How Are Obesity and Body Composition Related to Patellar Cartilage? A Systematic Review

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ABSTRACT. Objective. The aim of this review was to systematically examine the evidence for an association between measures of obesity [weight and body mass index (BMI)] and body composition (fat mass and fat-free mass) and patellar cartilage, assessed using magnetic resonance imaging.

Methods. Three electronic databases (MEDLINE, EMBASE, and CINAHL) were searched up to April 2016 using full text and MeSH terms to identify studies examining the associations between obesity and body composition, and patellar cartilage. Two independent reviewers extracted the data and assessed the methodological quality of included studies.

Results. Seventeen studies were included: 5 cross-sectional, 10 cohort studies measuring outcomes at 2 timepoints, and 2 longitudinal studies assessing outcome only at the timepoint. Eleven studies were of high or moderate quality. In asymptomatic middle-aged adults, elevated body weight and BMI were systematically associated with worse patellofemoral cartilage scores. There was more consistent evidence for patellar cartilage defects than patellar cartilage volume, particularly in women. Increased BMI was also consistently associated with increased cartilage loss in longitudinal studies, although not all attained statistical significance.

Conclusion. There is a need for more high-quality research to confirm these findings and to better explain the relative contributions of metabolic and biomechanical factors to the initiation of patellofemoral osteoarthritis, to devise effective strategies to manage this common and disabling condition. (First Release May 1 2017; J Rheumatol 2017;44:1071–82; doi:10.3899/jrheum.151384)

Key Indexing Terms:
CARTILAGE PATELLA OBESITY
OSTEOARTHRITIS MAGNETIC RESONANCE IMAGING

Patellofemoral osteoarthritis (OA) is associated with greater disability and contributes more to knee pain than tibiofemoral involvement[1,2,3]. In knee OA, affecting the whole joint, articular cartilage loss is often used to measure disease severity and progression. The knee's 2 joints, the tibiofemoral and patellofemoral, behave differently. The mechanical and biochemical properties of their articular cartilage differ, with patellar cartilage undergoing greater *in vivo* deformation with loading than tibiofemoral cartilage[4]. Further, risk factors for incident and progressive patellofemoral and tibiofemoral OA differ[5]. Knee injury is more closely associated with incident tibiofemoral than patellofemoral OA[6]. Although greater quadriceps strength protects against patellofemoral cartilage loss, it does not influence tibiofemoral OA progression[7]. Thus, it is important to consider the different compartments of the knee individually.

Measures of obesity, weight, body mass index (BMI), and body composition are recognized modifiable risk factors for tibiofemoral OA[8]. When body composition, which differentiates between fat mass and fat-free mass, is considered, a distinct effect of fat mass and fat-free mass has been shown[9]. Fat mass independent of fat-free mass is associated with a detrimental effect on cartilage volume, but not defects[9]. In contrast, fat-free mass independent of fat mass is positively associated with cartilage volume[9]. The effect on cartilage volume has been shown to be partially attributable to an independent effect of leptin[10], suggesting a metabolic component[10]. Thus, obesity influences the risk of tibiofemoral OA by both biomechanical and systemic factors[9,10].

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Though obesity is a recognized risk factor for patellofemoral OA[6,11], it is unclear whether it affects patellar cartilage, and if so, whether by biomechanical or systemic mechanisms. It is important to systematically analyze how obesity affects patellar cartilage prior to onset or during progression of OA. Magnetic resonance imaging (MRI), which visualizes all joint tissues and identifies early changes, can be used to study pathogenesis. Cartilage defects represent local focal cartilage abnormalities, which predict accelerated cartilage loss[12]. They are graded using a semiquantitative system where grade 0 is normal cartilage and grade 4 is a cartilage defect extending from the joint surface to subchondral bone[13]. The amount of patellar cartilage (cartilage volume) is associated with patellofemoral joint space narrowing and radiographic severity of patellofemoral OA[14]. Both cartilage defects and reduced cartilage volume have been independently related to increased risk of arthroplasty[13]. Determining these relationships can improve our understanding of the pathogenesis of patellofemoral OA, leading to development of more effective management strategies. Thus, the aim of our review was to systematically examine the evidence for an association between measures of obesity, weight, BMI, and body composition (fat mass and fat-free mass) and patellar cartilage assessed using MRI.

MATERIALS AND METHODS

The systematic review was performed according to the 2009 Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines[15].

Selection criteria. Studies that reported the association between obesity measures and patellar cartilage in adults aged ≥ 18 years in the general population, participants with or without knee pain or knee OA, or participants with or without overweight/obesity were considered for inclusion. Studies that evaluated patellar cartilage using MRI and related this to measures of obesity were also included. Studies were excluded if the results were unavailable as an original research article (conference reports, case studies, review articles, or images). Studies were excluded if they dealt with participants' post-knee arthroscopy, osteotomy, allograft, chondrocyte implantation, or meniscectomy or anterior cruciate ligament reconstruction, or if the underlying pathology was not OA, e.g., rheumatoid arthritis, gout, and malignancy. This was a systematic review of published articles and no ethical approval was needed.

Data sources and search strategy. Three electronic databases (MEDLINE, EMBASE, and CINAHL) were searched up to April 2016 using full text and MeSH terms to identify articles examining obesity or body composition, including "body weight," "body weights and measures," "obesity" and "adipose tissue," "body composition," "body mass index," "weight," "fat mass," and "muscle." To identify patellar cartilage, "patella" and "patellofemoral joint" were used. All terms were included as full text, with truncation used to identify variations in terminology. Reference lists of published articles were examined to identify additional sources. Searches were limited to human studies, published in English. Database search strategies are listed in Appendix 1 (available from the authors on request). Figure 1 shows the search results and study selection.

Selection of studies. Two authors (SMH and MT) independently reviewed records for eligibility by title, abstract, and then full text in a 3-stage determination method. Any disagreement was resolved by discussion with another author (AEW).

Risk of bias assessment. Two independent reviewers (SMH and LC) assessed the internal validity and risk of bias for each study using the US National Heart, Lung, and Blood Institute quality assessment tool for observational studies, which includes 14 criteria[16]. Each criterion is rated as "yes," "no," "cannot determine," "not applicable," or "not reported." Overall judgment of bias risk is rated as low, moderate, or high according to the provided guidance[16]. This tool has been used in assessing internal validity and risk of bias in systematic reviews of several diseases[17,18,19].

Data extraction. Three authors (SMH, MT, and YW) independently extracted data and tabulated them. These were cross-checked by another author (AEW). The data were extracted on (1) study characteristics: study design, year, country, number of participants, proportion of women, mean age of participants, years of followup, and OA status; (2) measures of obesity and body composition; (3) assessment techniques of structural change(s) in the patellofemoral joint; and (4) study results. The articles were presented according to measure of obesity, and then study design. A cohort study was considered the strongest study design because it potentially provides a higher grade of evidence than a case-control or cross-sectional study[20].

RESULTS

Study selection. The database search identified 1446 studies (400 MEDLINE, 1001 EMBASE, and 45 CINAHL; Figure 1). After removal of duplicates, 1081 studies were screened. Based on title and abstract, 1009 articles were excluded because their outcomes were patellar tendon rupture, patella dislocation, or patellar instability. The search retrieved studies in which BMI or obesity was included as a confounder, but not as an exposure. From the remaining 72 full-text articles, 17 articles met inclusion criteria. Screening of the reference lists of included articles did not identify any additional articles.

Characteristics of included studies. Seventeen studies examined the relationship between measures of obesity, body composition, and patellar cartilage (Table 1)[12,21–30,31,32,33,34,35,36]. Of these, 5 were cross-sectional[21,22,23,24,25], 2 related current patella cartilage to both obesity measured at the time of imaging and also change in obesity over the 10 years prior to imaging[26,27], and 10 cohort studies examined the relationship between measures of obesity and change in patellar cartilage over time[12,28,29,30,31,32,33,34,35,36]. Thus, 7 studies reported the association between obesity and cartilage volume measured at the same time[21,22,23,24,25,26,27], 2 assessed whether change in obesity over the preceding decade was associated with current patellar cartilage[26,27], and 10 examined whether measures of obesity affected change in patellar cartilage over time[12,28,29,30,31,32,33,34,35,36].

Of the 17 studies, 12 were performed in Australia[12,21,23,26,27,28,30,31,32,33,35,36], 4 in the United States[24,25,29,34], and 1 in Turkey[22] (Table 1). Most participants were recruited from the community[12,22,23,25,31,33,34,36], with the remainder recruited from existing cohorts (Melbourne Collaborative Cohort Study[27,35], Osteoarthritis Initiative[29], Geelong Osteoporosis Study[26], Tasmanian Older Adult Cohort[30]). One study examined participants who were in an ongoing study evaluating the effects of exercise on OA[24]. Three studies examined adult children of knee replacement recipients for primary knee OA matched to controls from the electoral roll[21,28,32].

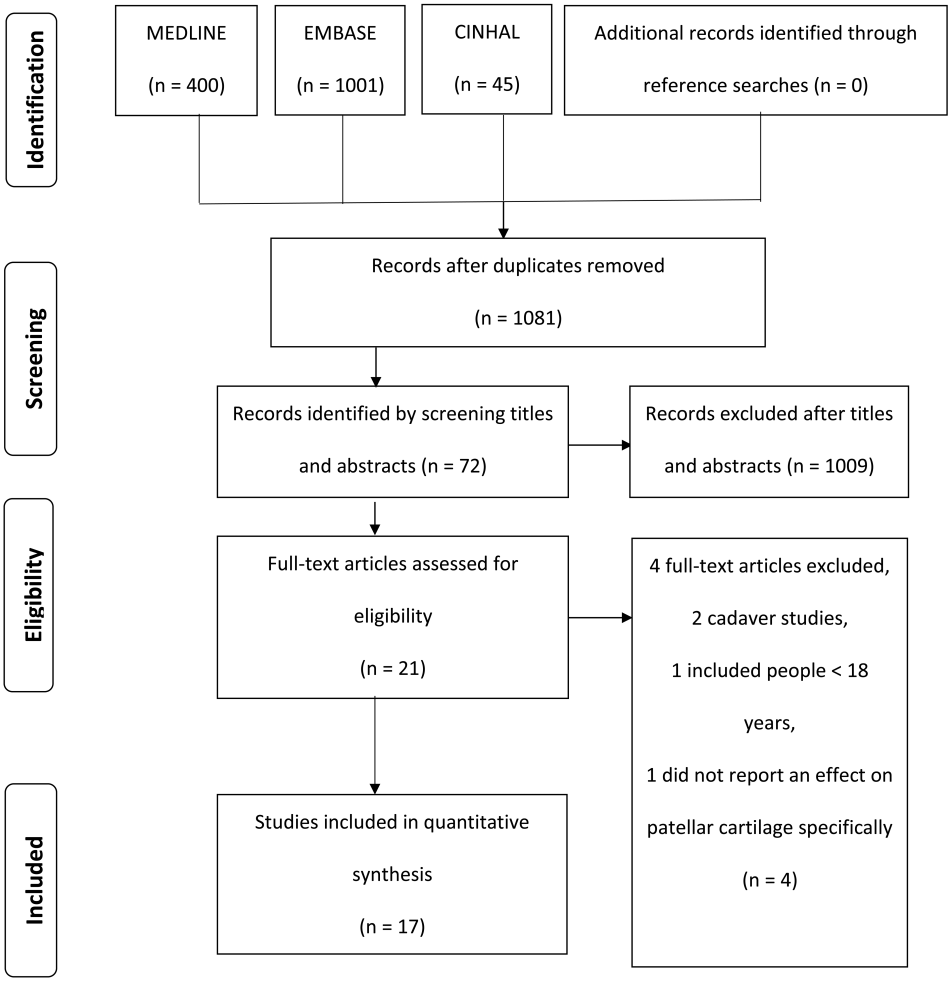

Figure 1. Flow diagram for preferred reporting items for systematic reviews and metaanalyses.

The participants' ages ranged from 24–82 years. The proportion of women ranged from 0% to 100% (median 60%). Nine studies included participants with neither clinical nor radiographic patellofemoral OA[12,23,25,26,27,29,33,35,36] with the remainder including participants both with and without radiographic or clinical patellofemoral OA[21,28,30,32]. Only 3 studies consisted predominantly of participants with knee OA[24,31,34]. One study did not mention the OA status of participants[22] (Table 1).

All 17 studies assessed measures of patellar cartilage, including patellar cartilage volume, thickness, defects/semiquantitative measures (whole-organ magnetic resonance imaging score), and quality. Three studies examined patellar cartilage volume and presence of patellar cartilage defects[23,26,27], 3 examined cartilage volume only[28,33,35], 1 examined the presence of cartilage defects and cartilage thickness[21], 3 examined the presence of patellar cartilage defects only[22,29,34] (including 2 that measured patellar cartilage defects semiquantitively[29,34]), 3 examined change in patellar cartilage defects[12,30,32], 4 examined change in patellar cartilage volume[12,28,31,36], and 2 examined cartilage quality by measuring either transverse relaxation (T2) time[24] or cartilage strain[25].

Obesity was measured using body weight and BMI, and body composition, fat-free mass, and fat mass using bioimpedance analysis. Nine studies used BMI only as the measure of obesity[21,22,24,25,28,29,31,32,33], 4 studies used BMI and body weight[12,23,26,36], 2 studies used BMI, weight, fat mass, and fat-free mass[27,35].

Bias and methodological quality assessment. Table 2 provides details of the risk of bias and quality assessment. Six studies were judged to be at high risk of bias[21,22,23,24,25,32], 6 were judged as moderate[12,26,28,29,30,36], and 5 were low risk[27,31,33,34,35]. For most of the studies, the power calculation was not shown. However, apart from 2 studies[25,33], others had large numbers of samples (≥ 100 participants). Many studies did not report the frequency of measurement of exposure. The reviewers were not blinded to the study (authors, title, and source). The rate of initial agreement between the 2 reviewers was 98.3%. Differences in scoring between reviewers were evaluated and resolved by consensus. Where the 2 reviewers could not achieve

Table 1. Characteristics of the included studies.

Study	Study Population	Women, n (%)	Age, Yrs, Mean (± SD) or Range	OA Status	Outcome Assessed, Method for Assessing Outcome	Measures of Obesity/body Composition	Outcome Followup, Yrs, Mean ± SD
Antony, *et al*[28]	(1) 162 adult children of subjects with OA, (2) 162 community-based controls, offspring status taken into account	324 (58)	45 (26–61)	14% radiographic PFOA	Change in patellar cartilage volume	BMI	2
Bucknor, *et al*[29]	100 participants with OA risk factors	100 (67)	59.1 (8.0) no change in weight, 58.0 (8.3) weight gain group	No clinical OA	Cartilage morphology Modified WORMS	BMI	4
Carnes, *et al*[30]	Community-based older adults	395 (50)	62.7	Knee cartilage defects: 18.2% medial femur, 8.9% lateral femur, and 38% patella	Change in patellar cartilage defects rate	BMI	2.9
Cicuttini, *et al*[31]	Community-based	110 (60)	Men: 63.2 (10.0), women: 63.1 (10.3)	100% radiographic OA	Change in patellar cartilage volume over 2 yrs	BMI	2
Ding, *et al*[21]	(1) 186 adult children of subjects with OA, (2) 186 community-based controls	372 (58)	45 (26–61)	17% radiographic OA	(1) Patellar cartilage defects, (2) patellar cartilage volume	BMI	NA
Ding, *et al*[32]	Adult children of subjects with OA and community-based controls	325 (58)	45 (26–61)	Not mentioned	Patellar cartilage defects	BMI	2
Duran, *et al*[22]	Patients who had undergone knee MRI analyses for any indication	100 (68)	43.3 (12.9) 18–60	Not mentioned	Patellar cartilage defect	BMI	NA
Gunardi, *et al*[26]	Community-based	160 (100)	41.7 (5.3)	No clinical knee OA	(1) Patellar cartilage volume, (2) presence of patellar cartilage defects	BMI, body weight	NA
Hanna, *et al*[33]	Healthy community-based people	85 (67)	55.5 (9.3)	No clinical OA	Patellar cartilage volume	BMI	2
Hanna, *et al*[23]	Community-based	176 (100)	52.3 (6.7)	Asymptomatic	(1) Patellar cartilage volume, (2) presence of patellar cartilage defects	BMI, body weight	NA
Koff, *et al*[24]	Volunteers	113 (74)	56.0 (11.0)	82.5% radiographic PFOA	Cartilage quality	BMI	NA
Roemer, *et al*[34]	Community-based participants with knee pain	177 (% women not reported)	52.3 (6.2)	71.2% radiographic OA	Cartilage quality	BMI	6 mos
Teichtahl, *et al*[35]	Community-based	297 (62)	60.1 (5.2)	No clinical knee OA	Annual change in patellar cartilage volume	BMI, weight, fat mass, fat-free mass	2
Teichtahl, *et al*[27]	Community-based	297 (63)	58.0 (5.5)	No clinical knee OA	(1) Patellar cartilage volume, (2) presence of patellar cartilage defects	BMI, weight, fat mass, fat-free mass	NA
Teichtahl, *et al*[36]	Community-based	112 (82)	45.4 (9.2)	Asymptomatic obese adults with no clinical OA	Change in patellar cartilage volume	BMI, weight	2.3 (0.4)
Wang, *et al*[12]	Community-based	124 (65)	Men: 52.5 (13.2), women: 57.1 (5.8)	8% radiographic PFOA	Change in patellar cartilage defects	BMI	2
Widmyer, *et al*[25]	Community-based	20 (20)	Normal weight: 30.0 (6.3), overweight: 31.0 (6.3)	Asymptomatic adults	Cartilage strain	BMI	NA

OA: osteoarthritis; PFOA: patellofemoral OA; WORMS: whole-organ magnetic resonance imaging score; BMI: body mass index; MRI: magnetic resonance imaging; NA: not applicable.

consensus through discussion, a third reviewer (AEW) adjudicated.

Body weight and patellar cartilage. Three cross-sectional studies[23,26,27], including 2 that also examined change in weight over the previous decade[26,27], assessed the relationship between body weight and patellar cartilage (Table 3).

1. Body weight and patellar cartilage defects: All cross-sectional analyses found that higher weight was signifi-

Table 2. Risk of bias assessment of included studies.

Study	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8	Criterion 9	Criterion 10	Criterion 11	Criterion 12	Criterion 13	Criterion 14	Overall Risk of Bias
Patellar cartilage volume															
Cohort studies															
Cicuttini, *et al*[31]	Yes	Yes	NR	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	NR	Yes	Low
Hanna, *et al*[33]	Yes	Yes	NR	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Low
Antony, *et al*[28]	Yes	Yes	NR	No	No	Yes	Yes	Yes	Yes	No	Yes	NR	Yes	Yes	Moderate
Gunardi, *et al*[26]	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	NR	NR	Yes	Moderate
Teichtahl, *et al*[36]	Yes	Yes	NR	Yes	No	Yes	Yes	Yes	Yes	No	Yes	NR	No	Yes	Moderate
Patellar cartilage defect															
Cross-sectional studies															
Ding, *et al*[21]	Yes	Yes	NR	No	No	No	No	Yes	Yes	No	Yes	NR	NA	Yes	High
Duran, *et al*[22]	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No	Yes	NR	NA	Yes	High
Cohort studies															
Ding, *et al*[32]	Yes	Yes	NR	No	No	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	High
Wang, *et al*[12]	Yes	Yes	NR	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Moderate
Carnes, *et al*[30]	Yes	Yes	NR	Yes	No	Yes	Yes	Yes	Yes	No	Yes	NR	Yes	Yes	Moderate
Bucknor, *et al*[29]	Yes	Yes	NR	Yes	No	Yes	Yes	NA	Yes	No	Yes	Yes	No	Yes	Moderate
Roemer, *et al*[34]	Yes	Yes	No	Yes	No	Yes	No	NA	Yes	No	Yes	Yes	Yes	Yes	Low
Patellar cartilage volume and cartilage defect															
Cross-sectional studies															
Hanna, *et al*[23]	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	No	Yes	No	NA	Yes	High
Cohort studies															
Teichtahl, *et al*[27]	Yes	Yes	NR	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	NR	Yes	Low
Teichtahl, *et al*[35]	Yes	Yes	NR	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Low
Cartilage quality															
Cross-sectional studies															
Koff, *et al*[24]	Yes	Yes	NR	Yes	Yes	No	No	Yes	Yes	No	No	No	NA	No	High
Widmyer, *et al*[25]	Yes	No	NR	Yes	No	No	No	NA	Yes	No	Yes	No	NA	No	High

Items included on the risk of bias tool:
1. Was the research question or objective in this paper clearly stated?
2. Was the study population clearly specified and defined?
3. Was the participation rate of eligible persons at least 50%?
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?
5. Was a sample size justification, power description, or variance and effect estimates provided?
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured? (For cross-sectional analyses, the answer to Question 6 should be "no.")
7. Was the time frame sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed? (For cross-sectional analyses, the answer to Question 6 should be "no.")
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)? (if binary NA)
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
10. Was the exposure(s) assessed more than once over time?
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
12. Were the outcome assessors blinded to the exposure status of participants?
13. Was loss to follow-up after baseline 20% or less?
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?
NR: not reported; NA: not applicable.

cantly associated with greater prevalence of patellar cartilage defects ranging from 4% to 9%[23,26,27]. The 2 studies that examined whether change in weight over the previous decade related to patellar cartilage defects found inconsistent results[26,27]. Gunardi, *et al* found no significant relationship between increasing weight and the prevalence of patellar cartilage defects in women[26]. In contrast, Teichtahl, *et al* identified a significant positive relationship between increasing weight and prevalence of patellar cartilage defect in women, but not in men[27].

2. Body weight and patellar cartilage volume: Three studies[23,26,27] assessed the relationship between current weight and patellar cartilage volume, with 1 showing reduced cartilage volume associated with greater weight in women only[27]. Of the 2 studies that also assessed the association between change in weight over the past decade and cartilage

Table 3. Studies examining the association between body weight and patellar cartilage.

Study	Definition of Outcome	OA/non-OA	Variables Adjusted For	Results (95% CI or p value)	Conclusion
Patellar cartilage defects					
Cross-sectional studies: association between body weight and patellar cartilage defects					
Gunardi, *et al*[26]	Presence of patellar cartilage defects	Non-OA	Age, bone and cartilage volume	Increased odds of defects, OR 1.04 (1.02–1.06), p = 0.001	Higher body weight was significantly associated with increased odds of patellar cartilage defects in women
Teichtahl, *et al*[27]	Presence of patellar cartilage defects	Non-OA	Age, patellar cartilage volume	Men, increased odds of defects, OR 1.09 (95% CI 1.04–1.15), p = 0.001; women, increased odds of defects, OR 1.09 (95% CI 1.06–1.13), p < 0.0001	Higher body weight was significantly associated with higher odds of patellar cartilage defects in men and women
Hanna, *et al*[23]	Patellar cartilage defects	Non-OA	Age, bone volume	Increased odds of defects, OR 1.04 (95% CI 1.01–1.07), p = 0.006	Higher body weight was significantly associated with higher odds of patellar cartilage defects in women
Longitudinal studies: association between change in weight over previous period and current patellar cartilage defects					
Gunardi, *et al*[26]	Presence of patellar cartilage defects	Non-OA	Age, bone and cartilage volume, baseline weight	No increased odds of defects, OR 1.00 (0.96–1.05), p = 0.96	No significant association between increase in body weight and patellar cartilage defects in women
Teichtahl, *et al*[27]	Presence of patellar cartilage defects	Non-OA	Age, patellar cartilage volume	Women, OR 1.10 (95% CI 1.02–1.18), p = 0.01; men, OR 1.06 (95% CI 0.95–1.17), p = 0.31	Increased body weight was significantly associated with higher odds of patellar cartilage defects among women only
Patellar cartilage volume					
Cross-sectional studies: association between body weight and patellar cartilage volume					
Gunardi, *et al*[26]	Patellar cartilage volume	Non-OA	Age, patella bone volume	β coefficient: –3.21 (–7.93 to 1.5), p = 0.18	No significant association between body weight and patellar cartilage volume in women
Teichtahl, *et al*[27]	Patellar cartilage volume	Non-OA	Age, patella bone volume	Women, patellar cartilage volume, regression coefficient: –6.8 (95% CI –12.2 to –1.5), p = 0.01; men, patellar cartilage volume, regression coefficient: 6.5 (95% CI –3.9 to 16.9), p = 0.26	Higher body weight was significantly associated with reduced cartilage volume among women only
Hanna, *et al*[23]	Patellar cartilage volume	Non-OA	Age, bone volume	No increased odds of reduced patellar cartilage volume, OR –4.3 (95% CI –9.2 to 0.7), p = 0.09	No significant association between body weight and patellar cartilage volume in women
Longitudinal studies: association between change in weight over previous period and patellar cartilage volume					
Gunardi, *et al*[26]	Patellar cartilage volume	Non-OA	Age, bone volume, baseline weight	β coefficient: –10.4 (–20.0 to –0.78), p = 0.03	Increased body weight significantly associated with reduced patellar cartilage volume in women
Teichtahl, *et al*[27]	Patellar cartilage volume	Non-OA	Age	Men, current patellar cartilage volume, regression coefficient: –0.3 (95% CI –26.0 to 25.5), p = 0.98; women, current patellar cartilage volume, regression coefficient: 2.1 (95% CI –10.4 to 14.6), p = 0.74	No significant relationship between body weight and cartilage volume
Longitudinal studies: association between baseline weight and change in patellar cartilage volume					
Teichtahl, *et al*[35]	Annual change in patellar cartilage volume	Non-OA	Age, patella bone volume, participation in strenuous physical activity	Relationship with annual change in patellar cartilage volume, regression coefficient: women 1.0 (95% CI –0.01 to 2.0), p = 0.05; men 1.1 (95% CI –0.3 to 2.6), p = 0.13	Higher body weight was not associated with loss of cartilage volume
Longitudinal studies: association between changes in weight and change in patellar cartilage volume					
Teichtahl, *et al*[36]		Asymptomatic population	Sex, baseline age, BMI, time between measures, respective baseline measure	–0.9 (–2.7 to 0.9), p = 0.32	Percentage weight change was not associated with change in patellar cartilage volumes

OA: osteoarthritis; BMI: body mass index.

volume[26,27], 1 study that examined only women found that increased weight was significantly associated with reduced cartilage volume[27]. The only longitudinal study[35] to examine the relationship between baseline weight and subsequent patellar cartilage volume loss found no significant relationship. Similarly, the only longitudinal study[36] to

examine the relationship between weight change and change in patellar cartilage volume found no significant association.

BMI and patellar cartilage. Eight cross-sectional analyses[21,22,23,24,25,26,27,33], including 2 from longitudinal studies that examined change in BMI over the previous years[26,27], and 6 longitudinal studies[28,29,31,33,34,35] assessed the relationship between BMI and patellar cartilage (Table 4).

1. BMI and patellar cartilage defects: All 5 cross-sectional analyses found that BMI was associated with increased odds of patellar cartilage defects, ranging from 9% to 29%[21,22,23,26,27]. One study showed that change in BMI over the past decade was not associated with cartilage defects[26,29], whereas another found a significant association in women[27]. Four cohort studies found that higher baseline BMI was not associated with the progression of cartilage defects[12,30,32,34]. In the Osteoarthritis Initiative, a 5% increase in BMI over time was associated with progression of patellar cartilage defects[29].

2. BMI and patellar cartilage volume: Although 3 cross-sectional analyses showed that increased BMI was associated with reduced cartilage volume in women only[23,26,27], 1 study found no association between BMI and rate of patellar cartilage volume change[23]. Change in BMI over previous years was not associated with patellar cartilage volume change[27]. Three cohort studies found that higher baseline BMI was associated with increased patellar cartilage volume loss[28,31,35]. However, in 1 study, the association applied only to those in the top BMI tertile (cutoff points not specified)[28].

3. BMI and patellar cartilage quality: Two studies examined the relationship between BMI and cartilage quality[24,25]. One showed that higher BMI was associated with higher T2 values, signifying structural changes of patellofemoral OA[24]. The other found that higher BMI was not associated with cartilage strain[25].

Body composition and patellar cartilage. Two studies examined the relationship between body composition and patellar cartilage (Table 5)[27,35].

1. Fat mass and patellar cartilage defects: One study examined the relationship between fat mass and defects, and found that increased fat mass was associated with increased patellar cartilage defects among men only[27]. Change in fat mass over the past decade was not associated with increased prevalence of cartilage defects[27].

2. Fat mass and patellar cartilage volume: Cartilage volume was not significantly related to fat mass or change in fat mass over the past decade[27]. Higher fat mass was associated with increased cartilage loss in women, but not men[35]. In the longitudinal study, change in fat mass was not significantly related to change in patellar cartilage volume[35].

3. Fat-free mass and patellar cartilage defects: The presence of patellar cartilage defects was associated with fat-free mass and change in fat-free mass over the preceding decade[27]. In cross-sectional analysis, higher fat-free mass was associated with increased prevalence of cartilage defects in women only[27]. An increase in fat-free mass over the previous decade was associated with a higher prevalence of cartilage defects in men and women[27].

4. Fat-free mass and patellar cartilage volume: One study examined the relationship between patellar cartilage volume and fat-free mass[27]. There was no significant association between fat-free mass and patellar cartilage volume at the time of the MRI. There was also no change in fat-free mass over the previous decade significantly associated with current patellar cartilage volume[27].

Summary of the evidence synthesis. There was consistent cross-sectional evidence for a positive association between weight or BMI, and patellar cartilage defects[21,22,23,26,27]. Evidence for the relationship between prior change in weight or BMI and the prevalence of cartilage defects was varied[26,27]. The 4 studies that examined the relationship between BMI and subsequent change in patellar cartilage defects showed no significant relationship[12,30,32,34]. There was a consistent direction of a detrimental effect of measures of obesity and patellar cartilage volume in cross-sectional analyses, although 2 found significant results[23,26,27]. The 4 studies examining whether BMI was associated with increased cartilage volume loss showed results in the same direction[28,31,33,35]. However, only 3 studies showed a significant relationship, 1 involving both sexes and at low risk of bias[31], 1 involving both sexes but only in participants in the top BMI tertile and at moderate risk of bias[28], and 1 involving only women[35]. Two studies examined the association between body composition and cartilage defect/volume[27,35]; thus, no definitive conclusion could be drawn relating to body composition. When the 4 studies at high risk of bias were excluded from the summary of the evidence, the conclusions did not change[21,22,23,32].

DISCUSSION

Our systematic review examined the relationship between obesity and the patellar cartilage across the spectrum of OA, from healthy to preclinical and then to symptomatic and radiographic disease. In asymptomatic middle-aged adults, a consistent detrimental influence of elevated weight and BMI on patellar cartilage was seen in all significant studies. Results from the few available cohort studies showed no effect of obesity on the progression of cartilage defects, but a tendency toward increased cartilage loss, with half the studies showing statistically significant results. No studies found a statistically significant beneficial effect of obesity on patellar cartilage.

The relationship between obesity and patellar cartilage change seemed stronger in women. A number of factors may contribute to this observation. First, women have relatively higher fat mass compared to men[37]. Increased fat mass is associated with higher levels of inflammatory cytokines (e.g., C-reactive protein, interleukin 6), which are detrimental to knee structure, cartilage in particular[10,38]. The sex difference may therefore relate to differences in the metabolic milieu.

Table 4. Studies examining the relationship between BMI and patellofemoral structure.

Study	Definition of Outcome	OA/non-OA	Variables Adjusted For	Results (95% CI or p value)	Conclusion
Patellar cartilage defects					
Cross-sectional studies: association between BMI and patellar cartilage defects					
Gunardi, *et al*[26]	Patellar cartilage defects	Non-OA	Age, bone and cartilage volume	Increased odds of defects, OR 1.09 (1.03–1.16), p = 0.004	Higher BMI significantly associated with increased odds of patellar cartilage defects in women
Teichtahl, *et al*[27]	Patellar cartilage defects	Non-OA	Age	Men, increased odds of defects, OR 1.29 (95% CI 1.09–1.52), p = 0.003; women, increased odds of defects, OR 1.17 (95% CI 1.08–1.27), p < 0.0001	Higher BMI was significantly associated with higher odds of patellar cartilage defects
Hanna, *et al*[23]	Patellar cartilage defects	Non-OA	Age, bone volume	Increased odds of defects, OR 1.09 (95% CI 1.02–1.17), p = 0.01	Higher BMI was significantly associated with higher odds of patellar cartilage defects in women
Ding, *et al*[21]	Patellar cartilage defects	OA (17%), non-OA	Age, sex, case-control status, bone size, ROA	Increased odds of defects, OR 1.08 (95% CI 1.02–1.14)	Higher BMI was significantly associated with higher odds of patellar cartilage defects
Duran, *et al*[22]	Patellar cartilage defects	Non-OA	Not adjusted	Mean BMI, no patellar cartilage defect vs patellar cartilage defect, 26 ± 4.0 vs 29 ± 4.3, p < 0.05	Cartilage defect was associated with higher BMI
Longitudinal studies: association between change in BMI over previous period and patellar cartilage defects					
Gunardi, *et al*[26]	Patellar cartilage defects	Non-OA	Age, bone and cartilage volume, baseline BMI	No increased odds of defects, OR 0.98 (0.87–1.12), p = 0.80	No significant association between increased BMI and patellar cartilage defects in women
Teichtahl, *et al*[27]	Patellar cartilage defects	Non-OA	Age, patellar cartilage volume	Men, no increased odds of defects, OR 1.18 (95% CI 0.86–1.63), p = 0.31; women, increased odds of defects, OR 1.22 (95% 1.03–1.47), p = 0.02	Higher BMI was significantly associated with higher odds of patellar cartilage defects for women only
Longitudinal studies: association between baseline BMI and change in patellar cartilage defects					
Carnes, *et al*[30]	Change in patellar cartilage defects	Knee cartilage defects: 18.2% medial femur, 8.9% lateral femur, and 38% patella	Age, sex, BMI, baseline cartilage volume, tibial bone size, ROA	No association, OR 0.97 (95% CI 0.92–1.02), p = 0.27	No significant association between BMI and increase in patellar cartilage defects
Ding, *et al*[32]	Change in cartilage defect	Cases were adult children of subjects who had a knee replacement for knee OA, controls were selected from electoral roll	Offspring-control status, baseline cartilage defects	Increase in patellar cartilage defect, OR 1.03, p = 0.38; decrease in patellar cartilage defect OR 0.99, p = 0.72	BMI was not associated with increase or decrease in patellar cartilage defect
Wang, *et al*[12]	Change in patellar cartilage defects	OA (8%) and non-OA	Age, sex, physical activity, baseline bone size	Association with progression of cartilage defects, regression coefficient: 0.034 (–0.002 to 0.070), p = 0.06	No significant association between BMI and patellar cartilage defects
Roemer, *et al*[34]	Patellar cartilage morphology/defect semiquantitative measures, WORMS	71.2% radiographic OA	Age, BMI, sex, presence of cartilage damage, subchondral bone marrow lesions, synovitis, effusion	BMI was not associated with cartilage loss in the patellofemoral joint, data were not presented by the authors	There was no effect of BMI on the patellofemoral joint cartilage loss
Longitudinal studies: association between change in BMI and change in patellar cartilage defect					
Bucknor, *et al*[29]	Cartilage morphology scored by the WORMS system	No clinical OA	Age, sex, baseline BMI, PASE score, KL score	5% increase in BMI was associated with progression of patellar cartilage lesion, OR 8.9 (95% CI 2.2–60.0), p = 0.006	Higher BMI was significantly associated with worsening in patellar cartilage morphology
Patellar cartilage volume					
Cross-sectional studies: association between BMI and patellar cartilage volume					
Gunardi, *et al*[26]	Patellar cartilage volume	Non-OA	Age, bone volume	β coefficient: –13.1 (–25.7 to –0.55), p = 0.04	Higher BMI was associated with reduced cartilage volume in women
Teichtahl, *et al*[27]	Patellar cartilage volume	Non-OA	Age	Women, patellar cartilage volume, regression coefficient: –15.8 (95% CI –29.8 to –1.8), p = 0.03; men, patellar cartilage volume, regression coefficient: 7.5 (95% CI –30.0 to 45.0), p = 0.69	Higher BMI was significantly associated with reduced cartilage volume among women only

Table 4. Continued.

Study	Definition of Outcome	OA/non-OA	Variables Adjusted For	Results (95% CI or p value)	Conclusion
Hanna, *et al*[23]	Patellar cartilage volume	Non-OA, middle-aged women	Age, bone volume	Relationship with patellar cartilage volume, regression coefficient: –12.6 (95% CI –25.3 to 0.1), p = 0.05	Higher BMI was not associated with higher odds of reduced cartilage volume in women
Longitudinal studies: association between change in BMI over previous period and patellar cartilage volume					
Gunardi, *et al*[26]	Patellar cartilage volume	Non-OA	Age, bone volume, baseline BMI	β coefficient: –27.0 (–52.6 to –1.5), p = 0.04	Higher BMI significantly associated with reduced cartilage volume in women
Teichtahl, *et al*[27]	Patellar cartilage volume	Non-OA	Age	Men, relationship between change in BMI and current patellar cartilage volume, regression coefficient: –1.6 (95% CI –83.3 and 80.0), p = 0.97; women, relationship between change in BMI and current patellar cartilage volume, regression coefficient: 7.3 (–25.7 to 40.4), p = 0.66	Higher BMI was not significantly associated with loss of cartilage volume
Longitudinal studies: association between baseline BMI and change in patellar cartilage volume					
Antony, *et al*[28]	Change in patellar cartilage volume	OA (14%), non-OA	Sex, age, offspring-control status, baseline bone size	BMI (highest tertile), loss of patellar cartilage volume, β: –0.24 (95% CI –0.37 to –0.10); BMI (middle tertile), loss of patellar cartilage volume, β: –0.01, (95% CI –0.15 to 0.13), p = NS; BMI (lowest tertile), loss of patellar cartilage volume, β : –0.07 (95% CI –0.21 to 0.08), p = NS	Higher BMI was significantly associated with loss of patellar cartilage volume but only among those in the highest BMI tertile
Teichtahl, *et al*[35]	Annual change in patellar cartilage volume	Non-OA	Age, sex, baseline patella bone volume, participation in physical activity	Men, no association with annual change in patellar cartilage volume, regression coefficient: 2.9 (95% CI –2.2 to 8.0), p = 0.26; women, association with annual change in patellar cartilage volume, regression coefficient: 3.0 (0.5–5.6), p = 0.02	Higher BMI was significantly associated with loss of patellar cartilage volume for women only
Hanna, *et al*[33]	Change in patellar cartilage volume	Non-OA	Age, sex, initial patella bone volume	Association with loss of patellar cartilage volume, regression coefficient: 2.0 (95% CI –3.9 to 8.0), p = 0.51	BMI did not affect rate of change of patellar cartilage volume
Cicuttini, *et al*[31]	Change in patellar cartilage volume	OA (100%)	Age, sex	Association with loss of patellar cartilage volume, regression coefficient: -1.9×10^{-3} (95% CI –0.004 to 0.000), p = 0.04	Higher BMI was significantly associated with increased loss of patellar cartilage volume
Longitudinal studies: association between change in BMI and change in patellar cartilage volume					
Teichtahl, *et al*[35]	Annual change in patellar cartilage volume	Non-OA	Data not shown	Data not shown	No significant association between BMI and annual rate of patellar cartilage volume loss
Cartilage quality					
Cross-sectional studies: association between BMI and patellar cartilage quality					
Koff, *et al*[24]	Average transverse relaxation (T2) time constant, increased measures signify structural change	OA (82.5%), non-OA	NA	BMI was positively associated with the average transverse relaxation time constant (T2) of patellar cartilage: r = 0.3, p < 0.0001	Higher BMI was significantly associated with increased T2 values
Widmyer, *et al*[25]	Cartilage strain	Asymptomatic	Matched age and sex	High BMI group has significantly thicker patellar cartilage compared with normal BMI group: p = 0.2 for diurnal strain, p = 0.05 for BMI, p = 0.3 for diurnal strain	There was no effect of BMI on the magnitude of the patellar strain

BMI: body mass index; OA: osteoarthritis; WORMS: whole-organ magnetic resonance imaging score; ROA: radiographic OA; PASE: Psoriatic Arthritis Screening and Evaluation; KL score: Kellgren-Lawrence arthritis grading scale; NS: not significant; NA: not applicable.

Table 5. Studies examining the relationship between body composition and patellar cartilage.

Study	Outcome(s) Assessed	OA/non-OA	Variables Adjusted For	Results (95% CI or p value)	Conclusion
Fat mass					
Patellar cartilage defects					
Cross-sectional studies: association between fat mass and patellar cartilage defects					
Teichtahl, *et al*[27]	Presence of patellar cartilage defects	Non-OA	Age, patellar cartilage volume, and fat-free mass	Men, increased odds of defects, OR 1.11 (95% CI 1.01–1.23), p = 0.04; women, no increased odds of defects, OR 1.06 (95% CI 0.99–1.13), p = 0.09	Higher fat mass was significantly associated with patellar cartilage defects for men only
Longitudinal studies: association between change in fat mass over previous period and patellar cartilage defects					
Teichtahl, *et al*[27]	Presence of patellar cartilage defects	Non-OA	Age, patellar cartilage volume, and fat-free mass	Men, no increased odds of defects, OR 1.03 (95% CI 0.89–1.18), p = 0.71; women, no increased odds of defects, OR 1.10 (95% CI 0.99–1.21), p = 0.08	No significant association between change in fat mass over the previous 10 yrs and patellar cartilage defects
Patellar cartilage volume					
Cross-sectional studies: association between fat mass and patellar cartilage volume					
Teichtahl, *et al*[27]	Patellar cartilage volume	Non-OA	Age and fat-free mass	Men, patellar cartilage volume, regression coefficient: –14.8 (95% CI –50.2 to 20.7), p = 0.41; women, patellar cartilage volume, regression coefficient: 2.2 (95% CI –15.4 to 19.8), p = 0.80	No significant association between fat mass and patellar cartilage volume
Longitudinal studies: association between change in fat mass over previous period and current patellar cartilage volume					
Teichtahl, *et al*[27]	Patellar cartilage volume	Non-OA	Age and fat-free mass	Men, relationship between change in fat mass and current patellar cartilage volume, regression coefficient: –15.3 (95% CI –50.9 to 20.3), p = 0.40; women, relationship between change in fat mass and current patellar cartilage volume, regression coefficient: 2.3 (95% CI –15.7 to 20.3), p = 0.80	No significant association between change in fat mass over the previous 10 yrs and patellar cartilage volume
Longitudinal studies: association between baseline fat mass and change in patellar cartilage volume					
Teichtahl, *et al*[35]	Annual change in patellar cartilage volume	Non-OA	Age, gender, baseline patella bone, and participation in physical activity	Men, association with annual loss of patellar cartilage volume, regression coefficient: 1.8 (95% CI –0.8 to 4.4), p = 0.17; women, association with annual loss of patellar cartilage volume, regression coefficient: 1.8 (95% CI 0.2–3.4), p = 0.03	Higher fat mass was significantly associated with increased loss of patellar cartilage volume for women only
Longitudinal studies: association between change in fat mass and change in patellar cartilage volume					
Teichtahl, *et al*[35]	Annual change in patellar cartilage volume	Non-OA	Age, baseline patella bone and cartilage volume, and physical activity	Data not shown	No significant association between change in fat mass and change in knee cartilage
Fat-free mass					
Patellar cartilage defects					
Cross-sectional studies: association between fat-free mass and patellar cartilage defects					
Teichtahl, *et al*[27]	Presence of patellar cartilage defects	Non-OA	Age, patellar cartilage volume, and fat mass	Men, increased odds of defects, OR 1.07 (95% CI 0.94–1.21), p = 0.34; women, increased odds of defects, OR 1.19 (95% CI 1.03–1.38), p = 0.02	Higher fat-free mass was significantly associated with patellar cartilage defects for women only
Longitudinal studies: association between change in fat-free mass over previous period and patellar cartilage defects					
Teichtahl, *et al*[27]	Presence of patellar cartilage defects	Non-OA	Age, patellar cartilage volume, and fat mass	Men, increased odds of defects, OR 1.21 (95% CI 1.01–1.45), p = 0.04; women, increased odds of defects OR 1.34 (95% CI 1.11–1.63), p = 0.003	Greater increase in fat-free mass was significantly associated with patellar cartilage defects
Patellar cartilage volume					
Cross-sectional studies: association between fat-free mass and patellar cartilage volume					
Teichtahl, *et al*[27]	Patellar cartilage volume	Non-OA	Age, fat mass	Men, patellar cartilage volume, regression coefficient: 16.5 (95% CI –32.2 to 65.3), p = 0.50; women, patellar cartilage volume, regression coefficient: 0.1 (95% CI –40.2 to 40.3), p = 0.99	No significant association between fat-free mass and patellar cartilage volume
Longitudinal studies: association between change in fat-free mass over previous period and current patellar cartilage volume					
Teichtahl, *et al*[27]	Patellar cartilage volume	Non-OA	Age, fat mass	Men, relationship between change in fat-free mass and current patellar cartilage volume, regression coefficient: 17.4 (95% CI –31.5 to 66.3), p = 0.48; women, relationship between change in fat-free mass and current patellar cartilage volume, regression coefficient: –1.0 (95% CI –42.1 to 40.2), p = 0.96	No significant association between fat-free mass and patellar cartilage volume

OA: osteoarthritis.

Second, the biomechanics of the patellofemoral joint differ in men and women, affecting loading and risk of OA[39]. Cadaveric female knees showed greater change in contact pressures to varying vastus medialis load at knee flexion angles compared with male knees, suggesting sex differences in patellofemoral contact areas and pressures[39]. Third, studies may have had limited power to detect an association in men since OA is more common in women and participants were mainly women. In studies where results were found to be significant in women but not men, the point estimates of effect were in the same direction for men as women, but did not reach statistical significance. However, there were differences, such as a significant association between fat mass and cartilage defects seen in men, but not in women[27].

Despite increasing interest in a metabolic mechanism for the relationship between obesity and tibiofemoral OA[10,40,41], only 2 studies examined the relationship between body composition and patellar cartilage[27,35]. While they suggested a detrimental relationship between fat mass and patellar cartilage in women and men[27,35], 1 found a detrimental association of fat-free mass with cartilage defects in women[27]. This may suggest a stronger involvement of mechanical factors at the patellofemoral joint than at the tibiofemoral joint. At the tibiofemoral joint, a consistent detrimental relationship between fat mass and cartilage volume and defects was seen, with a beneficial relationship of fat-free mass and cartilage volume[8]. This finding at the patellofemoral joint in only 1 study requires further verification[27].

Both metabolic and biomechanical factors are likely to contribute to the relationship between obesity and patellofemoral OA. Metabolic factors exemplified by leptin, which is raised in obesity, have been associated with reduced patellar cartilage volume, independent of BMI[10]. Increased loading by obesity may also affect patellar cartilage and its biomechanical properties[42]. The relative contributions of metabolic and biomechanical mechanisms to the initiation and progression of patellofemoral OA have not been examined and require further work.

Our review was limited with few high-quality and cohort studies. It was not until the late 1990s that MRI began to be widely used to investigate knee structure, albeit with little emphasis on the patellofemoral joint. Most of the performed studies were cross-sectional, thus limiting the level of evidence able to be extracted. The few longitudinal studies had relatively brief followup periods (2 yrs on average)[12,30,31,32,33,35,36], which might be inadequate to detect patellar cartilage changes. Previous studies may have examined the relationship between patellar cartilage and obesity, but used an overall measure such as cartilage strain[25] or T2 relaxation time[24], and therefore did not identify separate relationships with cartilage volume and defects. Further, the magnitude of change in obesity measures was not large in the cohort studies. The differences in participants' characteristics such as mean age and body weight/BMI might explain the inconsistent results presented in our review. It is possible that the effect of obesity on patellar cartilage may differ according to age and the severity of OA in the joint. However, given the limited number of longitudinal studies that used a variety of measures, and few studies in those with OA, the existing data are restricted in their capacity to identify this possibility. Results were similar in studies examining those with and without OA. Patellofemoral degeneration associated with malalignment or patellar incongruity has been proposed to influence patellar cartilage and may be a confounding factor. Measures of incongruity have not been accounted for, which may explain differences between study results. Nevertheless, there is no consensus regarding which should be included in analyses or their determinants[43]. Incongruity may lie on the pathway between obesity and patellofemoral OA.

We did not perform a metaanalysis for several reasons. First, patellar cartilage was measured using a variety of measures, each identifying a complementary construct or dimension of cartilage. Second, even where the same outcome was used, results were presented differently and adjusted for different cofactors, possibly introducing publication bias. Thus, we performed a systematic review, including data from studies where the effect of obesity was not necessarily the primary outcome.

Our systematic review identified some evidence for a detrimental association between obesity and patellar cartilage. Specifically, evidence was consistent for a relationship between greater weight and BMI and prevalence of patellar cartilage defects, particularly in women. Evidence was suggestive for an association between BMI and patellar cartilage volume loss. No clear conclusion could be drawn for the association between body composition and patellar cartilage. Therefore, more high-quality research is required to confirm these findings and to better understand the relative contributions of metabolic and biomechanical factors to the pathogenesis of patellofemoral OA, so that effective strategies to manage this common and disabling condition can be devised.

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