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The Association of Recreational and Competitive Running With Hip and Knee Osteoarthritis: A Systematic Review and Meta-analysis

It is well accepted in the scientific and medical community that exercise is good for health. Running for health-related purposes is one of the best exercises to improve cardiovascular, musculoskeletal, respiratory, and general health.[13] In fact, running is a regular physical activity among millions of persons around the world. However, is running safe and healthy for weight-bearing joints in all circumstances? Some concerns have been raised about whether prescribing exercise such as running can cause osteoarthritis (OA) in weight-bearing joints, particularly in certain scenarios.[57] Given the fact that OA may cause severe impairment to the patient's quality of life and require joint replacement, clarification of the influence of running on the development of OA is warranted. This clarification may help determine whether health care providers can safely prescribe running for health-related purposes.

STUDY DESIGN: Systematic review and meta-analysis.

BACKGROUND: Running is a healthy and popular activity worldwide, but data regarding its association with osteoarthritis (OA) are conflicting.

OBJECTIVES: To evaluate the association of hip and knee OA with running and to explore the influence of running intensity on this association.

METHODS: PubMed, Embase, and Cochrane Library databases were used to identify studies investigating the occurrence of OA of the hip and/or knee among runners. A meta-analysis of studies comparing this occurrence between runners and controls (sedentary, nonrunning individuals) was conducted. Runners were regarded as "competitive" if they were reported as professional/elite athletes or participated in international competitions. Recreational runners were individuals running in a nonprofessional (amateur) context. The prevalence rate and odds ratio (with 95% confidence interval [CI]) for OA between runners (at competitive and recreational levels) and controls were calculated. Subgroup analyses were conducted for OA location (hip or knee), sex, and years of exposure to running (less or more than 15 years).

RESULTS: Twenty-five studies (n = 125 810 individuals) were included and 17 (n = 114 829 individuals) were meta-analyzed. The overall prevalence of hip and knee OA was 13.3% (95% CI: 11.6%, 15.2%) in competitive runners, 3.5% (95% CI: 3.4%, 3.6%) in recreational runners, and 10.2% (95% CI: 9.9%, 10.6%) in controls. The odds ratio for hip and/or knee OA in competitive runners was higher than that in recreational runners (1.34; 95% CI: 0.97, 1.86 and 0.86; 95% CI: 0.69, 1.07, respectively; controls as reference group; for difference, $P<.001$). Exposure to running of less than 15 years was associated with a lower association with hip and/or knee OA compared with controls (OR = 0.6; 95% CI: 0.49, 0.73).

CONCLUSION: Recreational runners had a lower occurrence of OA compared with competitive runners and controls. These results indicated that a more sedentary lifestyle or long exposure to high-volume and/or high-intensity running are both associated with hip and/or knee OA. However, it was not possible to determine whether these associations were causative or confounded by other risk factors, such as previous injury.

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A clear distinction must first be made between running and other sports. It has been observed that the risk of OA may not be equivalent among exercise activities.[1] It has been demonstrated that, in general, previous injury or a heavy occupational workload increases the risk of OA,[16,49,54] and the level of sports participation (whether elite/professional or recreational) may play an important role in the development of OA in sports.[8,9,21,29,45] Regarding exposure to running, specifically, there are contradictory data on the risk of OA. Some studies have found that running was not associated with an

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increased risk of OA (in fact, some researchers even found that it was protective),[5,7,24,47,56] but a fair number of studies have observed a higher risk of OA or abnormal cartilage changes, in animals and humans.[2,4,10,11,15,26,32,33,35,36,38-40,43,46,48] A likely explanation for these controversial results is the presence of differences in the type of running (level, intensity, and length of exposure) and the presence of confounding factors (ie, other risk factors for OA) not considered in the risk analysis for OA in runners. However, the influence of the level of exercise (elite/professional versus recreational) and the influence of other potential risk factors for OA (particularly body mass index [BMI]), occupational workload, and previous injury) on the risk of OA from running have not been well studied. The relevance of better knowledge of the influence of these factors on the risk of OA in runners is to obtain a better definition of the patients who could acquire health-related benefits from running, without increasing the risk of joint damage that would result in the impairment of their function and quality of life.

The purpose of this study was to evaluate the association of hip and knee OA with running and to further explore the influence of running intensity and years of exposure on this association. The study also aimed to assess the influence of concomitant risk factors on the association of running with hip and knee OA. It was hypothesized that running would not be associated with OA of the hip and knee, at least in recreational runners or whenever other risk factors are controlled.

METHODS

The methodology of this study was reported following the PRISMA statement for systematic reviews and meta-analyses.[37]

Eligibility Criteria

All prospective, cross-sectional, or retrospective human studies investigating the relationship between OA of the hip and/or knee and running were evaluated for eligibility. Studies were included in the qualitative analysis if (1) the level of evidence was between I and III, (2) they were written in English, (3) there was clearly defined physician-based hip and/or knee (tibiofemoral joint) OA (clinical and/or radiographic findings), and (4) running activity was clearly reported in the sample. Studies in which the diagnosis of OA was self-reported were included if the diagnosis was specifically made by a physician. In studies in which this information was not detailed enough but the participants had undergone joint replacement, it was assumed that the patients had physician-diagnosed OA and the studies were included in the systematic review/meta-analysis. Osteoarthritis was not considered to be equivalent to pain, osteophytes, or subchondral sclerosis alone. To be included in the meta-analysis, studies had to report the incidence or prevalence of OA in runners and a control group. Review articles, systematic reviews, and meta-analyses were not included, but reference lists were examined to ensure the completeness of the list of relevant studies. Studies that included subjects exposed to running and different types of physical activity altogether were not included.

Information Sources and Search

Electronic Search A systematic electronic literature search was conducted using PubMed (MEDLINE, with no start date), Embase (starting in 1980), and the Cochrane Library (no start date) in November 2016. Two librarians expert in electronic search methods performed the literature search. The search strategy and key words employed in this study are summarized in the **APPENDIX** (available at www.jospt.org).

Other Search Methods The reference lists of all included articles and review studies were scrutinized to search for potential studies not previously identified.

Data Collection and Analysis

Study Selection All abstracts were read, and articles of potential interest were reviewed in detail (full text) by 2 coauthors to decide on inclusion in or exclusion from this systematic review. In cases of disagreement, both coauthors reviewed and discussed the study and a final decision was made in consensus.

Data-Collection Process Information regarding the type of study, study and patient characteristics, duration of exposure to running, main results relating to OA and running, confounding factors considered, observations, and main conclusions was extracted from all the included studies. For the studies included in the meta-analysis, a database spreadsheet was created to extract the information for the analysis. The database included information on the joint involved, additional risk factors for OA considered in the analysis (age, sex, weight, occupational workload, and previous injury), years of exposure to running, running level (professional/competitive versus recreational), group (runners or controls), and the number of patients (total, men, and women) with and without OA in each of the 2 groups. Runners were regarded as being part of the elite/competitive group if the authors specifically reported that the runners were professional, elite, or ex-elite athletes, or in any case in which runners represented their countries in international competitions. The control group consisted of mainly sedentary, nonrunning individuals. One coauthor performed all the data extraction, which was then verified by a second coauthor.

Assessment of the Risk of Bias

The assessment of the risk of bias was based on the recommendations of the Cochrane Collaboration.[14] The most important items considered for the risk of bias included selection bias (random sequence generation and allocation concealment: systematic differences between the baseline characteristics of the groups that are compared), performance bias (blinding of participants and personnel: systematic differences between groups in the care that is provided, or in exposure to factors other than the interventions of interest), detection bias (blinding of outcome assessment: systematic differences between groups in how outcomes are determined), attrition bias (incomplete outcome data: systematic differences between groups in withdrawals from a study), and reporting bias (selective reporting: systematic differences between reported and unreported findings).[14] Each study was classified according to high risk, low risk, or unknown risk of bias for each item.

Statistical Analysis

Three different analyses were conducted. First, a comparison of the association of OA of the hip and/or knee, hip alone, and knee alone between runners and controls (for the overall population, males, and females, whenever available) was made, depending on the level of running (competitive versus recreational). Each subgroup (competitive or recreational) was compared with its respective control group in the included study. The same comparison was made depending on the years of exposure to running (less or more than 15 years), including the studies that reported this specific information. Finally, the association of OA of the hip and/or knee, hip alone, and knee alone was compared in the overall population (males and females, whenever data were available), depending on the confounding factors adjusted in the risk analysis of the included studies. The level of adjustment of the included studies was divided into 5 categories: studies not adjusting the risk of OA for any parameter; studies adjusting for age; studies adjusting for age and BMI; studies adjusting for age, BMI, and occupational workload; and studies adjusting for age, BMI, occupational workload, and previous injury.

For each parameter, the odds ratio (OR) with 95% confidence interval (CI) was calculated, based on the number of individuals with and without OA among the runners and controls. The overall prevalence (with 95% CI) was also calculated for competitive runners, recreational runners, and controls (runners with less than 15 or greater than 15 years). A meta-analysis of the association between running and OA was then conducted within each exposure group to produce combined estimates of measurements of effect (OR, with 95% CI), based on a random-effects model. For each meta-analysis conducted, overall OR estimates were calculated using an inverse, variance-weighted, random-effects model with 95% CIs. Random-effects analysis was used because the overall heterogeneity was moderate. Heterogeneity was characterized using the I^2 statistic. All analyses were made using SAS Version 9.4 (SAS Institute Inc, Cary, NC), Comprehensive Meta-Analysis Version 3.0 (Biostat, Englewood, NJ), and RevMan 5.3 (The Nordic Cochrane Centre, Copenhagen, Denmark).

RESULTS

Study Selection

The literature search elicited a total of 1907 references, of which 354 were duplicates and another 1515 were excluded (**FIGURE**). A total of 38 studies were reviewed in full text and 17 were included. In addition, 8 articles were added after reviewing the reference lists of the included studies. These 8 articles were

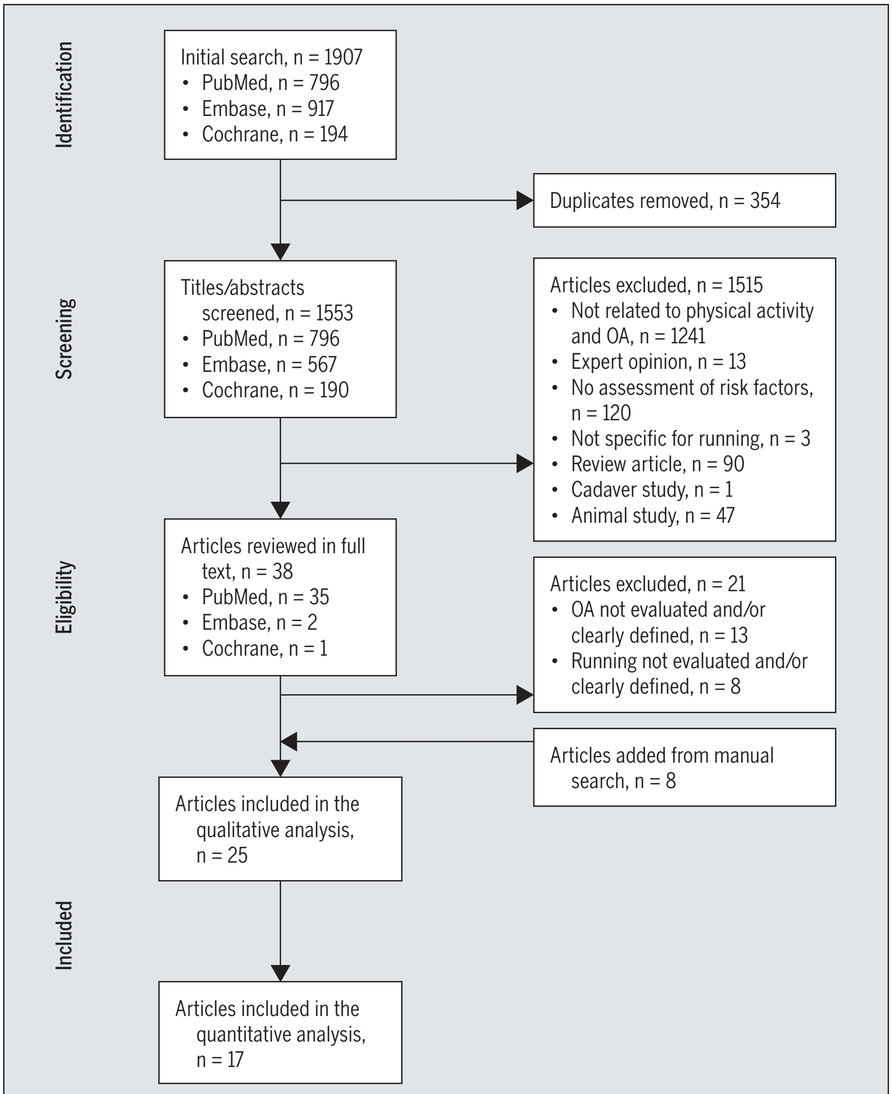

FIGURE. Flow chart of study identification, screening, and inclusion. Abbreviation: OA, osteoarthritis.

TABLE 1 Summary of Studies Evaluating the Risk of Osteoarthritis After Exposure to Running

Study	Type of Study	Study/Patient Characteristics	Exposure to Running	Results	Confounding Factors Considered	Observation	Conclusion
Chakravarty et al[5]	Cohort, level II evidence	45 long-distance runners (mean age, 71 y; 65% men; 44% previous knee injury; BMI, 23 kg/m²) and 53 age-, education-, and occupation-matched controls (mean age, 72 y; 70% men; 36% previous knee injury; BMI, 25 kg/m²) were followed for nearly 2 decades for radiographic knee OA	Vigorous exercise: runners, 293 min/wk; controls, 199 min/wk Running: runners, 95 min/wk; controls, 1 min/wk	Knee OA: runners, 20%; controls, 32% (*P* = .2) Severe knee OA: runners, 2.2%; controls, 9.4% (*P* = .2) Knee OA associated with BMI, initial radiographic damage, and longer follow-up. Knee OA not associated with sex, education, previous knee injury, and mean exercise time	Adjusted for age, sex, BMI, education, previous knee injury, and initial radiographic and disability scores Not clearly adjusted for occupational workload	Running not isolated Controls also exposed to running earlier in life	Running was not associated with accelerated radiographic knee OA
Cheng et al[6]	Cohort, level II evidence	16961 subjects aged 20-87 y (median age, 44 y for men [76%] and 43 y for women [24%]) were followed for a mean of 10.9 y for incidence of hip and knee OA Self-reported physician-diagnosed hip and knee OA	Physical activity: high (walking or jogging >20 mi/wk), moderate (10-20 mi/wk), low (<10 mi/wk), other (other activities than walking/jogging)	439 incident cases in men (3.4%) and 162 in women (3.9%); subjects >50 y: incident OA higher in women; subjects <50 y: incident OA similar between men and women Physical activity level, <50 y: men: high HR = 2.4 (95% CI: 1.5, 3.9), moderate HR = 1.2 (95% CI: 1, 1.4), low HR = 1 (95% CI: 0.6, 1.5), other HR = 1.4 (95% CI: 0.9, 2); women: high HR = 1.5 (95% CI: 0.4, 5.1), moderate HR = 1.2 (95% CI: 0.9, 1.5), low HR = 0.8 (95% CI: 0.4, 1.6), other HR = 1.1 (95% CI: 0.6, 2) Physical activity level, >50 y: men: high HR = 1.2 (95% CI: 0.6, 2.3), moderate HR = 1 (95% CI: 0.8, 1.2), low HR = 1.3 (95% CI: 0.9, 1.8), other HR = 1.1 (95% CI: 0.7, 1.5); women: high HR = 1.4 (95% CI: 0.4, 4.6), moderate HR = 1.2 (95% CI: 0.9, 1.5), low HR = 0.6 (95% CI: 0.3, 1.2), other HR = 0.7 (95% CI: 0.4, 1.3)	Adjusted for age, sex, BMI, smoking, and ethanol and caffeine use History of joint injury and occupational workload not controlled in the analysis	Kappa agreement was 0.68 between self-reported physician-diagnosed OA and chart review for OA Running not isolated	High levels of physical activity were associated with increased incidence of hip and knee OA in men <50 y, but not in the rest of the sample
Dahaghin et al[7]	Case-control, level III evidence	480 cases with knee OA (mean ± SD age, 57 ± 12 y) and 490 controls without knee OA (mean ± SD age, 46 ± 15 y) (*P*<.001); 70% women in cases, 65% in controls; BMI, 30 kg/m² in cases and 27 kg/m² in controls (*P*<.001)	Not reported	Participation in sports: cases, 32%; controls, 40% Running OR = 1.05 (95% CI: 0.7, 1.58)	Age, sex, and BMI adjusted History of knee injuries not reported Occupational workload collected Adjustment of knee OA in runners depending on workload not known	Running not isolated Minimum exposure to sports, 6 mo Low participation in sports in both groups	Running was not associated with increased risk of knee OA
Kettunen et al[18]	Case-control, level III evidence	Initial sample: male ex-elite athletes for runners, shooters, soccer, WLs Follow-up in 1992: 80% responded (28 runners)	Not reported; former athletes at an elite level	Long-distance runners, 14% knee OA and 12% hip OA, compared with 3% and 30% in shooters, respectively	Not adjusted for the running and OA comparison between groups	Controls not sedentary No statistics for running and OA	Running was not clearly associated with hip or knee OA

Table continues on page 377

TABLE 1 Summary of Studies Evaluating the Risk of Osteoarthritis After Exposure to Running (continued)

Study	Type of Study	Study/Patient Characteristics	Exposure to Running	Results	Confounding Factors Considered	Observation	Conclusion
Kettunen et al[17]	Case-control, level III evidence	Initial sample: 2448 male ex-elite athletes representing Finland in sport events from 1920 to 1965 versus 1712 healthy age-matched controls aged 20 y Follow-up in 1995: 1321 athletes available, 814 controls Hip and knee OA in those <45 y and ≥45 y Study through questionnaires	Not reported; former athletes at an elite level: Olympic Games, world championships, European championships	For age-, weight-, occupation-adjusted analysis (only significant results shown) Hip disability: endurance OR = 0.35 (95% CI: 0.14, 0.85), track and field OR = 0.3 (95% CI: 0.12, 0.73), all sports OR = 0.54 (95% CI: 0.36, 0.82) Knee disability: team sports OR = 1.76 (95% CI: 1.03, 3) Hip OA: no differences Knee OA: team sports OR = 2.04 (95% CI: 1.35, 3.07) Hip pain: endurance OR = 0.32 (95% CI: 0.17, 0.61), shooting OR = 0.32 (95% CI: 0.12, 0.87), all sports OR = 0.66 (95% CI: 0.5, 0.88) Knee pain: team sports OR = 1.56 (95% CI: 1.07, 2.28)	Adjusted for age, weight, and occupation History of joint injury not excluded from the analysis of OA	Exposure not quantified Likely influence of injury on hip and knee pain, disability, and OA	Running was not associated with increased risk of hip or knee OA
Kohatsu and Schurman[19]	Case-control, level III evidence	46 subjects (cases) with knee OA (mean age, 71 y; 60% women; BMI, 27 kg/m²; years of school, 14) and 46 matched controls (mean age, 71 y; 60% women; BMI, 23 kg/m²; years of school, 14) Diagnosed knee OA in patients undergoing TKA	Not reported	Similar exposure to running, team sports, racquet sports, and other sports in cases compared with controls (4.5% versus 8.7%, 12.2% versus 17.4%, 15.8% versus 22.2%, 59.5% versus 65.2%, respectively) Cases less exposed to walking compared with controls (35.7% versus 56.5%, *P*<.01)	Age-, sex-, and education-matched controls Unmatched for BMI Cases participated in heavier work for ages between 30 and 49 y compared with controls Cases had more history of knee injuries (*P*<.01)	Participation, 68% Cases had higher BMI (*P*<.001) Running not isolated Running not quantified	General leisure-time physical activity was not associated with significant risk of knee OA
Konradsen et al[20]	Cross-sectional, level III evidence	27 male orienteering runners (median age, 58 y; range, 50-68 y; median weight, 71 kg; range, 60-81 kg) and 27 matched controls (median age, 57 y; range, 53-65 y; median weight, 75 kg; range, 55-82 kg) Clinical and radiological OA	Running: median age, 40 y (range, 32-50 y). Median distance <30 y, 42 km/wk (range, 20-65 km/wk); 31-40 y, 34 km/wk (range, 15-65 km/wk); 41-50 y, 30 km/wk (range, 13-63 km/wk); 51-60 y, 28 km/wk (range, 13-63 km/wk); >61 y, 21 km/wk (range, 13-43 km/wk)	No significant differences between runners and controls with regard to OA and osteophytosis of hip, knee, ankle No differences in joint alignment, range of motion, or complaints of pain between groups 22% of runners had pain during running, with no radiological differences compared with subjects without pain	Age-, height-, weight-, and occupational load-matched controls No major joint injuries in the sample except for 3 subjects, 1 of whom was excluded from the analysis	Participation, 90% Statistics not very detailed Runners who were no longer active were excluded Small sample	Running at recreational level was not associated with hip, knee, and ankle OA

Table continues on page 378

TABLE 1 — SUMMARY OF STUDIES EVALUATING THE RISK OF OSTEOARTHRITIS AFTER EXPOSURE TO RUNNING (CONTINUED)

Study	Type of Study	Study/Patient Characteristics	Exposure to Running	Results	Confounding Factors Considered	Observation	Conclusion
Kujala et al[21]	Cohort, level II evidence	2448 male ex-elite athletes representing Finland in sport events from 1920 to 1965 versus 1712 healthy age-matched controls aged 20 y Follow-up in 1970: 2049 athletes available (mean age, 46 y; range, 21-85 y), 1403 controls (mean age, 44 y; range, 24-86 y) Follow-up in 1990: 1436 athletes available, 959 controls Study through questionnaires	Not reported; former athletes at an elite level: Olympic Games, world championships, European championships	More admissions for hip, knee, ankle OA in athletes (5.9%) than in controls (2.6%) (*P*<.001) Endurance (long-distance running): hip OA, 5.2% (95% CI: 2.6%, 10.2%); knee OA, 2.5% (95% CI: 0.7%, 6.3%); ankle OA, 0% Control group: 1.4% (95% CI: 0.9%, 2.2%), 1.3% (95% CI: 0.8%, 2%), and 0%, respectively OR for hip, knee, or ankle OA in runners compared with controls: 1.84 (95% CI: 0.93, 3.61) Adjusted OR for hip, knee, or ankle OA in runners compared with controls: 2.42 (95% CI: 1.26, 4.68) Mean age at first admission: higher in endurance than others (70.6 y compared with 58.2 y, 61.9 y, and 61.2 y in mixed sports, power sports, and controls, respectively)	Adjusted for age, weight, and occupation History of joint injury not controlled	Only considering admission may hide other patients with OA at lower stages Exposure not quantified Endurance mixes running and cross-country skiing	Running was not associated with increased risk of hip, knee, or ankle OA Endurance athletes had admissions for hip, knee, or ankle OA at older ages
Kujala et al[22]	Cohort, level II evidence	264 male orienteering runners (mean age, 58 y; range, 47-71 y; mean BMI, 23 kg/m^2) compared with 188 male nonsmoking controls (mean age, 60 y; range, 50-71 y; mean BMI, 25 kg/m^2) Clinical OA at 11 y of follow-up	Not specified	Hip OA: running OR = 0.78 (95% CI: 0.35, 1.73) Knee OA: running OR = 1.79 (95% CI: 1.1, 3.54) Hip pain: running OR = 0.74 (95% CI: 0.37, 1.46) Knee pain: running OR = 1.75 (95% CI: 0.96, 3.18) Hip pain on stairs: running OR = 0.47 (95% CI: 0.2, 1.08) Knee pain on stairs: running OR = 0.78 (95% CI: 0.4, 1.4) Runners: 23.5% had ligament or meniscus injury (versus 16.8% in controls); 38% of runners with knee injuries had OA (versus 7% without injury)	Age-, sex-, and area of residence-adjusted analysis Not adjusted for BMI and occupational workload History of previous knee injury likely influencing development of OA	Exposure to running not quantified Controls (11%) participated in other physical activities Differences in weight and BMI	Overall, running was not associated with greater lower-limb disability, except for knee OA
Lane et al[23]	Cross-sectional, level III evidence	41 long-distance runners (aged 50-72 y) compared with 41 matched controls Clinical and radiological lumbar, knee, and hand OA	Running: 224 min/wk; time running, 8.5 y; mean total distance run, 9552 mi	Female, but not male, runners had more sclerosis and spur formation in the spine and knee, but not the hand, on radiographs No differences in JSN, crepitation, joint stability, or symptomatic OA between groups	Age-, sex-, education-, and occupation-matched controls Control for history of joint injury in the analysis not reported	Controls were heavier than runners Controls also were exposed to running	Running was not associated with increased risk of lumbar spine, knee, and hand OA

Table continues on page 379

TABLE 1

Summary of Studies Evaluating the Risk of Osteoarthritis After Exposure to Running (continued)

Study	Type of Study	Study/Patient Characteristics	Exposure to Running	Results	Confounding Factors Considered	Observation	Conclusion
Lane et al[24]	Cohort, level II evidence	33 runners (mean age, 63.3 y; 60% men; weight, 67.8 kg) versus 33 matched controls (mean age, 63.5 y; 60% men; weight, 73.1 kg) Clinical and radiological OA at baseline and 5 y later	Runners (mean values): exercise, 304 min/wk; running, 185 min/wk	Lumbar OA: both groups progressed in spurs Knee OA: runners had no progression of spurs and combined JSN, sclerosis, and spurs; controls had progression of both parameters Hand OA: both groups progressed in spurs and combined JSN, sclerosis, and spurs No differences in age, sex, weight, exercise, running, and disability between subjects with and without hand and knee OA Running was not predictive of lumbar spine, knee, or hand OA	Age-, sex-, occupation-, and years of school-matched controls Injuries were collected, but their influence was not reported	Follow-up, 80% Controls were heavier than runners ($P<.05$) Running not isolated Spurs alone not enough for OA	Running was not associated with increased risk of lumbar spine, knee, and hand OA
Lane et al[25]	Cohort, level II evidence	28 runners (mean age, 66 y; range, 60-77 y; 60% men; mean BMI, 23.6 kg/m^2) and 27 nonrunners (mean age, 66 y; 74% men; mean BMI, 24.7 kg/m^2) Clinical and radiological OA at 9 y of follow-up	Runners: mean, 279 min/wk of exercise; mean, 107 min/wk of running; mean, 18 mi/wk; mean, 17 y running	Hip joint: osteophytes, JSN, total hip score not significantly different between both groups Knee joint: both groups progressed significantly in osteophytes; only controls progressed significantly in JSN; only runners progressed significantly in total knee score	Age, sex, education, and occupation adjusted History of injury not clearly controlled	Controls also exercised Small sample Potential risk of selection bias	Running was not associated with increased hip OA or progression of knee OA
Lau et al[27]	Case-control, level III evidence	138 subjects with hip OA and 414 controls 658 subjects with knee OA and 658 controls Clinical and radiological hip or knee OA	Not detailed	Hip OA: small number of cases in all sports, except gymnastics in women Knee OA: small number of cases, except running, soccer and running in men, and gymnastics and kung fu in women Hip OA in men: running OR = 0.7 (95% CI: 0.2, 2.3), soccer OR = 1.3 (95% CI: 0.3, 5.4), gymnastics OR = 1.2 (95% CI: 0.2, 6.9), kung fu OR = 0.8 (95% CI: 0.08, 6.7) Hip OA in women: running OR = 0.9 (95% CI: 0.2, 3.3), badminton OR = 1 (95% CI: 0.2, 5), gymnastics OR = 6 (95% CI: 2.1, 17.6) Knee OA in men: running OR = 0.6 (95% CI: 0.3, 1.4), soccer OR = 1.3 (95% CI: 0.6, 2.8), gymnastics OR = 2 (95% CI: 0.8, 5.3), kung fu OR = 1.4 (95% CI: 0.4, 4.4) Knee OA in women: running OR = 1.4 (95% CI: 0.7, 2.8), badminton OR = 0.5 (95% CI: 0.1, 2.7), gymnastics OR = 7.2 (95% CI: 3.1, 16.8), kung fu OR = 20 (95% CI: 2.7, 149)	Age, sex, weight, occupation, hip/knee injuries controlled, but analysis only differentiated for sex	Only includes worst grades of OA Risk of type II error in sports with small number of cases No data on number of injuries in each group or sport	Running was not associated with increased risk of hip and knee OA in both men and women

Table continues on page 380

TABLE 1 Summary of Studies Evaluating the Risk of Osteoarthritis After Exposure to Running (continued)

Study	Type of Study	Study/Patient Characteristics	Exposure to Running	Results	Confounding Factors Considered	Observation	Conclusion
Lo et al[30]	Case-control, level III evidence	2637 cases compared retrospectively for history of running and evaluated in a cross-sectional manner for knee OA (mean age, 64 y; 56% women; mean BMI, 28.5 kg/m^2)	Runners (30%): at least 250 bouts of running in their lives, 75%; at least 800 bouts, 50%; at least 2000 bouts, 25%; competitive, 2% to 5%	Radiographic knee OA: prior runners, OR = 0.98 (95% CI: 0.78, 1.25); current runners, OR = 0.91 (0.7, 1.19) compared with reference group (never running) (*P* value not significant) Symptomatic knee OA: prior runners, OR = 0.88 (95% CI: 0.67, 1.14); current runners, OR = 0.71 (95% CI: 0.53, 0.97) compared with reference group (never running) (*P* = .03)	Age, sex, BMI, other physical activities, and previous knee injury	Risk of recall bias Running not isolated in the sample Minor proportion of competitive runners (2%-5%)	Running not associated with symptomatic knee OA
Manninen et al[34]	Case-control, level III evidence	281 cases undergoing TKA for knee OA (men, 55; women, 226; mean age, 28 y) and 524 age- and sex-matched controls	Only a few at competitive level High exposure: >8654 h in men, >6862 h in women Low exposure: lower than these values	Men with high cumulative exercise were protected from knee OA compared with low exposure (OR = 0.28; 95% CI: 0.08, 0.96) for all ages Women with high exposure were protected from knee OA in the age ranges of 30 to 49 y and >49 y compared with low exposure (OR = 0.51; 95% CI: 0.23, 1.15 and 0.59; 95% CI: 0.3, 1.16, respectively) Running in men, OR = 0.26 (95% CI: 0.05, 1.3); running in women, OR = 0.7 (95% CI: 0.48, 1.02)	Analysis adjusted for age, BMI, physical work stress, knee injury, and smoking	Participation, 70% Running not isolated Controls not sedentary Specific sport exposure not provided	Running was not associated with increased risk of knee OA in men and women
Marti et al[35]	Case-control, level III evidence	27 former elite long-distance runners (mean age, 42 y), 9 former bobsled riders (mean age, 42 y), and 23 controls (mean age, 35 y) Clinical and radiological hip OA	Running: mean, 97 km/wk Bobsled riders: mean, 12 km/wk	Hip OA index (computed by summing JSN, sclerosis, and osteophytes): mean in runners, 1.37 (95% CI: 0.76, 1.98); in bobsled riders, 0.33 (95% CI: –0.05, 0.72); in controls, 0.32 (95% CI: 0, 0.64) (*P* = .006); runners had more osteophytes and sclerosis compared with controls Hip pain: 30% in runners, 0% in bobsled riders and controls Adjusting for age, runners had more hip OA Adjusting for mileage, runners did not have more hip OA	Analysis not adjusted for sex, BMI, occupational workload, or history of joint injury Adjusted for age and mileage	Participation, 92% Small sample Radiological blinding Controls also ran No baseline X-rays	Running was associated with an increased risk of OA
Panush et al[42]	Cross-sectional, level III evidence	17 male runners (mean age, 56 y; range, 50-74 y) compared with 18 male nonrunners (mean age, 61 y; range, 50-74 y) (no differences in age, height, weight) Clinical and radiological hip, knee, or ankle OA	Runners: mean time running, 12 y (range, 5-27 y); mean distance, 28 mi/wk (range, 20-40 mi/wk); mean lifetime distance, 17 343 mi (range, 6500-49 140 mi)	Runners versus nonrunners: hip pain, 26% versus 11%; knee pain, 29% versus 22%; ankle pain, 12% versus 5% Runners versus nonrunners: osteophytes per subject hip, 0.6 versus 0.9; knee, 3.9 versus 4.8; ankle, 2.2 versus 1.8. Cartilage thickness in the hip, 4.65 mm versus 4.3 mm; medial knee, 5 mm versus 5 mm; lateral knee, 5.8 mm versus 5.6 mm; ankle, 3 mm versus 3.1 mm. Degeneration: hip, 0% versus 0%; knee, 0.06% versus 0.17%; ankle, 0% versus 0% (all differences, *P*>.05)	Not controlled for occupational load and history of joint injury	Controls were sedentary Small sample Joint injury and occupational load influenced OA	Running was not associated with hip, knee, and ankle OA

Table continues on page 381

TABLE 1 Summary of Studies Evaluating the Risk of Osteoarthritis After Exposure to Running (continued)

Study	Type of Study	Study/Patient Characteristics	Exposure to Running	Results	Confounding Factors Considered	Observation	Conclusion
Panush et al[41]	Cohort, level II evidence	12 male runners (mean ± SD age, 63 ± 6 y) compared with 10 male nonrunners (mean ± SD age, 68 ± 8 y) (no differences in age, height, weight) Clinical and radiological hip, knee, or ankle OA at 8-y follow-up	Runners: mean ± SD time running, 22 ± 14 y; distance, 22 ± 11 mi/wk; lifetime distance, 25168 mi; 42% marathoners	Runners versus nonrunners: hip pain, 9% versus 10%; knee pain, 0% versus 0%; ankle pain, 0% versus 10% No differences in hip, knee, and ankle OA between runners and nonrunners	Adjustment of analysis for age, sex, BMI, occupation, and history of joint injury not known	Small sample Influence of joint injury and workload Running not isolated	Running was not associated with hip, knee, and ankle OA
Puranen et al[44]	Case-control, cross-sectional, level III evidence	74 ex-elite runners (mean age, 55 y; range, 31-81 y) and 115 controls (mean age, 56 y; range, 40-75 y)	Elite running: starting age, 15 y (range, 12-25 y); total participation, 21 y (range, 8-50 y)	Hip OA changes: runners, 4%; controls, 8.6% Osteophyte formation only: runners, 9.5%; controls, 14.8% (none had hip pain) Clear OA changes were associated with more hip pain	Control of main confounding factors not reported: sex, BMI, occupational load, other exposure to sports, history of joint injury, and so on	No statistics Influence of confounding factors Controls were not sedentary	Running was not associated with increased risk of hip OA
Sohn and Micheli[47]	Case-control, level III evidence	504 former runners (mean age, 57 y; range, 23-77 y) compared with 287 ex-swimmers; mean follow-up, 25 y (range, 2-55 y) Clinical hip and knee OA	Running distance by age: >70 y, 18 mi/wk; 60-69 y, 18 mi/wk; 50-59 y, 30 mi/wk; 40-49 y, 33 mi/wk; 0-40 y, 58 mi/wk Time running by age: >70 y, 8 y; 60-69 y, 9 y; 50-59 y, 12 y; 40-49 y, 14 y; 0-40 y, 10 y	Severe hip or knee pain: runners, 2%; swimmers, 2.4%. Any kind of hip or knee pain: runners, 15%; swimmers, 19% (*P*>.05). No differences in pain between groups for any age range Surgery for pain (mainly arthroplasties): runners, 0.8%; swimmers, 2.1% Runners with higher miles run per week did not have significantly more pain, nor did runners with higher cumulative years of running	Age, sex, weight, educational level, socioeconomic status, cardiovascular fitness, and attitude toward exercise matched Control for occupational workload, exposure to other sports, BMI not reported	Runner response, 76%; swimmer response, 58% Controls were not sedentary Only clinical (not radiographic) OA	There was no association between middle- and long-distance running and risk of hip or knee OA
Spector et al[48]	Case-control, level III evidence	81 ex-elite female athletes (67 long-distance runners and 14 tennis players) (mean ± SD age, 52 ± 6 y; BMI, 22 ± 2.8 kg/m^2) and 977 age-matched female controls Clinical and radiological OA	Mean competition time of 15 y in runners and 19 y in tennis players Mean hours of vigorous weight-bearing sports per week: runners, 2.6 h; tennis players, 5.7 h Mean running distance, 14.6 mi/wk Mean time spent playing tennis, 5.2 h/wk	Adjusted risk of TF osteophytes and JSN in ex-athletes: OR = 3.57 (95% CI: 1.89, 6.71) and OR = 1.17 (95% CI: 0.71, 1.94), respectively Adjusted risk of PF osteophytes and JSN in ex-athletes: OR = 3.5 (95% CI: 1.8, 6.81) and OR = 2.97 (95% CI: 1.15, 7.67), respectively Adjusted risk of hip osteophytes and JSN in ex-athletes: OR = 2.52 (95% CI: 1.01, 6.26) and OR = 1.6 (95% CI: 0.73, 3.48), respectively Adjusted mean joint space of subjects without OA was greater in ex-athletes	Age-, sex-, height-, and weight-adjusted analysis For knee, analysis also adjusted for knee injuries, knee pain, smoking, menopause, and BMI Knee injury: ex-athletes, 3.7%; controls, 13.7% (*P*<.05) Occupational workload not controlled	Participation, 71% Baseline between-group differences Running not isolated Controls also exposed to exercise	Running and tennis in women were associated with a 2- to 3-fold increase in the risk of radiological hip and knee OA

Table continues on page 382

TABLE 1 Summary of Studies Evaluating the Risk of Osteoarthritis After Exposure to Running (continued)

Study	Type of Study	Study/Patient Characteristics	Exposure to Running	Results	Confounding Factors Considered	Observation	Conclusion
Vingård et al[53]	Case-control, level III evidence	233 cases with hip replacement because of OA and 302 controls, aged 50-70 y	Not detailed for each sport. Reported as low, medium, or high exposure. Collected: hours per week, weeks per year, total years, and level achieved	Running: risk of hip OA in moderate and high exposure compared with low exposure: RR = 1.7 (95% CI: 0.4, 6.9) and 2.1 (95% CI: 0.6, 6.8), respectively	Controls were age, education, smoking, and BMI matched Sports analysis adjusted for age, BMI, occupational workload, and different kinds of sport simultaneously	Participation: cases, 92%; controls, 77% Running not isolated Controls were not sedentary	Running was not associated with hip OA
Vingård et al[54]	Case-control, level III evidence	230 (cases) women aged 50-70 y with hip OA compared with 273 age-matched controls	Details not reported Exposure to sports to the age of 50 y: hours per week, weeks per year, years of exposure graded as low (total <100 h), medium (total 100-800 h), or high exposure (total >800 h)	Hip OA: left, 26%; right, 35%; both, 39% Hip OA: high versus low exposure, RR = 2.3 (95% CI: 1.5, 3.7); medium versus low exposure, RR = 1.5 (95% CI: 0.9, 2.5) Match of sports and occupational load: risk only increased in the following combination: medium exposure to sports and high exposure to workload, RR = 2.7 (95% CI: 1.1, 7); high exposure to sports and medium exposure to workload, RR = 2.7 (95% CI: 1.2, 5.9); and high exposure to both, RR = 4.3 (95% CI: 1.7, 11)	Adjusted for age, BMI, occupational load, number of children, smoking, and hormone therapy Not controlled for history of hip injury	Participation: cases, 95%; controls, 89% Controls were not sedentary Running not isolated Only women included Small sample	Exposure to sports was not associated with increased risk of hip OA in women alone but was in combination with workload
Vrezas et al[55]	Case-control, level III evidence	295 male cases with knee OA and 327 male controls, aged 25-70 y Radiographic knee OA	Running: exposure from 0 h to 3530 h	Running, swimming, bodybuilding, weightlifting: no increase in risk of knee OA Exposure to running: 0-700 h, OR = 0.8 (95% CI: 0.4, 1.7); 700-1695 h, OR = 1 (95% CI: 0.5, 2.3); 1695-3530 h, OR = 1.9 (95% CI: 0.8, 4.1); >3530 h, OR = 1.9 (95% CI: 0.8, 4.3)	Age, sex, BMI, and occupation History of joint injury not reported	Mild OA not included Isolation of running not known Potential effect of joint injury	Running was not associated with increased risk of knee OA
Williams[56]	Cross-sectional, level III evidence	Runners (74752 subjects: 46819 men, 27933 women; mean age, 46 y and 40 y, respectively) compared with walkers (14625 subjects: 3122 men, 11503 women; mean age, 61 y and 52 y, respectively)	Time running, 13 y in men and 9.8 y in women Marathons in last 5 y, 1.9 in men and 1.1 in women	Runners: 2004 cases of OA and 259 cases of hip replacement during 7.1 y of follow-up Walkers: 695 cases of OA and 114 cases of hip replacement during 5.7 y of follow-up	Not adjusted for runner-versus-walker comparison for OA Age, sex, hormone use adjusted for in comparisons within the runner group	Controls (walkers) older than runners Running not isolated	Running was associated with less risk of hip OA

Abbreviations: BMI, body mass index; CI, confidence interval; HR, hazard ratio; JSN, joint space narrowing; OA, osteoarthritis; OR, odds ratio; PF, patellofemoral; RR, relative risk; TF, tibiofemoral; TKA, total knee arthroplasty; WL, weightlifter.

not identified by the literature search but met the inclusion criteria. As a result, 25 articles (involving 125 810 individuals) met the final inclusion criteria for the current systematic review. Seventeen of them (involving 114 829 individuals) could be included in the quantitative analysis.

Characteristics of the Studies

Of the 25 studies, 7 were prospective cohort studies and 18 case-control or cross-sectional studies. **TABLE 1** summarizes the characteristics and principal findings of the 25 studies included in the qualitative analysis. An assessment of the risks of bias is summarized in **TABLE 2**. It is worth noting that most of the studies had a high risk of bias for most of the evaluated parameters.

Running Level

The occurrence of hip and/or knee OA in the sample (overall population, males, and females), depending on the level of running, is summarized in **TABLE 3**. The overall prevalence of hip and/or knee OA was 3.66% (95% CI: 3.54%, 3.79%) in runners and 10.23% (95% CI: 9.89%, 10.58%) in control individuals. The overall prevalence was 13.3% (95% CI: 11.62%, 15.20%) in competitive runners and 3.5% (95% CI: 3.38%, 3.63%) in recreational runners. Compared with the control group, recreational runners had a lower association with hip and/or knee OA (OR = 0.86; 95% CI: 0.69, 1.07; I^2 = 50%) and knee OA alone (OR = 0.83; 95% CI: 0.7, 0.99; I^2 = 0%) in the overall population and in males (OR = 0.78; 95% CI: 0.68, 0.89; I^2 = 0% and OR = 0.7; 95% CI: 0.5, 0.97; I^2 = 0%, respectively). Compared with the control group, female recreational runners had a lower association with hip and/or knee OA (OR = 0.54; 95% CI: 0.41, 0.71; I^2 = 43%). Compared with recreational runners, competitive runners had a significantly higher association with hip and/or knee OA and knee OA alone in the overall population (P<.001 and P = .005, respectively) and in males (P = .004 and P = .01, respectively). In females, competitive runners had a higher association with hip and/or knee OA compared with recreational runners (P = .006) (**TABLE 3**).

TABLE 2 ASSESSMENT OF THE RISK OF BIAS IN INCLUDED STUDIES

Study	Type of Bias*				
	Selection	Performance	Detection	Attrition	Reporting
Chakravarty et al[5]	High	High	Low	Unknown	Unknown
Cheng et al[6]	High	High	Unknown	Unknown	Unknown
Dahaghin et al[7]	Low	High	High	Unknown	Unknown
Kettunen et al[18]	High	High	High	Unknown	High
Kettunen et al[17]	High	High	High	Unknown	High
Kohatsu and Schurman[19]	High	High	High	Unknown	Unknown
Konradsen et al[20]	High	High	High	Unknown	Unknown
Kujala et al[21]	High	High	High	Unknown	Unknown
Kujala et al[22]	High	High	High	Unknown	Unknown
Lane et al[23]	High	High	Low	Unknown	Unknown
Lane et al[24]	High	High	Low	Unknown	Unknown
Lane et al[25]	High	High	Low	Unknown	Unknown
Lau et al[27]	High	High	Unknown	Unknown	Unknown
Lo et al[30]	High	High	High	Unknown	Unknown
Manninen et al[34]	High	High	High	Unknown	Unknown
Marti et al[35]	High	High	Low	High	High
Panush et al[42]	High	High	Low	Unknown	Unknown
Panush et al[41]	High	High	Low	Unknown	Unknown
Puranen et al[44]	High	High	High	High	High
Sohn and Micheli[47]	High	High	High	High	High
Spector et al[48]	High	High	High	Unknown	Unknown
Vingård et al[53]	High	High	High	Unknown	Unknown
Vingård et al[54]	High	High	High	Unknown	Unknown
Vrezas et al[55]	High	High	High	Unknown	Unknown
Williams[56]	High	High	High	Unknown	Unknown

**Selection bias, random sequence generation or allocation concealment; performance bias, blinding of participants and personnel; detection bias, blinding of outcome assessment; attrition bias, incomplete data outcome; reporting bias, selective reporting.*

Years of Running

The association of hip and/or knee OA in the sample (overall population, males, and females), depending on years of running (less or more than 15 years), is summarized in **TABLE 4**. All studies in the greater-than-15-years subgroup corresponded to competitive runners (**TABLE 4**). The overall prevalence of hip and/or knee OA was 3.03% (95% CI: 2.92%, 3.15%) in people running for less than 15 years and 17.2% (95% CI: 13.3%, 22.01%) in people running for more than 15 years. Compared with the control group, individuals with exposure to running of less than 15 years had a lower association with hip and/or knee OA in the overall population (OR = 0.6; 95% CI: 0.49, 0.73; I^2 = 47%), in males (OR = 0.79; 95% CI: 0.68, 0.91; I^2 = 0%), and in females (OR = 0.52; 95% CI: 0.47, 0.57; I^2 = 0%). Compared with people running for less than 15 years, those running for more than 15 years had a higher association with hip and/or knee OA in the overall population (P = .01) and in females (P<.001) (**TABLE 4**).

Influence of Potential Confounding Factors

The association of hip and/or knee OA in the sample (overall population, males, and females), depending on the adjustment of potential confounding factors, is summarized in **TABLES 5** through **7**. It was observed that the 2 studies in which a larger number of variables were controlled in the risk analysis (both including recreational runners) had a significantly lower association with hip and/or knee OA compared with controls (**TABLE 5**). For the other levels of adjustment, and for males and females separately, the association of running with hip and/or knee OA could not be demonstrated (**TABLES 5-7**).

DISCUSSION

The principal finding in this study was that, in general, running was not associated with OA. In fact, running at a recreational level was associated with lower odds of hip and/or knee OA compared with individuals running competitively and more sedentary, nonrunning individuals. While competitive running led to an increased

TABLE 3 Comparison of the Association Between Osteoarthritis and Running Level

Outcome	Studies, n	Runners, n: Events	Runners, n: Total	Controls, n: Events	Controls, n: Total	Odds Ratio*	I^2, %	*P* Value
Overall population								
Hip and/or knee								<.001
Competitive[17,20-22,44,48]	6	184	1382	721	6276	1.34 (0.97, 1.86)	53	
Recreational[5-7,19,24,30,34,41,42,55,56]	11	2942	83939	2373	23959	0.86 (0.69, 1.07)	50	
Hip								.36
Competitive[17,20-22,48]	5	64	651	188	3067	1.65 (0.94, 2.89)	58	
Recreational[41,56]	2	2266	74764	810	14635	0.81 (0.19, 3.42)	48	
Knee								.005
Competitive[17,20-22,44,48]	6	120	731	533	3209	1.16 (0.86, 1.57)	15	
Recreational[5,7,19,24,30,34,42,55]	8	461	1456	1328	3520	0.83 (0.7, 0.99)	0	
Males								
Hip and/or knee								.004
Competitive[17,20-22,44]	5	147	1220	289	4322	1.45 (0.97, 2.17)	53	
Recreational[6,34,41,42,55,56]	6	1606	52996	520	8106	0.78 (0.68, 0.89)	0	
Hip								.17
Competitive[17,20-22]	4	55	570	115	2090	1.67 (0.78, 3.59)	68	
Recreational[41,56]	2	1352	46831	111	3132	0.86 (0.50, 1.49)	8	
Knee								.01
Competitive[17,20-22,44]	5	92	650	174	2232	1.29 (0.90, 1.83)	11	
Recreational[34,42,55]	3	88	230	247	539	0.70 (0.50, 0.97)	0	
Females								
Hip and/or knee								.006
Competitive[48]	1	37	162	432	1954	1.04 (0.71, 1.53)	...	
Recreational[6,34,56]	3	968	29726	932	13269	0.54 (0.41, 0.71)	43	

Abbreviation: I^2, heterogeneity index.
**Values in parentheses are 95% confidence interval.*

association with OA compared with recreational running, nonrunners also had a higher risk of joint degeneration compared with recreational runners. The influence of associated risk factors (age, sex, weight, occupational workload, and previous injury) on the association with OA in runners could not be clearly demonstrated. These findings are relevant for physicians, physical therapists, nurses, athletic trainers, and athletes planning to prescribe running for training, return to sports, or health-related purposes.

The ideal study to investigate the risk of OA associated with running would have been a prospective, randomized, double-blind study comparing individuals who run regularly over a long period to those who are sedentary, excluding or controlling for the influence of previous injury, highly demanding occupational workload, and body weight. In addition, individuals should be exposed to no other activities but running, which is also difficult to control. No study of this kind exists, and it would be extremely difficult to perform. Moreover, having a group behave as sedentary individuals could be ethically questionable. Most of the studies included in this review were case-control or cross-sectional studies. In addition, these studies were found to involve a high risk of the principal types of bias: selection, performance, detection, attrition, and reporting (**TABLES 1** and **2**). Despite the inherent limitations of the included studies, this investigation provides valuable information for health-related professionals.

There have been recent similar studies with comparable conclusions.[3,28,50-52] Overall, these systematic reviews and meta-analyses have not been able to demonstrate an association between running and hip and knee OA. However, some of these meta-analyses included case series, missed some relevant studies for inclusion, and did not differentiate the association depending on the intensity of running. Overall, our study drew similar conclusions. The novel finding in our investigation is the increased association between running and OA in competitive, but not in recreational, runners. In fact, running at a recreational level was even found to have a protective effect on hip and/or knee OA.

TABLE 4 COMPARISON OF THE ASSOCIATION BETWEEN OSTEOARTHRITIS AND THE LENGTH OF RUNNING EXPOSURE

Outcome	Studies, n	Runners, n: Events	Runners, n: Total	Controls, n: Events	Controls, n: Total	Odds Ratio*	I^2, %	*P* Value
Overall population								
Hip and/or knee								.01
<15 y[5,6,41,42,56]	5	2503	82545	1078	20510	0.60 (0.49, 0.73)	47	
>15 y[20,44,48]	3	50	290	450	2123	1.01 (0.72, 1.43)	0	
Hip								.45
<15 y[41,56]	2	2266	74764	810	14635	0.81 (0.19, 3.42)	48	
>15 y[20,48]	2	10	108	74	1004	1.51 (0.74, 3.06)	0	
Knee								.4
<15 y[5,42]	2	22	62	33	71	0.62 (0.29, 1.32)	0	
>15 y[20,44,48]	3	40	182	376	1119	0.90 (0.59, 1.36)	0	
Males								
Hip and/or knee								.92
<15 y[6,41,42,56]	4	1519	52783	276	7585	0.79 (0.68, 0.91)	0	
>15 y[20,44]	2	13	128	18	169	0.83 (0.29, 2.36)	38	
Hip								.92
<15 y[41,56]	2	1352	46831	111	3132	0.86 (0.50, 1.49)	8	
>15 y[20]	1	1	27	1	27	1.0 (0.06, 16.85)	...	
Knee								.47
<15 y[42]	1	1	17	3	18	0.31 (0.03, 3.34)	...	
>15 y[20,44]	2	12	101	17	142	0.83 (0.26, 2.60)	40	
Females								
Hip and/or knee								<.001
<15 y[6,56]	2	963	29717	772	12872	0.52 (0.47, 0.57)	0	
>15 y[48]	1	37	162	432	1954	1.04 (0.71, 1.53)	...	

Abbreviation: I^2, heterogeneity index.
**Values in parentheses are 95% confidence interval.*

The mileage of exposure to running very likely has a strong influence on the development of OA. Konradsen et al[20] found that running (orienteering running) was not associated with hip and knee OA, with a median kilometers per week ranging between 21 and 42. In contrast, Marti et al[35] observed an increased prevalence of hip OA in elite long-distance runners who were exposed to a mean of 92 km/wk. The present study was unable to establish the association of OA with running according to mileage, because most studies did not quantify the exposure to running or did so using different measurements. In terms of the level of running, the definition of elite/competitive or recreational was not always clear, and there is no quantification of the amount of running that is considered elite. Some individuals may run a high mileage per week at a considerably high intensity for recreational purposes. In general, the lower the number of miles per week, the lower the level of running; however, the distinction between elite/competitive and recreational has not been quantified. Studies included in this investigation were grouped according to the authors' definition of the level of running. In general, running at an elite/competitive level increases the association with OA compared with the recreational level, particularly for the knee, in the overall population and in males (**TABLE 3**). However, there are no original studies specifically comparing the prevalence or incidence of hip and/or knee OA in elite/competitive versus recreational runners. Interestingly, most of the studies demonstrating an increased risk of OA from running or sports in general included elite, ex-elite, professional, or high-level athletes.[8,9,21,29,35,36,45,48]

McDermott and Freyne[36] found that runners with OA had been running for significantly more years compared with runners without OA (mean, 19.6 years versus 11.9 years, respectively). This corresponds to the findings in the present study, where runners exposed to this activity for less than 15 years had a lower association with OA in the overall population compared with an exposure of more than 15 years (**TABLE 4**). The potential influence of number of years or mileage on the risk of OA may be explained by the findings observed by Galois et al.[11] These researchers found a chondroprotective effect of slight or moderate-intensity running (as determined by distance) in rats that was no longer present with intense running (longest distance). Interestingly, in all of the included studies, those who had less than 15 years of exposure to running were grouped as recreational runners[5,6,41,42,56] and those who had more than 15 years of exposure to running were grouped as competitive runners.[20,44,48] As a result, no information on the effects of recreational running for more than 15 years on the association with hip and knee OA is available.

TABLE 5 COMPARISON OF THE ASSOCIATION BETWEEN OSTEOARTHRITIS AND RUNNING DEPENDING ON THE LEVEL OF ADJUSTMENT FOR OTHER RISK FACTORS IN THE OVERALL POPULATION

Outcome	Studies, n	Runners, n: Events	Runners, n: Total	Controls, n: Events	Controls, n: Total	Odds Ratio*	I^2, %
Hip and/or knee							
No adjustment[5,7,17,19-22,24,34,41,42,44,48,55,56]	16	2942	84546	2544	28376	0.88 (0.68, 1.13)	82
Adjusted by age[7,17,21,22,34,48]	6	335	1636	1220	7226	1.15 (0.79, 1.69)	79
Adjusted by age and BMI[7,17,34,48]	4	263	782	1150	4062	0.94 (0.64, 1.36)	73
Adjusted by age and BMI and WL[17,34]	2	69	264	395	1494	1.00 (0.45, 2.25)	68
Adjusted by age and BMI and WL and PI[30,34†]	2	191	801	744	2364	0.73 (0.61, 0.89)	0
Hip							
No adjustment[17,20-22,41,48,56]	7	2330	75415	998	17702	1.35 (0.64, 2.83)	90
Adjusted by age[17,22,48]	3	54	461	167	1637	1.34 (0.79, 2.28)	50
Adjusted by age and BMI[17,48]	2	40	197	154	1458	1.72 (1.16, 2.57)	0
Adjusted by age and BMI and WL[17]	1	31	116	81	481	1.80 (1.12, 2.9)	...
Adjusted by age and BMI and WL and PI	0	...	...	...	...	...	...
Knee							
No adjustment[5,7,17,19-22,24,34,42,44,48,55]	13	397	1412	1311	4870	0.87 (0.70, 1.08)	27
Adjusted by age[7,17,22,34,48]	5	268	849	1015	2783	0.94 (0.68, 1.31)	58
Adjusted by age and BMI[7,17,34,48]	4	223	585	996	2604	0.81 (0.65, 1.01)	12
Adjusted by age and BMI and WL[17,34]	2	38	148	314	1013	0.91 (0.52, 1.6)	34
Adjusted by age and BMI and WL and PI[30,34†]	2	191	801	744	2364	0.73 (0.61, 0.89)	0

Abbreviations: BMI, body mass index; I^2, heterogeneity index; PI, previous injury; WL, workload.
**Values in parentheses are 95% confidence interval.*
†This study controlled for age, sex, BMI, other physical activities, and prior knee injury.

The risk of OA from sports participation is influenced by the control of other risk factors by either excluding their presence or performing an adjusted risk analysis.[16,49,54] Specifically for running, a very limited number of studies that adjusted the risk analysis for many of the most important associated risk factors, particularly obesity, occupational workload, and previous injury, were included in the present investigation (**TABLES 5-7**). These factors were found to influence the risk of OA and should therefore be considered whenever the risk of OA is investigated.[16,49,54] The present meta-analysis was unable to demonstrate a clear association with OA in studies adjusting the risk analysis for other risk factors for OA compared with studies not performing this adjustment. A limitation of this comparison is that some studies appeared in more than 1 of the subgroups created for the level of adjustment. It was then recommended not to perform a direct between-subgroup comparison (no *P* value) of the influence of associated risk factors. It still remains unclear whether prescribing running in the overweight/obese patient with an additional high-impact occupational workload and previous injury is safe for joints. It is very likely that the combination of these 3 factors in a patient who begins to run may increase the risk of OA.[16,31,49,54] Further original investigations should be conducted to obtain a response to this research question.

The present study has some limitations. First, it was difficult to find studies with a clearly sedentary control group. This is associated with the normal activities the general population may perform every day. Some studies did not clearly specify whether the control group was sedentary or reported anecdotal exposure to sports.[5,17,22,24,44,47,48,56] As a result, the control group in some studies was not completely sedentary. Second, in some studies, the runners were also exposed to other types of sport (ie, tennis), the runners included some individuals performing only walking exercise, or the study involved orienteering running.[6,17,20,22,48,55] Considering both limitations, the presence of joint-impact exercises in the control group or the presence of high-impact joint forces other than running in runners has to be considered when interpreting the risk of OA from running per se. Third, the running level could only be classified according to the researchers' information and could not be based on any quantified parameter for running (mileage per week, velocity of running, and so on). It is therefore not possible to formulate any recommendation from a practical standpoint on the quantity of running that would be safe for the hip and knee. Fourth, the inclusion of studies written only in English may imply a language bias.[12] This language restriction is commonly used in studies due to obvious linguistic limitations. Fifth, the assessment

TABLE 6 COMPARISON OF THE ASSOCIATION BETWEEN OSTEOARTHRITIS AND RUNNING DEPENDING ON THE LEVEL OF ADJUSTMENT FOR OTHER RISK FACTORS IN MALES

		Runners, n		Controls, n			
Outcome	Studies, n	Events	Total	Events	Total	Odds Ratio*	I^2, %
Hip and/or knee							
No adjustment[6,17,20-22,34,41,42,44,55,56]	11	1753	54216	809	12428	1.01 (0.76, 1.33)	69
Adjusted by age[17,21,22,34]	4	136	1109	305	4261	1.43 (0.85, 2.40)	69
Adjusted by age and BMI[17,34]	2	64	255	235	1097	0.76 (0.17, 3.37)	74
Adjusted by age and BMI and WL[17,34]	2	64	255	235	1097	0.76 (0.17, 3.37)	74
Adjusted by age and BMI and WL and PI[34]	1	2	17	34	108	0.29 (0.06, 1.34)	...
Hip							
No adjustment[17,20-22,41,56]	6	1407	47401	226	5222	1.41 (0.76, 2.64)	78
Adjusted by age[17,22]	2	45	380	94	660	1.20 (0.49, 2.94)	75
Adjusted by age and BMI[17]	1	31	116	81	481	1.80 (1.12, 2.90)	...
Adjusted by age and BMI and WL[17]	1	31	116	81	481	1.80 (1.12, 2.90)	...
Adjusted by age and BMI and WL and PI	0	...	...	...	...	...	...
Knee							
No adjustment[17,20-22,34,42,44,55]	8	180	880	421	2771	0.99 (0.67, 1.45)	47
Adjusted by age[17,22,34]	3	78	403	173	795	1.1 (0.58, 2.1)	60
Adjusted by age and BMI[17,34]	2	33	139	154	616	0.7 (0.2, 2.41)	63
Adjusted by age and BMI and WL[17,34]	2	33	139	154	616	0.7 (0.2, 2.41)	63
Adjusted by age and BMI and WL and PI[34]	1	2	17	34	108	0.29 (0.06, 1.34)	...

Abbreviations: BMI, body mass index; I^2, heterogeneity index; PI, previous injury; WL, workload.
**Values in parentheses are 95% confidence interval.*

TABLE 7 Comparison of the Association Between Osteoarthritis and Running Depending on the Level of Adjustment for Other Risk Factors in Females

		Runners, n		Controls, n			
Outcome	Studies, n	Events	Total	Events	Total	Odds Ratio*	I^2, %
Hip and/or knee							
No adjustment[6,34,48,56]	4	1005	29888	1364	15223	0.69 (0.46, 1.04)	80
Adjusted by age[34,48]	2	42	171	592	2351	1.09 (0.75, 1.57)	0
Adjusted by age and BMI[34,48]	2	42	171	592	2351	1.09 (0.75, 1.57)	0
Adjusted by age and BMI and WL[34]	1	5	9	160	397	1.85 (0.49, 7)	...
Adjusted by age and BMI and WL and PI[34]	1	5	9	160	397	1.85 (0.49, 7)	...
Hip							
No adjustment[48,56]	2	923	28014	772	12480	0.84 (0.29, 2.43)	88
Adjusted by age[48]	1	9	81	73	977	1.55 (0.74, 3.22)	...
Adjusted by age and BMI[48]	1	9	81	73	977	1.55 (0.74, 3.22)	...
Adjusted by age and BMI and WL	0	...	...	...	...	...	...
Adjusted by age and BMI and WL and PI	0	...	...	...	...	...	...
Knee							
No adjustment[34,48]	2	33	90	519	1374	0.99 (0.63, 1.54)	0
Adjusted by age[34,48]	2	33	90	519	1374	0.99 (0.63, 1.54)	0
Adjusted by age and BMI[34,48]	2	33	90	519	1374	0.99 (0.63, 1.54)	0
Adjusted by age and BMI and WL[34]	1	5	9	160	397	1.85 (0.49, 7)	...
Adjusted by age and BMI and WL and PI[34]	1	5	9	160	397	1.85 (0.49, 7)	...

Abbreviations: BMI, body mass index; I^2, heterogeneity index; PI, previous injury; WL, workload.
**Values in parentheses are 95% confidence interval.*

of the risk of bias was conducted using a tool not specifically designed for observational, etiologic association studies, and the use of other appraisal tools might therefore provide different insights. Last, due to high between-study heterogeneity (high I^2 statistic), the random-effects model, which can inappropriately weight smaller studies in some instances, was necessary. In some comparisons, the I^2 heterogeneity statistic was very low (**TABLES 3-7**). The use of a fixed-effects model did not significantly change the results in parameters with low I^2 values, and a decision was made to use the random-effects model throughout the statistical analysis. Overall, the heterogeneity was considerably lower for comparisons involving the knee joint alone as compared with the hip and knee or hip alone.

Despite these limitations, the present study is the first meta-analysis to investigate the occurrence of OA between competitive and recreational runners, and involved a very large sample (114 829 individuals from different countries). The study has high external validity and the conclusions are of general health interest, given the high popularity of running worldwide.

CONCLUSION

Running at the recreational level was associated with significantly lower odds of OA compared with competitive runners or control individuals. These results indicate that a more sedentary lifestyle or long exposure to high-volume and/or high-intensity running are both associated with hip and/or knee OA. Running was associated with lower hip and/or knee OA if it was performed for up to 15 years; for more than 15 years, there were few studies and no clear conclusion could be drawn. It was also not possible to clearly demonstrate the influence of associated risk factors (age, sex, weight, occupational workload, and previous injury) on the risk of OA in runners. ◉

KEY POINTS

FINDINGS: Running was found to have a beneficial association with hip and knee osteoarthritis risk in runners with less than 15 years of running exposure. For individuals exposed to longer periods of recreational running, the safety of running for weight-bearing joints could not be determined. Recreational runners may have lower association with osteoarthritis compared with competitive runners and controls.

IMPLICATIONS: Running at a recreational level can be safely recommended as a general health exercise, with the evidence suggesting that it has benefits for hip and knee joint health. The amount of running that is safe for the joints could not be determined.

CAUTION: The present results must be interpreted with caution due to the low quality of most of the evidence, the small number of studies for some comparisons, the potentially high risk of bias in included studies, the high heterogeneity of studies, and the wide confidence intervals for some parameters.

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APPENDIX

SEARCH STRATEGY USED FOR THE ELECTRONIC LITERATURE SEARCH USING PUBMED, EMBASE, AND THE COCHRANE LIBRARY DATABASES

Database/Search	Query
PubMed	
1	Search (degenerative[tiab] OR degeneration[tiab] OR degradation[tiab] OR damaged[tiab] OR damage[tiab]) AND (joints[mesh] OR joints[tiab] OR joint[tiab])
2	Search osteoarthritis[tiab] OR osteoarthrosis[tiab] OR osteoarthritic[tiab] OR osteo-arthritis[tiab] OR osteo-arthrosis[tiab] OR osteo-arthritic[tiab] OR arthritis[tiab] OR arthrosis[tiab]
3	Search "Osteoarthritis"[Mesh]
4	Search joint disease[tiab] OR joint diseases[tiab]
5	Search "Joint Diseases"[Mesh:NoExp]
6	Search "Jogging"[Mesh] OR "Running"[Mesh]
7	Search jogging[tiab] OR jogger*[tiab] OR runner*[tiab] OR run[tiab] OR runs[tiab] OR running[tiab]
8	Search 1 OR 2 OR 3 OR 4 OR 5
9	Search 6 OR 7
10	Search 8 AND 9
11	Search ((animals[mh]) NOT (animals[mh] AND humans[mh]))
12	Search Editorial[ptyp] OR Letter[ptyp] OR Comment[ptyp]
13	Search 10 NOT 11
14	Search 13 NOT 12
15	Search 13 NOT 12 Filters: English
Embase	
1	exp osteoarthritis/
2	arthropathy/ or exp joint degeneration/
3	exp joint/
4	(degenerative or degeneration or degradation or damaged or damage).ti,ab.
5	(joint or joints).ti,ab.
6	3 and 4
7	4 and 5
8	6 or 7
9	(joint diseases or joint disease).ti,ab.
10	(osteoarthritis or osteoarthrosis or osteoarthritic or osteo-arthritis or osteo-arthrosis or osteo-arthritic or arthritis or arthrosis).ti,ab.
11	1 or 2 or 8 or 9 or 10
12	exp running/
13	exp jogging/
14	(jogging or jogger$1 or runner$1 or run or runs or running).ti,ab.
15	12 or 13 or 14
16	11 and 15
17	(animal not (animal and human)).sh.
18	16 not 17
19	limit 18 to (embase and english and (article or conference paper or note or "review"))

APPENDIX

Database/Search	Query
The Cochrane Library	
1	MeSH descriptor: [Osteoarthritis] explode all trees
2	MeSH descriptor: [Joint Diseases] explode all trees
3	osteoarthritis or osteoarthrosis or osteoarthritic or osteo-arthritis or osteo-arthrosis or osteo-arthritic or arthritis or arthrosis:ti,ab,kw (Word variations have been searched)
4	(joint or joints) and (degenerative or degeneration or degradation or damaged or damage):ti,ab,kw (Word variations have been searched)
5	joint diseases or joint disease:ti,ab,kw (Word variations have been searched)
6	1 or 2 or 3 or 4 or 5
7	MeSH descriptor: [Jogging] explode all trees
8	MeSH descriptor: [Running] explode all trees
9	jogging or jogger* or runner* or run or runs or running:ti,ab,kw (Word variations have been searched)
10	7 or 8 or 9
11	6 and 10