubled the risk of rotator cuff syndrome when maintained for more than 18% of the time (adjusted OR 2.16, 95%CI 1.22-3.83). The combination of upper arm flexion ≥45° for more than 15% of the time was associated with rotator cuff syndrome either with a duty cycle of forceful exertions more than 9% of the time (OR 2.43, 95%CI 1.04-5.68) or a forceful pinch more than 0% of the time (OR 2.66, 95%CI 1.26-5.59) [17].

The cohort study by Meyers and colleagues failed to identify an association between rotator cuff syndrome and any single biomechanical exposure. However, it showed an increased risk of incident rotator cuff syndrome for interactions between forceful hand exertions and upper arm elevation. In particular, it was found i) an hazard ratio [HR] of 1.11 (95%CI 1.04-1.34) for each unit increase in total repetition rate when the upper arm is abducted 30° for 12%-21% of the working time; ii) an HR of 1.18 (95%CI 1.04-1.34) for each unit increase in forceful repetition rate when the upper arm is abducted 30° for 12%-21% of the working time; iii) an HR of 1.16 (95%CI 1.04-1.29) for each unit increase in forceful repetition rate when the upper arm is abducted ≥60° for 5% of the working time; iv) an HR of 1.11 (95%CI 1.01-1.22) for each unit increase in forceful repetition rate when the upper arm is flexed ≥45° for ≥29% of the working time [18].

The quality assessment of the five included studies is reported in Table 4.

Four studies were ranked with medium quality scores [15-18], and the other one was classified as low quality [22]. Four out of five studies controlled for confounding [15-18]; of these, only one adjusted for non-occupational biomechanical risk factors [15].

4. Discussion

This review showed limited evidence of a causal relationship between occupational exposure to biomechanical risk factors and shoulder tendinopathies.

We summarised the existing epidemiological evidence for the associations between shoulder tendinopathies and occupational exposure to biomechanical risk factors. This study has a specific focus on both outcome and exposure assessment; in particular, we included i) studies in which physical examination was part of the outcome definition with or without the support of imaging; and ii) the exposure assessment was based on direct measurements or estimated with video recordings. Studies that used as outcome shoulder pain or were based on MRI/US without physical examination [24-26] were not considered to provide evidence of any causation as well those reporting/using an indirect measure of the exposure.

US was reported to be as accurate as MRI for identifying and measuring the size of partial and full-thickness rotator cuff tears [27]. However, a high prevalence of rotator cuff tears in asymptomatic subjects was detected using MRI [28]. The study also revealed a relationship of rotator cuff tears with increasing age in subjects who had normal, painless shoulder function. This casts a shadow for those studies that used imaging alone to diagnose shoulder tendinopathy in the absence of positive physical findings, considering that the disease–exposure association might be underestimated and confounded by age.

Compared to MRI, US tends to be more operator dependent, less costly and more accessible [29]. However, imaging techniques are not routinely applied in large epidemiological studies and, as reported in a recent scoping review, some studies proposed the use of X-ray to assess shoulder degenerative changes, while others sustained the use of US, to exclude a rotator cuff rupture [30].

A range of methods have been developed for the assessment of exposure to risk factors for work-related musculoskeletal disorders. The choice between these methods depends upon the nature of the investigation and purposes of the study. Self-reports from workers can be used to collect data on

Table 4. Detailed assessment of study quality for each included study (minimum score of 3 and maximum of 17).

Items	Frost 2002	Svendsen 2004a	Werner 2005	Silverstein 2008	Meyers 2021
a. Study design (1-3)					
Cross-sectional (1)	1	1	-	1	-
Cohort with a follow-up≤1 year (2)	-	-	-	-	-
Cohort with a follow-up>1 year (3)	-	-	3	-	3
b. Study population (0-3), sum of:					
Adequate description of inclusion/exclusion criteria (1)	1	1	0	1	1
Participation rate ≥70% (1)	1	1	0	1	1
Sufficient description on completers vs withdrawals (1)	0	0	0	0	0
c. Outcome assessment (1-3)					
Physical examination (symptoms and clinical signs) (1)	1	1	1	1	1
Physical examination (symptoms and clinical signs) plus imaging techniques (2)	-	-	-	-	-
Blinding for exposure status (+1)	1	1	0	1	1
d. Exposure assessment (1-3)					
Observation and video analysis (1)	1	-	1	-	1
Quantitative measurements (2)	-	2	-	2	-
Blinding for outcome status (+1)	0	0	0	1	1
e. Data analysis (0-5)					
Confounders in descriptive tables only (1)	-	-	1	-	-
Control for confounding (age, gender) (2)	-	-	-	-	-
Control for confounding (age, gender, and others) (3)	3	3	-	3	3
Analysis adjusted for non-occupational biomechanical risk factors (e.g. sport, hobby) (+1)	1	0	0	0	0
Robustness of the results to missing data (+1)	0	0	0	0	0
Total quality score	10	10	6	11	12

workplace exposure by using, for instance, interviews or questionnaires. However, a major problem with these subjective methods is that worker perceptions of exposure have been found to be imprecise and unreliable. For example, having musculoskeletal complaints were found to increase the probability of workers reporting higher durations or frequencies of physical load in comparison with those workers without musculoskeletal complaints from the same occupational groups [31, 32]. On the contrary, direct measurement techniques can provide more reliable data than those based on subjective judgements only. For the purpose of the present study, we included studies that reported quantitative measures of the exposure (like force measurement or, at least, observations supported by video analysis). Direct measurements and video-based observation of exposure are more desirable considering that these methods are assumed to have a higher level of accuracy than subjective assessment and self-reports [31, 32].

With respect to high frequency shoulder movements, only a cross-sectional study was in favor of an association with shoulder tendinopathies [15], while a cohort study [18] and a cross-sectional study [17] did not support it. In addition, another cohort study did not report an association between repetitive hand movements and shoulder tendinopathies [22].

Two cross-sectional studies reported an association with rotator cuff syndrome or supraspinatus tendinopathy with upper arm elevation [16, 17]. Conversely, a cohort study did not support this association [18].

With respect to forceful exertions, two cross-sectional studies reported an association with rotator cuff syndrome [17] or with shoulder tendinopathy [15], while two cohort studies did not report this association [18, 22].

Regarding combined exposures, a cross-sectional study showed an association between upper arm flexion (≥45°) and frequent forceful exertions with rotator cuff syndrome [17]. The same study reported an association between upper arm flexion (≥45°) and forceful pinch as well [17]. Moreover, a cohort study found a weak association between rotator cuff syndrome and forceful hand exertions plus upper arm flexion or abduction [18]. Finally, a cross-sectional study found an association between high-force demands and a high frequency of shoulder movements with shoulder tendonitis [15].

Based on a cohort study and a cross-sectional study of medium quality, we found moderate evidence of a causal association between shoulder tendinopathy and combined exposures of working with arms above shoulder level with forceful hand exertion [17, 18]. On the other hand, the evidence is still insufficient for any single biomechanical exposure considered by itself.

These findings contrast with a recent systematic review with metanalysis that calculated a 21% risk increase (95%CI 4–41%) per 1000 h of work above the shoulder [11]. It should be noted that the studies included in this meta-analysis were heterogeneous in terms of study design, exposure assessment, and diagnosis [24, 25, 33].

In the present study, we searched PubMed only. Nevertheless, PubMed indexes the vast majority of high-quality studies published in biomedical journals [34]. In addition to that, we successfully tested our PubMed search strategy against the 34 studies included in the three selected reviews [9-11]. As a result, all 34 citations were retrieved.

5. Conclusion

High-quality cohort studies are needed. Direct exposure measures and objective diagnostic criteria are desirable to minimize potential biases. Furthermore, there is a need for a consensus on the minimal diagnostic criteria used in epidemiological studies on shoulder tendinopathies. Epidemiological studies on the possible occupational origin of shoulder tendinopathies should consider non-occupational risk factors (including sports) and comorbidities. So far, the occupational origin of shoulder tendinopathies is still an open question that needs to be properly answered.

Supplementary Materials: Supplementary Table 1, Supplementary Table 2, Supplementary Table 3.

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Supplementary Table 1. Level of evidence based on data quality for exposure assessment and diagnosis.

Diagnosis	Exposure assessment		
	Direct evaluation		Indirect evaluation
	Quantitative measures	Video analysis or video-based observations	Job title, self-reported assessment, job exposure matrix, experts' ratings
Imaging (plus physical examination)	++/++	++/+	++/-
Physical examination (symptoms plus clinical signs)	+/++	+/+	+/-
Self-reported symptoms	-/++	-/+	-/-

Modified from Curti S, Mattioli S, Bonfiglioli R, et al. Elbow tendinopathy and occupational biomechanical overload: A systematic review with best-evidence synthesis. J Occup Health. 2021 Jan;63(1):e12186.

Supplementary Table 2. Search strategy developed for PubMed.

Search strategy
#1
(shoulder pain[MH] OR shoulder impingement syndrome[MH] OR ((rotator cuff[MH] OR "rotator cuff" OR infraspinatus[TW] OR supraspinatus[TW] OR subscapularis[TW] OR biceps[TW] OR bicipital[TW] OR shoulder joint[MH] OR shoulder[MH] OR shoulder*[TW]) AND (cumulative trauma disorders[MH] OR pain[TW] OR complaint* OR disorder* OR discomfort* OR symptom* OR tendon* OR tendin*)) OR "rotator cuff tear*" OR "rotator cuff syndrome" OR "rotator cuff disease*" OR "subacromial impingement" OR "shoulder impingement*" OR "subacromial pain")
#2
(occupational diseases[MH] OR occupational exposure[MH] OR occupational medicine[MH] OR occupational risk[TW] OR occupational hazard[TW] OR (industry[MeSH Terms] mortality[SH]) OR occupational group*[TW] OR work-related OR occupational air pollutants[MH] OR working environment[TW] OR "at work"[TW] OR "repetitive work" OR "manual work" OR lifting[MH] OR workload[MH] OR physical exertion[MH] OR Moving and Lifting Patients[MH] OR "heavy lifting" OR "manual material handling" OR "manual lifting" OR "manual handling" OR "repetitive lifting" OR posture[MH] OR "awkward position*" OR "awkward postur*" OR "above shoulder" OR "upper arm elevation" OR "overhead work")
#3
#1 AND #2
#4
#3 NOT (animals[MH] NOT humans[MH])

Supplementary Table 3. References of excluded studies.

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Miranda 2005	Miranda H, Viikari-Juntura E, Heistaro S, et al. A population study on differences in the determinants of a specific shoulder disorder versus nonspecific shoulder pain without clinical findings. *Am J Epidemiol*. 2005 May 1;161(9):847-55.
Wang 2005	Wang LY, Pong YP, Wang HC, et al. Cumulative trauma disorders in betel pepper leaf-cullers visiting a rehabilitation clinic: experience in Taitung. *Chang Gung Med* J. 2005 Apr;28(4):237-46.
Melchior 2006	Melchior M, Roquelaure Y, Evanoff B, et al. Why are manual workers at high risk of upper limb disorders? The role of physical work factors in a random sample of workers in France (the Pays de la Loire study). *Occup Environ Med*. 2006 Nov;63(11):754-61.
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Chung 2013	Chung YC, Hung CT, Li SF, et al. Risk of musculoskeletal disorder among Taiwanese nurses cohort: a nationwide population-based study. *BMC Musculoskelet Disord*. 2013 Apr 23;14:144.
Rosenbaum 2013	Rosenbaum DA, Grzywacz JG, Chen H, et al. Prevalence of epicondylitis, rotator cuff syndrome, and low back pain in Latino poultry workers and manual laborers. *Am J Ind Med*. 2013 Feb;56(2):226-34.
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