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SYSTEMATIC REVIEW

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Musculoskeletal disorders among sonographers: a systematic review and meta-analysis

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Abstract

Introduction The job of sonographers exposes them to numerous ergonomic risk factors, making the sonography profession one of the high-risk job groups vulnerable to musculoskeletal disorders (MSDs). The present systematic review and meta-analysis specifically examined the prevalence of MSDs among sonographers.

Materials and methods The present review study was carried out in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. The protocol of the study was registered in the international prospective register of systematic review (PROSPERO) with the code CRD42024507972. Searches were conducted in databases including PubMed, Scopus, Web of Science, Science Direct, SID, ISC, and Google Scholar, without imposing a time limit until February 7th, 2024. The random-effects model was employed for meta-analysis, and the I^2 index was used to assess heterogeneity among studies. Finally, data analysis was performed using STATA (version 14).

Results Based on the search in different databases, a total of 4367 articles were identified. Finally, after screening, selecting, and quality evaluation of the studies, 30 studies were considered for meta-analysis in which 13,916 sonographers were examined. According to the results of the meta-analysis, the overall prevalence of MSDs among sonographers was reported as 75.80% (95% CI: 65.37–86.23, $I^2 = 99.7\%$, $P < 0.001$). Additionally, the prevalence rates of these disorders in the neck (63.73%), shoulder (60.13%), upper back (53.69%), lower back (49.84%), wrist (44.41%), elbow (27.46), hip (24.93%), knee (19.59), and ankle (16.92%) were determined.

Conclusion Given the relatively high prevalence of MSDs among sonographers and the importance of reducing specific risk factors associated with their duties, it is recommended to consider solutions such as carrying out ergonomic assessments and interventions, as well as providing training programs and appropriate corrective exercises to mitigate MSDs among sonographers.

Keywords Musculoskeletal disorders, Sonography, Risk factors, Prevention, Ergonomics

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Introduction

Musculoskeletal disorders (MSDs) are a heterogeneous collection of over 150 inflammatory and degenerative conditions that affect the muscles, bones, nerves, tendons, and ligaments [1]. These disorders are a common cause of job-related diseases in both industrialized and developing countries [2, 3]. Work-related musculoskeletal disorders (WRMDs) specifically refer to diseases or conditions that arise due to factors associated with one's occupation [1]. WRMSDs are the leading reason for lost working days, increased healthcare costs, human injuries, and disability [2].

Health care workers are among the most vulnerable groups to WMSDs during their shifts [4, 5]. A specific field in the health care industry that is of a particular importance is medical sonography. Since the inception of medical ultrasound, the health care field has heavily relied on this technique for diagnostics [6].

The nature of the sonographers' job exposes them to ergonomic risk factors, which mainly consist of physical factors. These physical factors include awkward postures, static muscle contractions, repetitive and precise movements of the upper limbs, particularly the wrists and hands [7], along with the use of push force and grip force [8]. During examinations, the sonographer's arm remains in a contracted position. In this position, the shoulder may elevate up to 200 degrees and abduct up to 90 degrees, especially when the sonographer attempts to scan an area on the opposite side of the patient's body. Additionally, the sonographer's neck and torso may twist when reaching for the control panel [4, 9, 10]. Studies have shown that twisted postures and other awkward positions account for approximately 67% of scanning time [11]. According to reports, the force applied to the hand and wrist during 90% of the scanning time is at least 1 kg, with the average grip force on the probe being 3.96 kg throughout the entire scanning session. During the scanning of an obese patient, this force may increase up to 27.6 kg [12]. Research has also demonstrated that using a pinch-grip of more than 0.9 kg to hold the probe and a power-grip of over 5.5 kg is associated with an increased risk of WMSDs [9]. Furthermore, performing these activities for more than four continuous hours per day has been linked to an elevated risk of WMSDs among sonographers [13].

In addition to physical factors, psychosocial and individual factors also contribute to the development of MSDs among sonographers. Low job satisfaction [14] and increased demand for examinations [15] are psychosocial factors that can heighten the risk of WMSDs. Individual factors, such as female gender [16], older age, longer work experience, and a higher body mass index (BMI), also play a significant role in the onset and severity of WMSDs [17]. Evidence suggests that advances in ultrasound technology have led to an increase in the number of ultrasounds performed, along with longer durations for each examination. Consequently, the focus on sonographers' work productivity can result in job stress and an excessive workload, which may lead to musculoskeletal complaints [6].

So far, numerous studies have been carried out in the field of MSDs among sonographers. Findings from a review study by Alshuwaer and Gilman indicated that the most common WMSDs among sonographers are associated with the shoulder region. These job-related diseases can impact the sonographer's performance and result in a decline in the quality of service provided to patients [18]. Reviewing the results of studies reveals that one in five sonographers suffers from WMSDs that could potentially end their careers. This issue underscores the significance and urgency of reducing WMSDs among sonographers [19]. Some studies have stated that the secondary effects of WMSDs, such as absenteeism, rising healthcare expenses, and reduced productivity, can be financially burdensome for both sonographers and employers [20]. Moreover, the quality of a sonographer's life may diminish due to the inability to carry out normal daily activities, leading some to switch jobs or consider early retirement due to WMSDs [21].

In addition to the aforementioned studies, the results of various ergonomic interventions demonstrate the positive impact of diverse strategies in reducing WMSDs among sonographers. Specifically, the use of modified probes [22, 23], arm support systems [24, 25], portable chairs [24], biplanar scanning [26], and ambidextrous scanning [27] has proven effective in reducing WMSDs. Furthermore, studies have shown that training in proper postural behavior leads to significant changes in sonographers' practices [28, 29]. These findings emphasize that a thorough understanding of the prevalence and types of MSDs can contribute to the development of effective ergonomic interventions and preventive strategies, highlighting the importance of evaluating and implementing appropriate measures to improve occupational health and reduce job-related injuries among sonographers.

Surveys indicate that the sonography profession is one of the most high-risk job groups vulnerable to MSDs [30, 31]. Therefore, given the significance of reducing MSDs in this occupation, it appears essential to conduct thorough and valid epidemiological studies on the prevalence of MSDs. Although several studies have been conducted in recent years to investigate the prevalence of MSDs among sonographers, our review reveals that there has been no comprehensive study on the overall prevalence and types of MSDs among sonographers. Various studies have been carried out with different sample sizes in various countries. However, conducting a meta-analysis by combining data from different studies can enhance the accuracy of the results. In fact, the results of a meta-analysis on the overall prevalence and types of MSDs among sonographers can assist public health policymakers in making more informed decisions regarding resource allocation and planning for the prevention and treatment of these disorders. Therefore, in the present study, we opt to conduct a systematic review and meta-analysis. This endeavor aims not only to establish a valuable information source on MSDs among sonographers but also to enhance the level of knowledge and awareness among healthcare industry managers. This enables better planning and implementation of training programs and corrective actions.

Table 1 Search strategy across various types of databases

Database	Search strategy
PubMed	((“Ultrasound*” OR “Ultrasound equipment*” OR “Sonographers*” OR “Sonography*”) AND (“WRMSDs” OR “Musculoskeletal symptom*” OR “Musculoskeletal pain” OR “Musculoskeletal problem*” OR “Muscle strain*” OR “Musculoskeletal complaint*” OR “Musculoskeletal disorder*” OR “Work related Musculoskeletal disorder*” OR “Musculoskeletal disease*” OR “MSDs” OR “Arthritis bone*” OR “Elbow pain*” OR “Hand pain*” OR “Neck pain*” OR “Back pain*” OR “Arthritis joint*” OR “Muscle problem*” OR “Shoulder pain*” OR “Dysfunction*”))
Scopus	(((TITLE-ABS-KEY(“Ultrasound equipment*”) OR TITLE-ABS-KEY(“Sonographers*”) OR TITLE-ABS-KEY(“Sonography*”)) AND (TITLE-ABS-KEY(“WRMSDs”) OR TITLE-ABS-KEY(“Musculoskeletal symptom*”) OR TITLE-ABS-KEY(“Musculoskeletal pain*”) OR TITLE-ABS-KEY(“Musculoskeletal problem*”) OR TITLE-ABS-KEY(“Muscle strain *”) OR TITLE-ABS-KEY(“Musculoskeletal complaint *”) OR TITLE-ABS-KEY(“Musculoskeletal disorder *”) OR TITLE-ABS-KEY(“Work related Musculoskeletal disorder*”) OR TITLE-ABS-KEY(“Musculoskeletal disease *”) OR TITLE-ABS-KEY(“MSDs”) OR TITLE-ABS-KEY(“Arthritis bone*”) OR TITLE-ABS-KEY(“Elbow pain *”) OR TITLE-ABS-KEY(“Hand pain*”) OR TITLE-ABS-KEY(“Neck pain*”) OR TITLE-ABS-KEY(“Back pain *”) OR TITLE-ABS-KEY(“Arthritis joint *”) OR TITLE-ABS-KEY(“Muscle problem *”) OR TITLE-ABS-KEY(“Shoulder pain *”) OR TITLE-ABS-KEY(“Dysfunction *”))))
Web of Science	(((TS=(“ Ultrasound*”) OR TS=(“ Ultrasound equipment*”) OR TS=(“Sonographers*”) OR TS=(“Sonography*”)) AND (TS=(“WRMSDs”) OR TS=(“Musculoskeletal symptom*”) OR TS=(“Musculoskeletal pain*”) OR TS=(“ Musculoskeletal problem*”) OR TS=(“Muscle strain*”) OR TS=(“ Musculoskeletal complaint *”) OR TS=(“ Musculoskeletal disorder*”) OR TS=(“Work related Musculoskeletal disorder *”) OR TS=(“ Musculoskeletal disease*”) OR TS=(“ MSDs”) OR TS=(“ Arthritis bone *”) OR TS=(“ Elbow pain *”) OR TS=(“ Hand pain *”) OR TS=(“ Neck pain*”) OR TS=(“ Back pain *”) OR TS=(“ Arthritis joint *”) OR TS=(“ Muscle problem *”) OR TS=(“ Shoulder pain *”) OR TS=(“ Dysfunction*”))))

Materials and methods

In this study, a systematic review and meta-analysis were conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [32]. The protocol for the present study is registered in international prospective register of systematic reviews (PROSPERO) under the code CRD42024507972. Various stages of the study were conducted based on the PRISMA protocol. These stages included the search strategy, screening, study selection, quality assessment, and data extraction. Two researchers independently carried out the study selection, quality assessment, and data extraction processes. In case of any disagreements between the researchers, decisions were made through discussion with a third researcher and group deliberation.

Databases and search strategy

In this phase of the study, information sources such as PubMed, Scopus, Web of Science, Science Direct, Iranian Scientific Information Database (SID), Islamic World Science Citation Center (ISC), Google Scholar, conference and congress article collections, and the reference lists of selected articles and systematic review studies were utilized to search for and extract relevant studies. To initiate the search process, appropriate keywords were chosen from related articles and Medical Subject Heading (MeSH) terms as well as keywords suggested by scientific experts. The search strategies for all database types were compiled using the following valid keywords:

> Ultrasound*”, “Ultrasound equipment*”, “Sonographers*”, “Sonography*”, “WRMSDs”, “Musculoskeletal symptom*”, “Musculoskeletal pain”, “Musculoskeletal problem*”, “Muscle strain*”, “Musculoskeletal complaint*”, “Musculoskeletal disorder*”, “Work related Musculoskeletal disorder*”, “Musculoskeletal disease*”, “MSDs”, “Arthritis bone*”, “Elbow pain*”, “Hand pain*”, “Neck pain*”, “Back pain*”, “Arthritis joint*”, “Muscle problem*”, “Shoulder pain*”, and “Dysfunction*.

To combine keywords, operators and search fields were employed. Additionally, searches were conducted without a time limit until February 7th, 2024. Table 1 illustrates the search strategies across various database types.

Inclusion criteria

Studies reporting the prevalence of MSDs among sonographers were included in the review.

Exclusion criteria

Review studies, case reports, interventional studies, non-English papers, letters to the editor, and reports on the prevalence of MSDs caused by accidents were excluded from the study.

Study selection

After the search, all articles were imported into the EndNote X7 software to manage the search results. Subsequently, duplicates were removed, and based on the inclusion criteria, the titles and abstracts of the remaining articles were screened. Then, the primary potentially relevant articles were identified. Subsequently, the full text of these articles was independently and thoroughly reviewed by two researchers. Ultimately, the eligible articles were selected.

Quality assessment and data extraction

In this step, the selected studies underwent qualitative evaluation by two researchers independently. The Appraisal tool for Cross-Sectional Studies (AXIS) [33, 34] was utilized for this evaluation, with a scoring system ranging from 0 to 20. In this study, articles scoring 12 and higher were selected for meta-analysis. Then, two researchers independently extracted the data. For each study, various characteristics such as the first author's name, sample size, mean age of the studied population, tools used, the number of male and female participants, and the overall prevalence of MSDs along with their distribution in different body regions were extracted. Subsequently, these details were recorded in a pre-designed checklist.

Statistical analysis

To calculate the variance for each study, binomial distribution was utilized, and a weighted average was employed to combine the prevalence of MSDs across different studies. The weighting of each study was determined based on its inverse variance. In this context, the weighting of each study was based on the inverse variance. This means that the variance of the effect estimate was calculated for each study, and then the weight of each study was determined as the inverse of its variance. Studies with lower variance received higher weights, as they indicate greater precision in effect estimation. After calculating the weights, the results from different studies were combined using a weighted average, resulting in a pooled effect. This method helps researchers obtain an overall estimate of the effect and assess the uncertainty and variability between studies, ultimately leading to a better interpretation of the meta-analysis results.

The I^2 index was utilized to assess heterogeneity among the studies. Heterogeneity levels were categorized into ranges of less than 25%, 25–50%, 50–75%, and above 75%, indicating no heterogeneity, medium heterogeneity, high heterogeneity, and very high heterogeneity, respectively [35]. Begg's test was employed to examine publication bias. Lastly, the data from the present study were analyzed using STATA (version 14).

Results

Systematic review results

First, 4367 articles were gathered through a primary search. After eliminating duplicate studies, the remaining 3478 articles underwent screening. Based on the screening of the primary studies, 53 studies were considered for a more detailed full text review. Finally, 30 studies were selected by reviewing the full text of the articles, which were evaluated qualitatively. In the next step, all 30 studies proceeded to the meta-analysis stage (Fig. 1). In total, 13,916 sonographers were assessed in this study for the prevalence of MSDs. Of the 30 studies reviewed, 27 examined the overall prevalence of MSDs, involving a total sample size of 11,450 sonographers. In Table 2, the characteristics of the reviewed studies are reported.

Meta-analysis results

Based on the results of the meta-analysis, 75.80% (95% CI: 65.37–86.23, $I^2=99.7\%$, $P<0.001$) of the sonographers had experienced pain or discomfort in at least one region of the body. In Fig. 2, the details of individual studies and their pooled effect estimate are displayed. Each black circle represents the effect size of a study, and its size corresponds to the weight assigned to that study in the meta-analysis. The horizontal line around each circle indicates the 95% confidence interval. At the bottom of the figure, a diamond is shown, which represents the pooled effect estimate based on the weights assigned to the circles, with its horizontal diameter reflecting the 95% confidence interval of the pooled effect of the outcome of interest.

Moreover, the heterogeneity among the reviewed studies, as indicated by the I^2 index in this study, was notably high (Fig. 2). It should be noted that due to the considerable difference in the prevalence rates of MSDs across different studies or heterogeneity (I^2 heterogeneity index), a random-effects model was employed in the meta-analysis. The random-effects model is used in meta-analyses and systematic reviews because of its ability to handle variability between the results of different studies. This model assumes that the true effect may vary from study to study, thereby enhancing the generalizability of the results to broader populations. Additionally, by reducing bias caused by study selection and focusing on the distribution of various effects, it can provide more accurate estimates of the true effects.

The publication bias regarding the prevalence of overall MSDs among sonographers, based on Begg's test results ($P=0.203$), was deemed insignificant (Fig. 3). Egger's test ($P=0.255$) also indicates negligible publication

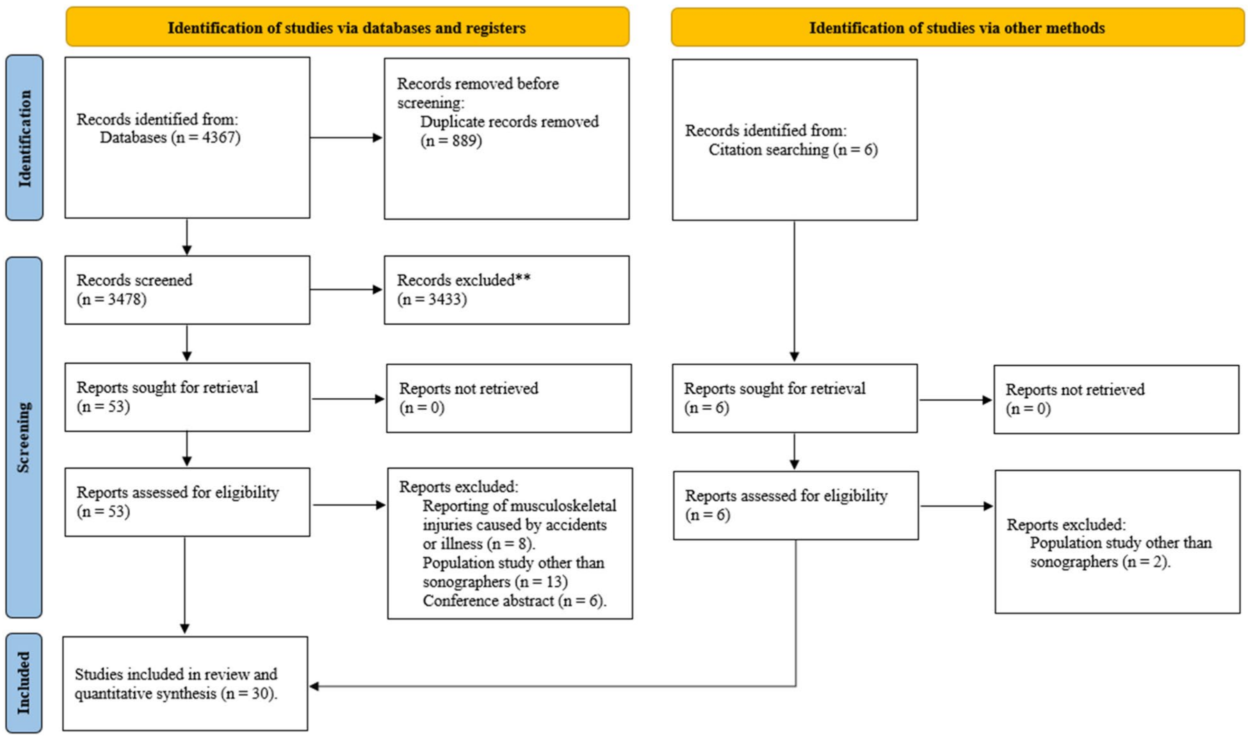

Fig. 1 Flowchart of study selection according to PRISMA

bias in the reported prevalence of overall MSDs among sonographers.

As seen in Table 3, based on the results of the subgroup analysis examining the rate of MSDs in different body regions, the highest prevalence is associated with the neck at a rate of 63.73% (95% CI: 56.17–71.30, I^2=98.9%, P<0.001), while the lowest rate is linked to the ankle at 16.92% (95% CI: 9.28–24.56, I^2=96.7%, P=0.001). Additionally, the I^2 values are notably high for all investigated regions. The publication bias in the prevalence of MSDs across different body regions among sonographers was insignificant for all nine regions investigated, as indicated by the results of both Begg's and Egger's tests.

Discussion

In this review study, which was conducted to explore the prevalence of MSDs among sonographers, 30 studies were chosen for meta-analysis. The findings of the meta-analysis revealed that the prevalence of MSDs among sonographers was 75.80%. In addition, the prevalence rates of these disorders in various body regions, including neck (63.73%), shoulder (60.13%), upper back (53.69%), lower back (49.84%), wrist (44.41%), elbow (27.46), hip (24.93%), knee (19.59), and ankle (16.92%) were estimated. According to the findings, the neck region exhibited the highest prevalence of MSDs among the surveyed population.

The results of a review study showed that the prevalence of MSDs among sonographers exceeded 90%, with the upper limbs, neck, and back being the most commonly affected regions. The reviewed studies mainly included general sonographers, while echocardiographers were in the second place [62]. In another review, Alaniz and Veale stated that 90% of sonographers experienced pain while performing examinations [63]. In a review study among Iranian dentists, the prevalence of MSDs was reported at 17.6%, with the highest pain related to the thorax (51.9%), elbow (37.3%), neck (33.7%), shoulder (33.4%), and knee (33.2%) [64].

The present study indicates that many of the examined individuals are at risk of MSDs due to exposure to ergonomic risk factors, including awkward postures, especially in the upper limb, neck, and trunk, as well as sedentary and prolonged sitting behaviors. Regarding the nature of sonographers' profession, their awkward postures of the upper limbs, particularly the right side, while holding the probe in contact with the patient's body, is one of the significant reasons for the incidence of MSDs among sonographers [46, 65]. Sonographers must bend or twist their trunk to access the left side of the patient's body and keep the probe in contact with the body during scanning. This not only forces them into a position with uneven body weight distribution but also compels them to turn their neck toward the monitor to view it. Each of these factors (trunk twisting/bending, neck rotation, and unsupported legs) increases the likelihood of injury to the neck, trunk, and legs. Therefore, when the examination regions on the patient's body are farther from the

Table 2 Study specifications considered in meta-analysis

First author/Year	Country	Sample size	Mean age	Total prevalence of MSDs	Prevalence of MSD types	Tools[a]
Fukumura (2024) [36]	USA	2924	ABD+: 47.9 Echo: 49.0 OB/GYN: 51.3 VT: 49.3	20.23%	Neck: 60.3% Lower back: 43% Hip: 35% Knee: 30.7% Ankle: 30% Shoulder: 70.5% Upper back: 40.3% Elbow: 36% Wrists/hand: 58.7%	WellBQ
Al Saikhan (2023) [37]	Saudi Arabia	152 (female: 112/male: 40)	32.1 ± 8.4	84.4%	Shoulder: 63.2% Neck: 51.3% Lower back: 48% Upper back: 42.8% Wrists/hand: 55.9% Elbow: 23%	NMQ
Bagley (2023) [38]	USA	127	PPDW: 39.2 ± 10.0 PWPDW: 35.9 ± 9.3	63.8%	NR	Self-administered questionnaire
Arvidsson (2020) [39]	Sweden	222	NR	24%	Lower back: 28% Shoulder: 53% Neck: 44% Feet: 12% Hand: 25%	NMQ
Bonutto (2020) [40]	Australia	39	29.41 ± 7.70	84.62%	NR	Self-administered questionnaire
Zhang (2020) [41]	China	249 (female: 183/male: 66)	33.5 ± 7.0	95.2%	Neck: 74.7% Left Shoulder: 29.3% Right shoulder: 81.1% Left forearm/elbow: 10.0% Right forearm/elbow: 48.2% Left wrist/hand: 16.1% Right wrist/hand: 59.4% Upper back: 23.7% Lower back: 57.0% Left thigh/hip: 10.0% Right thigh/hip: 18.9% Left knee: 10.0% Right knee: 15.3% Left ankle/foot: 7.2% Right ankle/foot: 9.2%	NMQ
Al-Rammah (2017) [42]	Saudi Arabia	100 (female: 76/male: 24)	NR	84%	Neck: 81% Shoulder: 81% Upper back: 72% Lower back: 64% Wrist: 64% Hand/fingers: 64% Forearm: 57%	Self-administered questionnaire

Table 2 (continued)

First author/Year	Country	Sample size	Mean age	Total prevalence of MSDs	Prevalence of MSD types	Tools[a]
Junejo (2017) [43]	Pakistan	145 (male: 86/ female: 59)	NR	75.17%	Lower back: 53.21% Shoulder: 6.42% Upper limb: 22% Neck: 24.77% Upper back: 38.4% Hand/wrist: 8.25% Finger: 7.33%	NMQ
Pallotta (2017) [44]	Australia	85	NR	30%	NR	Self-administered questionnaire
Simonsen (2017) [17]	Sweden	29 (female)	44	65%	Neck: 58% Shoulder: 58% Elbow: 30% Hand: 30%	Self-administered questionnaire
Scholl (2017) [31]	USA	1058	NR	85.5%	Shoulder: 60.8% Hand/wrist: 45.6% Neck: 43.3% Lower back: 27% Upper back: 26.2%	Self-administered questionnaire
Wareluk (2017) [45]	Poland	553	NR	83%	Spine: 81% Back: 81% Shoulder: 49.34% Elbow: 16.81% Wrist: 44.1% Hand/finger: 21.83%	Self-administered questionnaire
Zhang (2017) [46]	China	567 (female: 43/male: 128)	36.9 ± 7.6	99.3%	Neck: 95.1% Left shoulder: 66.1% Right shoulder: 84.1% Left forearm/elbow: 33.3% Right forearm/elbow: 72.0% Left wrist/hand: 25.2% Right wrist/hand: 81.0% Upper back: 78.1% Lower back: 82.4% Left thigh/hip: 25.6% Right thigh/hip: 39.5% Right knee: 26.6% Left knee: 22.2% Left ankle/foot: 10.2% Right ankle/foot: 12.3%	NMQ
Arvidsson (2016) [47]	Sweden	291 (female)	44 ± 13	NR	Neck: 44% Wrists/hand: 25% Shoulder: 51% Lower back: 29% Feet: 10%	NMQ
Feng (2016) [16]	China	232 (female: 174/male: 58)	33.1 ± 7.2	98.3%	Neck: 93.5% Shoulder: 92.2% Lower back: 83.2% Wrist/hand: 79.7% Upper back: 72.8% Elbow: 41.8%	NMQ

Table 2 (continued)

First author/Year	Country	Sample size	Mean age	Total prevalence of MSDs	Prevalence of MSD types	Tools[a]
Oke (2013) [48]	Nigeria	51 (male: 35/female:16)	NR	88%	Back: 41% Wrist joint: 27% Shoulder joint: 14% Elbow: 4%	Self-administered questionnaire
Randall (2012) [49]	USA	246	42.5 ± 9.6	62%	Shoulder: 11.6% Upper arm: 11.6% Hand/ wrist: 7.7%	Self-administered questionnaire
Roll (2012) [50]	USA & Canada	2163	NR	NR	Shoulder: 73% Neck: 70.8% Upper back: 48% Middle back: 19% Lower back: 32.3% Arm: 30.8% Elbow/forearm: 33.2% Wrist: 50% Hand/finger: 44.5%	Self-administered questionnaire
Burnett (2010) [6]	USA	7	38	86%	Neck: 86% Shoulder: 71% Upper back: 71% Lower back: 71% Hand/wrist: 43% Elbow: 29%	NMQ
Evans (2009) [51]	USA	2963	NR	90.4%	Neck: 65.8% Upper back: 44.3% Middle back: 17.9% Lower back: 33.2% Shoulder: 74.6% Shoulder blade: 37.7% Upper arm: 27.0% Elbow/forearm: 32.1% Wrist: 49.7% Hand/fingers: 44.2%	Self-administered questionnaire
Hill (2009) [52]	USA	26 (female)	36.9 ± 8.68	96%	Neck: 50% Knee: 23% Upper back: 15% Shoulder: 73% Hand/wrists: 54% Lower back: 69% Elbow: 27% Hip/thigh: 19% Foot/ankle: 8%	NMQ
Gibbs (2008) [53]	England	12 (female: 10/male: 2)	NR	NR	Shoulder: 58.3% Neck: 25% Forearm: 8.3% Back: 8.3% Wrists: 16.6%	Self-administered questionnaire

Table 2 (continued)

First author/Year	Country	Sample size	Mean age	Total prevalence of MSDs	Prevalence of MSD types	Tools[a]
Friesen (2006) [54]	Canada	12 (female: 8/male: 4)	40	75%	Neck: 81% Shoulder: 81% Upper back: 72% Lower back: 64% Wrist: 64% Hand/fingers: 64% Forearm: 57%	Self-administered questionnaire
Muir (2004) [55]	Canada	67	NR	91%	Lower back: 40% Wrist: 52% Shoulder: 78% Neck: 71% Knee: 7% Hip/thigh: 13% Foot/ankles: 7% Upper back: 61% Hand/finger: 55% Upper leg: 6% Lower leg: 6% Upper Arm: 34% Forearm: 5%	Self-administered questionnaire
Russo (2002) [56]	Canada	211	NR	91%	Shoulder: 84% Upper back: 77% Neck: 83% Lower back: 58% Upper arm: 77% Wrist: 61% Hand/fingers: 56% Middle back: 40% Forearm: 40%	Self-administered questionnaire
Schoenfeld (1999) [57]	Israel	44 (female: 34/male: 10)	38.2	57%	NR	Self-administered questionnaire
Pike (1997) [58]	Canada	983	NR	81%	Upper leg: 8.5% Lower leg: 11.5% Hip: 27% Forearm: 34.5% Upper arm: 38% Middle back: 39% Knee: 18% Hand/finger: 61.5% Neck: 74.1% Upper back: 61% Shoulder: 74% Wrists: 65.2% Lower back: 65% Foot/ankle: 22.5%	Self-administered questionnaire
Smith (1997) [59]	USA	113	NR	80%	NR	Self-administered questionnaire

Table 2 (continued)

First author/Year	Country	Sample size	Mean age	Total prevalence of MSDs	Prevalence of MSD types	Tools[a]
Wihlidal (1997) [60]	Canada	96 (male: 83/female: 13)	NR	89.4%	Shoulder: 46.9% Neck: 42.7% Elbow: 20.8% Lower back: 33.3% Hand/wrist: 33.3% Finger: 25%	Self-administered questionnaire
Necas (1996) [61]	USA	149 (male: 126/female: 23)	NR	66%	Lower back: 46% Shoulder: 66% Neck: 76% Hand/wrist: 61% Elbow: 33% Upper back: 53% Foot/ankles: 27% Finger: 40%	Self-administered questionnaire

[a] *NMQ* Nordic musculoskeletal questionnaire, *WellBQ* Well-Being Questionnaire

NR Not Reported

ABD+ Abdominal sonographers

Echo Echocardiographers

OB/GYN Obstetrics/gynecology sonographers

VT Vascular technology sonographers

PPDW Participants with Pain During Work

PWPDW Participants without Pain During Work

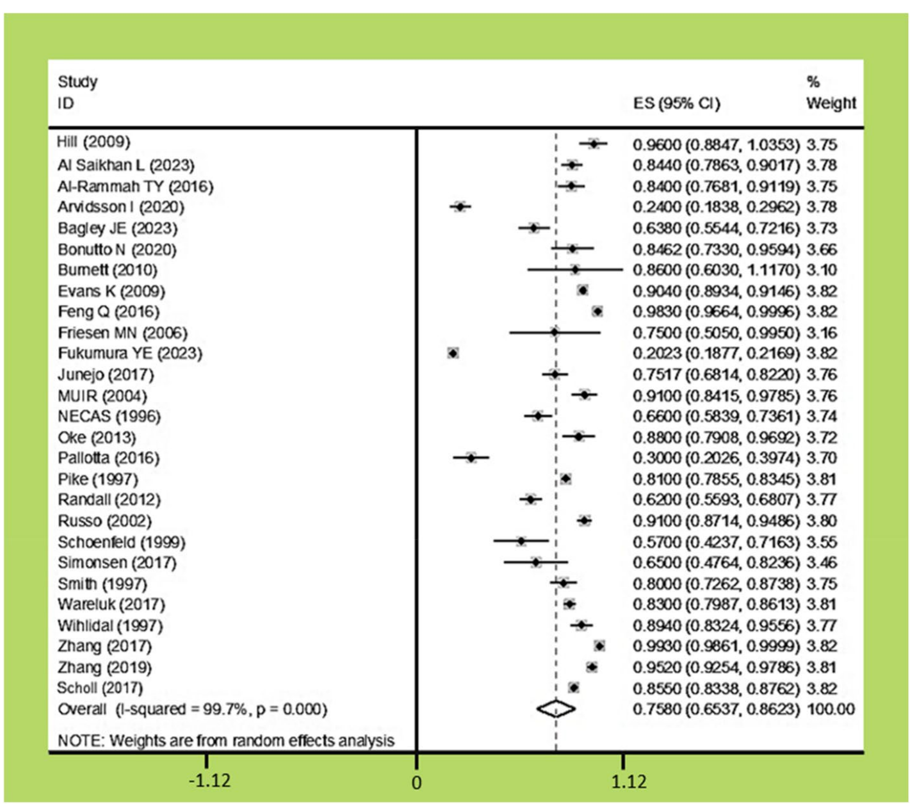

Fig. 2 Overall prevalence of MSDs among sonographers and 95% confidence interval for each of the reviewed studies and all studies

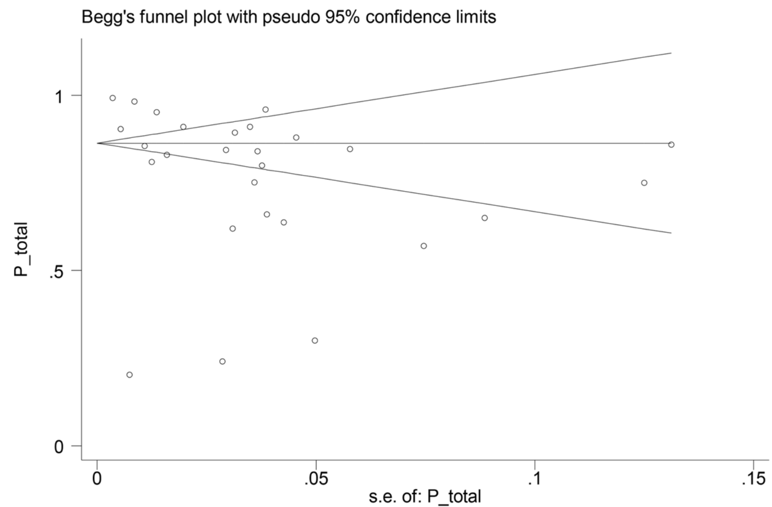

Fig. 3 Publication bias based on Begg's test for overall prevalence of MSDs among sonographers

Table 3 Meta-analysis results for different body regions

MSDs	Number of studies	Sample size	Prevalence of MSDs	95% CI	I^2	Begg's test	Egger's test
Neck	4	12,658	63.73%	56.17 – 71.30%	98.9%	$P=0.174$	$P=0.360$
Shoulder	23	12,692	60.13%	51.65 – 68.62%	99.1%	$P=0.476$	$P=0.192$
Upper back	18	12,561	53.69%	45.43 – 61.95%	98.8%	$P=0.570$	$P=0.334$
Lower back	23	13,233	49.84%	41.43 – 58.25%	99%	$P=0.653$	$P=0.290$
Wrist	23	12,692	44.41%	36.94 – 51.88%	98.5%	$P=0.328$	$P=0.413$
Elbow	19	10,976	27.46%	22.45 – 35.46%	96.2%	$P=0.506$	$P=0.308$
Hip	4	4,000	24.93%	16.85 – 33%	93.8%	$P=0.497$	$P=0.204$
Knee	4	4,000	19.59%	9.11 – 30.08%	97.3%	$P=1.00$	$P=0.448$
Ankle	7	4,662	16.92%	9.28 – 24.56%	96.7%	$P=0.881$	$P=0.077$

($P<0.05$)

CI: Confidence Interval, I^2: I Squared

examiner, the neck and trunk must bend and twist more, imposing an unbalanced posture on the lower limbs as well [66, 67].

Among other occupations, several studies have been conducted on the prevalence of MSDs. In this regard, Sun et al. reported the annual prevalence of WMSDs among nurses as 77.2%, with the three regions of the upper back, neck, and shoulders having the highest prevalence rate [68]. In another review study conducted on farmers, researchers revealed a prevalence of MSDS at 76.9%, with the lower back region showing the highest prevalence compared to other body regions [69]. According to the results of another meta-analysis study, the 12-month prevalence of WMSDs among Chinese automobile manufacturing industry workers stood at 56.1%, with the lower back being the most commonly affected region [70]. Based on the findings of the reviewed studies, the prevalence of MSDs among sonographers was higher than that among automobile manufacturing industry workers but relatively similar to the prevalence among farmers and nurses. The high prevalence of MSDs among sonographers, similar to the mentioned professions, especially in the neck region, may be due to increased static work in various regions of the spine, particularly the cervical region, and repetitive movements of the hands and arms. Although sonographers may expend less energy during work compared to nurses, farmers, and automobile manufacturing industry workers, the biomechanical load on the spine and the joints of the hands and arms in this occupational group is likely greater. Moreover, low mobility in the lower limbs can itself be one of the causes of MSDs in these regions. In any case, the specific nature of the sonographers' job, similar to other dynamic professions, is likely the reason for the high prevalence of MSDs among them.

Among the studies reviewed, the lowest reported prevalence of MSDs was 20.23%, while the highest was 99.3%. The high level of heterogeneity observed in the present meta-analysis may reflect significant differences in the results of the primary studies, potentially due to factors such as study design or the assessment tools used for MSDs. This heterogeneity suggests that the findings might have been influenced by specific characteristics of each study. Nonetheless, the use of a random-effects model in this meta-analysis likely aids in generalizing the results to broader populations, due to its ability to manage variability among different study outcomes.

It is worth noting that the tool used for assessing MSDs in most initial studies was the Nordic questionnaire, which has acceptable validity in the field of MSDs assessment [71]. However, some studies also utilized various Self-administered questionnaire. Due to the diversity of the tools, subgroup analysis was not possible. Nevertheless, the prevalence of MSDs reported in all studies was estimated through self-report, which can be considered one of the limitations of the study.

Identifying and reducing the risk factors contributing to MSDs among sonographers are likely to be effective in lowering the prevalence of MSDs. The studies conducted in this context have pinpointed various risk factors. Evidence shows that the most common causes of MSDs among sonographers are linked to the two main factors of ultrasound work environment and equipment design [72]. Many studies have reported awkward postures, such as shoulder abduction and continuous rotation of the neck and trunk, as aggravating factors for MSDs [16, 50, 60]. In several studies, researchers have stated that the characteristics of the ultrasound workstation are related to shoulder and neck pain and discomfort, eye complaints, and headaches among sonographers [31, 48, 49]. Bagley et al. demonstrated that symptoms of MSDs significantly decreased in 53% of sonographers when using ergonomic equipment [73]. In this context, the results of a comparative study between conventional and ergonomic ultrasound devices demonstrated that features like extended range of movement and probe cable support in the ergonomic design reduces the physical load on sonographers [74]. In other studies, long examination hours per day [43], an increasing number of patients per day [42, 46], and lack of rest between examinations were mentioned as factors causing MSDs among sonographers [45]. In addition, evidence indicates that factors such as forcefully gripping the probe, applying continuous pushing force through the probe, and examination of obese patients are associated with the occurrence or exacerbation of MSD symptoms [24]. The risk factors for the occurrence of WMSDs among sonographers include not only physical ergonomic risk factors but also psychosocial factors as well as individual factors such as workflow, health status, mental stress, age of sonographers, and various characteristics of patients [62].

Anyway, sonography (ultrasound imaging) is a very important tool for diagnosing various health problems and diseases in the medical field [75] due to its non-invasive nature [76]. Considering the relatively high prevalence of MSDs among sonographers and the importance of their musculoskeletal health for conducting examinations and correctly diagnosing patients' problems, it is essential to implement effective coping strategies.

To achieve this, ergonomic workstation layout should be optimized to minimize unnecessary physical strain [77]. This includes proper adjustment of table and chair heights, easy access to devices and monitors, and reducing repetitive and stressful movements. Equipping the workspace with adjustable devices and equipment, such as adjustable monitors, lightweight probes with cable holders, and adjustable-height examination tables, can also significantly reduce physical strain on sonographers [30].

In addition, scheduling regular and adequate breaks between examinations is crucial for allowing body rest and recovery, which helps prevent MSDs. Managing the number of visits appropriately by determining the daily number of examinations based on the physical capacity of sonographers is also important to avoid over-scheduling and prevent fatigue and MSDs occurrence [20].

Training on proper postural behaviors and body positioning during examinations is essential for reducing MSDs incidence [78]. Finally, developing and implementing stretching and strengthening exercise programs tailored to the physical needs of sonographers is vital for reducing muscle tension and improving body flexibility [79].

From a health policy and workplace regulation perspective, establishing and enforcing standards that meet the ergonomic needs of sonographers can probably help reduce the incidence of MSDs. Implementing these regulations will improve workplace health, increase job satisfaction, and decrease lost workdays. Economically, reducing MSDs among sonographers can likely lead to lower costs associated with treatment and rehabilitation of these disorders, reduced absenteeism, and increased productivity. These measures can presumably help organizations reduce costs associated with MSDs while enhancing overall productivity.

Therefore, incorporating these strategies into health policies and regulations can probably significantly alleviate the economic burden of MSDs and ensure improved health and quality of life for sonographers. The findings of this study probably a crucial step in raising awareness among managers and designers for developing and implementing MSDs prevention programs for sonographers.

Conclusion

The results of this review study indicated that sonographers are at a high risk of MSDs due to the nature of their work. MSDs are among the most prevalent job-related diseases that can lead to reduced work capacity, increased healthcare costs, and diminished labor productivity. Therefore, to prevent the occurrence of MSDs or to reduce them in this occupational group, some measures can be helpful. These measures include periodic screening for MSDs, risk assessment of ergonomic factors, designing ergonomic interventions, providing the necessary training programs through holding workshops and conferences in the field of correct postural behavior and the proper use of adjustable workstation equipment, and offering appropriate corrective exercises.

Limitations

Among the limitations of the present study, we can mention the heterogeneity among the studies. This heterogeneity may be due to different tools, sample sizes, and cut-off points in the original studies. Another limitation was the inability to report the prevalence of MSDs separately for men and women because the original studies did not provide data on the prevalence of MSDs by gender. Additionally, due to the limited number of tools assessed for MSDs prevalence, conducting subgroup analysis based on the tools was not feasible.

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Authors' contributions
S.T and Z.Z managed the project. S.T, Z.Z, and F.S developed the inclusion criteria, screen titles, and abstract. Screening, qualitative assessment and data extraction were done by H.M, F.M and F.S. A.S, as a statistician, performed the statistical analyses. S.T, Z.Z made a major contribution to the writing of this manuscript. The final version was read and approved by all authors.

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Declarations

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