Systematic Review

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A scoping review of the effectiveness of underwater treadmill exercise in clinical trials of chronic pain

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Abstract
Objective – The objective of this scoping review was to investigate the available literature on physical and quality of life (QoL) outcomes of underwater treadmill exercise trials in clinical chronic pain samples.
Methods – A scoping search of studies of the effectiveness of underwater treadmill exercise trials from 1947 to 2024 was conducted using the following databases: EMBASE, MEDLINE, SPORTDiscus, CINAHL, and Cochrane Reviews. To be included, studies were required to have included adult participants living with chronic pain (defined as pain lasting for 3 months or longer) who participated in an active underwater treadmill exercise intervention. No restrictions on pain diagnosis were applied. All clinical trials, including but not limited to randomized controlled trials (RCTs), feasibility trials, and pilot studies, were included in the search. Two independent reviewers determined whether studies met inclusion criteria, and a third reviewer resolved any disagreement on study inclusion.
Results – The initial search identified 2,209 studies: 314 articles were removed for duplications, 1,781 were removed because they did not meet inclusion criteria, and 113 were retained for full-text review. The full-text review yielded nine studies, all of which included samples consisting of participants with osteoarthritis. The following variables were investigated in the included studies to varying degrees: pain, QoL, mobility, balance, strength, and changes in gait kinematics. Multiple studies identified significant differences between control groups or pre-intervention groups and underwater treadmill groups or post-intervention groups in chronic pain, balance, mobility, strength, and QoL.
Conclusion – Findings suggest that underwater treadmill exercise leads to positive changes in chronic pain, balance, mobility, strength, and QoL. However, more studies, particularly RCTs with larger samples that include individuals with chronic pain conditions other than osteoarthritis, are warranted.

Keywords: underwater treadmill exercise, scoping review, clinical trials, chronic pain

1 Introduction

Chronic pain is a pervasive and debilitating condition affecting 20.5% of adults [1]. Qualitative and quantitative studies have elucidated the negative impacts that chronic pain has on many domains of individuals' lives, including physical functioning, professional, family, and social life of individuals [2], and overall quality of life (QoL; e.g., the study of Dysvik et al. [3]). Given the far-reaching effects of chronic pain, continued research into interventions to help patients manage their pain is much needed.

There is clear evidence that physical activity has many beneficial effects on pain management for those living with chronic pain, including potential improvements in pain severity, physical function, and QoL [4,5]. These potential benefits have prompted numerous investigators to examine how participation in aquatic therapy, a form of rehabilitation and physical activity that is often performed in a

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community or specialized therapy pool, may impact pain and other related outcomes [6–8]. The results of these examinations have been compiled into at least two systematic reviews, which have demonstrated the benefits of aquatic therapy on chronic pain levels, disability, fitness, and QoL [9,10].

Underwater treadmills have been used as a novel form of aquatic therapy for fitness, health, and rehabilitation. Underwater treadmills provide individuals with the positive effects of walking, with the added benefit of decreased joint weight bearing. In addition, the various properties of water surrounding the treadmill, such as resistance, buoyancy, and thermodynamics, provide an environment that may be suitable for a variety of individuals with chronic pain, such as osteoarthritis (OA) [11]. Indeed, evidence is quickly mounting on the potential utility of underwater treadmills to treat chronic pain. For instance, Bressel et al. [12] found that participants with OA who completed a 6-week underwater treadmill exercise program showed significant improvements in joint pain, balance, sit-to-stand function, and mobility after completing the intervention. This mounting evidence speaks to the need for research that maps the existing literature on the treatment technique. This is especially so given that the two existing reviews on the utility of aquatic therapy for chronic pain did not include studies on underwater treadmill exercise [9,10]. Mapping the research will help identify the extent and nature of the existing literature on the utility of underwater treadmills for chronic pain and identify gaps in current research. Therefore, the objective of this scoping review was to explore the available literature on the physical and QoL outcomes of underwater treadmill exercise trials in clinical chronic pain samples.

2 Methods

The scoping review followed the checklist outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) Checklist [13]. A review protocol does not exist for the current scoping review.

2.1 Eligibility criteria

Based on the recommendation for scoping reviews to include the breadth of literature on a topic [14], we did not exclude studies based on the research approach the trial used. All clinical trials, including but not limited to randomized controlled trials (RCTs), feasibility trials, and pilot study publications of clinical trials examining the effectiveness of underwater treadmill exercise for human participants living with pain, were included. To be eligible for the scoping review, studies were required to include adult participants (i.e., individuals aged 18 or older) living with chronic pain, defined as pain lasting for 3 months or longer [15]. Though the patient population was restricted to those living with chronic pain, there were no restrictions on the chronic pain diagnoses that participants had. Articles published since the inception of the searched database until May 9, 2024, were included in the scoping review. Review eligibility was restricted to articles that specifically included underwater treadmill exercise as an active intervention in the trial. Eligibility was limited to English-language, peer-reviewed published studies with full-text available. When full-text versions of articles were not available, an attempt was made to contact the primary author via email. Published studies that examined acute pain (i.e., pain lasting less than 3 months) or exercise training recovery (i.e., delayed onset muscle soreness) were excluded.

2.2 Information sources

An initial search of EMBASE was undertaken on June 28, 2022 with an update of the search strategy being conducted on May 12, 2024, using all identified keywords and index terms [14]. The search included articles published between the inception of the searched database (e.g., 1947 for EMBASE) and May 9, 2024. Second, MEDLINE, SPORTDiscus, CINAHL, and Cochrane Reviews were systematically searched on June 28, 2022, with an update of the search strategy being conducted on May 12, 2024. The same search strategy was applied to each database. This search strategy can be found in the Appendix. In addition, a search of gray (i.e., difficult to locate) material was completed through a manual Google Scholar search by reviewing the first ten pages of the search results to identify any other potential studies that met review inclusion criteria. Finally, the reference list of identified articles included in the review was searched to identify any additional sources.

2.3 Study selection

All articles identified through the search strategy were uploaded into Covidence (Melbourne, Australia), a software application for literature reviews. Duplicates were then identified and removed by Covidence and by manual search. Of the remaining articles, titles and abstracts were

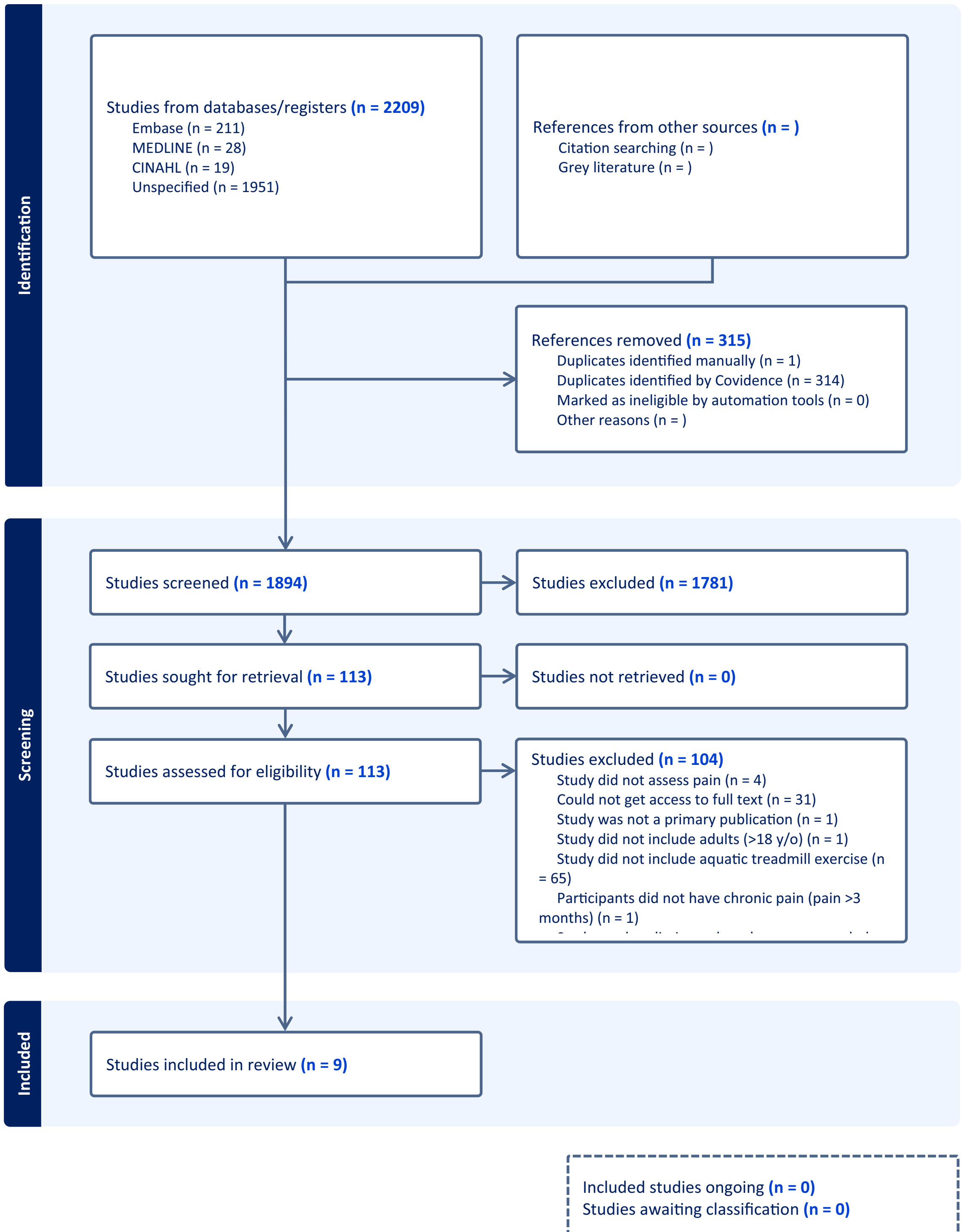

Figure 1: PRISMA flow diagram of the study selection process.

screened by two independent reviewers (EG and PR) to determine if they met study eligibility criteria and were excluded if they did not meet the identified inclusion criteria. The remaining articles underwent a full-text review by two independent reviewers (SK and GD) to assess eligibility again. In both processes, a third reviewer (MM) determined eligibility when consensus on whether to include a study in the review was not reached by the independent reviewers. A PRISMA flow diagram is provided to detail the screening process (Figure 1).

2.4 Data charting process

Two reviewers (MM and PR) independently carried out data extraction from the nine included clinical trials. Microsoft Excel was used to compile data extracted from the trials. To ensure accuracy and reduce the risk of bias, data extraction was independently performed and then crosschecked by a third independent reviewer (GD). For every publication, the author(s), year of publication, country the study was completed in, type of clinical trial (e.g., RCT), number of intervention groups, intervention type(s) (e.g., underwater treadmill exercise and wait-list control), group sample sizes, gender of participants, average and standard deviation of age of participants, pain diagnosis of participants, intervention characteristics (including frequency and length of intervention time per week, duration of intervention in weeks, and perceived exertion from exercise), and outcome measures (i.e., pain-related measures, mobility, strength, joint kinematics and/or velocity, balance, and QoL), were extracted. The data charting underwent iterative amendments as the review progressed to ensure all information relevant to the research question was captured.

3 Results

3.1 Included study demographics

Our initial search identified 2,209 studies. No additional studies were identified from a perusal of study reference lists or our search of gray material. Covidence identified 314 duplicate studies, and manual search identified 1 additional duplicate study. Of the 1,894 remaining studies that were screened at the title and abstract level, 1,781 were removed because they did not meet inclusion criteria, and 113 were retained for full-text review. The full-text review yielded a total of 9 articles that met eligibility criteria for inclusion in the scoping review, with publication dates ranging from 2010 to 2023. Six of the studies were conducted in the United States [12,16–20], and three of the studies were conducted in Thailand [11,21,22]. Table 1 shows the characteristics of each study included in the scoping review.

3.2 Clinical trial types

The types of studies included in this scoping review were five quasi-experimental research designs [12,16–19], two randomized controlled prospective trials [20,22], one single-blind RCT [21], and one cohort pre-posttest study [11]. Of the quasi-experimental research designs, three involved a single-group double pretest posttest design in which participants were assessed before and after a control period and after the aquatic exercise period [12,16,17]. The remaining two quasi-experimental research designs were crossover designs [18,19]. In addition, Coons et al. [16,17] used the same sample in two separate studies included in this review.

3.3 Participant characteristics

Total number of participants from the 9 included studies was 337 (women = 289). The average age of participants from all of the studies was 61.2 (SD = ±2.91). The mean age in the studies ranged from 58.1 (SD = ±3.39) to 66.2 (SD = ±3.39) when participants from all intervention groups in each study were included.

3.3.1 Pain population

Participants from all studies included in the scoping review were diagnosed with OA, even though all forms of chronic pain diagnoses were eligible for inclusion. Knee OA participants were included in all nine studies and were the most extensively investigated condition. Other conditions in the included studies consisted of hip and ankle OA [12,18].

3.4 Intervention types

All of the studies included walking-based underwater treadmill exercises. This intervention was often compared to either land-based exercise interventions or other alternatives such as pneumatic partial weight supported treadmill [21]. The average training frequency in the studies was three times per week, with exercise duration ranging between 10 and 45 min. Intervention length ranged between 1 and 8 weeks. Of these walking programs, most did not outline a rate of perceived exertion that was targeted during training times. A majority of the studies did not state an exercise intensity or specify a rate of perceived exertion regarding participant activity.

3.5 Key outcome measure findings

Several different outcome measures were used by the included studies to identify the effectiveness of underwater

Table 1: Characteristics of nine included studies in a scoping review of the effect of underwater treadmill exercise in patients with chronic pain

Study	Country of origin	Sample size	Pain population	Type of clinical trial	Intervention type	Outcome measures	Key findings/effectiveness
Bressel et al. [12]	United States of America	*n* = 18 (16 women), average age 64.5 ± 10.2	Diagnosed knee or hip OA	Quasi-experimental research design (single group double pretest posttest design)	Six-week aquatic exercise intervention period, three sessions per week for 30 min or less	Pain Scale Assessment	Posttest values for knee injury and OA outcome score and pain scale assessment were significantly lower as compared to pretest values ($p < 0.05$)
						Knee Injury and Osteoarthritis Outcome Score	Sit-to-stand testing improved from pretest 2 to posttest (p = 0.02–0.007), lunge test scores for both legs were 53–59% less than pretest 2 (p = 0.05–0.004) at posttest, and 10 m walk tests were 10% lower at posttest than pretest ($p = 0.008$)
					RPE intensity of 14–19	Posturography for balance	
					Underwater treadmill high-intensity interval training program	Sit-to-stand and lunge for testing function	Participants demonstrated an improvement in their ability to complete the sit-to-stand at post-intervention. Participants lunged more quickly on one leg and walked 10 m with greater speed at post-intervention
					Water depth at xiphoid process	10 m walk test for mobility	
Denning et al. [18]	United States of America	*n* = 19 (16 women), average age = 59.4 ± 7.4	Diagnosed knee, hip, or ankle OA	Quasi-experimental crossover design	Each participant completed three consecutive exercise sessions on an underwater treadmill and a land-based treadmill	Visual analog scale for pain	Participants demonstrated greater mobility and balance levels after underwater treadmill than land treadmill exercises when assessed by the timed-up-and-go test
					Exercise bouts separated by at least 24 h	VO_2 max	Gain scores, which were computed as the difference between pretest and posttest values, were not significantly different between groups. This included gain scores assessed for pain, timed-up-and-go, stride length, stride rate, and strike rate
					Walking protocol of 20 min (four stages of 5 min)	Motion analysis system for gait kinematics	Patients with OA may receive the same aerobic conditioning

(Continued)

Table 1: *Continued*

Study	Country of origin	Sample size	Pain population	Type of clinical trial	Intervention type	Outcome measures	Key findings/effectiveness
					Water depth at xiphoid process (moderate to light RPE)	Timed-up –and-go to assess basic mobility and balance	during underwater treadmill exercise with less joint pain as compared to performing the same exercise on land
Kittichaikarn and Kuptniratsaikul [11]	Thailand	*n* = 30 (29 women), average age = 62.8 ± 6.9	Knee OA	Pre–posttest design	Underwater treadmill exercise, 30-min sessions, 3 days per week for 4 weeks	Numerical pain rating scale	Underwater treadmill training significantly improved numerical pain rating scores ($p < 0.001$)
						Six-min walk test	Underwater treadmill training also significantly improved quadriceps strength (kg) ($p < 0.001$)
					Walking speed ranging from 0.4 to 0.8 m/s	Quadriceps strength	Both 6-min walk test and body weight were not significantly improved ($p = 0.697$)
						Body weight	Underwater treadmill group statistically improved numerical pain rating scale pain, and quadriceps strength at the end of the study, with two-thirds of patient's describing themselves as being "very satisfied" with underwater treadmill exercise
Kuptniratsaikul et al. [22]	Thailand	*n* = 109 (100 women), average age for pneumatic partial weight supported treadmill group = 63.9 ± 5.5, average age for underwater treadmill group (control) = 66.2 ± 6.4	Knee OA	Prospective randomized controlled noninferiority trial	30 min/session, 3 days per week for 8 weeks Walking speed increased by 1 level in speed every week	Numerical pain rating scale Western Ontario and McMaster Universities Osteoarthritis Index Pain Subscale	Significant pain reduction using both the numerical pain rating scale, and the Western Ontario and McMaster Universities Osteoarthritis Index pain subscale were seen in both groups ($p < 0.001$)
					Pneumatic partial weight supported treadmill and underwater treadmill protocol: 50% weight reduction week 1, 40% reduction week 2, and 30%	Quadriceps strength	Quadriceps strength was also significantly greater in the pneumatic partial weight supported treadmill group as compared to the underwater treadmill group ($p < 0.005$),

(Continued)

Table 1: *Continued*

Study	Country of origin	Sample size	Pain population	Type of clinical trial	Intervention type	Outcome measures	Key findings/effectiveness
					reduction week 3 until end of study		though both groups recorded improvements
					Water depth: hip week 1, between hip and mid-thigh week 2, mid-thigh week 3 and onwards	Body weight Six-min walk test QoL	For body weight, 6-min walk test, and QoL measures, there was no significant difference between groups at baseline and week 8. However, both groups recorded improvements from baseline to week 8 in these three measures
Kuptniratsaikul et al. [21]	Thailand	n = 80 (75 women), the average age in the home exercise group = 61.7 ± 6.9, the average age in underwater treadmill group = 62.1 ± 6.4	Knee OA	Single-blind RCT	At-home exercise: preformed daily for 4 weeks for up to 30 min in duration	Numerical pain rating scale Six-min walk test	All outcomes in both groups were significantly improved at posttest recording as compared to baseline, except for the body weight measure. Yet, there was no statistically significant difference in the mean differences (95% CI) between the study and control groups at posttest. This includes values for pain score, 6-min walk test distance (m), quadriceps strength, and body weight
					Underwater treadmill: 30 min, 3 days per week for 4 weeks performed at moderate intensity	Quadriceps strength Body weight	Underwater treadmill was as effective as the home exercise regimen in decreasing knee pain, increasing quadriceps strength, and increasing 6-min walk distance
Roper et al. [19]	United States of America	n = 14 (12 women), age range = 43–70	Knee OA	Quasi-experimental crossover design	Three exercise sessions in each condition (exercise and land), separated by at least 24 h and completed within 1 week	Visual analog scale	Perceived pain was significantly reduced by 100% post underwater treadmill exercise as compared to land-based treadmill exercise ($p < 0.05$). posttest

(Continued)

Table 1: *Continued*

Study	Country of origin	Sample size	Pain population	Type of clinical trial	Intervention type	Outcome measures	Key findings/effectiveness
					20 min of walking in four stages of 5 min (moderate to hard rating of perceived exertion)		For joint angular velocity, gain scores that were significantly different for either stance or swing included: left knee extension ($p = 0.004$), knee internal rotation ($p = 0.004$), left hip flexion ($p = 0.007$), right hip extension ($p = 0.01$), and left ankle abduction ($p = 0.003$)
					Water depth for underwater treadmill at the xiphoid process	Gait kinematics	Step rate and step length did not demonstrate significant differences between conditions with respect to gain scores Acute underwater treadmill training decreased arthritis-related joint pain and certain joint angular velocities
Silvis et al. [20]	United States of America	*n* = 61 (38 women), the average age of groups: land treadmill = 58.1, water treadmill = 59.0, exercise cycle = 57.6	Knee OA	Randomized prospective study	Exercise conditions: upright cycle, land treadmill, and water treadmill Exercise sessions completed three times per week for 8 weeks	Western Ontario and McMaster Universities Arthritis Index	All groups demonstrated significant improvements in Western Ontario and McMaster Universities Osteoarthritis Index and Knee Injury and Osteoarthritis Outcome Score; however, there were no statistically significant differences recorded between groups
					Goal to achieve 30 min of moderate aerobic exercise (3.0–6.0 METs and 4–6 RPE) per session by week 4 Underwater treadmill depth at mid-chest	Knee Injury and Osteoarthritis Outcome Score SF-12 Health Survey	There was no significant difference in SF-12 Physical Component Summary scores and Mental Component Summary scores within or between groups other than land treadmill exercise, being greater for Mental Component Summary score ($p = 0.003$). Osteoarthritis may be effectively managed by regular

(Continued)

Table 1: *Continued*

Study	Country of origin	Sample size	Pain population	Type of clinical trial	Intervention type	Outcome measures	Key findings/effectiveness
							moderate exercise regardless of modality
Coons et al. [16]	United States of America	*n* = 6 (3 women), average age = 62.7 ± 14.2	Knee OA	Pre–posttest design	Underwater treadmill walking was conducted at a self-selected pace that increased in duration from 10 to 45 min throughout the study	Western Ontario and McMaster Universities Osteoarthritis Index Numerical pain rating scale	A significant reduction in Numerical pain rating scale from pre-control to post-intervention groups was identified (p = 0.03). However, there was no significant difference noted between measurements of 10 m walk and timed-up-and go scores
					Exercise was completed for 8 weeks, three sessions per week	Timed-up-and-go 10 m walk test	A significant decrease in Western Ontario and McMaster Universities Osteoarthritis Index Pain scores was observed between pre-control to post-intervention groups (n = 0.04). In addition, it was observed that self-selected walking speed increased as knee pain reduced during training sessions
Coons et al. [17]	United States of America	*n* = 6 (3 women), average age = 62.7 ± 14.2	Knee OA	Pre–posttest design	Underwater treadmill walking was conducted at a self-selected pace that increased in duration from 10 to 45 min throughout the study	Knee outcome survey	A significant improvement was noted in the sections of the Knee Outcome Survey regarding stiffness (p = 0.004) Significant improvements were also noted in the section of the Knee Outcome Survey regarding functional limitation, which included: walking (p = 0.03), going upstairs (p = 0.01), going downstairs (p = 0.02), and squatting (p = 0.005)
					Exercise was completed for 8 weeks, three sessions per week	20 cm step down	There was also significant improvement in both total ADL score (p = 0.008) and global rating score (p = 0.02)

(Continued)

Table 1: *Continued*

Study	Country of origin	Sample size	Pain population	Type of clinical trial	Intervention type	Outcome measures	Key findings/effectiveness
						10 m walk test	In 10 m walk test, a significant increase in range of motion was noted only during knee flexion excursion (p = 0.01)

Abbreviations: VO_2 max: maximal oxygen consumption, METs: metabolic equivalent, SF-12: 12-item Short Form Survey, ADL: activities of daily living, RPE: rate of perceived exertion.

treadmill exercise. The pain was the most investigated outcome [11,12,16–22], followed by QoL [11,12,17,20–22], mobility [11,12,16,18,21,22], and strength [11,21,22], respectively. Measures of joint kinematics and/or velocity [17–19] and balance [12,18] were also investigated. VO_{2max} [18] and body weight [11,22] were also investigated. (The results of these latter outcome measures will not be reported here.)

3.6 Pain

All of the nine studies measured pain outcomes in participants with OA who participated in the study's underwater treadmill exercise program (note that two of the included studies used the same sample of participants). Of the included studies, five were quasi-experimental research designs [12,16,18,19], two were randomized controlled prospective trials [20,22], one was a single-blind RCT [21], and one was a cohort pre-posttest study [11]. Eligible studies utilized a variety of outcome measures to report changes in pain levels after participating in the underwater treadmill exercise trial. These included the Western Ontario and McMaster Universities (WOMAC) Index of Osteoarthritis, the Knee Osteoarthritis Outcome Score (KOOS), the Knee Outcome Survey (KOS), the visual analog scale (VAS), and the Numerical Pain Rating Scale (NPRS) ranging from 0 to 12 (with 0 being "No pain" and 12 being "Agonizing pain").

In Bressel et al. [12] (n = 18), participants completed a 4-week non-exercise control period, followed by a 6-week underwater treadmill exercise program. Participants were assessed before the control period (pretest 1), after the control period (pretest 2), and after the underwater treadmill exercise program (posttest). Participants had significantly higher KOOS and lower VAS scores (pretest 1 M = 57.1, SD = ±26.9, pretest 2 M = 50.3, SD = ±24.8, posttest M = 15.8, SD = ±12.6) after completing the underwater treadmill exercise program in comparison to their pretest two scores, reflecting a significant reduction in their reported pain.

Roper et al. [19] (n = 19) completed a quasi-experimental crossover design in which all participants completed three underwater treadmill walking sessions and three land treadmill walking sessions, with each session lasting 20 min. Each of the three sessions in each condition was separated by at least 24 h and completed within 1 week. Before switching exercise conditions, participants did not engage in exercise for 1 week. Using the VAS, Roper et al. [19] found that the reduction in perceived pain after underwater treadmill exercise (M = –15.4, SD = ±20.7) was significantly greater than the reduction in pain after land exercise (M = 0.1, SD = ±19.2) at posttest, p = 0.02. Similarly, Denning et al. [18], who used the same cross-over design as Roper et al. [19], found the reduction in perceived pain scores was significantly less after land exercise (M = –8.19, SD = ±12.3) compared with after underwater treadmill exercise (M = 3.36, SD = ±12.3), p = 0.01.

Using the NPRS, Kittichaikarn and Kuptniratsaikul [11] (n = 30) documented a significant 2.3-point decrease in pain from weeks 0 to 4 of underwater treadmill exercise attended three times weekly for 30 min each (pretest M = 6.4, SD = ±1.2, posttest M = 4.1, SD = ±2.0, p < 0.001). Kuptniratsaikul et al. [22] (n = 109) randomized participants into a pneumatic partial weight support treadmill group or an underwater treadmill group. Participants in both groups completed 30 min of exercise three times per week for 8 weeks. Participants demonstrated significant improvements in NPRS scores (week 0 M = 6.25, SD = ±1.39, week 8 M = 3.38, SD = ±1.98) and all dimensions of the WOMAC (week 0 M = 5.23, SD = ±1.48, week 8 M = 2.61, SD = ±1.58) for the underwater treadmill group, at levels equivalent to the pneumatic partial weight support treadmill training group. Similarly, Silvis et al. [20] (n = 61) found equal WOMAC score improvements in the underwater treadmill group (M change in score = –46.36, 95% CI [–65.32, –27.39]) compared to the land treadmill group (M change in score = –31.21, 95% CI [–50.66, –11.74]), p = 0.27, or upright cycle group (M change in score = –30.28, 95% CI [–50.37, –12.20]), p = 0.25. A similar finding for KOOS scores was obtained (M change in score = –13.05, 95% CI [–18.98, –7.11]), with a significant improvement found within the group but no difference between groups. Participants in this randomized prospective study were randomized into underwater treadmill walking, land-based treadmill walking, or upright cycling. They completed three exercise sessions per week for 8 weeks. Sessions gradually increased in duration from 12 min per session (sessions 1 and 2) to 40 min per session (sessions 12–24).

Kuptniratsaikul et al. [21] (n = 80) conducted a single-blind RCT in which participants were randomized into one of two groups. The control group preformed home exercises daily for 4 weeks, for 30 min per session, and the experimental underwater treadmill group exercised for 30 min, 3 days per week for 4 weeks at a moderate intensity. They found statistically significant improvements in pain outcomes within both groups post-intervention (M pain score change home exercise = –1.8, SD = ±1.7; M pain score change underwater treadmill = –2.3, SD = ±1.9), but no significant differences between groups (M difference = –0.53, 95% CI [–1.31, 0.26], p = 0.184).

Coons et al. [16] (n = 6) conducted an exploratory study investigating the effects of underwater treadmill walking on knee OA. The six participants involved in this study performed underwater treadmill walking at a self-selected pace that increased from 10 to 45 min during an 8-week study period, with sessions taking place three times per week. They found a significant reduction in NPRS scores from pre-control to post-intervention (M pre-control = 5.3, SD = ±2.3, M post-intervention = 2.1, SD = ±1.4, p = 0.03) and WOMAC pain subscale scores (M pre-control = 8.0, SD = ±2.8, M post-intervention = 4.8, SD = ±1.5, p = 0.04). In addition, they observed that self-selected walking speed increased as knee pain reduced during training sessions.

3.7 Patient-reported outcomes

One of the main patient-reported outcomes was QoL. A number of studies documented changes in QoL using subscales of the KOOS, participant satisfaction ratings, the KOS, ratings of subjective symptom improvement, the Euro-QoL-5Dimensions-5Levels (EQ-5D-5L) Survey, and the 12-Item Short Form (SF-12) Health Survey. Bressel et al. [12] used the KOOS, which, in addition to pain measures, includes items assessing function in daily living, function in sport and recreation, and knee-related QoL. All KOOS subscale scores improved post-underwater treadmill exercise program compared to pretest 2 (i.e., after the control period), with statistical improvements ranging from 30 to 49%. In the Kittichaikarn and Kuptniratsaikul [11] (n = 30) study, two-thirds of patients were "very satisfied" with the underwater treadmill exercise program, and 90% rated their symptoms as "improved" or "much improved." Kuptniratsaikul et al. [22] (n = 109) used a more generic QoL measure, the EQ-5D-5L. They found that the underwater treadmill exercise group's EQ-5D-5L scores improved at post-intervention testing at a level equivalent to the pneumatic partial weight support treadmill training group. Moreover, Kuptniratsaikul et al. [21] (n = 80) noted greater self-reported global improvement (on a scale of "No change," "Improved," and "Much improved") in the underwater treadmill group and better self-reported patient satisfaction (on a scale of "Unsatisfied," "Satisfied," and "Very satisfied") compared to the home exercise program group. Coons et al. [17] (n = 6) also identified a significant improvement in total Activities of Daily Living Scale score of the KOS when comparing pre-intervention and post-intervention measurements (M pre-intervention = 57.4, SD = ±11.0, M post-intervention = 79.5, SD = ±7.4, p = 0.008).

Although Roper et al. [19] (n = 14) did not specifically measure differences in QoL between aquatic and land treadmill exercise groups, subjective feedback from a majority of commenters indicated a preference for underwater treadmill exercise. Silvis et al. [20] (n = 61) used the SF-12 Health Survey to document effects on QoL, but no statistical differences from baseline to post-treatment were observed for any of the interventions (underwater treadmill, land treadmill, or upright cycle).

3.8 Joint kinematics and velocity

Three studies in this scoping review compared measures of gait kinematics between interventions. Denning et al. [18] (n = 19) measured stride length and rate to determine whether changes in these variables could explain potential changes in Timed-Up-and-Go (TUG) scores. Posttest gain scores (i.e., the difference between pretest and posttest scores) for these variables did not differ between aquatic and land treadmill groups, despite Denning et al. [18] finding significantly greater TUG gain scores after land versus underwater treadmill exercise.

In addition, Coons et al. [17] (n = 6) noted a significant difference in knee flexion excursion (in degrees) between post-intervention and pre-intervention values (M pre-intervention = 51.4, SD = ±8.0, M post-intervention = 55.1, SD = ±8.1, p = 0.01).

However, Roper et al. [19] (n = 14) found no statistical difference in step rate and step length gain scores between underwater treadmill and land treadmill conditions. This was also the only study to complete a comprehensive analysis of joint angular velocities, and of note, participants consisted primarily of individuals with left-sided OA. Underwater treadmill exercise resulted in statistically significant improvements in angular velocity for left knee extension during stance (p = 0.004), as well as left knee internal rotation and extension during swing (p = 0.004, p = 0.008, respectively). This is in contrast to the increases in left hip flexion and ankle abduction during stance following land exercise, the changes that were not found in the underwater treadmill exercise group. These statistically significant changes in gait kinematics were reported after just three exercise sessions.

Compared with 6MWT scores, Kuptniratsaikul et al. [22] (n = 109) found that significant improvements were reported in post-intervention compared to pre-intervention for both the underwater treadmill and pneumatic partial weight supported treadmill training groups (p < 0.001 for both), though there were not any statistically significant differences identified when 6MWT post-intervention values were compared between the underwater treadmill group and the pneumatic partial weight supported treadmill training group. Kuptniratsaikul et al. [21] (n = 80) also found significant improvements in distance walked during the 6MWT at the end of the underwater treadmill intervention compared to baseline, but no significant differences were found between the underwater treadmill and at-home exercise group, p = 0.34. Kittichaikarn and Kuptniratsaikul [11] (n = 30), whose study did not include a comparison group, nonetheless found significant improvements in walk distance (i.e., 34.9 m) between baseline and the end of the underwater treadmill intervention, p = 0.002. Denning et al. [18] (n = 19) investigated TUG performance scores in both underwater and land-based treadmill groups. After computing the gain scores (i.e., the difference between pre-intervention and post-intervention values), a statistically significant improvement in TUG performance scores was found for the underwater treadmill group (M = 0.83, SD = ±2.85), p < 0.05), but no significant improvement was noted for the land-based treadmill group. In fact, an increase in score time was noted (M = −0.55, SD = ±1.38). When examining 10 MWT scores in underwater treadmill participants, Bressel et al. [12] (n = 18) found a 12% reduction in posttest times compared to pretest two times (i.e., after the control period; p = 0.008).

Coons et al. [16] (n = 6) found no significant differences in measurements of 10MWT (M pre-control = 1.11, SD = ±0.25, M post-intervention = 1.18, SD = ±0.27) and TUG scores (M pre-control = 9.7, SD = ±2.5, M post-intervention = 9.6, SD = ±2.6). However, they observed an increase in self-selected walking speed during the exercise intervention as the 8-week study progressed.

3.9 Mobility

Three outcome measures were utilized to report changes in mobility: the 6-min walk test (6MWT), the 10 m walk test (10MWT), and the TUG. The 6MWT was the most frequently used outcome measure, being employed in three studies [11,21,22]. The TUG was only investigated by Denning et al. [18] and Coons et al. [16], and the 10MWT by Bressel et al. [12] and Coons et al. [16].

3.10 Balance

Two outcome measures were used to assess balance: the TUG and computerized dynamic posturography (CDP). The TUG was classified by Denning et al. [18] (n = 19) as assessing both mobility and balance; their TUG results are noted above. Bressel et al. [12] (n = 18) employed CDP using the SMART EquiTest system. This system measured balance using three tests: a sensory organization test, a motor control test, and a limits of stability (LOS) test. The researchers found that all specific balance measures, including sensory organization, motor control, and LOS, except for the LOS directional score, were significantly improved after the 6-week underwater treadmill exercise intervention [12].

3.11 Strength

Quadriceps strength was measured in three studies using hand-held dynamometers and each reported improvements after completion of the underwater treadmill exercise intervention. However, Kuptniratsaikul et al. [22] (n = 109) reported that the pneumatic partial weight supported treadmill group demonstrated greater improvement in quadriceps strength as compared to the underwater treadmill group ($p < 0.05$), whereas Kuptniratsaikul et al. [21] (n = 80) reported no statistically significant differences between the underwater treadmill group and the at-home exercise group ($p = 0.088$). Although no control group was utilized, Kittichaikarn and Kuptniratsaikul [11] (n = 30) also reported a statistically significant improvement ($p < 0.001$) in quadriceps strength using their study design of testing quadriceps strengthen pre- and post-intervention.

4 Discussion

This study comprised a scoping review of the available literature on clinical trials of underwater treadmill interventions for chronic pain. All eligible studies in the scoping review included adult participants with lower extremity OA chronic pain. The review explored the effect of the interventions on pain, QoL, mobility, balance, strength, and changes in gait kinematics. The collated results of these studies suggest that underwater treadmill exercise can be equally as effective [20–22] or perhaps superior to other exercise regimens [18,19] in decreasing reported pain in patients with OA.

Underwater treadmill exercise was shown to improve QoL over time in three of the four studies that included a generic QoL assessment measure [12,17,20,21] and demonstrated higher participant satisfaction rates [11] or greater participant satisfaction than participation in home exercise [21] or land treadmill exercise [19]. High patient satisfaction with the exercise regimen may encourage patients to engage in more exercise sessions, reduce intervention dropout levels, and lead to better management of patients' chronic pain conditions. Silvis et al. [20] noted that study completion rates were highest for the underwater treadmill group.

Two of the studies that measured gait kinematics found no differences in stride rate or length between participants who completed underwater versus land treadmill exercise interventions [18,19]. The study of Roper et al. [19] was the only study in the scoping review to complete a comprehensive assessment of joint angles when walking on an aquatic treadmill compared to a land treadmill. The authors stated that the improvements shown in joint angular velocity following underwater treadmill exercise may indicate better functional use of the affected joints compared to greater compensatory gait deviations observed following traditional land treadmill training [19]. When examining the effect of underwater treadmill training on mobility, five of the six studies that investigated mobility found statistically significant increases in mobility from pre- to post-intervention [11,12,18,21,22]. Kittichaikarn and Kuptniratsaikul [11] and Kuptniratsaikul et al. [22] found significant improvements in 6MWT values from pre- to post-intervention completion, with both of these studies meeting the MCID (a change between 14 and 30.5 m) identified for the 6MWT [23].

Additionally, Denning et al. [18] and Bressel et al. [12] found mobility and balance improvements after completion of the underwater treadmill exercise intervention. As the 6MWT, TUG, and 10MWT are commonly utilized outcome measures to examine mobility, improvements that surpass traditional training interventions are of considerable interest. Our scoping review results suggest that with respect to improving mobility and balance, underwater treadmill exercise could be an effective exercise alternative for patients unable to tolerate traditional active exercise methods.

Finally, all three studies examining quadriceps strength reported significant improvements after participants completed the underwater treadmill exercise intervention [11,21,22]. This suggests that this intervention may be effective for lower extremity strengthening in patients with OA, which may contribute, in addition to other factors, to improvements in function and ability to participate in activities of daily living [24].

4.1 Future research and practice

This scoping review provided valuable insights into the effectiveness of underwater treadmill exercise for chronic pain. The results of the review suggest that participation in underwater treadmill training can lead to improvements in pain, mobility, balance, strength, and QoL in patients with chronic pain over time. However, only three RCTs were available in the literature and included in this review, making definitive conclusions about the effectiveness of underwater treadmill exercise compared to other interventions difficult to make. This highlights the need for a greater number of RCTs comparing the efficacy of underwater treadmill exercise to wait-list control groups or other intervention groups. Additionally, the low number of men participants in the aggregated clinical trials (n = 48) and the lack of gender-diverse individuals included in the trials point to a need to increase recruitment of these participants in future clinical trials. This will allow for data to be disaggregated by gender/sex and for researchers to determine if the efficacy of this intervention differs by gender/sex. Additionally, based on the evidence available within the literature, further research is warranted that investigates an optimal protocol for underwater treadmill exercise, the long-term effects of this exercise modality on physical and QoL outcomes, and includes additional chronic pain populations other than individuals with primarily knee OA, such as back pain, fibromyalgia, and other forms of arthritis.

Examining the effect of properties of water, such as resistance, buoyancy, and water temperature, on underwater treadmill exercise outcomes may also be beneficial. Moreover, studies should determine and outline the most beneficial duration, frequency, and intensity of underwater treadmill exercise, as this will allow this intervention to be applied outside of clinical trial settings and into community and therapy pools. Prospective research studies investigating the long-term outcomes of this exercise modality are also important to assess the impact of this intervention on QoL, physical fitness, and chronic pain over an extended period of time. Such studies would help identify appropriate treatment frequencies and follow-up sessions needed for patients to optimize their rehabilitation.

4.2 Strengths and limitations

This scoping review is the first to identify research examining the effectiveness of underwater treadmill exercise in reducing chronic pain in adults. By doing so, it highlights the positive outcomes of this intervention and sheds light on the areas that require more research, which may promote the utilization of this exercise modality in future research and practice, giving clinicians another tool with which to treat chronic pain. Furthermore, this review can be used to help clinicians compare the utility of underwater treadmill exercise to research the utility of other forms of aquatic therapy. In addition, several of the included studies did not record adverse events within their protocols. However, of those that did, two recorded no adverse events in the underwater treadmill intervention [12,20]. A subsequent two studies recorded adverse events, which included joint pain, muscle pain, nausea and/or vomiting, dyspepsia, and vertigo. However, the number of adverse events was not significantly different in regards to occurrence between groups [19,20]. It was also observed by Kuptniratsaikul et al. [21] that there were more adverse events in the control group than in the underwater treadmill intervention group. This lends support to the contention that underwater treadmill interventions are effective and safe for patients in supervised settings.

There are several limitations to this scoping review. The included studies lack variation in their pain samples. In the nine studies, all included participants were diagnosed with OA. Additionally, the evidence obtained from all studies was primarily low-grade evidence. Five of the 9 studies had a sample size of less than 20 participants [12,16–19], and out of the 9 included studies, none incorporated a follow-up assessment of participants. Designing a longitudinal study and increasing the sample size to observe the long-term effects of underwater treadmill exercise will be required in future studies. Despite the apparent utility of underwater treadmill exercise for at least OA chronic pain, a limitation of this form of exercise modality is its cost and the limited availability of underwater treadmills. Scarce access to the device may impede individuals' ability to participate in and continue with underwater treadmill exercise programs. Additionally, the control groups in all studies were not consistent. Four out of nine studies used pretest results as a "control group" [11,12,16,17] and others used either land treadmill training or other forms of exercise. A greater number of RCTs are needed to determine the effectiveness of underwater treadmill exercise relative to other interventions and no intervention. In addition, many of the included studies had short intervention periods and did not report on long-term outcomes, which may limit the impact and generalizability of the results found. Furthermore, all the studies included in this scoping review that used the VAS to measure changes in pain did not meet the MCID (23 mm) for the VAS [25]. This may indicate that underwater treadmill training reduces pain perception, but not to a level that is clinically important for patients. Further RCTS of higher-quality evidence will need to be conducted to confirm whether this is the case. Finally, several of the included studies only used 3-level satisfaction anchors to evaluate self-reported treatment efficacy, with only 1 indicating the percentage of participants that self-reported improvement [11]. It should be noted that pre-existing studies have identified that patients are influenced by their current health status when making improvement ratings [26]. Theoretically, this means that healthier individuals, regardless of diagnosis, have a greater tendency to report more satisfied improvement ratings. As such, 3-level satisfaction anchors may have biased some of the data found in the included studies.

5 Conclusion

This scoping review aimed to determine the utility of underwater treadmill exercise in reducing chronic pain and improving physical health and QoL outcomes. Overall, findings suggest that underwater treadmill exercise leads to positive changes in chronic pain, balance, mobility, strength, and QoL. Many of the studies included in the scoping review had short intervention periods and did not report on long-term outcomes. More studies, particularly RCTs with larger samples, longer intervention and follow-up periods, and that include individuals with chronic pain conditions other than OA, are warranted.

Research ethics: Not applicable as it is an evidence syntheses.

Informed consent: Not applicable. Only secondary analysis of already existing literature was performed.

Author contributions: All authors supported the development and review of the manuscript. All authors gave final approval for publication, and agree to be accountable for all aspects of the work.

Competing interests: The authors state no conflict of interest.

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Data availability: Raw data are not available; however, all eligible studies are listed within the manuscript for review.

Artificial intelligence/Machine learning tools: Not applicable.

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Appendix

Search strategy

The following search strategy was used for each database. Note that Embase is used as an example database to illustrate the search strategy.

https://proxy.queensu.ca/login?url=http://ovidsp.ovid.com?T=JS&NEWS=N&PAGE=main&SHAREDSEARCHID=gsXk7jiKKdWL3R5zBWnsgaRBK7i531U3v0oOpcQsOofNol7-WVnJMqvymTEraXOX0

Embase Classic + Embase <1947 to 2024 May 09>

1. Aqua*.mp. 169749

Table A1: Distribution of various osteoarthritis populations identified in the included studies

Osteoarthritis location	Number of studies
Knee	9
Hip	2
Ankle	1

Two studies included more than one pain population group.

Table A2: Distribution of exercise intensities targeted in the included studies

Target exercise intensity	Number of studies
Light to moderate RPE	1
Moderate RPE	1
Moderate to hard RPE	2
Unspecified RPE	5

RPE = rate of perceived exertion. RPE values based on the Modified Borg Scale (range = 0–12).

2. Hydro*.mp. 3087614
3. exp hydrotherapy/or Hydrotherap*.mp. 5912
4. water.mp. or exp water/ 1525031
5. underwater.mp. 12212
6. 1 or 2 or 3 or 4 or 5 4352847
7. exp moderate intensity exercise/or exp aerobic exercise/or exp exercise/or exp high intensity exercise/or exp low intensity exercise/or exp treadmill exercise/ 494145

Table A3: Distribution of outcome measures analyzed by studies included in the scoping review

Outcome	Number of studies
Pain	8
QoL	6
Kinematics/velocity	3
Mobility	6
Balance	2
Strength	3

Outcome measures not depicted in the table: VO_{2max} and body weight.

8. exercis*.mp. 707936
9. aerobic*.mp. 170405
10. exp rehabilitation/ 531820
11. rehab*.mp. 501342
12. fit*.mp. 580478
13. 7 or 8 or 9 or 12 or 11 or 12 2052126
14. Treadmill.mp. or exp treadmill exercise/or exp treadmill/ 62297
15. belt.mp. or exp locomotion/or exp walking/ 304509
16. 14 or 15 351977
17. Pain*.mp. or exp visceral pain/or exp pelvic pain/or exp bone pain/or exp neuropathic pain/or exp pain intensity/or exp arm pain/or exp pain/or exp spinal pain/or exp leg pain/or exp myofascial pain/or exp pelvis pain syndrome/or exp postoperative pain/or exp chronic inflammatory pain/or exp inflammatory pain/or exp knee pain/or exp low back pain/or exp musculoskeletal pain/or exp chronic pain/or exp pain severity/or exp pain assessment/ or exp thorax pain/ 2319795
18. exp fibromyalgia/ 26751
19. exp knee osteoarthritis/or exp hip osteoarthritis/or exp osteoarthritis/ 178332
20. exp multiple sclerosis/ 171475
21. 17 or 18 or 19 or 20 2583697
22. 6 and 13 and 16 and 21 1251

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	3
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	5-6
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	6
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	7
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	8
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	9
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	46-47
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	10
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	12
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	12
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	Not applicable
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	12
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	11
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	14-16
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	Not applicable
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	17-30
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	17-30

Figure A1: PRISMA-ScR Checklist [10].

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	31-32
Limitations	20	Discuss the limitations of the scoping review process.	35-36
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	37
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	39

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.

Figure A1: (*Continued*)