What Is the Effect of Physical Activity on the Knee Joint? A Systematic Review

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ABSTRACT

URQUHART, D. M., J. F. L. TOBING, F. S. HANNA, P. BERRY, A. E. WLUKA, C. DING, and F. M. CICUTTINI. What Is the Effect of Physical Activity on the Knee Joint? A Systematic Review. *Med. Sci. Sports Exerc.*, Vol. 43, No. 3, pp. 432–442, 2011. **Purpose**: Although several studies have examined the relationship between physical activity and knee osteoarthritis, the effect of physical activity on knee joint health is unclear. The aim of this systematic review was to examine the relationships between physical activity and individual joint structures at the knee. **Methods**: Computer-aided searches were conducted up until November 2008, and the reference lists of key articles were examined. The methodological quality of selected studies was assessed based on established criteria, and a best-evidence synthesis was used to summarize the results. **Results**: We found that the relationships between physical activity and individual joint structures at the knee differ. There was strong evidence for a positive association between physical activity and tibiofemoral osteophytes. However, we also found strong evidence for the absence of a relationship between physical activity and joint space narrowing, a surrogate method of assessing cartilage. Moreover, there was limited evidence from magnetic resonance imaging studies for a positive relationship between physical activity and cartilage volume and strong evidence for an inverse relationship between physical activity and cartilage defects. **Conclusions**: This systematic review found that knee structures are affected differently by physical activity. Although physical activity is associated with an increase in radiographic osteophytes, there was no related increase in joint space narrowing, rather emerging evidence of an associated increase in cartilage volume and decrease in cartilage defects on magnetic resonance imaging. Given that optimizing cartilage health is important in preventing osteoarthritis, these findings indicate that physical activity is beneficial, rather than detrimental, to joint health. **Key Words:** OSTEOARTHRITIS, EXERCISE, RISK FACTOR, SYNTHESIS

The promotion of physical activity is a major public health initiative in western countries worldwide. It is well recognized that physical activity is beneficial in the management of numerous major health problems, including cardiovascular disease, mental illness, and obesity (31,43). However, the influence of physical activity on the development and progression of osteoarthritis (OA), particularly on weight-bearing joints such as the knee, is unclear. Given the prevalence of OA is predicted to increase in the coming decades and physical activity is being highly promoted (48), it is important that we understand the effect of physical activity on the health of the knee joint.

Although a large number of epidemiological studies have examined the relationship between physical activity and knee OA, the results are conflicting. Not only is there evidence to suggest that physical activity is detrimental to the knee joint (12,40) but studies have also reported physical activity to have no effect (17,27) and even be beneficial to joint health (13,36). A previous systematic review by Vignon et al. (45) concluded that sport and recreational activities are risk factors for knee OA and that the risk correlates with the intensity and duration of exposure. Although this systematic review investigated a broad range of different types of activity, including daily life, exercises, sports, and occupational activities, only the results of six studies

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that examined sports activity were retained in the review after evaluation.

Moreover, although the knee joint is a complex, synovial joint consisting of a variety of different structures, and epidemiological studies have assessed the effect of physical activity on osteophytes (26,33), joint space width (as a surrogate measure of cartilage thickness) (27,41,42), and subchrondral bone (46), no systematic review has summarized the effect of physical activity on individual joint structures. Given that previous studies have reported the development of osteophytes with physical activity, but no effect on joint space narrowing (40), it may be hypothesized that physical activity may have different effects on structures within the knee joint. The aim of this systematic review was to examine the effect of physical activity on the health of specific joint structures within the knee joint.

METHODS

Data sources and searches. To identify relevant studies for this review, we performed electronic searches of MEDLINE, EMBASE, and CINAHL up to November 2008. Search terms used included MeSH headings ''knee'' and ''osteoarthritis'' and the free text word ''physical activity.'' The search was restricted to studies of humans and those published in English. We also screened the reference lists of key articles and previous systematic reviews.

Study selection. We included studies that met the following criteria: 1) investigated the association between physical activity and development and/or progression of knee OA and 2) reported radiographic or magnetic resonance imaging (MRI) evidence of knee OA when investigating OA progression and healthy knees when investigating OA incidence. Studies that examined sporting and recreational activity, which has been previously defined as activities pursued by professional athletes or physical educators and trainers, as well as amateur sports activities performed competitively or recreationally were included (45). We excluded studies if they investigated only the patellofemoral joint, subchondral bone, children, subjects after knee arthroplasty, osteotomy, or underlying pathology (e.g., rheumatoid arthritis) or examined activities of daily living, prescribed exercises (e.g., by a physiotherapist), and non–weight-bearing or occupational activities.

Data extraction and quality assessment. Data on the characteristics of the included studies were tabulated. This included details of the study population, including the mean ± SD age and percentage of female participants, whether information on previous injuries was provided, the method of assessment of both OA and physical activity, and study results and conclusions.

The methodological quality of the studies was independently assessed by two investigators (F.H. and P.B.) using standardized criteria that examined internal validity and informativeness of the study (30). Not all items were appropriate for cross-sectional, case–control, and cohort studies; thus, only relevant criteria contributed to the total score for each study. The total score was calculated as a sum of the positive scores. If the methodological quality score was greater than the mean of the quality scores, the study was considered to be of high quality (30).

Data synthesis and analysis. Because of the heterogeneity of the studies included in this review, we chose to perform a best-evidence synthesis rather than statistically pooling the data. Studies were classified according to their study design, with the prospective cohort study considered the preferred design, followed by the case–control study, and then the cross-sectional design. Studies were also ranked according to their methodological quality score using the levels of evidence adapted from Lievense et al. (30): ''strong evidence''—generally consistent findings in multiple high-quality cohort studies; ''moderate evidence''—generally consistent findings in one high quality cohort study and more than two high-quality case–control studies or more than three high-quality case–control studies; ''limited evidence''—generally consistent findings in a single cohort study, one or two case–control studies, or multiple cross-sectional studies; ''conflicting evidence''—inconsistent findings in <75% of the trials; and ''no evidence''—no studies could be found.

RESULTS

Identification and Selection of the Literature

We identified a total of 1362 studies from our electronic database searches, of which 37 studies were potentially eligible for inclusion. Nine studies were excluded as they examined tibial plateau bone area (46), the patellofemoral joint (16,47), children (20), prescribed strength training (34), non–weight-bearing activities (35), and knee structure during a short period (9,24,38). Once we excluded these studies, 28 studies remained.

Characteristics of Included Studies

We identified 22 radiological studies and 6 MRI studies that examined the relationship between physical activity and knee OA (Table 1, A and B). Of the 22 radiological studies, 2 studies were cross-sectional (2,25), 6 studies were case–control (7,10,19,22,23,29), and 14 studies were longitudinal in design (3,6,11,12,17,18,26–28,32,33,40–42). Three of the six MRI studies were cross-sectional (4,8,15), two were longitudinal (13,14), and one study had both a cross-sectional and longitudinal component (36).

Of the 28 studies included in the review, 9 were undertaken in the United States (3,11,12,17,19,26–28,32) and 8 in Australia (4,7,13–15,36,41,42), with the remaining 11 studies from the United Kingdom, Hong Kong, North Africa, and several European countries, including Finland, Sweden, Denmark, Switzerland, and Germany (2,6,8,10,18,22,23,25,29,33,40) (Table 1, A and B). Most of the participants were either recruited from elite or community sporting clubs, including

TABLE 1. Characteristics of radiological (A) and MRI (B) studies.

Author (Country, yr)	Study Population	No. of Participants (% Women)	Age[a] (yr)	Previous Knee Injury	OA Assessment	Physical Activity Assessment	Follow-Up[a] (yr)	Quality Score
(A) Radiological								
Cross-sectional radiological studies								
Kujala et al. (Finland, 1995) (25)	117 former top-level athletes, including 28 long-distance runners, 31 soccer players, 29 weight lifters, and 29 shooters	117 (0)	N/A (45–68)	Subjects included. Adjustments made in the analysis.	K/L scale	Interview	N/A	82
Bagge et al. (Sweden, 1991) (2)	340 subjects (from two cohorts) recruited from 70-yr-old people from the Göteborg population study	350 (60.3)	Both cohorts: 79 (N/A)	Information not provided.	K/L scale	Interview	N/A	73
Case–control radiological studies								
Klunder et al. (Denmark, 1980) (22)	■ 57 retired soccer players recruited from the Vejle soccer club ■ 57 age- and weight-matched controls recruited from a local hospital	114 (0)	Soccer players: 56.4 (40–79) Controls: 56.6 (42–80)	Subjects included. Controls with hospital admission for a lower limb condition were excluded). No adjustments were performed.	Diminution of joint space, sclerosis, and/or subchondral cyst formation	Not specified	N/A	50
Konradsen et al. (Denmark, 1990) (23)	■ 27 long-distance runners who qualified for county teams from 1950 to 1955 ■ 27 controls, matched for age, height, weight, and occupation, recruited from a hospital radiology department	Runners: 27 (0) Controls: 27 (N/A)	Runners: median = 58 (50–68) Controls: median = 57 (53–65)	Subjects included. No adjustments were performed.	Ahlback-derived grading system No osteophytes	Not specified	N/A	55
Imeokparia et al. (United States, 1994) (19)	A substudy from the Clearwater Osteoarthritis Study: ■ 239 cases with radiographic knee OA ■ 239 age- and gender-matched controls without structural changes on knee radiographs	Cases: 239 (64.4) Controls: 239 (64.4)	Cases: Men: 66.7 Women: 66.3 Controls: Men: 66.7 Women: 66.2	Subjects included. Adjustments made in the analysis.	K/L scale	Questionnaire	N/A	71
Deacon et al. (Australia, 1997) (7)	■ 50 retired, elite footballers from four Australian Football League clubs ■ 50 age-matched controls who had played no contact sport since their teenage years	100 (N/A)	Footballers: 53.7 ± 11.4 Controls: 55.7 ± 12.4	Controls were excluded for a previous injury, but cases were not. Cases were grouped based on presence and injury type.	Investigators developed their own scoring system which included: joint space, osteophytes, cysts, sclerosis, loose bodies, and malalignment	Questionnaire	N/A	64
Lau et al. (Hong Kong, 2000) (29)	■ 658 cases with knee OA (K/L grade 3 or 4) recruited from regional hospitals' orthopedic units ■ 658 age- and sex-matched controls without knee pain and OA from general practice clinics in the same region	658 (74.8)	N/A	Subjects included. Adjustments made in the analysis.	K/L scale	Interview	N/A	79
Elleuch et al. (Tunisia, 2008) (10)	■ 50 former top-level soccer players aged between 45 and 55 yr ■ 50 male, nonsporting volunteers matched with respect to age, BMI, and frequency of knee axis deviation	100 (0)	Soccer players: 49.2 ± 3.8 Controls: 47.8 ± 4.2	Subjects excluded.	K/L scale	Questionnaire	N/A	64

Longitudinal radiological studies								
Lane et al. (United States, 1990) (26)	■ 34 long-distance runners recruited from the 50-Plus Runners Association ■ 34 community controls, matched for age, sex, level of education, and occupation, recruited from the Lipid Research Clinics Study	Runners: 34 (38.2) Controls: 34 (38.2)	Runners: 59.8 SE 0.9 Controls: 59.1 SE 0.7	Subjects included. No multivariate analysis performed.	Altman atlas	Questionnaire	2	85
Michel et al. (Switzerland, 1992) (33)	51 subjects recruited from a larger parent cohort consisting of members of a runner club and a community population	51 (37.3)	59.6 ± 4.6	Subjects included. Adjustments not specifically made for injury.	Altman atlas	Questionnaire	2	77
Lane et al. (United States, 1993) (27)	■ 35 long-distance runners recruited from the 50-Plus Runners Association ■ 38 community controls, matched for age, level of education, and occupation, recruited from the Lipid Research Clinics Study	73 subjects including; 13 female pairs and 20 male pairs	Runners: 63.3 SE 0.9 Controls: 63.1 SE 0.9	Subjects included. No adjustments made in analysis.	Altman atlas	Questionnaire	5	85
Hannan et al. (United States, 1993) (17)	1404 subjects recruited from the Framingham Study cohort	1404 (58.4)	73 (63–93)	Subjects included. Adjustments made in the analysis.	K/L scale	Interview Framingham physical activity score	N/A	77
Spector et al. (United Kingdom, 1996) (40)	■ 81 ex-elite athletes including 67 middle- and long-distance runners from the International Athletics Club and 14 tennis players from Lawn Tennis Association ■ 977 age-matched controls from a register of a London group general practice	1058 (100)	Ex-athletes: 52.3 ± 6.1 Controls: 54.2 ± 6.0	Subjects included. Adjustments made in the analysis.	Osteophytes and JSN assessed using an Atlas (2a)	Questionnaire Allied Dunbar Health Survey	N/A (retrospective)	85
Felson et al. (United States, 1997) (12)	598 subjects from the Framingham Knee OA Study	598 (63.7)	70.5 ± 4.9	Subjects included. Adjustments made for past and interim knee injury.	Modified K/L scale	Framingham Physical Activity Index	8	85
Lane et al. (United States, 1998) (28)	■ 28 long-distance runners recruited from the 50-Plus Runners Association ■ 27 community controls, matched for age, level of education, and occupation, recruited from the Lipid Research Clinics Study	Runners: 28 (39.3) Controls: 27 (25.9)	Runners: 66.4 SE 0.9 Controls: 66.4 SE 1.0	Limited information provided.	Altman atlas	Questionnaire	9	77
Hart et al. (United Kingdom, 1999) (18)	830 women from the Chingford Study cohort	830 (100)	54.1 ± 5.9	Subjects included. No adjustment specifically made for knee injury.	Validated atlas (39a)	Questionnaire	4	77
McAlindon et al. (United States, 1999) (32)	470 subjects recruited from the Framingham Heart Study cohort	470 (62.3)	70.1 ± 4.5	Subjects included. Adjustments made in the analyses.	Modified K/L scale	Interview Framingham Physical Activity Index	10	92
Cooper et al. (United Kingdom, 2000) (6)	354 subjects recruited from a cohort at a large general practice in Bristol	354 (72.0)	Median 75.8 (interquartile range = 69.5–80.9)	Subjects included. No adjustments specifically made for knee injury.	K/L scale Additional assessments of JSN and osteophytes (using a validated atlas (39a))	Interview	5.1 ± 0.4	62
Szoeke et al. (Australia, 2006) (41,42)	224 subjects recruited from a prospective population-based study; The Melbourne Women's Mid-life Health Project	224 (100)	Baseline: 49.66 ± 2.47 Follow-up: 59.91 ± 2.49	Information not available to investigators.	Altman atlas	Validated questionnaire	11	85/85

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TABLE 1. *(Continued)*

Author (Country, yr)	Study Population	No. of Participants (% Women)	Age[a] (yr)	Previous Knee Injury	OA Assessment	Physical Activity Assessment	Follow-Up[a] (yr)	Quality Score
Felson et al. (United States, 2007) (11)	1279 subjects recruited from the Framingham Offspring cohort	1279 (NA)	53.2 (26–81)	Subjects included. Adjustments made in the analyses.	K/L scale	Interview	8.75 ± 1.04	85
Chakravarty et al. (United States, 2008) (3)	■ 45 long-distance runners from the nationwide Fifty-Plus Runners Association	Cases: 45 (35.6)	Cases: 59.8 SE 0.98	Subjects included.	Modified K/L scale	Self-reported questionnaire	11.7	85
	■ 53 controls, matched on age, education level, and occupation, from the Stanford University Lipid Research Clinics Prevalence Study	Controls: 53 (30.2)	Controls: 60.2 SE 0.88	Adjustments made in the analyses.				
(B) MRI								
Cross-sectional MRI studies								
Eckstein et al. (Germany, 2002) (9)	■ 18 triathletes who had been physically active through life (training >10 $h \cdot wk^{-1}$) for the last 3 yr ■ 18 volunteers who had never been active on a regular basis	36 (50)	NA (19–31)	Excluded subjects	Cartilage volume	Not specified	N/A	75
Cicuttini et al. (Australia, 2003) (4)	45 Caucasian male subjects recruited through newspaper advertisement, sporting clubs, and staff association	45 (0)	52.5 ± 13.2	Excluded subjects	Cartilage volume	Allied Dunbar Health Survey	N/A	82
Hanna et al. (Australia, 2007) (15)	176 healthy subjects without clinical knee OA or previous knee injury	176 (100)	52.3 ± 6.7	Excluded subjects	Cartilage volume Cartilage defects	Questionnaire	N/A	82
Racunica et al. (Australia, 2007) (36)	297 healthy from a prospective cohort study of community-based adults; the Melbourne Collaborative Cohort Study	297 (62.6)	58.0 ± 5.5	Excluded subjects	Cartilage volume Cartilage defects	Questionnaire	10	82
Longitudinal MRI studies								
Hanna et al. (Australia, 2005) (14)	28 healthy men without knee OA from a parent cohort of community-based subjects	28 (0)	51.9 ± 12.8	Excluded subjects	Cartilage volume	Questionnaire	2	92
Foley et al. (Australia, 2007) (13)	325 subjects, of which: ■ Half were adult children of people who had knee replacement surgery for knee OA between 1996 and 2000 ■ The other half were randomly selected from the 2000 electoral role	170 (52.3)	45 (26–61)	Included subjects. Adjustments made in the analyses.	Cartilage defects	Modified questionnaire (50)	2.3 (1.8–2.6)	100
Racunica et al. (Australia, 2007) (36)	297 healthy subjects from a prospective cohort study of community-based adults; the Melbourne Collaborative Cohort Study	297 (63)	Follow-up: 58.0 (5.5)	Excluded subjects	Cartilage volume Cartilage defects	Questionnaire	10	85

[a] Values are mean ± SD/(range).
K/L, Kellgren and Lawrence; JSN, joint space narrowing; N/A, not available or not applicable.

TABLE 2. Cross-sectional and case–control studies examining the association between physical activity and radiological knee OA.

Author (yr)	Assessment of Physical Activity	Assessment of OA	Results (with 95% CI or *P*)	Conclusions	Quality Score
Kujala et al. (1995) (25)	Interview examining lifetime history of physical activities/sports with different loading patterns	K/L scale	Risk of radiographic knee OA (K/L grade >1) in soccer players compared with runners, weight lifters, and shooters: OR = 5.21 (1.14–23.8).	The risk of knee OA was greater in subjects who participated in soccer than those involved in sports with different loading patterns.	82
Bagge et al. (1991) (2)	Interview assessing spare time physical activity levels	K/L scale	Association between spare time physical activity level and OA: $r = -0.06$, P = NS.	There was no association found between spare-time physical activity and radiographic OA.	73
Klunder et al. (1980) (22)	Information on average number of soccer playing hours per week and the length of the period of sporting activity were recorded	Diminution of joint space, sclerosis, and/or subchondral cyst formation	Knee OA was found in right of the soccer players and seven of the controls (P = NS).	There was no difference in the prevalence of knee OA between retired soccer players and controls.	50
Konradsen et al. (1990) (23)	Information on number of years running and mileage per week training and in competition	■ Ahlback-derived grading system for cartilage thickness, bony sclerosis, bony changes. ■ Number of osteophytes	Differences between runners and controls in grades of degenerative change or osteophytes (P = NS).	Distance running was not found to be associated with premature OA of knee joint.	55
Imeokparia et al. (1994) (19)	Questionnaire assessing the subjects' leisure sport and home-based activities, along with the amount and type of exercise performed on a weekly basis	K/L scale	Risk of knee OA associated with high levels of physical activity in: Women: OR = 1.66 (1.01–2.72) Men: OR = 0.95 (0.49, 1.83)	In contrast to men, women undertaking high levels of physical activity were at increased risk of knee OA.	71
Deacon et al. (1997) (7)	Questionnaire assessing number of games and years of football played and number of years of other sports played	Own scoring system examining osteophytes, joint space, cysts, sclerosis, loose bodies, and joint malalignment.	Risk of developing radiological OA in footballers with a 1) previous meniscal or cruciate ligament injury and 2) without a previous injury or only a collateral ligament injury (compared with controls): OR = 105.0 (11.8–931.8), $P < 0.0001$, and 17.7 (2.2–146.2), $P = 0.0075$, respectively.	Footballers had an increased risk of developing radiological OA compared with active controls, which was further increased by a previous intra-articular injury.	64
Lau et al. (2000) (29)	Interview examining whether subjects undertook sports regularly and which types of activities were performed	K/L scale	Risk of OA (K/L grade 3 or 4) in women who performed: ■ Gymnastics: OR = 7.4 (2.6–20.8) ■ Martial arts (kung fu): OR = 22.5 (2.5–199)	Women who practiced gymnastics and martial arts were at increased risk of knee OA.	79
Elleuch et al. (2008) (10)	Questionnaire regarding sporting history, including age on commencing soccer and professional career, total duration of sporting practice, and total length of career	K/L scale	Prevalence of K/L stages III and IV in: ■ Soccer players: 57.5% ■ Controls: 29.4%, $P = 0.05$	Although the difference was not significant, knee OA was more common in soccer players than in nonsporting subjects.	64

CI, confidence interval; NS, not significant; OR, odds ratio.

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TABLE 3. Longitudinal studies examining the association between physical activity and radiological knee OA.

Author (yr)	Assessment of Physical Activity	Assessment of OA	Results (with 95% CI or *P*)	Conclusions	Quality Score
Lane et al. (1990) (26)	Questionnaire assessing past and present physical activity, including average exercise minutes, average running minutes, and average running miles per week	Altman atlas	■ Progression of osteophytes in runners (3.6 vs 4.2, $P < 0.01$) compared with controls (2.8 vs 3.0, P = NS). ■ Comparison of the number of osteophytes in female runners compared with controls at baseline (4.0 vs 2.1, $P < 0.05$) and follow-up (4.7 vs 2.3, $P < 0.01$).	■ There was progression of knee osteophytes in runners, unlike controls, during a 2-yr period. ■ Female runners had more osteophyte formation in the knee joint than control subjects.	85
Michel et al. (1992) (33)	Questionnaire assessing amount and type of exercise	Altman atlas	Association between changes in weight-bearing exercise and changes in the rate of osteophyte formation: R^2 (%) = 28, $P < 0.001$.	Increasing weight-bearing exercise did not promote the development of osteophytes.	77
Lane et al. (1993) (27)	Questionnaire assessing exercise history, including exercise and running minutes per week	Altman atlas (combined score based on joint space narrowing, osteophytes and sclerosis).	Comparison of combined radiographic score from baseline to follow-up in runners (4.2 vs 4.6, P = NS) and controls (3.8 vs 4.6, $P < 0.05$).	Development of radiographic OA was not accelerated in runners.	85
Hannan et al. (1993) (17)	Framingham physical activity score	K/L scale	Association between habitual physical activity and knee OA both for men: OR = 1.34 (0.66–2.74) and women: OR = 1.09 (0.63–1.90) in the highest quartile compared with the lowest quartile of physical activity.	Habitual physical activity does not increase the risk of radiographic OA in men or women.	77
Spector et al. (1996) (40)	■ Allied Dunbar Health Survey: examining current weight-bearing sports activity ■ Self-administered questionnaire assessing past sports activity and walking frequency (in controls)	Using a validated atlas examined: ■ Osteophytes ■ JSN	Risk of radiographic OA in ex-elite athletes compared with controls: ■ Osteophytes: OR = 3.57 (1.89–6.71) ■ JSN: OR = 1.17 (0.71–1.94) Risk of OA in control population reporting long-term sports activity (OR = NA).	Ex-elite athletes and women from the general population that have participated in long-term sports activity have a greater risk of knee OA.	85
Felson et al. (1997) (12)	Framingham Physical Activity Index	Modified K/L scale	Risk of developing OA for subjects in the highest quartile of physical activity compared with those in the lowest quartile: OR = 3.3 (1.4–7.5), $P < 0.001$.	Higher levels of physical activity increased the risk of radiographic knee OA in the elderly.	85
Lane et al. (1998) (28)	Questionnaire assessing exercise history, including average exercise minutes, running minutes and running miles per week and no. of years run	Altman atlas TKS = JSN + osteophytes + subchondral sclerosis	Difference in the progression of the TKS between the runner and nonrunner groups from baseline (1.5 vs 1.57) to follow-up (2.46 vs 2.60), respectively (P = 0.48).	Runners did not have an accelerated radiographic progression of OA when compared with nonrunners.	77
Hart et al. (1999) (18)	Questionnaire assessing medical history	Validated atlas to examine osteophytes and JSN in each knee compartment (39a)	Risk of osteophytes for subjects in the top tertile of physical activity: ■ Osteophytes: OR = 1.23 (0.54–2.81) ■ JSN: OR = 0.98 (0.42–2.30)	Individuals in the top tertile of physical activity did not have an increased risk of knee OA.	77
McAlindon et al. (1999) (32)	■ Framingham Physical Activity Index ■ Additional questions regarding flights of stairs climbed and blocks walked daily	Modified K/L	Risk of incident radiographic OA in subjects with ≥4 h of daily heavy physical activity compared with no heavy physical activity: OR = 7.0 (2.4–20), P = 0.0002.	Heavy physical activity is a risk factor for developing knee OA in the elderly.	92
Cooper et al. (2000) (6)	Interview asking about lifetime history of leisure activity, including information on sports since leaving school and duration of other leisure activities	K/L scale	Risk of OA (K/L grade >2 threshold) with regular sports participation: ■ Incidence: OR = 1.0 (0.5–2.1) ■ Progression: OR = 0.9 (0.3–2.5)	Physical activity influences incidence more than progression of OA.	62
Szoeke et al. (2006) (41,42)	Questionnaire assessing the frequency of participation in "physical activity or sports for fitness or recreational purposes" (validated based on Minnesota leisure-time physical activity questionnaire)	Altman atlas	Association between physical activity and: Osteophytes: OR = 6.99 (0.75–65.49), P = 0.08 JSN: OR = 5.91 (0.87–40.10), P = 0.07 Risk of knee OA in women aged 20–29 yr who exercise: Daily: OR = 10.1 (0.3–13.1) 2–6 wk^{-1}: OR = 8.1 (0.3–3.1) 1 wk^{-1}: OR = 6.7 (0.1–7.3) 1–2 $month^{-1}$: OR = 1.8 (0.04–4.0), P = 0.03	A relationship between physical activity and knee osteophytes and JSN approached significance (40). There was a trend for increasing levels of physical activity at age 20–29 yr to be a risk factor for knee OA (41).	85/85
Felson et al. (2007) (11)	Interview to identify and quantify the subjects' regular activities, including their involvement in walking and running	■ K/L scale ■ OARSI Atlas (anteroposterior view) ■ Atlas created for the project (lateral view)	Relationship between physical activity and the risk for individuals "more active than others": ■ Radiographic OA: OR = 0.94 (0.63–1.40) ■ Joint space loss: OR = 0.89 (0.60–1.31)	Physical activity did not affect, neither protect, against OA development in middle-aged and elderly persons.	85
Chakravarty et al. (2008) (3)	Questionnaire assessing type and amount of activity (particularly vigorous activity)	TKS: the sum of K/L, JSN, sclerosis, and osteophytes from the modified K/L scale.	Risk of OA in community controls compared with runners: ■ TKS: OR = 0.72 (−1.64 to 3.08), P = NS ■ JSW: OR = −0.15 (−0.71 to 0.41), P = NS	Long-distance running among healthy older individuals was not associated with accelerated radiographic OA.	85

JSW, joint space width; OARSI, Osteoarthritis Research Society International Atlas; TKS, total knee score.

the Australian Football League (7) and the 50-Plus Runners Association (3), or from existing cohorts, such as the Chingford (18) and Melbourne Collaborative Cohorts (36). The age of the subjects ranged from 45.0 to 79.0 yr, and the percentage of women in the studies varied from 0% to 100%. Whereas 8 studies excluded subjects and/or controls with previous injury (4,7,8,10,14,15,22,36), 16 studies included subjects with injury (3,6,11–13,17–19,23,25–27, 29,32,33,40), but only 10 made adjustments for this in their analyses (3,11–13,17,19,25,29,32,40). The remaining four studies provided no or limited information regarding previous injury (2,28,41,42).

A variety of methods was used to examine different joint structures in the assessment of radiological OA. The Kellgren and Lawrence scale (or a modified version), which predominately assesses osteophytes, was the most commonly used instrument, with 11 studies implementing this scale (2,3,6,10–12,17,19,25,29,32). However, measurement of joint space narrowing, a surrogate measure of cartilage thickness, was also used either in isolation or combined with other radiological measures. In contrast, the six MRI studies measured cartilage volume and/or the presence of cartilage defects (4,8,13–15,36). Most studies assessed physical activity using study-specific questions asked via an interview or questionnaire, with only seven studies using a validated instrument, such as the Allied Dunbar Health Survey or the Framingham Physical Activity Index (4,12,17,32,40–42).

Methodological Quality Assessment

The mean score for methodological quality of the included studies was 78%, with a range from 50% to 100%. A total of 16 studies were considered to be of high quality (3,4,11–15,25–27,29,32,36,40–42). Of the methodological criteria assessed, most studies scored well on criteria 9 and 16, which involved assessing OA identically in the studied population and adjusting for at least age and sex. However, several studies scored poorly on criteria 6, 8, and 12, which assessed whether the physical activity assessment was blinded and examined before the outcome and whether a prospective design was used respectively.

Cross-sectional and nested case–control radiographic studies. Of the two cross-sectional and six case–control studies that examined the association between physical activity and radiographic knee OA (2,7,10,19,22, 23,25,29) (Table 2), only one of the eight studies was of high quality. The study by Kujala et al. (25), which examined joint space narrowing as a surrogate for cartilage thickness, reported a greater risk of knee OA in soccer players compared with runners, weight lifters, and shooters (odds ratio = 5.21, confidence interval = 1.14–23.8).

Longitudinal radiographic studies. Of the 14 cohort studies that examined the relationship between physical activity and radiographic knee OA (3,6,11,12,17,18,26–28, 32,33,40–42) (Table 3), 9 were considered to be of high quality (3,11,12,26,27,32,40–42). Three high-quality studies used the Kellgren and Lawrence scale, which is heavily focused on the presence of osteophytes, and each found an association between physical activity and osteophyte formation (12,26,32). Moreover, four of the high-quality cohort studies that used a combination of both osteophyte and joint space measures found no association between radiographic OA and physical activity (3,11,27,41).

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TABLE 4. Cross-sectional studies examining the association between physical activity and OA-related MRI structural changes.

Author (yr)	Assessment of Physical Activity	Assessment of OA	Results (with 95% CI or *P*)	Conclusions	Quality Score
Eckstein (2002) (8)	■ Method of assessment not specified. ■ Assessed the number of hours of exercise per week and lifetime involvement in exercise.	Cartilage volume (medial and lateral tibial and femoral)	Relative differences (%) in cartilage volume between triathletes and physically inactive controls: ■ Medial tibial: F = 17.5%, M = 3.7%, P = NS ■ Lateral tibial: F = 12.7%, M = 4.9%, P = NS ■ Femoral: F = 4.4%, M = 10.2%, P = NS	These findings suggest that cartilage is not modulated with changes in mechanical stimulation.	75
Cicuttini (2003) (4)	The current total amount of physical activity: a composite score of the total amount of walking, activity at home and sporting activity.	Tibial cartilage volume (total, medial, and lateral)	Association between physical activity and tibial cartilage volume: ■ Total: $r = -0.01$ (-0.16 to -0.03), $P = 0.007$ ■ Medial: $r = -0.07$ (-0.013 to -0.014), $P = 0.017$ ■ Lateral: $r = -0.14$ (-0.23 to -0.04), $P = 0.0001$.	Tibial cartilage volume was found to be inversely associated with the amount of physical activity performed.	82
Hanna (2007) (15)	Questionnaire assessing the participation in and frequency of strenuous exercise in the last 14 d.	Tibial cartilage volume (medial and lateral) Tibial cartilage defects (medial and lateral)	Association between exercise and cartilage volume: ■ Medial: $\beta = 0.12$ (0.02–0.21), $P = 0.02$ ■ Lateral: $\beta = 0.04$ (-0.09 to 0.16), $P = 0.54$ Association between exercise and the presence of cartilage defects: ■ Medial: $\beta = 1.24$ (0.45–3.37), $P = 0.68$ ■ Lateral: $\beta = 1.19$ (0.51–2.76), $P = 0.69$	Exercise increased cartilage volume without increasing the risk of cartilage defects	82
Racunica (2007) (36)	Questionnaire assessing the frequency and type of vigorous and nonvigorous activity in the past 7 d.	■ Tibial cartilage volume ■ Tibial cartilage defects	Association between participation in recent weight-bearing vigorous activity and: ■ Cartilage volume: OR = 209 (46–411), $P = 0.02$ ■ Cartilage defects: OR = 0.5 (0.3–0.9), $P = 0.02$ Association between frequency of weight-bearing vigorous activity and: ■ Cartilage volume: OR = 84 (-1.0 to 169), $P = 0.05$ ■ Cartilage defects: OR = 0.8 (0.6–1.0), $P = 0.11$	Participation, but not frequency, in recent weight-bearing vigorous activity was associated with an increase in tibial cartilage volume and inversely associated with cartilage defects.	82

F, female; M, male.

TABLE 5. Longitudinal studies examining the association between physical activity and OA-related MRI structural changes.

Author (yr)	Assessment of Physical Activity	Assessment of OA	Results (with 95% CI or *P*)	Conclusions	Quality Score
Hanna (2005) (14)	Current total activity was determined from the total amount of walking, activity at home and sporting activity	Tibial cartilage volume	Relationship between cartilage volume and physical activity: $r = -25.0$ (-116.7 to 66.6), $P = 0.57$	There was no significant association between cartilage volume loss and levels of physical activity.	92
Foley (2007) (13)	Validated, epidemiological questionnaire assessing the amount and intensity of sports and leisure time activity (modified to include Australian sports) (1)	Tibial cartilage defects	Risk of progression of lateral and medial knee cartilage defects with strenuous exercise: ■ Lateral: OR = 0.73, $P = 0.039$ ■ Medial: OR = 0.86, $P = 0.24$	Strenuous exercise protects against lateral knee cartilage defects.	100
Racunica (2007) (36)	Questionnaire assessing vigorous activity, activity at home and work, and walking	Tibial cartilage volume Tibial cartilage defects	Association between cartilage volume and defects and: Frequency of vigorous physical activity: ■ Cartilage volume: OR = 115 (24–206), $P = 0.01$ ■ Cartilage defects: OR = 1.0 (0.8–1.4), $P = 0.8$ Duration of activity: ■ Cartilage volume: OR = 114 (48–181), $P = 0.001$ ■ Cartilage defects: OR = 1.1 (0.8–1.3), $P = 0.6$	Vigorous physical activity had a beneficial effect on tibial cartilage volume and was protective against cartilage defects.	85

NS, not significant; NA, not available.

Cross-sectional and longitudinal MRI studies. Of the three cross-sectional MRI studies (4,8,15), two longitudinal studies (13,14) and one cross-sectional/longitudinal study (36) that examined the relationship between physical activity and knee OA (Tables 4 and 5), all studies, with the exception of one (8), were of high quality. Of the three high-quality cross-sectional studies, one study of 45 healthy men reported an inverse relationship between physical activity and tibial cartilage volume (4), whereas the other two studies of healthy, community-based subjects found a positive association for tibial cartilage volume and an inverse relationship for cartilage defects (15,36). Moreover, although one high-quality longitudinal MRI study found no association between cartilage volume loss and levels of physical activity (14), there was one high-quality longitudinal MRI study that found a positive relationship between physical activity and tibiofemoral cartilage volume (36) and two high-quality cohort studies that found an inverse relationship between physical activity and cartilage defects (13,36).

Best-evidence synthesis. If all studies in the review were collectively examined, we would conclude that there is conflicting evidence for the relationship between physical activity and knee OA. However, if we consider the relationship between physical activity and individual joint structures, we conclude that:

i. there is strong evidence (from multiple high-quality cohort studies) that there is a positive relationship between osteophytes and physical activity;
ii. there is strong evidence (from multiple high-quality cohort studies) that there is no relationship between joint space narrowing, as a surrogate for cartilage thickness, and physical activity;
iii. there is limited evidence (from a cohort study and two cross-sectional studies) that there is a positive relationship between cartilage volume and physical activity; and
iv. there is strong evidence (from multiple high-quality cohort studies) that there is an inverse relationship between cartilage defects and physical activity.

DISCUSSION

This systematic review found that the relationships between physical activity and individual joint structures at the knee joint differ. Although we found strong evidence for a positive association between physical activity and tibiofemoral osteophytes, there was also strong evidence for no effect of physical activity on radiological joint space narrowing, a surrogate method of assessing knee cartilage. Moreover, we found limited evidence, particularly from longitudinal studies, for a positive relationship between physical activity and tibial cartilage volume, and strong evidence for an inverse relationship between physical activity and cartilage defects. Although further investigation is needed, these results suggest that osteophytes are a functional adaption to mechanical stimuli and, in the absence of cartilage degeneration, that physical activity is not detrimental to the knee joint but is actually beneficial to joint health.

On the basis of three high-quality cohort studies (12,26,32), we found strong evidence for a positive relationship between physical activity and knee joint osteophytes. We also found strong evidence, based on four high-quality longitudinal studies (3,11,27,41), for the absence of a relationship between joint space narrowing and physical activity. There are several possible explanations for the discordance in the relationships between physical activity and the presence of osteophytes and joint space narrowing. It has previously been suggested that this may be due to the lower reproducibility of joint space narrowing compared with osteophytes, which may result in nondifferential misclassification and reduce the likelihood of detecting an association (40). In

addition, a large number of studies have previously used the Kellgren and Lawrence grading system, which is a composite measure commonly used to assess radiographic OA, which relies heavily on the presence of osteophytes for the identification of knee OA.

However, an alternative explanation may be that physical activity has different effects on osteophytes and joint space narrowing. Although osteophytes, bony outgrowths covered by fibrocartilage, are highly associated with cartilage damage, there is also evidence to suggest that osteophytes can develop without explicit injury to cartilage (44). This is consistent with the findings that osteophytes do not correlate with cartilage volume measured on MRI, but joint space narrowing, a surrogate measure of articular cartilage, shows a strong correlation (5). Moreover, joint space narrowing has been used as the primary outcome in studies of disease progression in OA (37) and in recent clinical trials investigating treatment strategies (21,39). Thus, in response to mechanical stimuli, such as physical activity, osteophytes may enhance the functional properties of the joint by increasing the joint surface area for the greater distribution of load or by reducing motion at a joint and improving joint stability (44). In contrast, articular cartilage may not be affected by mechanical stimuli or may actually enhance the loading properties of cartilage. Although it is possible the higher prevalence of osteophytes identified in people exercising may be detrimental to the knee joint, it could also be argued, in the absence of cartilage destruction, that physical activity is beneficial and osteophytes are simply a response to mechanical stimuli.

To further investigate the relationship between physical activity and knee joint cartilage, we identified six MRI studies that directly measured cartilage volume and defects within the knee joint. Although limited evidence was provided for a beneficial effect of physical activity on knee cartilage volume, there was strong evidence for a protective effect against cartilage defects. With respect to the three high-quality cohort studies, Racunica et al. (36) found vigorous physical activity to be positively associated with tibial cartilage volume and inversely associated with cartilage defects, and Foley et al. (13) found a reduced risk of tibial cartilage defects with strenuous exercise. Although Hanna et al. (14) found no association between physical activity and knee joint cartilage, the study had limited power to show an effect because it only included 28 male subjects with a limited range of ages, BMI, and physical activity scores. Although further MRI investigation is warranted, these findings indicate that physical activity has a protective effect on knee joint cartilage.

There are several limitations to our study. We were not able to perform a meta-analysis to summarize our results because of the heterogeneity of the studies included in this review and therefore undertook a best-evidence synthesis. Moreover, given there were a limited number of MRI studies that specifically examined the effect of physical activity on the tibiofemoral cartilage volume, some of the conclusions we could make from this review were limited.

In summary, this review found that the relationship between physical activity and specific knee structures differed, with strong evidence for a positive relationship between physical activity and tibiofemoral osteophytes, absence of an association between physical activity and joint space narrowing, and strong evidence for an inverse relationship between physical activity and cartilage defects. These findings highlight the need to examine the effect of physical activity on individual structures of the knee joint rather than the joint as a whole. Moreover, these findings suggest that physical activity may not have a detrimental effect on the knee joint but may be beneficial to joint health.

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