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Osteoarthritis in Sports and Exercise: Risk Factors and Preventive Strategies

Eduard Alentorn-Geli and Lluís Puig Verdié
Department of Orthopedic Surgery, Hospital del Mar i l'Esperança, Parc de Salut MAR, Barcelona, Spain

1. Introduction

Osteoarthritis in people participating in sports have considerably increased over the last decades (Hunter DJ & Eckstein F, 2009; Wolf BR & Amendola A, 2005). Sports have many psychological, social and health benefits (Hunt A, 2003; Maffulli N et al., 2011), but individuals with past exposure to maintained vigorous exercise may have an increased risk of developing articular cartilage degeneration (Buckwalter JA, 2003; Kujala UM et al., 2003). Mechanical loading is crucial for an adequate growth and development of articular cartilage (Darling EM & Athanasiou KA, 2003). While too high of a mechanical load can damage normal articular cartilage, some stimulation is necessary to promote chondrogenesis (Darling EM & Athanasiou KA, 2003). Articular cartilage that is not mechanically stimulated will become thinner and will atrophy with time (Vanwanseele B et al., 2002). Given that the cartilage responses to mechanical loading, any type of physical activity may play a role in either the etiology or the protection against osteoarthritis. Where is the threshold at which exercise is no longer hazardous for articular cartilage but instead provides the exact stimulus for its homeostasis? There is no easy answer to this question as each individual has a unique response to each stimulus based on his own genetics but also on many associated factors that have been linked to cartilage damage.

Osteoarthritis is a clinical syndrome caused by joint degeneration that results in permanent and often progressive joint pain and dysfunction (Buckwalter JA, 2003). Osteoarthritis has a multifactorial etiology with the influence of both systemic and local factors (Zhang Y & Jordan JM, 2010). Older age, female gender, obesity, osteoporosis, genetic factors, history of traumatic joint injuries, repetitive use of joints at high loads (either in sports, occupational work, or recreational exercise), muscle weakness, poor neuromuscular control, joint laxity, joint instability, lower extremity malalignment, or leg-length discrepancy may contribute to osteoarthritis (Astephen Wilson JL et al., 2011; Blagojevic M et al., 2010; Bosomworth NJ, 2009; Harvey WF et al., 2010; Neogi T & Zhang Y, 2011; Pietrosimone BG et al., 2011; Roos EM et al., 2011; Sharma L et al., 2010; Zhang Y & Jordan JM, 2010). The knowledge of these risk factors is of great relevance to implement adequate preventive strategies for a highly debilitating disease with a clear impact on the patient's quality of life (Guccione AA et al., 1994). Prevention is also crucial because patients with osteoarthritis have an overall higher risk of death compared with the general population (Nüesch E et al., 2011).

The purpose of this chapter is to review the existing literature regarding the risk factors for osteoarthritis, paying special attention to past exposure to sports and exercise and also to prior joint injury and neuromuscular disorders. This chapter also reports proposed or potential preventive strategies for the development or progression of osteoarthritis.

2. Overview of risk factors for osteoarthritis

This chapter is focused on the risk of exercise and sports participation in the development and progression of osteoarthritis. In addition, there are many other identified risk factors that should be covered in order to better understand the problem of osteoarthritis and offer effective preventive measures. There are several recognized risk factors for developing osteoarthritis (Bosomworth NJ, 2009): older age, female sex, obesity, osteoporosis, occupation, sports activities, previous trauma, muscle weakness or dysfunction, proprioceptive deficit, lower limb malalignment, leg-length inequality, and genetic factors. Age, sex, and genetic factors are non-modifiable, whereas the others may be modified by an appropriate intervention. This chapter will be focused on the analysis of history of joint injury, neuromuscular dysfunction, and exercise and sports participation as risk factors for osteoarthritis.

Each body's tissue looses its optimum properties with ageing, which may contribute to any disorder. Older age is a well accepted risk factor for osteoarthritis (Bosomworth NJ, 2009; Hunter DJ & Sambrook PN, 2002; Stevens-Lapsley JE & Kohrt WM, 2010; Thelin N et al., 2006; Vrezas I et al., 2010; Ward MM et al., 1995). In fact, osteoarthritis is rare among young individuals. Articular cartilage changes with aging have been well documented both clinically and experimentally (Bosomworth NJ, 2009; Hardingham T & Bayliss M, 1990; Horton WE et al., 2006; Hunter DJ & Sambrook PN, 2002). This is a non-modifiable risk factor the prevention of its influence should begin in early ages and continue throughout the rest of the life. Obviously, this factor is always related to subject exercising or participating in sports. Thus, any investigation dealing with a certain risk factor must be adjusted for age.

Females have been reported to have an increased risk of osteoarthritis (Bosomworth NJ, 2009; Hunter DJ & Sambrook PN, 2002; Jordan JM et al., 1996; Stevens-Lapsley JE & Kohrt WM, 2010). It was suggested that this difference from males would be explained by the influence of sex hormones, primarily estrogen (Hunter DJ & Sambrook PN, 2002; Riancho JA et al., 2010; Rosner IA et al., 1986; Stevens-Lapsley JE & Kohrt WM, 2010). The risk of osteoarthritis between males and females is similar under 50 years old, but significantly increases above this age in females (Felson DT et al., 1995; Oliveria SA et al., 1995). Thus, in postmenopausal women the risk of osteoarthritis is increased with respect to an age-matched cohort of males (Hunter DJ & Sambrook PN, 2002). A potential preventive pharmacological strategy with estrogen replacement therapy has been proposed for these patients (Spector TD et al., 1997). However, a recent systematic review concluded that there is some evidence for a protective effect of this therapy for hip, but not for knee osteoarthritis (de Klerk BM et al., 2009). De Klerk and colleagues stated that heterogeneity between the hormones used and outcome measurements made statistical data pooling impossible (de Klerk BM et al., 2009). Relationship between the exogenous hormone use and osteoarthritis was not clearly observed. They concluded that other aspects, yet to be determined, may play a role in the increased incidence in women aged over 50 years (de Klerk BM et al., 2009). Hunter and Sambrook suggested randomized, prospective clinical trials to clarify the effects of hormone replacement therapy on the development of osteoarthritis (Hunter DJ & Sambrook PN, 2002).

One of the most accepted risk factors for developing osteoarthritis is obesity (Hunter DJ & Sambrook PN, 2002). Increased weight may overload joints and alter the normal physiology of cartilage (Pallu S et al., 2010). Obesity is a clear modifiable risk factor, so there is an evident preventive measure that can be offer to patients. Weight loss would not only reduce the risk of osteoarthritis by unloading joints, but also by the fact that exercise would be of benefit for joints if performed through an adequate progression, beginning with non-weight-bearing exercises until the weight has been reduced (Felson DT et al., 1992). There are a lot of studies concluding on the increased risk of osteoarthritis in patients with obesity (Anderson JJ & Felson DT, 1988; Chaganti RK & Lane NE, 2011; Hart DJ & Spector TD, 1993; Kohatsu ND & Schurman DJ, 1990). The combination of risk factors may elicit a further increased risk of osteoarthritis, as exemplified by obesity and physical activity among elderly patients (odds ratio of 13 for developing knee osteoarthritis) (McAlindon TE et al., 1999), or obesity and female sex (Davis MA et al., 1988). The risk of osteoarthritis in obese patients is higher for knee and hand joints than for the hip joints (Grotle M et al., 2008). Interestingly, men with overweight during their 20's had higher rate than those who became overweight during their 40's on the incidence of self-reported osteoarthritis (Gelber AC et al., 1999). Hunter and Sambrook have concluded that there is consistent and conclusive evidence demonstrating the association between obesity and osteoarthritis (Hunter DJ & Sambrook PN, 2002).

Osteoporosis has been considered a risk factor for osteoarthritis (Bosomworth NJ, 2009; Hannan MT et al., 1993; Hunter DJ & Sambrook PN, 2002; Nevitt MC et al., 1995; Zhang Y et al., 2000). Although some initial studies suggested that osteoporosis would decrease the incidence of this disorder (Hunter DJ & Sambrook PN, 2002), more recent studies demonstrated that an increase in bone mineral density of 5%-10% is consistently related to both hip and knee osteoarthritis (Hannan MT et al., 1993; Nevitt MC et al., 1995). Low bone mineral density is associated with the incidence, but decreased progression of radiographic knee osteoarthritis (Zhang Y et al., 2000). The relationship between bone mineral density and osteoarthritis has been linked to vitamin D (McAlindon TE et al., 1996). Both low intake and low serum levels of vitamin D have been related to the progression of knee osteoarthritis (McAlindon TE et al., 1996).

Special attention is required for occupational osteoarthritis. Physical workload has been shown to be an important risk factor for the development of articular cartilage degeneration (Aluoch MA & Wao HO, 2009; Maetzel A et al., 1997). It is not the purpose of this chapter to review in detail the association between osteoarthritis and exposure to occupational physical activity. For a deeper knowledge of this risk factor, the reader is referred to the comprehensive review performed by Aluoch and Wao (Aluoch MA & Wao HO, 2009). Essentially, there is a strong relationship between high physical workload (frequent knee bending, heavy lifting, frequent stair climbing, and prolonged squatting) and risk of hand, hip, knee, and foot osteoarthritis (Aluoch MA & Wao HO, 2009). Jobs involved in occupational osteoarthritis include construction, agriculture, forestry, fishing, transportations, mining, and manufacturing (Aluoch MA & Wao HO, 2009). Occupational osteoarthritis is a modifiable risk factor. Measures aimed to prevent new cases of osteoarthritis or to decrease its progression should be taken (Hunter DJ & Sambrook PN, 2002).

Lower limb malalignment and leg-length inequality would also be risk factors for progression, but not onset, of osteoarthritis (Brouwer GM et al., 2007; Golightly YM et al., 2007; 2010; Hunter DJ et al., 2007). Both factors may not initiate or cause osteoarthritis, but just worsen the already damaged articular cartilage. Knee varus malalignment but not knee valgus was associated with both onset and progression of osteoarthritis (Brouwer GM et al., 2007). This observation was particularly applicable to obese individuals, again showing the bad consequences of having various risk factors associated in the same subject. Unfortunately, this finding has not been reproducible (Hunter DJ et al., 2007). Leg-length inequality was associated with progression of radiographic knee osteoarthritis, but not with incident radiographic knee or hip osteoarthritis, progression of chronic knee symptoms, and incident and progression of chronic hip symptoms (Golightly YM et al., 2010). Both factors may be modifiable by surgery or raised insoles (Neogi T & Zhang Y, 2011).

Genetics, epigenetics, and genomics are probably the most promising areas to be developed in relation to the study of osteoarthritis. The study of these areas is yielding valuable insights into the etiology of osteoarthritis but there is still much to know (Meulenbelt I et al., 2011). It is likely that individuals with a genetic predisposition would have osteoarthritis in many joints (Felson DT et al., 2000). Genetic factors may account for at least 50% of cases of osteoarthritis in the hands and hips, and a smaller percentage in the knees (Spector TD et al., 1996a). Overall, Loughlin considers that the search for osteoarthritis susceptibility loci has been limited (Loughlin J, 2011). Genes affected for most common forms of osteoarthritis would include vitamin D receptor gene, insulin-like growth factor I gene, cartilage oligomeric protein genes, and HLA region (Felson DT et al., 2000). Genetics may contribute to osteoarthritis to a different extend depending on each individual. The heterogeneous nature of the disease in terms of potential causes and presentation may explain why genetics are not the only aspect to consider. In other words, genetic and environmental factors must be considered altogether for an adequate prevention of osteoarthritis.

3. History of joint injury

Any kind of physical activity implies a chance of injury. Former athletes have a high rate of joint injury (Krajnc Z et al., 2010). Individuals with a history of joint injury have a higher risk of developing osteoarthritis (Hunter DJ & Eckstein F, 2009). The role of joint injury in the development of osteoarthritis has been mainly studied in the knee joint. Previous knee injury may be one of the most important modifiable risk factors for subsequent knee osteoarthritis in men, and second only after obesity in women (Felson DT et al., 2000; Hunter DJ & Sambrook PN, 2002). Knee injuries typically occur in the younger population thus causing prolonged disability and high economic costs (Hunter DJ & Sambrook PN, 2002; Yelin E & Callahan LF, 1995). Knee joint injuries increase the risk of osteoarthritis by increasing tibiofemoral contact area and pressures in meniscal injuries, by causing joint instability in ligament injuries, by chondral lesions itself, or by impairing the neuromuscular system.

The menisci are responsible for load-bearing, shock-absorption, joint stability, joint lubrication, and joint congruity (King D, 1936). All these functions contribute to the preservation of articular cartilage, which may be injured whenever meniscal disorders develop. Meniscal tears may be classified in acute-traumatic or chronic-degenerative. Acute-traumatic tears mainly occur in young patients, usually participating in sports, and increase the risk of developing knee osteoarthritis (Englund M et al., 2003). Acute tears mainly occur

in patients with no previous cartilage injuries. Long-term consequences of acute-traumatic meniscal tears in terms of osteoarthritis may be influenced by length of follow-up, age at the time of injury, sex, and associated injuries (Lohmander LS et al., 2007). In contrast, chronic-degenerative tears may affect one third of the general population over 50 years after no trauma at all (Englund M et al., 2008; Lohmander LS et al., 2007), and are associated with pre-existing and progression of knee osteoarthritis (Englund M et al., 2003). These meniscal injuries are more commonly associated with pre-existing joint cartilage damage than acute-traumatic tears (Christoforakis J et al., 2005; Englund M & Lohmander LS, 2004). The pre-existing osteoarthritis is worsened by meniscal tears (Hunter DJ et al., 2006; Raynauld JP et al., 2006). Therefore, their risk of osteoarthritis in chronic-degenerative meniscal injuries is explained by two factors; that is, the presence of prior cartilage injury, and the meniscus tear itself. The "double" mechanism of osteoarthritis in these injuries may explain the worst long-term radiographic and clinical outcomes compared to acute-traumatic tears (Englund M et al., 2001; 2003; 2004).

Repetitive increased loading in a patient with unrepaired meniscal tear also increases the risk of developing knee osteoarthritis (Lohmander LS et al., 2007). Also, articular cartilage degeneration is produced when meniscectomy is performed. Partial or total meniscectomies increase the tibiofemoral contact area and increase the joint contact pressures (Baratz M et al., 1986; Burke DL et al., 1978; Fairbank TJ, 1948; Seedhom BB & Hargreaves DJ, 1979), thus explaining the early onset knee osteoarthritic changes (Hoser C et al., 2001; Jorgensen U et al., 1987; Roos H et al., 1998). The contralateral healthy knee is also affected although to a lesser degree (Englund M & Lohmander LS, 2004). The greater the area of meniscectomy, the greater the mechanical distress on the knee, and a greater chondral deterioration can be expected. Meniscal resection of only 15% to 34% increases the contact pressure more than a 350%, whereas a total meniscectomy increases the contact load on the cartilage up to a 700% (Ahmed AM & Burke DL, 1983; Fukubayashi TK & Kurosawa H, 1980). Roos and colleagues compared the risk of knee osteoarthritis in a cohort of 123 patients 21 years after total meniscectomy (Roos H et al., 1998). The relative risk of developing knee osteoarthritis after total meniscectomy was 14 (95% confidence interval 3.5-121.2), using age- and sex-matched pairs for comparison. Forty-eight percent of patients in the meniscectomy group had grade II or more radiographic osteoarthritis with the Kellegren-Lawrence classification compared to only a 7% in the control group. In addition, knee symptoms were reported twice as often in meniscectomized patients compared to controls (Roos H et al., 1998). The authors found no relationship with knee osteoarthritis depending on the localization of the compartment or type of meniscus tear. In contrast, Lohmander and colleagues stated in their review that the symptoms and functional outcomes of lateral meniscectomy in relation to knee osteoarthritis were worst compared to medial meniscectomy (Lohmander LS et al., 2007). In accordance with Roos and colleagues, Neuman and colleagues observed that the primary risk factor for tibiofemoral osteoarthritis was a prior meniscectomy after prospectively evaluating the occurrence of knee osteoarthritis 15 years after non-operative treatment of anterior cruciate ligament injury (Neuman P et al., 2008). Cooper and colleagues found that patients with previous knee injury had 3 times more risk of knee osteoarthritis compared to uninjured subjects. This risk was increased 4-fold if meniscectomy had to be performed (Cooper C et al., 1994). Specifically, meniscectomy was a strong risk factor for medial tibiofemoral osteoarthritis. In their excellent review article about the long-term consequences of anterior cruciate ligament and meniscal tears, Lohmander and colleagues found that some 50% of patients undergoing meniscectomy 15 to

20 years earlier had radiographic knee osteoarthritis, with an odds ratio of about 10 compared to age- and sex-matched controls (Lohmander LS et al., 2007). The authors stated that symptoms and functional outcomes of meniscectomy were worst if other risk factors were present (i.e., women and obesity). Also, Hunter and Sambrook stated that older age at the time of injury predicts a more rapid progression to knee osteoarthritis (Hunter DJ & Sambrook PN, 2002). Patients with finger joint osteoarthritis at the time of meniscectomy had a higher risk of developing knee osteoarthritis compared to patients without finger osteoarthritis (Englund M et al., 2004). This may indicate the potential relationship between genetic predisposition and osteoarthritis. Lohmander and colleagues considered that studies assessing radiographic osteoarthritic changes after meniscus tears had large variations in sample sizes, patients lost at follow-up, age and sex distribution, and, overall, they had concerns on the quality of study designs. The review performed by Lohmander and colleagues did not provide support of meniscus suture or meniscus allograft transplantation to prevent future development of knee osteoarthritis (Lohmander LS et al., 2007).

Anterior cruciate ligament tears also occur more commonly in young patients, usually under 30 years old (Lohmander LS et al., 2007). Therefore, these injuries explain a large number of early-onset knee osteoarthritis cases with associated pain, functional limitations, and decreased quality of life in the individuals between 30 and 50 years (Lohmander LS et al., 2004; 2007; von Porat A et al., 2004). Radiographic knee osteoarthritis following an anterior cruciate ligament injury ranges from 10% to 90% at 10 to 20 years of follow-up (Gillquist J & Messner K, 1999; Lohmander LS & Roos H, 1994). Such a wide range may be explained by differences in the assessment method of radiographic osteoarthritis, sample size, loss of patients to, and length of, follow-up, sex distribution, age at the time of injury, and associated knee injuries (Lohmander LS et al., 2007). Lohmander and colleagues reported an approximate rate of radiographic knee osteoarthritis of more than 50% after 10 to 20 years of anterior cruciate ligament injury (Lohmander LS et al., 2007). The great majority of their reviewed studies using the Lysholm score had a mean follow-up values around 90 (good or excellent) (Lohmander LS et al., 2007). Scores for quality of life and sport and recreation after anterior cruciate ligament rehabilitation and/or surgery were found to be at its best at 1 to 2 years of follow-up, gradually deteriorating afterwards (Lohmander LS et al., 2007). After 12 years of an anterior cruciate ligament rupture with a mean age at follow-up of 31 years, 75% of female soccer players had a significant impairment of knee-related quality of life and 42% symptomatic radiographic knee osteoarthritis (Lohmander LS et al., 2004). Similar consequences were reported in male soccer players 14 years after this injury, with a mean age at follow-up of 38 years (von Porat A et al., 2004).

Anterior cruciate ligament injuries are often associated with other knee injuries. Keays and colleagues found that concomitant meniscal and chondral damage significantly increased the risk of tibiofemoral osteoarthritis in patients undergoing anterior cruciate ligament reconstruction (Keays SL et al., 2010). Partial meniscectomy at the time of reconstruction significantly increases the risk of developing knee osteoarthritis compared to those with normal menisci (Magnussen RA et al., 2009). If complete meniscectomy is needed, then patients will develop radiographic knee osteoarthritis in near 100% of cases at 5-to-10-year follow-up (Magnussen RA et al., 2009). Meniscal repair was found to have inconsistent influence on the prevention of developing knee osteoarthritis after anterior cruciate ligament reconstruction (Magnussen RA et al., 2009). The presence of cartilage injury at the time of a meniscus tear requiring operation accelerates knee osteoarthritis in patients under 40 years old undergoing anterior cruciate ligament reconstruction (Ichiba A & Kishimoto I,

2009). Although improvements in knee function were observed up to 15 years after ligament reconstruction, combined injuries (ACL, menisci, and chondral injuries) led to a higher risk of knee osteoarthritis compared with isolated anterior cruciate ligament tears (Oiestad BE et al., 2010a).

The technique of anterior cruciate ligament reconstruction has conflicting evidence regarding the influence on the development of knee osteoarthritis (Keays SL et al., 2010; Vairo GL et al., 2010). The use of bone-patellar tendon bone would seem to increase the risk of knee osteoarthritis compared to the use of hamstring tendons autograft (Keays SL et al., 2010; Vairo GL et al., 2010). However, other authors have reported that at a median of 7 years after ligament reconstruction with either autograft, the prevalence of osteoarthritis as seen on standard weight-bearing radiographs and the clinical outcomes was comparable (Lidén M et al., 2008).

Overall, there is a clear consensus that meniscal, ligament, and chondral injuries increase the risk of knee osteoarthritis (Ichiba A & Kishimoto I, 2009; Keays SL et al., 2010; Lidén M et al., 2008; Lohmander LS et al., 2007; Maffulli N et al., 2003; Magnussen RA et al., 2009; Neuman P et al., 2008; Oiestad BE et al., 2010a; 2010b; Roos H et al., 1998). Anterior cruciate ligament and menisci injuries increase the risk of joint degeneration whether or not being surgically treated (Lohmander LS et al., 2004; 2007; von Porat A et al., 2004). In addition, a past history of knee surgery is associated with a rapid progression to knee arthroplasty (Riddle DL et al., 2011). Therefore, prevention of injuries should be considered as one of the most important parts of training programs in athletes or subjects who wish to participate in sports (Roos H et al., 1998).

4. Muscle weakness and afferent sensory dysfunction

The neuromuscular system is crucial to prevent joint damage. Muscles provide dynamic stability, aid in shock absorption, and provide adequate force transmission across joints (Brandt KD, 1997; Mikesky AE et al., 2000; Palmieri-Smith RM & Thomas AC, 2009). Therefore, deconditioned muscles or poor neuromuscular control may increase the risk of osteoarthritis (Roos EM et al., 2011). Impairment of the neuromuscular system may be caused by inadequate training or joint injuries. Preventive programs aimed to improve this system are essential to reduce the risk of osteoarthritis (Keays SL et al., 2010; Neuman P et al., 2008; Roos EM et al., 2011; Segal NA et al., 2010). Muscle weakness is considered a predictor of knee osteoarthritis onset, but there is no clear consensus regarding its role in osteoarthritis progression. In contrast, afferent sensory dysfunction has been related to progression, but not onset, of osteoarthritis (Roos EM et al., 2011).

Anterior cruciate ligament injuries may cause muscle inhibition, muscle atrophy, and changes in activation patterns and knee kinematics (Berchuck M et al., 1990; Palmieri-Smith RM & Thomas AC, 2009; Snyder-Mackler L et al., 1993; Suter E & Herzog W, 2000). Oiestad and colleagues did not detect association between quadriceps weakness after anterior cruciate ligament reconstruction and knee osteoarthritis as measured 10-15 years later (Oiestad BE et al., 2010b). However, it is accepted that muscle weakness and neuromuscular impairment do exist after anterior cruciate ligament injuries (Berchuck M et al., 1990; Palmieri-Smith RM & Thomas AC, 2009; Roos EM et al., 2011). Palmieri-Smith and Thomas used the term arthrogenic inhibition to refer to the neurological "shutdown" of muscles surrounding an injured joint, preventing full activation, reducing strength, and promoting atrophy (Palmieri-Smith RM & Thomas AC, 2009). Neuromuscular impairment following

anterior cruciate ligament injuries would also cause knee instability and a loss of smooth control of agonist and antagonist muscle interaction, contributing to the accelerated degeneration of the joint (Brandt KD, 1997; Herzog W & Longino D, 2007; Roos EM et al., 2011).

Neuman and colleagues observed the incidence of radiographic osteoarthritis in a cohort of patients with unilateral, acute anterior cruciate ligament tears undergoing non-operative treatment with neuromuscular training and early activity modification after 10-to-15 years (Neuman P et al., 2008). The authors found that all patients developing knee osteoarthritis were previously meniscectomized. None of the remaining non-meniscectomized patients had radiographic signs of knee osteoarthritis at 10-to-15 years of follow-up. Sixty-eight percent of patients had asymptomatic knees. The authors concluded that non-operative treatment of anterior cruciate ligament tears by means of neuromuscular training and early activity modification might also have been related to the low prevalence of radiographic knee osteoarthritis (Neuman P et al., 2008). Ageberg and colleagues reported a longitudinal prospective cohort study of 100 anterior cruciate ligament-deficient patients undergoing conservative treatment with neuromuscular training and activity modification (Ageberg E et al., 2007). The majority of patients in this study demonstrated good functional performance and knee muscle strength throughout the 15-year study with this treatment without undergoing reconstructive surgery. The main concern of this study was the lack of a matched comparative group. If reconstruction of anterior cruciate ligament is performed, Keays and colleagues found that the restoration of quadriceps-to-hamstring strength balance was associated with less osteoarthritis (Keays SL et al., 2010). Therefore, protection of articular cartilage when anterior cruciate ligament injury occurs may be more related to the neuromuscular training than the reconstruction of the torn ligament itself (Keays SL et al., 2010; Lohmander LS et al., 2007; Neuman P et al., 2008). Thus, early activity modification and neuromuscular knee rehabilitation after anterior cruciate ligament injury may be a very important aspect to decrease the impairment of the neuromuscular system.

Quadriceps and hip muscles weakness are common in patients with knee osteoarthritis (Felson DT et al., 2000; Hinman RS et al., 2010). Roos and colleagues suggested that muscle weakness might be a risk factor related to all of the most important risk factors for osteoarthritis, as muscle strength is lower in women than in men, is reduced following injury, decreases with age and is lower relative to overall body mass in obese individuals (Roos EM et al., 2011). Taking into account this relationship, the study of the isolated role of muscle weakness in osteoarthritis may be difficult. The combination of muscle weakness with other risk factors would increase the risk of osteoarthritis more than muscle weakness alone (Roos EM et al., 2011). It has been argued that muscle weakness would be the consequence of atrophy due to minimized use of painful joints (Felson DT et al., 2000). However, it is also present in patients with knee osteoarthritis who have no history of joint pain (Felson DT et al., 2000), so it would be a risk factor for structural damage to the joint and not only a consequence of a painful joint (Slemenda C et al., 1998). Thus, muscle weakness may be considered an independent risk factor for knee osteoarthritis (Roos EM et al., 2011). Slemenda and colleagues evaluated the baseline knee extensor strength in a cohort of women without radiographic knee osteoarthritis (Slemenda C et al., 1998). After 30 months, radiographs were taken from this sample and results demonstrated that those women with radiographic knee osteoarthritis had lower baseline strength values compared to subjects without it (Slemenda C et al., 1998). For each 10-lb-ft increase in knee extensor strength, Slemenda and colleagues found a 20% reduction in the odds ratio of prevalent

radiographic knee osteoarthritis and a 29% reduction in the odds ratio of symptomatic knee osteoarthritis (Slemenda C et al., 1997). In an experimental animal model study, Longino and colleagues induced quadriceps muscle weakness by injecting botulinum toxin A into muscles (Longino D et al., 2005). Only 4 weeks after the induction of muscle weakness, the authors found retropatellar cartilage degeneration in the experimental rabbits compared to control rabbits. Segal and colleagues found that greater knee extensor strength protected against development of incident symptomatic, but not radiographic, knee osteoarthritis in both sexes (Segal NA et al., 2009; 2010). Subjects with greater quadriceps strength also had less knee pain and better physical function over follow-up (Amin S et al., 2009). Some of the benefits of neuromuscular training on knee osteoarthritis may be explained by induced changes in glycosaminoglycan content (Roos EM & Dahlberg LE, 2005). While there seems to be a protective effect of muscle strengthening against the onset of osteoarthritis, that seems to be controversial for osteoarthritis progression (Roos EM et al., 2011). Further well-designed studies are needed to elucidate if muscle strengthening would prevent osteoarthritis progression.

The afferent somatosensory system comprises the receptors, afferent neurons and central processing centers that permit the detection of environmental sensory inputs, including the tactile sense, proprioception, temperature, and nociception (Roos EM et al., 2011). Proprioception, including the sense of position in space, underlies the ability to maintain erect posture, control joint movements and respond to perturbations (Roos EM et al., 2011). The link between proprioception and osteoarthritis is not only based on theoretical reasoning. Patients with knee osteoarthritis had significantly worse proprioceptive capacities than age-matched, normal individuals (Koralewicz LM & Engh GA, 2000; Pai YC et al., 1997; Roos EM et al., 2011; Sharma L, 1999). Impaired proprioception contributes to articular cartilage damage (Roos EM et al., 2011; Sharma L & Pai YC, 1997). Functional consequences of impaired proprioception include lower gait velocity, shorter stride length, and slower stair walking time (Sharma L & Pai YC, 1997). The study of long-term influence of proprioception impairment on osteoarthritis has a major confounding factor, as proprioception declines with age (Hurley MV et al., 1998; Pai YC et al., 1997), and older age is the most important risk factor for developing osteoarthritis (Roos EM et al., 2011). Proprioception would have a role as a risk factor for osteoarthritis progression (Roos EM et al., 2011), but not for osteoarthritis onset (Felson DT et al., 2009). Unfortunately, the relationship between afferent somatosensory system and protective or damaging muscle activity has been minimally evaluated in the setting of osteoarthritis (Sharma L & Pai YC, 1997).

Roos and colleagues summarized their extensive review of this factor in two main issues. First, exercise training interventions should address both muscle weakness and afferent sensory dysfunction (Roos EM et al., 2011). Second, exercise regimens that aim to achieve modification of joint loading or cartilage structure seem to be more promising in at-risk individuals or those with early disease (Roos EM et al., 2011).

5. Exercise and sports participation

Professor Joseph A. Buckwalter established a clear differentiation between the occurrences of osteoarthritis after exercise and sports exposition in normal or previously injured joints (Buckwalter JA, 2003; 2004). The investigation of the link between sports and osteoarthritis should not take into account athletes with significant joint injuries, as osteoarthritis may be a

consequence of the injury instead of the exposition to exercise itself. Professor Buckwalter differentiated between activities like running and others with higher impact and torsional loads (Buckwalter JA & Martin JA, 2004), as higher impact loads produce a higher cartilage deformation compared to lower loads (Eckstein F et al., 2005). Although running may be the main action of many sports, this type of exercise will be differentiated from cutting sports because of his different prognosis with respect to osteoarthritis (Buckwalter JA & Martin JA, 2004). Following this distinction, an up-to-date review of the existing literature is presented in chronological order throughout the coming paragraphs.

5.1 Running

All identified studies dealing with the association between running and osteoarthritis are summarized in Table 1. As shown, 39 articles were found but only 15 were specifically conducted to assess the risk of running in the development of osteoarthritis (Fries JF et al., 1994; Konradsen L et al., 1990; Kujala UM et al., 1999; Lane NE et al., 1986; Lane NE et al., 1987; Lane NE et al., 1990; Lane NE et al., 1993; Lane NE et al., 1998; Marti B et al., 1989; McDermott M & Freyne P, 1983; Panush RS et al., 1986; Panush RS et al., 1995; Puranen J et al., 1975; Wang BW et al., 2002; Ward MM et al., 1995). The other 24 studies have combined the exposure of running and other sports to assess the risk of osteoarthritis or general disability. Among these studies, some have included subjects exposed to running and other sports (Cheng Y et al., 2000; Imeokparia RL et al., 1994; Kettunen JA et al., 2001; Kohatsu ND & Schurman DJ, 1990; Krampla WW et al., 2008; Rogers LQ et al., 2002; Spector TD et al., 1996b; Sutton AJ et al., 2001; Vingard E et al., 1998; Wijayaratne SP et al., 2008), and others have included runners compared to subjects performing other sports (Chakravarty EF et al., 2008; Dahaghin S et al., 2009; Felson DT et al., 2007; Hart DJ et al., 1999; Hootman JM et al., 2003; Kettunen JA et al., 2000; Kujala UM et al., 1994; Kujala UM et al., 1995; Lau EC et al., 2000; Manninen P et al., 2001; Raty HP et al., 1997; Sohn RS & Micheli LJ, 1985; Vingard E et al., 1993; Vrezas I et al., 2010). Of all studies dealing with running, 10.2% studied general disability and 10.2% spine, 7.7% hand, 46% hip, 74.3% knee, and 10.2% ankle osteoarthritis. All but 4 studies concluded that running was not associated with an increased risk of osteoarthritis. Four studies found that running increased the risk of hip and knee osteoarthritis (Cheng Y et al., 2000; Marti B et al., 1989; McDermott M & Freyne P, 1983; Spector TD et al., 1996b), but 2 of them involved subjects exposed to more physical activities (Cheng Y et al., 2000; Spector TD et al., 1996b). No studies have demonstrated a clear increase in the risk of spine, hand or ankle osteoarthritis after running exposure. Most common sources of bias in these reviewed studies were recall and selection bias, and lack of control of other potential risk factors for osteoarthritis. In fact, many of them did not adjusted the analysis for previous joint injury, body mass index or occupational workload (Table 1). Fifteen studies may be classified as Level II-evidence (38%), 19 as Level III-evidence (49%), and 5 as Level IV-evidence (13%).

5.2 Sports participation

Sports with higher impact and torsional loads may increase the risk of osteoarthritis more than straight-ahead sports or exercise. Theoretically, sports such as cycling, swimming, or golf may not be considered among those with higher risk of osteoarthritis. For a complete classification of sports depending on the intensity of joint impact and torsional loads, the reader is directed towards the article by Buckwalter and Martin (Buckwalter JA & Martin JA, 2004).

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to running	Joints	Results	Confounding factors considered	Observations	Conclusions
Puranen et al., 1975	Case-control, Cross-sectional study, Level III evidence	74 ex-élite runners (mean age 55y, range 31-81) and 115 controls (mean age 56, range 40-75);	Running	Élite running: starting age 15y (range 12-25), total participation 21y (range 8-50)	Hip	Hip OA changes: runners 4% (controls 8.6% Osteophyte formation only: runners 9.5%, controls 14.8% (none had hip pain). Clear OA changes associated with more hip pain	Control of main confounding factors not reported: sex, BMI, occupational load, other exposure to sports, history of joint injury, etc.	No statistics reported Lack of control of confounding factors Controls might have been exposed to run	Running was not associated with increased risk of hip OA
McDermott and Freyne, 1983	Case series, Level IV evidence	20 male middle and long distance runners with at least 3 months of knee pain Clinical and radiological knee OA	Running	Miles/week: mean between 41-62 in all runners. Years of running: mean 12-19 in all runners	Knee	All subjects with OA had genu varum 4/6 subjects with OA (3/14 in the group without OA) had previous injury Knee OA associated with injury and genu varum Miles/week: mean 62 in runners with, and 41 in runners without knee OA. Years of running: 19 in runners with, and 12 in runners without knee OA ($p<0.05$)	Control of main confounding factors not reported: sex, BMI, occupational load, exposure to sports, etc. History of joint injury and malalignment not isolated	No control group Joint injury and genu varum influenced the development of OA Small sample size	Longer exposure in years of running may increase the risk of knee OA
Sohn and Micheli, 1985	Case-control, Level III evidence	504 former runners (mean age 57y, range 23-77) compared to 287 ex-swimmers; mean follow-up 55y (range 2-25). Clinical hip and knee OA	Running Swimming	Running: miles/week by age: >70y 18, 60-69y 18, 50-59y 30, 40-49y 33, 0-40y 58; number of years running by age: >70y 8, 60-69y 9, 50-59y 12, 40-49y 14, 0-40y 10	Hip Knee	Severe hip or knee pain: 2% runners, 2.4% swimmers; any kind of hip or knee pain: 15% runners, 19 swimmers ($p>0.05$); no differences in pain between groups for any age range. Surgery for pain (mainly arthroplasties): runners 0.8%, swimmers 2.1%. Runners with higher miles run per week had not significantly more pain nor runners with higher cumulative years of running.	Age, sex, weight, educational level, socioeconomic status, cardiovascular fitness and attitude towards exercise-matched Control of occupational workload, exposure to other sports, BMI not reported	Runners response 76%, swimmers 58% Comparative group was not sedentary. Swimmers with history of running excluded No radiographs taken, pain may not be explained by OA	There was no association between middle- and long-distance running and risk of hip or knee OA
Lane et al., 1986	Cross-sectional, Level III evidence	41 long-distance runners (aged 50-72y) compared to 41 matched controls Clinical and radiological lumbar, knee and hands OA	Running	Running: min/week 224, years run 8.5, mean total miles run 9552	Lumbar spine Knee Hands	Female, but not male, runners had more sclerosis and spur formation in spine and knee, but not hand, radiographs. No differences in JSN, crepitation, joint stability, or symptomatic OA between groups	Age, sex, education, and occupation-matched controls. Control for history of joint injury in the analysis not reported	Controls heavier than runners Controls also exposed to running, although significantly less	Running was not associated with increased risk of lumbar spine, knee and hand OA

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to running	Joints	Results	Confounding factors considered	Observations	Conclusions
Panush et al., 1986	Cross-sectional, Level III evidence	17 male runners (mean age 56y, range 50-74) compared to 18 male non-runners (mean age 61y, range 50-74) (no differences in age, height, weight). Clinical and radiological hip, knee, and ankle OA	Running	Runners: mean years running 12y (range 5-27); mean miles/week 28 (range 20-40); mean lifetime mileage 17343 (range 6500-49140)	Hip Knee Ankle	Runners vs non-runners: Hip pain 26% vs 11%, knee pain 29% vs 22%, ankle pain 12% vs 5%. Runners vs non-runners: Osteophytes per subject hip 0.6 vs 0.9, knee 3.9 vs 4.8, ankle 2.2 vs 1.8; cartilage thickness mm hip 4.65 vs 4.3, knee medial 5 vs 5 and lateral 5.8 vs 5.6, ankle 3 vs 3.1; degeneration % hip 0 vs 0, knee 0.06 vs 0.17, ankle 0 vs 0 (all differences p>0.05).	Not controlled for occupational load and history of joint injury.	Controls not exposed to exercise/sports. Small sample size Joint injury and occupational load influenced OA	Running was not associated with hip, knee and ankle OA
Lane et al., 1987	Cross-sectional, Level III evidence	498 long-distance runners (mean age 58y, SEM 0.3, male ratio 0.86, mean BMI 22.8) compared to 365 controls (mean age 63y, SEM 0.4, male ratio 0.56, mean BMI 24.3). General musculoskeletal disability	Running	Exercise: min/week mean 322 (SEM 20). Running: min/week mean 228 (SEM 11), miles run per week 25 (1), years run 11 (1.5)	General physical disability	Runners less physical disability than age-matched controls. Runners had greater functional capacity, sought medical care less frequently, and weighted less than controls.	Age, sex, education, and occupation-matched controls. Control for history of joint injury in the analysis not reported	Controls also exposed to running and exercise (less than runners) Runners significantly different than controls in age, sex, and BMI No targeted to OA	Running was related to improved general musculo-skeletal health
Marti et al., 1989	Case-control, Level III evidence	27 former elite long-distance runners (mean age 42y) 9 former bobsleigh riders (mean age 42y), and 23 controls (mean age 35y. Clinical and radiological hip OA	Running	Running: mean 97km/week Bobsleigh riders: mean 12km/week	Hip	Hip OA index (computed by summing JSN, sclerosis and osteophyte): mean 1.37 (0.76-1.98 95% CI) in runners, 0.33 (-0.05-0.72) in bobsleigh, and 0.32 (0-0.64) in controls (p=0.006). Runners more osteophyte and sclerosis compared to controls. Hip pain: 30% in runners, and 0% in bobsleigh and controls. Adjusting for age: runners more hip OA. Adjusting for mileage: runners not more hjp OA	Analysis not adjusted for sex, BMI, occupational workload or history of joint injury. Adjusted for age and mileage	Participation 92% Small sample size Radiological blinding Controls and bobsleigh also exposed to running No baseline x-rays Reference values of OA in community not known	Running was associated with an increased risk of OA
Konradsen et al., 1990	Cross-sectional, Level III evidence	27 male orienteering runners (median age 58y, range 50-68; median weight 71kg, range 60-81) and 27 matched controls (median age 57y, range 53-65; median weight 75kg, range 55-82). Clinical and radiological OA	Running	Running: median ages 40y (range 32-50); median km/week <30y: 42 (range 20-65); 31-40y: 34 (15-65); 41-50y: 30 (13-63); 51-60y: 28 (13-63); >61y: 21 (13-43)	Hip Knee Ankle	No significant differences between runners and controls with regard to OA and osteophytosis of hip, knee, ankle. No differences in joint alignment, range of motion, or complaints of pain between groups. 22% of runners had pain during running, with no radiological differences compared to subjects without pain.	Age, height, weight, and occupational load-matched controls No major joint injuries in the sample, except 3 subjects, 1 of them excluded for the analysis	Participation 90% Controls were sedentary Statistics not much detailed Runners no longer active excluded Small sample size	Running at a recreational level was not associated with hip, knee, and ankle OA

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to running	Joints	Results	Confounding factors considered	Observations	Conclusions
Kohatsu and Schurman, 1990	Case-control, Level III evidence	46 subjects (cases) with knee OA (mean age 71y, 60% females, BMI 27, years of school 14) and 46 matched controls (mean age 71y, 60% females, BMI 27, years of school 14) Diagnosed knee OA in patients undergoing TKA	Running Walking Team sports Racquet sports Others	Not reported	Knee	Similar exposure to running, team sports, racquet sports, and other sports in cases compared to controls (4.5% vs 8.7%, 12.2% vs 17.4%, 15.8% vs 22.2%, 59.5% vs 65.2%, respectively). Cases less exposed to walking compared to controls (35.7% vs 56.5%, p<0.01)	Age, gender, and educational-matched controls Unmatched for BMI Cases participated in heavier work for ages between 30 to 49y compared to controls Cases had more history of knee injuries (p<0.01)	Participation 68% Cases had higher BMI (p<0.0001) Subjects exposed to different sports Running not quantified	General leisure-time physical activity was not associated with significant risk of knee OA
Lane et al., 1990	Cohort study, Level II evidence	34 runners (mean age 59.8y, 62% males, BMI 22.7) vs 34 matched controls (mean age 59.1y, 62% males, BMI 24.2) Clinical and radiological OA at baseline and 2 years later	Running	Runners (mean values): exercise (min/week) 336, running (min/week) 173, miles/week 21.6	Lumbar spine Knee Hands	Runners had lower disability score (p<0.05) Lumbar OA: similar progression for JSN and sclerosis between groups; runners more progression of spurs in males. Knee OA: more progression of spurs in runners compared to controls Hand OA: more progression of JSN and sclerosis in runners, similar progression of spurs	Age, sex, occupation, and years of school-matched controls. Injuries collected but not reported (only reports on joint pain in those subjects who stopped running).	Follow-up 83% Controls higher BMI than runners, p<0.01 Controls also exposed to running JSN and sclerosis for knee OA unknown Spurs alone not enough for OA	Running was not associated with increased risk of lumbar spine, knee, and hands OA
Lane et al., 1993	Cohort study, Level II evidence	33 runners (mean age 63.3y, 60% males, weight 67.8kg) vs 33 matched controls (mean age 63.5y, 60% males, weight 73.1kg) Clinical and radiological OA at baseline and 5 years later	Running	Runners (mean values): exercise (min/week) 304, running (min/week) 185	Lumbar spine Knee Hands	Lumbar OA: both groups progressed in spurs. Knee OA: runners had no progression of spurs and combined JSN, sclerosis and spurs; controls had progression of both parameters. Hand OA: both groups progressed in spurs and combined JSN, sclerosis and spurs. No differences in age, sex, weight, exercise, running and disability between subjects with and without hand and knee OA. Running was not predictive of lumbar spine, knee or hand OA.	Age, sex, occupation, and years of school-matched controls. Injuries collected but its influence not reported	Follow-up 80% Controls were heavier than runners, p<0.05 Sample also exposed to other exercises (cycling, swimming, racquet sports) Controls increased min/week of exercise during the follow-up Spurs alone not enough for OA	Running was not associated with increased risk of lumbar spine, knee, and hands OA

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to running	Joints	Results	Confounding factors considered	Observations	Conclusions
Vingard et al., 1993	Case-control, Level III evidence	233 cases with hip replacement because of OA and 302 controls, aged 50-70y.	Running, soccer, track and field, ice hockey, racquet sports, golf, bowling, cycling, swimming, handball,…	Not detailed for each sport. Reported as low, medium or high exposure. Collected: hours/week, week per year, total years, and level achieved.	Hip	Running: risk of hip OA in moderated and high exposure compared to low exposure: RR 1.7 (0.4-6.9) and 2.1 (0.6-6.8), respectively.	Controls were age, education, smoking, and BMI-matched Sports analysis adjusted for age, BMI, occupational work load, and different kind of sports simultaneously.	Participation: 92% cases, 77% controls. Subjects likely participated in different kind of sports. Controls also exposed to sports. No conclusive information on specific sports	Running was not associated with hip OA
Imeokparia et al., 1994	Case-control, Level III evidence	239 cases (85 men, 154 women) with knee OA vs 239 age and sex-matched controls, mean age 66y for both Radiographic knee OA	Running, cycling, swimming, racquet, soccer, golf, bowling	Not reported; Most subjects doing moderate (dance, weight lift, tennis, basketball) or light activities (volleyball, golf)	Knee	Sports exposure (cases): running 22%, cycling 84.5%, swimming 83.7%, racquet 51.5%, soccer 25.9%, Golf 62.7%, bowling 82.9% High physical activity only increased risk of knee OA in women OR 1.74 (1.01-3) adjusting for age, education, marital status and BMI. After adjusting by age, BMI, education, knee injuries, no association remained significant	Controlled for education level, BMI, age, smoking, hormone use, history of knee injury (12% cases and 2.5% controls) Confounders controlled in 2 analysis: age, education, marital status and BMI, and age, BMI, education, and knee injury	Limited to cases with < grade 3 OA Confounders controlled in 2 analyses Subjects exposed to different sports Running not isolated	Running not clearly associated with knee OA in women
Kujala et al., 1994	Cohort study, Level II evidence	2448 male ex-elite athletes representing Finland in sport events from 1920-1965 vs 1712 healthy age-matched controls at age 20y; Follow-up in 1970: 2049 athletes available, mean age 46y (range 21-85), 1403 in controls, mean age 44y (range 24-86); Follow-up in 1990: 1436 athletes available, 959 in controls. Study through questionnaires Athletes 3 groups: endurance, mixed sports, power sports Study compares admissions to hospitals because of hip, knee and ankle OA	Endurance: Running Cross-country ski; Mixed sports: Soccer Ice hockey Basketball Track & field; Power sports: Boxing Wrestling Weight lifting Throwing	Not reported; Former athletes at an elite level: Olympic games, World championships, European championships	Hip Knee Ankle	More admissions for hip, knee, ankle OA in athletes (5.9%) than controls (2.6%) (p<0.0001) Endurance (long-distance running): hip OA 5.2% (95% CI 2.6-10.2), knee OA 2.5% (0.7-6.3%), ankle OA 0%, compared to 1.4% (0.9-2.2), 1.3% (0.8-2), and 0% in the control group, respectively. OR for hip, knee, or ankle OA in runners compared to controls: 1.84 (95% CI 0.93-3.61). Adjusted OR for hip, knee, or ankle OA in runners compared to controls: 2.42 (1.26-4.68) Mean age at first admission: higher in endurance than others: 70.6y compared to 58.2y, 61.9y, and 61.2y in mixed sports, power sports, and controls, respectively.	Adjusted for age, weight and occupation History of joint injury not controlled	P value not reported for some comparison Only considering admission may hide other patients with OA at lower stages Exposure not quantified Endurance mixes running and cross-country skiing	Running was not associated with increased risk of hip, knee, or ankle OA Endurance athletes had admissions for hip, knee, or ankle OA at older ages

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to running	Joints	Results	Confounding factors considered	Observations	Conclusions
Fries et al., 1994	Cohort study, Level II evidence	451 long-distance runners (mean age 58y, males 83%, mean BMI 22.7) compared to 330 controls (mean age 61y, male 56%, mean BMI 24.1). General musculoskeletal disability at 8 years of follow-up	Running	Runners: mean 16869 miles run over 12.4y before study Running (min/week): runners 118 vs controls 6.6 Other vigorous exercise (min/week): runners 160 vs controls 117 Past running: runners 98% vs controls 24% Currently running: runners 62% vs controls 5%	General physical disability	After 8 years, runners had a lower progression of disability compared to controls ($p<0.001$). The difference was consistent for men and women.	Analysis adjusted for age, sex, BMI, baseline disability, smoking, history of arthritis. There were between-group differences in musculoskeletal complaints and injuries, and analysis only adjusted for history of arthritis. Analysis not adjusted for occupational workload.	Follow-up 84% runners, 78% controls All subjects also exposed to other vigorous exercises (runners 262 and controls 118 min/week Runners significantly different than controls in age, sex, smoke, and BMI No targeted to OA	Running was related to slower development of general musculoskeletal disability
Panush et al., 1995	Cohort study, Level II evidence	12 male runners (mean age 63y, SD 6) compared to 10 male non-runners (mean age 68y, SD 8) (no differences in age, height, weight). Clinical and radiological hip, knee, and ankle OA at 8-year follow-up	Running	Runners: mean years running 22y (SD 14); mean miles/week 22 (SD 11); lifetime mileage 25168; 42% marathoners	Hip Knee Ankle	Runners vs non-runners: Hip pain 9% vs 10%, knee pain 0% vs 0%, ankle pain 0% vs 10%. No differences in hip, knee, and ankle OA between runners and non-runners.	Adjustment of analysis for age, sex, BMI, occupation and history of joint injury not known.	Statistics poorly reported Small sample size Joint injury and occupational load influenced OA 20% of runners and 10% of non-runners participated in other type of exercises	Running was not associated with hip, knee and ankle OA

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to running	Joints	Results	Confounding factors considered	Observations	Conclusions
Kujala et al., 1995	Case series, Level IV evidence	Ex-elite athletes from 1920-1965 ages 45-68y; 28 runners (long-distance), 31 soccer, 29 WL, 29 shooters; subjects interviewed for weight and height at age 20y Clinical and radiographic OA	Running, Soccer, WL, Shooters	Runners: endurance training for 31y (range 4-68y), total hours 9408 (1300-18752); Soccer: team sport training for 17y (0-41), total hours 2607 (0-9936); WL: power sport training for 15y (0-69), total hours 2269 (0-8483); Shooters: endurance training for 20y (0-46), total hours 2845 (0-8536)	Knee	Knee injuries: runners 10%, soccer 38%, WL 20%, shooters 3% Knee OA: runners 14%, soccer 29%, WL 31%, shooters 3%. Runners not significantly different. TF OA runners 4%, soccer 26%, WL 17%, shooters 0%. Runners not different. PF OA: runners 11%, soccer 16%, WL 28%, shooters 3%. Runners not different. Monthly knee pain: runners 21%, soccer 45%, WL 28%, shooters 17%. Runners not different. Knee disability: runners 11%, soccer 35%, WL 24%, shooters 7%. Runners not different. Age-adjusted OA compare to shooters: runners OR 4.8 Age-adjusted risk of OA with hours spent in training: endurance OR 1.06 (0.94-1.2)	Age-, BMI-, occupation-, and injured-adjusted Leisure-time activity controlled Exposure to exercise highly detailed Interviews, physical exam and radiography by independent investigator Comparison of knee OA between groups in non-injured subjects not detailed	Participation 80% Data on weight and height under risk of recall bias Runners and WL more exposed to occupational workload Number of runners and shooters with OA was low (risk type II error) No control group	Runners exposed to lower risk of OA compared to other types of sports
Ward et al., 1995	Cohort study, Level II evidence	454 runners (mean age 58y (range 50-85), male 82%, smokers 1.5%) and 292 non-runners (mean age 62y (range 50-83), male 54%, smokers 6.2%) General physical disability	Running	Runners: mean minutes of vigorous exercise per week 293 (vs 90 in non-runners); mean years of running 10.6; mean miles run per week 25.6y; mean minutes of running per week 224	General physical disability	Some physical disability: runners 49% vs non-runners 77% Major risk factors for physical disability were: arthritis symptoms, older age, greater BMI, strenuous work-related physical activity, use of more medication.	Several risk factors considered Similar baseline proportion of family history of arthritis, arthritis symptoms, lower extremity injury, history of bone fracture, and occupation workload between groups.	Former runners included in the non-runners group Non-runners also participating in other vigorous exercises Both groups exposed to other risk factors Study not targeted towards study of effects of running on OA	Running was not associated with increased risk of physical disability compared to non-runners
Spector et al., 1996	Case-control study, Level III evidence	81 ex-elite female athletes (67 long-distance runners and 14 tennis players) aged 52y (SD 6), BMI 22 (SD 2.8) and 977 age-matched female controls Clinical and radiological OA	Running Tennis	Mean competition for 15y in runners and 19y in tennis; mean hours of vigorous weight-bearing sports per week: runners 2.6, tennis 5.7; mean miles per week of running 14.6; mean hours per week of tennis player 5.2	Hip Knee	Adjusted risk of TF osteophytes and JSN in ex-athletes: OR 3.57 (1.89-6.71), OR 1.17 (0.71-1.94), respectively. Adjusted risk of PF osteophytes and JSN in ex-athletes: OR 3.5 (1.8-6.81), OR 2.97 (1.15-7.67), respectively. Adjusted risk of hip osteophytes and JSN in ex-athletes: OR 2.52 (1.01-6.26) and OR 1.6 (0.73-3.48), respectively. Adjusted mean joint space of subjects without OA greater in ex-athletes.	Age, sex, height, and weight-adjusted analysis For knee, analysis adjusted also for knee injuries, knee pain, smoking, menopause, BMI. Knee pain: ex-athletes 33%, controls 25% Knee injury: ex-athletes 3.7%, controls 13.7% ($p<0.05$) Hip pain: 18.5% both groups Occupational workload not controlled	Participation 71% Ex-athletes were younger, taller, lighter and less smokers than controls Athletes participated in running and tennis Controls also exposed to exercise	Running and tennis in women was associated with a 2-3-fold increase in the risk of radiological OA

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to running	Joints	Results	Confounding factors considered	Observations	Conclusions
Raty et al., 1997	Case series, Level IV evidence	Ex-elite athletes from 1920-1965; 29 runners mean age 59y (long-distance), 30 soccer mean age 56y, 27 WL mean age 59y, 28 shooters mean age 61y	Running, Soccer, WL, Shooters	Median lifetime train (h): runners 9650; soccer 9120; WL 8410; shooters 2750. Mean years in elite level: runners 9.7y, soccer 13.4y, WL 11.7y, shooters 14.5y	Lumbar spine	Lumbar pain: current: runners 0%, soccer 7%, WL 3%, shooters 4% (p=0.6); past year: runners 48%, soccer 37%, WL 38%, shooters 64% (p=0.13); > 10 episodes lifetime: runners 7%, soccer 23%, WL 28%, shooters 29% (p=0.2). ROM: runners 55°, soccer 53°, WL 55°, shooters 51° (p=0.41)	Age- and occupation-adjusted History of back pain reported, but not past lumbar injuries Interviews, physical exam and radiography by independent investigator No control group	Not clear information on lumbar OA Lumbar injuries not reported Extreme lumbar ROM not involved in included sports	Lumbar mobility was not impaired in runners
Lane et al., 1998	Cohort study, Level II evidence	28 runners mean age 66y (range 60-77), 60% males, mean BMI 23.6, and 27 non-runners mean age 66y, 74% males, mean BMI 24.7. Clinical and radiological OA at 9 years of follow-up	Running	Runners: mean 279 min/week of exercise; mean 107 min/week running; mean miles run/week 18; mean years running 17	Hip Knee	Hip joint: osteophytes, JSN, total hip score not significantly different between both groups. Knee joint: both groups significantly progressed in osteophytes; only controls significantly progressed in JSN; only runners significantly progressed in total knee score	Age, sex, education and occupation-adjusted History of injury not clearly controlled	Controls participated in mean 169 min/week of exercise Small sample size Potential risk of selection bias.	Running was not associated with increased risk of hip OA and progression of knee OA
Vingard et al., 1998	Case-control, Level III evidence	230 (cases) women aged 50-70y with hip OA compared to 273 age-matched controls	Running, and many other sports: handball, soccer, tennis, badminton, track and field, cross-country skiing, and others	Details not reported Exposure to sports to the age of 50y: hours per week, weeks per year, how many years. Exposure graded as: low (total of <100h), medium (total of 100-800h), high exposure (total of >800h).	Hip	Hip OA: left 26%, right 35%, both 39% Hip OA: high vs low exposure RR 2.3 (1.5-3.7), medium vs low exposure RR 1.5 (0.9-2.5). Match of sports and occupational load: risk only increased in the following combination: Medium exposure to sports and high exposure to work load RR 2.7 (1.1-7), high exposure to sports and medium exposure to work load RR 2.7 (1.2-5.9), and high exposure to both RR 4.3 (1.7-11)	Adjusted for age, BMI, occupational load, number of children, smoking, and hormone therapy. Not controlled for history of hip injury	Participation 95% cases, 89% controls Controls have been exposed to sports Subjects exposed to different sports at various intensities Only women included Overall low participation in sports Running not isolated Low number of running cases	Exposure to sports was not associated with increased risk of hip OA in women alone, but in combination to work load.

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to running	Joints	Results	Confounding factors considered	Observations	Conclusions
Kujala et al., 1999	Cohort study, Level II evidence	264 male orienteering runners (mean age 58y, range 47-71; mean BMI 23) compared to 188 male non-smoking controls (mean age 60y, range 50-71; mean BMI 25). Clinical OA at 11 years of follow-up	Running	Not specified	Hip Knee	Hip OA: running OR 0.78 (0.35-1.73) Knee OA: running OR 1.79 (1.1-3.54) Hip pain: running OR 0.74 (0.37-1.46) Knee pain: running OR 1.75 (0.96-3.18) Hip pain in stairs: running OR 0.47 (0.2-1.08) Knee pain in stairs: running OR 0.78 (0.4-1.4) Runners: 23.5% had ligament or meniscus injury (vs 16.8% in controls); 38% of runners with knee injuries had OA (vs 7% without injury)	Age, sex, and area of residence-adjusted analysis Not adjusted for BMI and occupational workload. History of previous knee injury likely influencing development of OA	Exposure to running not quantified 11% of controls have participated in other physical activities Differences in weight and BMI	Overall, running was not associated with greater lower-limb disability, except for knee OA
Hart et al., 1999	Cohort study, Level II evidence	830 women (mean age 54y, BMI 24, knee injury 12.7%, knee pain 24%) assessed for risk factors for incidence of radiological knee OA at 4 years of follow-up.	Walking Sports	Not reported	Knee	Osteophytes: walking OR 0.6 (0.22-1.71); sports OR 1.23 (0.54-2.81). JSN: walking OR 0.38 (0.15-0.93); sports: OR 0.98 (0.42-2.3)	Adjusted hysterectomy, ERT, smoking, physical activity, knee pain, social class. History of knee injury and occupational load collected but adjustment in the analysis unknown	Participation 83% Poorly detailed exposure to physical activity Specific effects of running unknown Short follow-up	Physical activity was not associated with incident knee OA
Cheng et al., 2000	Cohort study, Level II evidence	16961 subjects aged 20-87y (median age 44y for men (76%) and 43y for women (24%)) followed-up for a mean of 10.9y for incidence of hip and knee OA. Self-reported physician-diagnosed hip and knee OA	Running, walking, other physical activity	Physical activity: high (walking or jogging >20 miles/week), moderate (between 10-20 miles/week), low (<10 miles/week), other (other activities than walkin/jogging)	Hip Knee	439 incident cases in men (3.4%) and 162 in women (3.9%); subjects >50y: incident OA higher in women; subjects <50y: incident OA similar between men and women Physical activity <50y: men high HR 2.4 (1.5-3.9), moderate 1.2 (1-1.4), low 1 (0.6-1.5), other 1.4 (0.9-2); women high HR 1.5 (0.4-5.1), moderate 1.2 (0.9-1.5), low 0.8 (0.4-1.6), other 1.1 (0.6-2). Physical activity >50y: men high HR 1.2 (0.6-2.3), moderate 1 (0.8-1.2), low 1.3 (0.9-1.8), other 1.1 (0.7-1.5); women high HR 1.4 (0.4-4.6), moderate 1.2 (0.9-1.5), low 0.6 (0.3-1.2), other 0.7 (0.4-1.3).	Adjusted for age, gender, BMI, smoking and ethanol and caffeine use. History of joint injury and occupational workload not controlled in the analysis.	Kappa agreement 0.68 between self-reported physician-diagnosed OA and chart review for OA Subjects participated in running and other kind of exercises	High levels of physical activity were associated with increased incidence of self-reported physician-diagnosed hip and knee OA in men < 50y, but not in the rest of the sample

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to running	Joints	Results	Confounding factors considered	Observations	Conclusions
Kettunen et al., 2000	Case series, Level IV evidence	Ex-elite athletes from 1920-1965; 28 runners mean age 59y (range 51-67y) (long-distance), 31 soccer mean age 56y (45-67y), 29 WL mean age 59y (46-66y), 29 shooters mean age 61y (50-687) Hip pain, disability, occupation and athletic loading	Running, Soccer, WL, Shooters	Runners: median lifetime endurance training (h): 8980 (range 1300-18752); team sport training 0 (range 0-3072); power training 0 (0-1280)	Hip	Hip OA: runners 12%, soccer 12%, WL 20%, Shooters 24%; Hip pain: runners 21%, soccer 13%, WL 7%, Shooters 17%; Hip disability: runners 7%, soccer 3%, WL 3%, Shooters 3% In hip OA, more disability but not necessarily more pain	Age- and occupation-adjusted History of hip injury not reported Interviews, physical exam and radiography by independent investigator	No control group Small sample Only includes worst grades of hip OA Study not targeted towards hip OA; Statistics for between-groups differences in hip OA not reported Runners also exposed to other types of exercise	Running was not associated with increased risk of hip OA compared to other kind of sports
Lau et al., 2000	Case-control, Level III evidence	138 subjects with hip OA and 414 controls. 658 subjects with knee OA, 658 controls. Clinical and radiological hip and knee OA	Running, badminton, soccer, gymnastics, kung fu	Not detailed	Hip Knee	Hip OA: Low number of cases in all sports, except gymnastics in women; Knee OA: Low number of cases except running, soccer in men, and running, gymnastics, kung-fu in women. Hip OA: men: running OR 0.7 (0.2-2.3), soccer 1.3 (0.3-5.4), gymnastics 1.2 (0.2-6.9), kung-fu 0.8 (0.08-6.7); women: running 0.9 (0.2-3.3), badminton 1 (0.2-5), gymnastics 6 (2.1-17.6). Knee OA: men: running OR 0.6 (0.3-1.4), soccer 1.3 (0.6-2.8), gymnastics 2 (0.8-5.3), kung-fu 1.4 (0.4-4.4); women: running 1.4 (0.7-2.8), badminton 0.5 (0.1-2.7), gymnastics 7.2 (3.1-16.8), kung-fu 20 (2.7-149).	Age-, sex-, weight-, occupation-, hip/knee injuries-controlled, but analysis only differentiating for sex	Only includes worst grades of OA Too high risk of type II error in sports with low number of cases No data on number of injuries in each group or sport	Running was not associated with increased risk of hip and knee OA in both men and women

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to running	Joints	Results	Confounding factors considered	Observations	Conclusions
Kettunen et al., 2001	Case-control, Level III evidence	Initial sample: 2448 male ex-elite athletes representing Finland in sport events from 1920-1965 vs 1712 healthy age-matched controls at age 20y; Follow-up in 1995: 1321 athletes available, 814 in controls. Hip and knee OA in <45y / >45y Study through questionnaires Athletes of endurance, track and field, mixed and power sport Mean age: endurance 68y, track and field 64y, team sports 61, Power sport 64y, Shooters 70y, controls 62y	Endurance: Running Cross-country ski; Track & field; Other sports (team and power sports)	Not reported; Former athletes at an elite level: Olympic games, World championships, European championships	Hip Knee	For age, weight, occupation-adjusted analysis (only significant results showed): -Hip disability: endurance OR 0.35 (0.14-0-85), Track and field OR 0.3 (0.12-0.73), All sports OR 0.54 (0.36-0.82) -Knee disability: Team sport OR 1.76 (1.03-3) -Hip OA: no differences. -Knee OA: Team sport OR 2.04 (1.35-3.07) -Hip pain: Endurance OR 0.32 (0.17-0.61), Shooting OR 0.32 (0.12-0.87), all sports OR 0.66 (0.5-0.88) -Knee pain: Team sports OR 1.56 (1.07-2.28)	Adjusted for age, weight and occupation History of joint injury not excluded from the analysis of OA	Exposure not quantified Likely influence of injury on hip and knee pain, disability, and OA	Running was not associated with increased risk of hip or knee OA Running associated with decreased risk of hip disability
Manninen et al., 2001	Case-control, Level III evidence	281 cases undergoing TKA for knee OA (men 55, women 226, mean age 28y) and 524 age-, sex-matched controls	Running, cross-country skiing, biking, track and field, volleyball, tennis, baseball, and others	Only few at competitive level. Exposure: hours per week, month per year, total years, cumulative hours of physical exercise. High exposure: >8654h in men, >6862h in women. Low exposure lower than these values.	Knee	Men with high cumulative exercise were protected against knee OA compared to low exposure OR 0.28 (0.08-0.96) for all ages. Women with high exposure were protected against knee OA in age ranges 30-49y, and >49y compared to low exposure OR 0.51 (0.23-1.15) and 0.59 (0.3-1.16), respectively. Running: men OR 0.26 (0.05-1.3), women OR 0.7 (0.48-1.02)	Analysis adjusted for age, BMI, physical work stress, knee injury, and smoking.	Participation 70% Subjects participated in more than 1 sport. Controls exposed to same sports. Specific sport exposure not provided.	Running was not associated with increased risk of knee OA in men and women

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to running	Joints	Results	Confounding factors considered	Observations	Conclusions
Sutton et al., 2001	Case-control, Level III evidence	216 cases (66 men, 150 women) mean age 57y (range 40-96) and 864 age, and sex-matched controls. Sports: Vigorous (team sports, boxing, weight lift, skiing, running, martial arts, racquet sports, etc.), moderate (swimming, cricket, gymnastics, aerobics, sailing, horse riding, etc.), gentle (shooting, golf, yoga, motor sports, fishing, etc.).	Running but many other sports, grades as vigorous, moderate, and gentle activities	Exposure detailed, but reported as number of activities instead of details on training parameters. Exposure to sports considered for 2 time periods: 5-14y before, and 15-24y before the age of diagnosis.	Knee	Neither activity level in any of the 2 periods elicited a significant increased risk of knee OA. Walking for both time periods had a risk of knee OA: OR 1.7 (1.1-2.4) and OR 2.1 (1.5-3), respectively. Performing lot of exercise increased the risk of knee OA OR 1.8 (1-3) for exposure 15-24y. Being physically active did not increase the risk of knee OA in either period.	Analysis adjusted for knee injuries and BMI. Use of age-, and sex-matched controls. Occupational load not assessed.	Subjects participated in more than 1 sport. Controls exposed to same sports. Specific sport exposure not provided Knee OA was self-reported; knee replacement cases not collected. No details in average time spent in sports per week/month. Running not isolated	Increased levels of regular physical activity throughout life did not increase the risk of knee OA.
Rogers et al., 2002	Case-control, Level III evidence	415 cases (men 306, women 109) with diagnosis of hip/knee OA at follow-up compared to 1995 controls (men 1521, women 474). Self-reported hip and knee OA	Running, walking, treadmill, cycling, swimming, aerobic, weight train, racquet sports, soccer, basketball	Not detailed. Sports categorized in low and moderate/high joint stress	Hip Knee	Activities associated with moderate/high joint stress were associated with the lowest risk of hip/knee OA in both men and women: men OR 0.62 (0.43-0.89); women OR 0.24 (0.11-0.52).	Analysis adjusted for age, BMI, history of knee or hip injury, and years of follow-up.	Minimum 2y follow-up Minimum exposure to sports 3 months. Controls not exposed to sports Combination of moderate and high joint stress activities. Hip/knee OA not disclosed Running not isolated	Physical activity in terms of sports may reduce the risk of hip/knee OA, especially in women.
Wang et al., 2002	Cohort study, Level II evidence	370 runners mean age 58y (82% men, 18 women) and 249 controls mean age 60y (56% men, 44% women) General disability assessed through Health Assessment Questionnaire	Running	Runners: mean 10.8y running with average 25851Km; 235 min/week (19 in controls); other vigorous exercise 76 min/week (83 in controls); mean distance run 2203Km/year (200 in controls)	General disability	Runners significantly lower disability levels. Loss of disability delayed in runners. Running protected against mortality.	Not much details in adjusted variables. Sex-adjusted. Age-matched controls. History of joint injury collected but unknown if considered for analysis.	Controls also exposed to running (1374Km in 2.2y) Running not isolated	Running and other aerobic exercise in elderly persons protected against disability.

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to running	Joints	Results	Confounding factors considered	Observations	Conclusions
Hootman et al., 2003	Cohort study, Level II evidence	5284 prospectively followed for incident hip and knee OA in relation to physical activity levels, mean follow-up 12.8y Self-reported physician-diagnosed hip and knee OA	Running Walking Other sports	Women 13.2 miles/week (range 2-48); men 13.8 miles/week (range 1-70)	Hip Knee	Hip/knee OA: miles/week of running: 10-20 OR 0.83 (0.52-1.31), 20-30 OR 1 (0.49-2.05), 30-40 0.67 (0.14-3.12), >40 OR 1.16 (0.3-4.43); min/mile 1.02 (0.92-1.13); sessions/week 0.99 (0.86-1.15)	Adjusted for training parameters, gender, age, BMI, previous hip and knee injury and surgery, smoking status, and comorbid conditions. Occupational workload not adjusted (although subjects had no heavy works)	Running not isolated Subjects participated in other sports	Physical activity was not associated with increased risk of hip and knee OA
Szoeke et al., 2006	Cohort study, Level II evidence	224 women assessed for hand and knee OA 11y after inclusion in a prospective study. Radiological hand and knee OA.	General physical activity	Not detailed. Baseline: 25% daily physical activity, 20 no physical activity; Follow-up: 40% daily physical activity, 13% no physical activity	Knee hand	Overall OA 56%: 21% knee OA, 44% hand OA. Physical activity not associated with hand OA. Physical activity at ages 20-29y associated with higher risk of knee OA (p=0.03): daily exercise 10 times greater (0.3-13.1), exercise 2-6 times a week 8 times greater (0.3-13.1), once a week 7 times greater (0.1-7.3), and few times per month 1.8 times greater (0.04-4).	Controlled for age, BMI, hormone use and smoking. Occupational load and joint injuries not controlled.	Participation 51% Subjects exposed to many sports. Intensity not reported Sports not reported. Sports involving hand use not known Running not isolated	High physical activity was associated with knee, but not hand, OA.
Felson et al., 2007	Cohort study, Level II evidence	1279 subjects (mean age at baseline 53.2y) followed-up for a mean of 8.75y for incident clinical and radiographic knee OA	Running Walking	Not detailed Walking: divided in walking <6 or >6 miles/week	Knee	Neither recreational walking, jogging, nor high activity levels were associated with an increased risk of knee OA.	Adjusted by age, sex, BMI, and history of joint injury. Not adjusted by occupational workload	Follow-up of 75% of subjects Large sample, prospective study Sample size of runners too small Running not clearly evaluated	Recreational exercise in middle-to-elderly subjects was not associated with increased knee OA
Krampla et al., 2008	Case series, Level IV evidence	8 ex-long-distance runners (mean age 46y) evaluated at 10y of follow-up for MRI-based knee OA	Running Other sports	Runners completed total of 34 races, mean race time 3'5h, mean min/km 5'5; runs of >20Km 435	Knee	Signs of knee OA based on MRI studies in 37.5%, all with associated meniscal tears. All subjects with knee OA demonstrated a progression of the disease in the follow-up (no new cases)	Not adjusted for age, sex, BMI, family history of OA, knee injuries and occupational workload	Follow-up 80% No statistics reported Small sample size Subjects exposed to other kind of sports	Running was not clearly associated with knee OA
Chakravarty et al., 2008	Cohort study, Level II evidence	45 long-distance runners (mean age 71y, 65% men, 44% previous knee injury, BMI 23) and 53 age-, education-, and occupation-matched controls (mean age 72y, 70% men, 36% previous knee injury, BMI 25) followed for nearly 2 decades for radiographic knee OA	Running Other sports	Vigorous exercise: runners 293 min/week, controls 199 min/week Running: runners 95 min/week, controls 1 min week	Knee	Knee OA: runners 20%, controls 32% (p=0.2). Severe knee OA: runners 2.2%, controls 9.4% (p=0.2) Knee OA associated with BMI, initial radiographic damage and longer follow-up. Knee OA not associated with gender, education, previous knee injury, and mean exercise time.	Adjusted for age, gender, BMI, education, previous knee injury, and initial radiographic and disability scores. Not clearly adjusted for occupational workload.	Subjects performed other kind of exercises Running not isolated Controls also exposed to running earlier in life	Running was not associated with accelerated radiographic knee OA

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to running	Joints	Results	Confounding factors considered	Observations	Conclusions
Wijayaratne et al., 2008	Cohort study, Level II evidence	148 women (mean age 53y, BMI 27) followed for 2y for modification of MRI-based patella cartilage volume changes	Running, walking, aerobics, swimming, others	Not reported	Knee	Fortnightly exercise for at least 20 minutes tended to be associated with a reduced rate of patella cartilage volume loss (p=0.09).	Adjusted for age, height, weight, initial patella cartilage volume, and patella bone volume. Not adjusted for occupational workload	Subjects with previous joint injury excluded Life-long exposure to exercise not assessed	Running was not associated with increased risk of patellofemoral OA
Dahaghin et al., 2009	Case-control, Level III evidence	480 cases with knee OA (mean age 57y SD 12y) and 490 controls without knee OA (mean age 46y SD15y) (p<0.00001); 70% women in cases, 65% in controls; BMI 30 cases, 27 controls (p<0.00001)	Running, Body-building, Soccer, Volleyball, Others	Not reported	Knee	Participation in sports: 32% cases, 40% controls Running OR 1.05 (0.7-1.58)	Age, sex, and BMI-adjusted History of knee injuries not reported Occupational workload collected Adjustment of knee OA in runners depending on workload not known	Subjects exposed to different sports Minimum exposure to sports = 6 months Low participation in sports in both groups Controls also exposed to sports	Running was not associated with increased risk of knee OA
Vrezas et al., 2010	Case-control, Level III evidence	295 male cases with knee OA and 327 male controls, aged 25-70y Radiographic knee OA	Running, cycling, swimming, soccer, ball games, gymnastics, weight lifting, body building	Running: exposure from 0h to 3530h	Knee	Running, swimming, body-building, weight lifting: not increase risk of knee OA Exposure to running: 0-700h OR 0.8 (0.4-1.7), 700-1695h OR 1 (0.5-2.3), 1695-3530h 1.9 (0.8-4.1), >3530h 1.9 (0.8-4.3)	Age, sex, BMI and occupation History of joint injury not reported	Participation 55-61% Mild OA not included Isolation of running not known Potential effect of joint injury on OA	Running was not associated with increased risk of knee OA

y, years; OA, osteoarthritis; BMI, body mass index; min, minutes; JSN, joint space narrowing; vs, versus; SEM, Standard error of the mean; kg, kilogram; TKA, total knee arthroplasty; Kcal, kilocalories; OR, odds ratio (95% interval confidence); RR, relative risk (95% interval confidence); SD, standard deviation; WL, weight lifters; TF, tibiofemoral; PF, patellofemoral; h, hours; ERT, estrogen replacement therapy; HR, hazard ratio (95% interval confidence); km, kilometre; MRI, magnetic resonance imaging.

Table 1. Summary of studies evaluating the risk of osteoarthritis after exposure to running.

Table 2 summarizes all identified studies regarding the association between sports and osteoarthritis. As shown, 53 articles were found but 34 of them included different sports in the same study. In 13 of the 53 studies the exercise in which subjects had participated was not reported in detail (Cooper C et al., 2000; Eastmond CJ et al., 1979; Felson DT et al., 1997; Juhakoski R et al., 2009; Lane NE et al., 1999; McAlindon TE et al., 1999; Ratzlaff CR et al., 2011; Sutton AJ et al., 2001; Szoeke CE et al., 2006; Verweij LM et al., 2009; Vingard E, 1991; Wang Y et al., 2011; White JA et al., 1993). Of the 19 studies conducted specifically for a certain sport, 12 involved soccer (64%), 2 ballet (11%), and 1 baseball (5%), 1 track and field (5%), 1 Australian football (5%), 1 javelin throw (5%), and 1 high jump (5%). Of all 53 studies, 1 was not joint-specific (Turner AP et al., 2000), and 4 (7.7%) assessed spine (Raty HP et al., 1997; Sortland O et al., 1982; Vingard E et al., 1995; White JA et al., 1993), 2 (3.8%) shoulder (Schmitt H et al., 2001; Vingard E et al., 1995), 2 (3.8%) elbow (Adams JE, 1965; Schmitt H et al., 2001), 1 (1.9%) hand (Szoeke CE et al., 2006), 25 (48%) hip (Andersson S et al., 1989; Cooper C et al., 1998; Drawer S & Fuller CW, 2001; Eastmond CJ et al., 1979; Juhakoski R et al., 2009; Kettunen JA et al., 2000; Kettunen JA et al., 2001; Klunder KB et al., 1980; Kujala UM et al., 1994; Lane NE et al., 1999; Lau EC et al., 2000; Lindberg H et al., 1993; Ratzlaff CR et al., 2011; Rogers LQ et al., 2002; Schmitt H et al., 2004; Shepard GJ et al., 2003; Solonen KA, 1966; Spector TD et al., 1996b; Van Dijk CN et al., 1995; Vingard E, 1991; Vingard E et al., 1993; Vingard E et al., 1995; Vingard E et al., 1998; Wang Y et al., 2011; White JA et al., 1993), 34 (65.4%) knee (Andersson S et al., 1989; Chantraine A, 1985; Cooper C et al., 2000; Dahaghin S et al., 2009; Deacon A et al., 1997; Drawer S & Fuller CW, 2001; Eastmond CJ et al., 1979; Elleuch MH et al., 2008; Felson DT et al., 1997; Frobell RB et al., 2008; Hart DJ et al., 1999; Imeokparia RL et al., 1994; Kettunen JA et al., 2001; Klunder KB et al., 1980; Krajnc Z et al., 2010; Kujala UM et al., 1994; Kujala UM et al., 1995; Lau EC et al., 2000; Manninen P et al., 2001; McAlindon TE et al., 1999; Rogers LQ et al., 2002; Roos H et al., 1994; Sandmark H, 2000; Sandmark H & Vingärd E, 1999; Solonen KA, 1966; Spector TD et al., 1996b; Sutton AJ et al., 2001; Szoeke CE et al., 2006; Thelin N et al., 2006; Verweij LM et al., 2009; Vingard E et al., 1995; Vrezas I et al., 2010; Wang Y et al., 2011; White JA et al., 1993), 7 (13.5%) ankle (Andersson S et al., 1989; Brodelius A, 1961; Drawer S & Fuller CW, 2001; Kujala UM et al., 1994; Schmitt H et al., 2003; Solonen KA, 1966; Van Dijk CN et al., 1995), and 3 (5.8%) foot (Andersson S et al., 1989; Van Dijk CN et al., 1995; Vingard E et al., 1995) osteoarthritis. Ten studies may be classified as Level II-evidence (18.8%), 33 as Level III-evidence (62.4%), and 10 as Level IV-evidence (18.8%). Most common sources of bias were recall and selection bias, and lack of control of other potential risk factors like body mass index, history of knee injury and occupational workload. In addition, many control subjects were also exposed to some type of sport in their life (Table 2).

6. Preventive strategies for osteoarthritis

Preventive strategies against osteoarthritis require a knowledge of risk factors that influence the initiation of the disorder and its subsequent progression (Cooper C et al., 2000). Principal risk factors for osteoarthritis were older age, female sex, obesity, osteoporosis, occupation, sports activities, previous trauma, muscle weakness or dysfunction, proprioceptive deficit, and genetic factors. Only age, sex, and genetic factors are non-modifiable. Therefore, there is a potential to prevent osteoarthritis from all modifiable risk factors. Surprisingly, prevention of osteoarthritis has not been the focus of most of the existing references. In fact, there is a scarcity of studies aimed to assess prevention measures for osteoarthritis.

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to sport	Joints	Results	Confounding factors considered	Observations	Conclusions
Brodelius, 1961	Cross-sectional, Level III evidence	34 male soccer players (mean age 27y, range 21-46y), 16 female dancers (aged 18-39y), and 195 controls Radiographic OA assessed	Soccer, Dance	Soccer mean 12y (range 5-20y) Dance > 3-30y	Ankle	OA higher in athletes Controls: OA increases with age but not related to sex Soccer: 33/34 had ankle OA; 13/15 players with previous injury had ankle OA Dancers: 14/16 ankle OA	Previous injury and age controlled No information on control of other risk factors Age related to OA in all groups	No statistical analysis reported; Volunteers enrolment in soccer players Only radiographic OA assessed	Overuse and injury may cause ankle OA
Adams, 1964	Cross-sectional, Level III evidence	162 baseball players aged 9-14y (pitchers and non-pitchers) and Radiographic elbow OA	Baseball	Not reported; mean length of play in pitchers 3y	Elbow	Elbow soreness 45%; Accelerated growth and fragmentation of medial epicondylar epiphysis: 95% pitchers, 15% non-pitchers, 8.5% controls; Fragmentation of medial epicondylar epiphysis: 48%, non-pitchers 12%, controls 6%; Osteochondritis 7.5%, 0% in others	Prior fracture, infection or deformity not included No control of potential confounders, although patients were young and probably pretty homogeneous	Cross-sectional study at young ages (patients may develop OA later in life). No statistics reported	Baseball participation elicits elbow radiographic changes in young players
Solonen, 1966	Cross-sectional, Level III evidence	60 male soccer players compared to 40 non-soccer matched controls Soccer aged 18 to 37y (mean 26y), controls aged 18 to 88y (mean 41y) Clinical and radiographic OA assessed	Soccer	Amateur soccer mean 13y (range 5-23y)	Hip Knee Ankle	No hip disorders; Knee: chondromalacia 30%, ligament insufficiency 13%, PF OA 28% (21% in controls); Ankle: OA in 92% (20% in controls)	Age and other risk factors uncontrolled History of knee / ankle injuries in both groups Soccer: 18 players sprained knee, 20 rupture of ligament, 6 meniscus tear; 48 players ankle sprain, 5 ankle LCL rupture, 3 malleolus fracture	No statistical analysis reported; Controls with joint injuries; Reasons not to participate not reported	No hip OA in soccer Ankle OA more common than knee OA
Eastmond et al., 1979	Cross-sectional, Level III evidence	364 female physical education teachers aged 46-60y, and 527 controls from the general population aged 45-64y Radiographic hip and knee OA	General sports	Not reported; 51% of teachers playing at least twice weekly	Hip Knee	68.5% still participating in sports; non-competitive tennis the most common sport; Hip OA (46-54y): Teachers grades 2-4 6.7% vs 3.9% controls; Hip OA (55-64y): Teachers grades 2-4 9.1% vs 8.3% Knee OA (46-54y): Teachers grades 0-1 93.2% vs 81.6%; grades 2-4 6.8% vs 18.4%, respectively; ($p<0.001$); Knee OA (55-64y): Teachers grades 0-1 89.4% vs 48.7% controls; grades 2-4 10.6% vs 51.3%, respectively.	Only partially controlled by age. Not controlled by other risk factors, including history of joint injury	Participation 76% Controls obtained from reference values Subjects exposed to different sports	Exposure to general sports at a non-competitive level does not increase the risk of hip and knee OA

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to sport	Joints	Results	Confounding factors considered	Observations	Conclusions
Klunder & Hansen, 1980	Cross-sectional, Level III evidence	57 former soccer players vs 57 age- and weight-matched controls Soccer mean age 56y (range 40-79y), weight 78kg (61-104kg) in both groups; Controls mean age 56y (42-80y) Radiographic OA assessed	Soccer	Mean playing hours/week 6.7 (3-10); Mean years played 22.8y (11-41y)	Hip Knee	Soccer more OA compared to controls (53% vs 33%) (p<0.05) Hip OA: More in soccer 49% than controls 26% (p<0.05) Knee OA: Soccer 14%, Controls 12% (n.s.)	Controlled by main risk factors Age- and weight-matched controls No hip/knee injuries in controls at the time of evaluation; 3 (5%) controls had history of lower extremity injury, 13 (22%) in soccer Exposure to soccer detailed Exposure to heavy job: soccer 26%, controls 47%	Gender of soccer players not specified (assumed all men) Low number of knee OA cases Statistics not used controlling for injury & occupation Only radiographic OA assessed	Hip, but not knee, OA in soccer
Sortland et al., 1982	Cross-sectional, Level III evidence	43 former soccer players mean age 49y; 43 age-matched controls mean age 50y Clinical and radiographic OA assessed	Soccer	Competitive level; Mean 26 international (range 2-104), 326 national matches (120-626)	Cervical spine	Both groups: cervical OA in lower part affecting discs and uncovertebral joints; Soccer higher cervical OA in upper part (p<0.02), and lower part in intervertebral joints (p<0.02) No difference headers or not	Controls no history of neck trauma 21% of soccer players with cervical injuries, not isolated in the analysis	Gender of soccer players not specified (assumed all men) OA influenced by injuries in 21% of players	Soccer increases the risk of early development cervical OA
Chantraine, 1985	Case series, Level IV evidence	81 (162 knees) former players mean age 48y (range 40-74y) Clinical and radiographic OA assessed	Soccer	Competitive level for mean 19y (range 6-25y)	Knee	Overall 56% knees with OA: only 30% symptomatic Operated (meniscectomized) knees = 100% OA Not operated knees = 41% OA: age 40-49y = 32% OA, 50-59y = 43% OA, 60-69 60% OA, >70y 83% OA	Exposure highly detailed Players with cruciate ligament injury excluded 28% knees prior meniscectomy (10-27y before the study) Natural history of disease not controlled	Poor control of important confounders Knee injuries not isolated No control group Poor causal-effect relationship	Knee OA increased in former soccer players Meniscectomy increases risk of OA
Andersson et al., 1989	Case series, Level IV evidence	42 dancers of high level, mean age 57y (range 44-80); 35% men, 65% women	Classic ballet dance	Mean 18y of exposure (range 10-57y)	Hip Knee Ankle 1MTTP	13% hip OA all symptomatic (higher than general population); 9% of TF OA and 9% PF OA (and 14% with osteophytes) all symptomatic; 2.3% ankle OA; 54% 1MTTP OA all symptomatic	Not compared to control group, lack of control for potential confounders	Only compared to reference values (many not available) No control group Radiographic OA only considered if joint space narrowing	Ballet may increase the risk of 1MTTP joint OA, but not hip, knee and ankle
Vingard E, 1991	Case-control, Level III evidence	239 men with THR and 302 controls without THR, compared for BMI, aged 20-50y Radiographic hip OA	General sports	Not reported	Hip	Relative risk of hip OA as a function of BMI did not change after adjusting for sports activity	Controlled for age, smoking, occupation, but not for injuries	Subjects exposed to different sports Study not aimed to study sports-OA	Adjusting BMI-induced hip OA is not affected by sports

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Lindberg et al., 1993	Case-control, Level III evidence	286 former soccer players mean age 55y (range 40-88y), and 572 age-matched controls Radiographic OA assessed	Soccer	71 players elite level, 215 amateur level Soccer exposure at least to the age of 25y	Hip	Hip OA higher in soccer: 5.6% vs 2.8%; OR 2.1 (1-4.2); bilateral hip OA equal in both groups (25%); no differences in type & severity Hip OA: Elite players 14%, all others 4.2% Elite players > risk of hip OA than amateur: OR 3.7 (1.4-10.1); no differences amateurs & controls; for 40-64y elite players more risk of hip OA than amateurs: OR 5.6 (2.5-20)	Age controlled Poor control of other potential confounding factors Only radiographic OA assessed	Exposure to soccer in controls not known	Soccer higher risk of hip OA Elite soccer much more risk of hip OA compared to amateurs
White et al., 1993	Cross-sectional, Level III evidence	12 year-follow-up of the postal survey from original sample Eastmond et a., 1979. 248 female physical education teachers aged 48-60y and 301 female controls aged 48-73y, divide in middle-aged (45-59y) and elderly (60-74y); 12 Clinical OA	General sports	Not reported; 21% sports at international level	Hip Knee Lumbar spine	70% of those with OA at middle age had played representative sport vs 9% in controls. No differences between subjects with moderate-severe and nil-minimal radiographic OA in the study of 1979 with respect to sports duration and number of activities participated. Control women had more any joint joint stiffness and pain in both ages (48-60y, 61-73y) compared to teachers	Controlled by age, occupation, prior fractures, BMI, family history of arthritis, but no information on past history of other injuries.	Participation 68% Subjects exposed to different sports. Physical activity and sports participation also in controls No radiographs	Active women participating in general sports have less pain and joint stiffness compared to less active controls
Imeokparia et al., 1994	Case-control, Level III evidence	239 cases (85 men, 154 women) with knee OA vs 239 age and sex-matched controls, mean age 66y for both Radiographic knee OA	Running, cycling, swimming, racquet, soccer, golf, bowling	Not reported; Most subjects doing moderate (dance, weight lift, tennis, basketball) or light activities (volleyball, golf)	Knee	Sports exposure (cases): running 22%, cycling 84.5%, swimming 83.7%, racquet 51.5%, soccer 25.9%, Golf 62.7%, bowling 82.9% High physical activity only increased risk of knee OA in women OR 1.74 (1.01-3) adjusting for age, education, marital status and BMI. After adjusting by age, BMI, education, knee injuries, no association remained significant	Controlled for education level, BMI, age, smoking, hormone use, history of knee injury (12% cases and 2.5% controls) Confounders controlled in 2 analysis: age, education, marital status and BMI, and age, BMI, education, and knee injury	Limited to cases with < grade 3 OA Confounders controlled in 2 separate analysis Subjects exposed to different sports at various intensities	Women are at increased risk of knee OA after high intensity sports, but not if adjusting for knee injuries

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Vingard et al., 1993	Case-control, Level III evidence	233 cases with hip replacement because of OA and 302 controls, aged 50-70y.	Running, soccer, track and field, ice hockey, racquet sports, golf, bowling, cycling, swimming, handball, etc.	Not detailed for each sport. Reported as low, medium or high exposure. Collected: hours/week, week per year, total years, and level achieved.	Hip	Sports more common in younger years. Risk of hip OA compared to low exposure: Exposure <29y RR medium exposure 2 (1-2-3.2), high exposure RR 3.5 (2.2-5.6); >49y RR 2.6 (1.5–4.5), RR 4.5 (2.7-7.6), respectively. Significant risk factors for hip OA: Racquet and track and field for high exposure (compared to low exposure): RR 3.3 (1.2-12.7) and RR 3.7 (1.1-13.2), respectively. Combination sports & workload: high exposure to both factors in men RR of hip OA 8.5 (4-18).	Controls were age, education, smoking, and BMI-matched Sports analysis adjusted for age, BMI, occupational work load, and different kind of sports simultaneously.	Participation: 92% cases, 77% controls. Subjects likely participated in different kind of sports. Controls also exposed to sports. No conclusive information on specific sports	Long-term exposure to sports participation increases the risk of hip OA, especially if added to high workloads.
Kujala et al., 1994	Case-control, Level III evidence	2448 male ex-elite athletes representing Finland in sport events from 1920-1965 vs 1712 healthy age-matched controls at age 20y; Follow-up in 1970: 2049 athletes available, mean age 46y (range 21-85), 1403 in controls, mean age 44y (range 24-86); Follow-up in 1990: 1436 athletes available, 959 in controls. Study through questionnaires Athletes 3 groups: endurance, mixed sports, power sports Study compares admissions to hospitals because of hip, knee and ankle OA	Endurance: Running Cross-country ski; Mixed sports: Soccer Ice hockey Basketball Track & field; Power sports: Boxing Wrestling Weight lifting Throwing	Not reported; Former athletes at an elite level: Olympic games, World championships, European championships	Hip Knee Ankle	More admissions for hip, knee, ankle OA in athletes (5.9%) than controls (2.6%) (p<0.0001) OA athletes vs controls: Hip 3.3 vs 1.4%, knee 2.4 vs 1.3%, ankle 0.4 vs 0% (p unknown) Hip OA: Endurance 5.3%, Mixed sports 2.5%, Power sports 3.5%, Controls 1.4% (p unknown) Knee OA: Endurance 2.5%, Mixed sports 1.9%, Power sports 3%, Controls 1.3% (p unknown) Ankle OA: Endurance 0%, Mixed sports 0.6%, Power sports 0.4%, Controls 0% (p unknown) OA adjusted for age, weight and occupation: Endurance OR 2.42 (1.26-4.68) (p=0.011); Mixed sports OR 2.37 (1.32-4.24) (p=0.002); Power sports OR 2.68 (1.5-4.7) (p=0.0005); All sport OR 2.5 (1.5-4.1) (p=0.0001); Control OR 1 Mean age admission: higher in endurance than others; Median days in hospital higher in power sports than others (p=0.02)	Adjusted for age, weight and occupation Ice hockey and basketball players lower age History of joint injury not controlled	Ice hockey, basketball & weight lifters had no matched controls P value not reported for some comparison Only considering admission may hide other patients with OA at lower stages Exposure not quantified	Ex-elite athletes have a higher risk of hospital admission for hip and knee OA Endurance athletes have admissions at older ages

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Roos et al., 1994	Case-control, Level III evidence	286 former soccer players (71 elite, 215 non-elite), and 572 age-matched controls (whole-sample mean age 55y (range 40-88y); mean age elite 62y, non-elite 53y Radiographic OA assessed	Soccer	71 players elite level, 215 amateur level Soccer exposure at least to the age of 25y	Knee	Knee OA in soccer 7% vs 1.6% controls; Knee OA: Elite 15.5% vs age-matched non-elite (4.2%) and controls (2.8%). Knee OA: elite vs non-elite OR 3.7 (1.5-9.3); non-elite vs controls OR 2.7 (1-6.8). Mean age at diagnosis: soccer 45y, controls 49y. Knee OA in non-injured subjects: elite 10.7%, non-elite 2.7%, controls 1.2%; Elite: 11 knee OA (5 in injured subjects); Non-elite 9 OA (4 in injured); Controls; 9 OA (2 in injured). Knee injuries: elite 33%, age-matched non-elite 7%, controls 2.1% Joint injury: increases risk of knee OA x3 in elite, x4 in non-elite, x13 In controls	Age and history of injury controlled History of sports participation poorly detailed for the control group	Exposure to exercise in controls only reported for those with knee OA Statistical analysis not reported for injured vs non-injured subjects	Elite, but not amateur, soccer increases risk of knee OA Joint injury increases the risk of OA in all groups, especially in controls
Kujala et al., 1995	Case series, Level IV evidence	Ex-elite athletes from 1920-1965 ages 45-68y; 28 runners (long-distance), 31 soccer, 29 weight lifters (WL), 29 shooters; subjects interviewed for weight and height at age 20y Clinical and radiographic OA	Running, Soccer, WL, Shooters	Runners: endurance training for 31y (range 4-68y), total hours 9408 (1300-18752); Soccer: team sport training for 17y (0-41), total hours 2607 (0-9936); WL: power sport training for 15y (0-69), total hours 2269 (0-8483); Shooters: endurance training for 20y (0-46), total hours 2845 (0-8536)	Knee	Knee injuries: runners 10%, soccer 38%, WL 20%, shooters 3% Knee OA: runners 14%, soccer 29%, WL 31%, shooters 3%; soccer and WL significantly higher than shooters (p<0.05). TF OA runners 4%, soccer 26%, WL 17%, shooters 0%: soccer significantly higher that shooters (p<0.05). Soccer significantly more knee disability and extension deficit than shooters (p<0.01) Higher knee OA with higher BMI (p=0.0002); Higher knee OA with injuries (p=0.0003) Age-adjusted OA compare to shooters: soccer OR 12.3 (1.35-111), WL OR 12.9 (1.47-113), runners OR 4.8; Age-adjusted risk of OA with hours spent in training: team sport OR 1.14 (1.03-1.27), power training OR 1.12 (1-1.25), endurance OR 1.06 (0.94-1.2); Hours of team sports increase risk of TF (OR 1.2 (1.03-2.29)) but not PF OA	Age-, BMI-, occupation-, and injured-adjusted Leisure-time activity controlled Exposure to exercise highly detailed Interviews, physical exam and radiography by independent investigator Runners and WL exposed to much more years of heavy work WL exposed to much more years of kneeling/squatting at work Comparison of knee OA between groups in non-injured subjects not detailed	Participation 80% Data on weight and height under risk of recall bias Runners and WL more exposed to occupational workload Number of runners and shooters with OA was low (risk type II error) No control group	Soccer and WL more knee OA than runners and shooters Risk of OA in soccer largely due to injuries Running low risk of knee OA

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Van Dijk CN et al., 1995	Cross-sectional study, Level III evidence	19 ex-ballet dancers (mean age 59 aged 50-66y) vs 19 female controls	Ballet dance	Mean duration career 37y (range 13-54); mean dance time per week 45h (range 10-70)	Hip Ankle Subtalar 1MTTP	Hip OA: No differences between 2 groups Subtalar OA: 18% cases, 0% controls (p=0.04) Ankle and 1MTTP OA: Higher in cases (p<0.05)	Age-, Height-, Weight-matched controls. Not controlled for occupation in cases All ballet dancers had joint injuries Some controls with history of sports	47% controls had been involved in recreational sports (average 2h/week for 8y)	Dancers more ankle and 1MTTP OA compared to controls
Vingard et al., 1995	Case-control, Level III evidence	114 ex-elite men aged 50-80y and 355 age-matched controls Musculoskeletal disorders	Track and field	Not reported; ex-elite athletes	Spine Shoulder Hip Knee Feet	No increase in spine, shoulder, feet and knee OA in ex-elite athletes Hip OA higher in ex-elite athletes compared to controls PR 3.6 (1.4-9.3)	Age-adjusted analysis Information on other risk factors collected but not used for the statistical analysis	Not specific for OA No radiographs Not control of confounders	Track and field may increase the risk of hip OA
Spector et al., 1996	Case-control study, Level III evidence	81 ex-elite female athletes (67 long-distance runners and 14 tennis players) aged 52y (SD 6), BMI 22 (SD 2.8) and 977 age-matched female controls Clinical and radiological OA	Running Tennis	Mean competition for 15y in runners and 19y in tennis; mean hours of vigorous weight-bearing sports per week: runners 2.6, tennis 5.7; mean miles per week of running 14.6; mean hours per week of tennis player 5.2	Hip Knee	Adjusted risk of TF osteophytes and joint space narrowing in ex-athletes: OR 3.57 (1.89-6.71), OR 1.17 (0.71-1.94), respectively. Adjusted risk of PF osteophytes and joint space narrowing in ex-athletes: OR 3.5 (1.8-6.81), OR 2.97 (1.15-7.67), respectively. Adjusted risk of hip osteophytes and joint space narrowing in ex-athletes: OR 2.52 (1.01-6.26) and OR 1.6 (0.73-3.48), respectively. Adjusted mean joint space of subjects without OA greater in ex-athletes. No significant differences in tennis players compared to ex-runners with respect to TF, PF and hip osteophytes, and PF JSN.	Age, sex, height, and weight-adjusted analysis For knee, analysis adjusted also for knee injuries, knee pain, smoking, menopause, BMI. Knee pain: ex-athletes 33%, controls 25% Knee injury: ex-athletes 3.7%, controls 13.7% (p<0.05) Hip pain: 18.5% both groups Occupational workload not controlled	Participation 71 % Ex-athletes were younger, taller, lighter and less smokers than controls Athletes participated in running and tennis Controls also exposed to exercise	Running and tennis was associated with a 2-3-fold increase in the risk of radiological OA. Tennis was not associated with greater risk of OA compared to ex-runners

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Deacon A et al., 1997	Case-control, Cross-sectional study, Level III evidence	50 retired Australian football players (mean age 53y range 34-85) and 50 controls (mean age 55y range 35-79) Clinical and radiological knee OA	Australian football	Participation in sports (excluding football): players mean 25y controls 39y Number of football games: mean 360 over mean 19y	Knee	Knee injuries: 62% players (46% meniscal and 26% cruciate ligaments), 6% controls. Players had higher functional knee OA OR 10 (3.7-28), and higher radiographic knee OA OR 4 (1.9-8) compared to controls No differences in functional, and radiographic knee OA (after adjusting for weight) between injured and non-injured players. Players with cruciate and menisci injuries had higher risk of OA compared to players with other knee injuries and to controls	3 Controls had prior knee injuries Similar family history of OA Adjusted for age, height, weight, BMI, knee injuries	Participation 78% Players had higher BMI, height, and weight ($p<0.0001$), and were excluded from the regression analysis Controls had participated in sports	Ex-elite Australian football players had a higher risk of clinical and radiological knee OA compared to controls
Felson et al., 1997	Cohort study, Level II evidence	Framingham study cohort: 598 participants without knee OA in whom risk factors for developing the disease were studied: mean age 70y (SD 5), 63% women, mean BMI 26, prior knee injury 6%	Not reported Sports probably mixed & not reported	Not reported. Level of physical activity through the Framingham Physical Activity Index (considers number of hours of physical activity during a typical day and Kcal spent with those activities)	Knee	Adjusted risk of physical activity level for knee OA: 1st quartile OR 1, 2nd quartile 2.4 (1-5.3), 3rd quartile 3.1 (1.4-6.9), 4th quartile 3.3 (1.4-7.5). Adjusted risk of physical activity level for knee OA by sex (1st quartile vs 4th quartile): men 3.8 (0.9-17.3); women 3.1 (1.1-8.6). Adjusted risk of physical activity level for knee OA by knee symptoms (1st, 2nd, 3rd, 4th quartile): presence of symptoms: OR 1, OR 13.7 (0.5-362), OR 6.4 (0.1-320), OR 57 (1.6-2107), respectively; no symptoms: OR 1, OR 2.4 (1-5.3), OR 3.1 (1.4-6.9), OR 3.3 (1.4-7.5), respect.	Adjusted for age, sex, BMI, weight, smoking, knee injuries, chondrocalcinosis, and hand OA, simultaneously in the same analysis Not adjusted for occupation and family history.	Grade I radiographic OA not considered knee OA at baseline Subjects developing grade I in the follow-up not considered incident cases Not aimed to assess long-term effects of specific sports on knee OA	Most physically active subjects are at increased risk of developing knee OA
Raty et al., 1997	Case series, Level IV evidence	Ex-elite athletes from 1920-1965; 29 runners mean age 59y (long-distance), 30 soccer mean age 56y, 27 weight lifters (WL) mean age 59y, 28 shooters mean age 61y	Running, Soccer, WL, Shooters	Median lifetime train (h): runners 9650; soccer 9120; WL 8410; shooters 2750. Mean years in elite level: runners 9.7y, soccer 13.4y, WL 11.7y, shooters 14.5y	Lumbar spine	Lumbar pain: current: runners 0%, soccer 7%, WL 3%, shooters 4% ($p=0.6$); past year: runners 48%, soccer 37%, WL 38%, shooters 64% ($p=0.13$); > 10 episodes lifetime: runners 7%, soccer 23%, WL 28%, shooters 29% ($p=0.2$). ROM: runners 55°, soccer 53°, WL 55°, shooters 51° ($p=0.41$)	Age- and occupation-adjusted History of back pain reported, but not past lumbar injuries Interviews, physical exam and radiography by independent investigator No control group	Not clear information on lumbar OA Lumbar injuries not reported Extreme lumbar ROM not involved in included sports	Lumbar mobility not impaired in running, soccer, WL, shooters

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Cooper et al., 1998	Case-control, Level III evidence	611 subjects waiting for hip replacement because primary OA compared to paired 611 controls; Cases: mean age 70y; men (34%) and women (66%) similar age, pain duration, and severity of OA	Tennis, swimming, soccer, cricket, golf	At least weekly for 3 months each year for 10 years since leaving school	Hip	Risk hip OA in with injury: Men OR 24.8 (3-199), women OR 2.8 (1.4-5.8), all OR 4.3 (2.2-8.4). Risk of hip OA significantly higher for tennis & swimming in women (OR 1.6 (1.1-2.2) and 1.5 (1.1-2), respectively), but not in men. Risk hip OA in all: soccer OR 1.1 (0.7-1.6), cricket OR 0.9 (0.5-1.4), golf OR 1.4 (0.9-2.3), any sport participation OR 1.2 (0.9-1.6)	Age-, sex-, and family physician-adjusted Risk of OA in sports not analyzed excluding injured subjects	Exposure to sports heterogeneous and not much detailed Injuries influencing hip OA in subjects with history of sports	Risk of hip OA not increased because in sports Women more risk of hip OA in tennis and swimming
Vingard et al., 1998	Case-control, Level III evidence	230 (cases) women aged 50-70y with hip OA compared to 273 age-matched controls	Handball, soccer, tennis, badminton, track and field, bowling, running, orienteering, cross-country skiing, skating, swimming, gymnastics, horse ride, golf, and others	Details not reported Exposure to sports to the age of 50y: hours per week, weeks per year, how many years. Exposure graded as: low (total of <100h), medium (total of 100-800h), high exposure (total of >800h).	Hip	Hip OA: left 26%, right 35%, both 39% Hip OA: high vs low exposure RR 2.3 (1.5-3.7), medium vs low exposure RR 1.5 (0.9-2.5). Match of sports and occupational load: risk only increased in the following combination: Medium exposure to sports and high exposure to work load RR 2.7 (1.1-7), high exposure to sports and medium exposure to work load RR 2.7 (1.2-5.9), and high exposure to both RR 4.3 (1.7-11)	Adjusted for age, BMI, occupational load, number of children, smoking, and hormone therapy. Not controlled for history of hip injury	Participation 95% cases, 89% controls Controls have been exposed to sports Subjects exposed to different sports at various intensities Only women included Overall low participation in sports	Exposure to sports does not increase risk of hip OA in women alone, but in combination to work load.
Hart et al., 1999	Cohort study, Level II evidence	830 women (mean age 54y, BMI 24, knee injury 12.7%, knee pain 24%) assessed for risk factors for incidence of radiological knee OA at 4 years of follow-up.	Walking Sports	Not reported	Knee	Osteophytes: walking OR 0.6 (0.22-1.71); sports OR 1.23 (0.54-2.81). Joint space narrowing: walking OR 0.38 (0.15-0.93); sports: OR 0.98 (0.42-2.3)	Adjusted hysterectomy, estrogen replacement therapy, smoking, physical activity, knee pain, social class. History of knee injury and occupational load collected but adjustment in the analysis unknown	Participation 83% Poorly detailed exposure to physical activity Specific effects of running unknown Short follow-up	Physical activity was not associated with incident knee OA

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Lane et al., 1999	Cohort study, Level II evidence	5818 subjects evaluated for radiographic hip OA at baseline (aged 65y or above) Clinical and radiological hip OA	Many sports	Details not reported. Times per week and year exposed to many activities during teenagers, age 30 and 50y. Results reported as: 1) general physical activity; 2) Only weight-bearing activities	Hip	Hip OA: grades 0-I 88%, grade II 7%, grades III-IV 5%. Patients with grade III-IV were significantly older, taller and with higher BMI compared to others. General physical activity: Patients with grades III-IV and grades <II of hip OA had greater past exposure to physical activity (times/week) as teenagers and at 50y. Weight-bearing activities: Subjects with grades III-IV hip OA showed greater exposure (times/week) compared to others. Risk of radiographic hip OA was higher in quartile 4 of exposure at age 30y and quartile 3 at 50y (OR 1.4 for both). Clinical hip OA was higher in quartile 4 at teenagers (OR 1.7) and quartile 4 at 50y (OR 1.6).	Adjusted for age and BMI at age 25y Not controlled for other risk factors, mainly occupational work load and past history of hip injuries.	Exposure to exercise obtained retrospectively Exposure to physical activity was too general (no details on sports exposure known). Subjects exposed to different sports at various intensities.	Recreational physical activities before menopause may increase the risk of radiographic and clinical hip OA.
McAlindon et al., 1999	Cohort study, Level II evidence	Framingham study cohort: 473 participants without knee OA in whom risk factors for developing the disease were studied: mean age 70y (SD 4.5), 62% women. Clinical and radiological knee OA	Not reported Sports probably mixed & not reported	Exposure to sports not reported. Level of physical activity: heavy (lifting weights, gardening with heavy tools, digging, sports, etc.), moderate (lifting light weights, brisk walking, sweeping, etc.), light (leisure walk, standing, etc.)	Knee	Adjusted risk of radiographic knee OA: only increased in heavy physical activity if 1, 3 or >4h of exposure per day (OR 2.2 (1.2-4.2, OR 2.9 (1.2-6.9), OR 7.2 (2.5-21), respectively). Sex-adjusted risk of radiographic knee OA: increased only in heavy physical activity: men if >4h of exposure per day (OR 7 (1.7-29)) and women for 1 and >4h of exposure per day (OR 2.6 (1.3-5.3), OR 9 (1.7-48), respectively). Adjusted risk of clinical knee OA: only increased in heavy physical activity if >3h of exposure per day OR 5.3 (1.2-24).	Adjusted for age, sex, BMI, weight, smoking, knee injuries, health status, and total calorie intake, simultaneously in the same analysis Occupational work load not isolated and mixed in the physical activity exposure.	Grade I radiographic OA not considered knee OA at baseline Subjects developing grade I in the follow-up not considered incident cases Not aimed to assess long-term effects of specific sports on knee OA	Heavy general physical activity is an important risk factor for the development of clinical and radiological knee OA
Sandmark and Vingard, 1999	Case-control, Level III evidence	625 cases with and 548 controls without knee prosthesis Cases: men 52%, women 48%; Controls: men 48%, women 52%	Soccer, cross-country ski, track and filed, ice hockey, many others	Total number of self-reported hours in all sports reported	Knee	21% women and 57% men had participated in regular sports activity Risk of knee OA in exposed to sports compared to not or low exposure:<65y 2.9 (1.3-6.5), >65y 1.1 (0.7-1.7); men soccer OR 2 (1.4-2.8), track and field OR 1.6 (1-2.7), cross-country OR <65y 2.5 (1.3-5.1), >65y 0.9 (0.6-1.4), Ice hockey OR 1.9 (1.2-1.9); women all sports OR 0.9 (0.6-1.6)	Subjects with prior injury excluded Age, weight, smoking, hormone therapy, and occupation controlled	Exposure to sports heterogeneous Exposure to sports not much detailed Women were active in sports to a limited extend	Cross-country ski, soccer, and ice hockey increases OA in men; Moderate daily activity not related to OA

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Cooper et al., 2000	Cohort study, Level II evidence	Baseline data collection was obtained from a cohort and after mean 5y of follow-up, 354 (99 men, 255 women) were included, mean age 75y. Radiographic knee OA.	Not reported	Not reported.	Knee	Incident radiographic knee OA: K-L grade 1: regular sports participation had an OR 3.2 (1.1-9.1); K-L grade 2 OR for sports participation of 1 (0.5-2.1). Progression radiographic knee OA: K-L grade 1: regular sports participation had an OR 0.7 (0.4-1.6); K-L grade 2 OR for sports participation of 0.9 (0.3-2.5).	Information on smoking, alcohol, family history, knee injuries obtained. Analysis for sports adjusted for age, sex, BMI, knee pain, Heberden's node. Occupational load not controlled.	Participation 60%. Subjects exposed to different types of sports. Details on sports exposure and level not provided.	Sports increase the incidence, but not progression of radiographic knee OA
Kettunen et al., 2000	Case series, Level IV evidence	Ex-elite athletes from 1920-1965; 28 runners mean age 59y (range 51-67y) (long-distance), 31 soccer mean age 56y (45-67y), 29 weight lifters (WL) mean age 59y (46-66y), 29 shooters mean age 61y (50-687) Hip pain, disability, occupation and athletic loading	Running, Soccer, WL, Shooters	Soccer: median lifetime endurance training (h): 1530 (range 0-9936); team sport training 8240 (3864-18514); power training 0 (0-1600) WL: median lifetime endurance training (h): 1520 (range 0-8483); team sport training 1150 (0-4888); power training 9460 (284-16752)	Hip	Hip OA: runners 12%, soccer 12%, WL 20%, Shooters 24%; Hip pain: runners 21%, soccer 13%, WL 7%, Shooters 17%; Hip disability: runners 7%, soccer 3%, WL 3%, Shooters 3% In hip OA, more disability but not necessarily more pain	Age- and occupation-adjusted History of hip injury not reported Interviews, physical exam and radiography by independent investigator	No control group Small sample Only includes worst grades of hip OA Study not targeted towards hip OA; Statistics for between-groups differences in hip OA not reported Runners also exposed to other types of exercise	Sports had no influence on hip OA
Lau et al., 2000	Case-control, Level III evidence	138 subjects with hip OA and 414 controls. 658 subjects with knee OA, 658 controls. Clinical and radiological hip and knee OA	Running, badminton, soccer, gymnastics, kung fu	Not detailed	Hip Knee	Hip OA: Low number of cases in all sports, except gymnastics in women; Knee OA: Low number of cases except running, soccer in men, and running, gymnastics, kung-fu in women. Hip OA: men: running OR 0.7 (0.2-2.3), soccer 1.3 (0.3-5.4), gymnastics 1.2 (0.2-6.9), kung-fu 0.8 (0.08-6.7); women: running 0.9 (0.2-3.3), badminton 1 (0.2-5), gymnastics 6 (2.1-17.6). Knee OA: men: running OR 0.6 (0.3-1.4), soccer 1.3 (0.6-2.8), gymnastics 2 (0.8-5.3), kung-fu 1.4 (0.4-4.4); women: running 1.4 (0.7-2.8), badminton 0.5 (0.1-2.7), gymnastics 7.2 (3.1-16.8), kung-fu 20 (2.7-149).	Age-, sex-, weight-, occupation-, hip/knee injuries-controlled, but analysis only differentiating for sex.	Only includes worst grades of OA Too high risk of type II error in sports with low number of cases. No data on number of injuries in each group or sport.	Gymnastics increase the risk of hip and knee OA in women Kung-fu increases the risk of knee OA in women

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Turner et al., 2000	Case series (soccer players), cross-sectional, Level IV evidence	284 ex-professional soccer players, mean age 56y, mean age at retirement 32y Diagnosis, treatments, disability and HRQOL in former players	Soccer	Exposure of mean 13.5y (SD 5.3); 60% played > 450 matches	Not joint-specific	49% (138 players) had OA, mean age 40.4y (SD 12.5y): Frequency: 1) knee; 2) ankle; 3) spine; 4) hip. OA patients had worst scores of HRQOL, more surgeries, medications, & other treatments	Not controlled for other risk factors	Response rate 55% No control group Low causal-effect relationship for OA	Professional soccer causes health problems later in life
Sandmark 2000	Case-control, Level III evidence	416 physical education teachers graduated between 1957-1965 median age 57y (range 53-65), and 512 age-matched controls General health, musculoskeletal dysfunction, including OA	Soccer, cross-country ski, downhill ski, jogging, swimming, gymnastics	Sports at elite level: men cases 73%, women cases 40%, men controls 17%, women controls 3% 63% men, 47% women exercised 4 times/week for at least 30 years, vs 13% and 5% in controls, respectively	Knee	Cases more knee, but not hip, injuries than controls Men and women cases more symptomatic knee OA after adjusting for age, BMI, sports compared to controls, but not more OA if knee injury excluded (PR 2.1 (0.5-8.5) men, 2 (0.6-6.7). Men cases not more hip OA compared to controls; Women cases more hip OA than controls after adjusting for age, BMI and sports (PR 3 (1.1-8.1), 3.2 (1.1-9), 5.5 (1.2-25.2, respectively).	Age, BMI, sports, injury adjusted for OA Exposure to each sport not detailed; OA can not be related to any sport	Controls had participated in sports Radiographic OA not known	OA can not be attributed to any sport General sports exposure: not increases risk of hip OA, knee OA not increased if controlled by knee injury
Kettunen et al., 2001	Case-control, Level III evidence	Initial sample: 2448 male ex-elite athletes representing Finland in sport events from 1920-1965 vs 1712 healthy age-matched controls at age 20y; Follow-up in 1995: 1321 athletes available, 814 in controls. Hip and knee OA in <45y / >45y Study through questionnaires Athletes of endurance, track and field, mixed and power sport Mean age: endurance 68y, track and field 64y, team sports 61, Power sport 64y, Shooters 70y, controls 62y	Endurance: Running Cross-country ski; Track & field; Mixed sports: Soccer, hockey Basketball Power: Boxing Wrestling Weight lifting Throwing; Shooters	Not reported; Former athletes at an elite level: Olympic games, World championships, European championships	Hip Knee	For age, weight, occupation-adjusted analysis (only significant results showed): -Hip disability: endurance OR 0.35 (0.14-0-85), Track and field OR 0.3 (0.12-0.73), All sports OR 0.54 (0.36-0.82) -Knee disability: Team sport OR 1.76 (1.03-3) -Hip OA: no differences. -Knee OA: Team sport OR 2.04 (1.35-3.07) -Hip pain: Endurance OR 0.32 (0.17-0.61), Shooting OR 0.32 (0.12-0.87), all sports OR 0.66 (0.5-0.88) -Knee pain: Team sports OR 1.56 (1.07-2.28)	Adjusted for age, weight and occupation History of joint injury not excluded from the analysis of OA	Exposure not quantified Likely influence of injury on hip and knee pain, disability, and OA	Sports protective against hip pain and disability Team sports risk for knee pain, disability, and OA

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to sport	Joints	Results	Confounding factors considered	Observations	Conclusions
Sutton et al., 2001	Case-control, Level III evidence	216 cases (66 men, 150 women) mean age 57y (range 40-96) and 864 age, and sex-matched controls. Sports: Vigorous (team sports, boxing, weight lift, skiing, running, martial arts, racquet sports, etc.), moderate (swimming, cricket, gymnastics, aerobics, sailing, horse riding, etc.), gentle (shooting, golf, yoga, motor sports, fishing, etc.).	Many sports, grades as vigorous, moderate, and gentle activities	Exposure detailed, but reported as number of activities instead of details on training parameters. Exposure to sports considered for 2 time periods: 5-14y before, and 15-24y before the age of diagnosis.	Knee	Neither activity level in any of the 2 periods elicited a significant increased risk of knee OA. Walking for both time periods had a risk of knee OA: OR 1.7 (1.1-2.4) and OR 2.1 (1.5-3), respectively. Performing lot of exercise increased the risk of knee OA OR 1.8 (1-3) for exposure 15-24y. Being physically active did not increase the risk of knee OA in either period.	Analysis adjusted for knee injuries and BMI. Use of age-, and sex-matched controls. Occupational load not assessed.	Subjects participated in more than 1 sport. Controls exposed to same sports. Specific sport exposure not provided Knee OA was self-reported; knee replacement cases not collected. No details in average time spent in sports per week/month.	Increased levels of regular physical activity throughout life did not increase the risk of knee OA.
Drawer and Fuller, 2001	Case series (soccer players), cross-sectional, Level IV evidence	185 ex-professional soccer players, mean age 47y (range 20-84y); Players became professional mean 18y (16-27), retired from soccer 32y (17-42) Assessment of diagnosed lower limb OA through questionnaires	Soccer	Professional level for mean 4.1y (SD 2) Mean hours/week: Schoolboy stage soccer specific 4.8 (SD 4.9), endurance 1.6 (3), power 0.3 (0.8); Professional soccer specific 8.1 (4), endurance 3.3 (2.6) power 1.5 (1.2); Retired: soccer specific 3.5 (2.1), endurance 1.1 (1.6), power 0.8 (1.5)	Hip Knee Ankle	Injuries: Hip acute 0%, chronic 9%; knee acute 46%, chronic 37%; ankle acute 21%, chronic 7% OA at least in 1 location in 32%. OA in players retired because of injury 51% vs 25% in retired for other reasons. More knee OA than hip and ankles (p<0.001) OA: 20-29y 0%, 30-39y 36%, 40-49y 35%, 50-59y 32%, 60-69 42%, >70y 50% (p>0.05)	47% retired because of injury Significant differences in level of soccer between included subjects OA not evaluated adjusting for joint injury	Low response rate (37%) Rates of OA likely affected by joint injury Direct causal-effect relationship between soccer itself and OA can not be established	Soccer at professional increases the risk of lower limb OA

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Manninen et al., 2001	Case-control, Level III evidence	281 cases undergoing TKR for knee OA (men 55, women 226, mean age 28y) and 524 age-, sex-matched controls	Running, cross-country skiing, biking, track and field, volleyball, tennis, baseball, walking, swimming, motor sports, gymnastics	Only few at competitive level. Exposure: hours per week, month per year, total years, cumulative hours of physical exercise. High exposure: >8654h in men, >6862h in women. Low exposure lower than these values.	Knee	Men with high cumulative exercise were protected against knee OA compared to low exposure OR 0.28 (0.08-0.96) for all ages. Women with high exposure were protected against knee OA in age ranges 30-49y, and >49y compared to low exposure OR 0.51 (0.23-1.15) and 0.59 (0.3-1.16), respectively. Women participating in cross-country skiing, walking, and swimming were protected against knee OA: OR 0.59 (0.37-0.94), 0.32 (0.16-0.65), and 0.64 (0.43-0.96), respectively; not for other sports in women, and for any sport in men.	Analysis adjusted for age, BMI, physical work stress, knee injury, and smoking.	Participation 70% Subjects participated in more than 1 sport. Controls exposed to same sports. Specific sport exposure not provided.	Moderate recreational exercise (especially cross-country skiing, walking and swimming) is associated with decreased risk of knee OA
Schmitt et al., 2001	Case series, Level IV evidence	21 ex-élite javelin throwers at an average of 19y after retirement, mean age at examination 50y (range 35-60). Clinical and radiological shoulder and elbow OA.	Javelin throwers	Details provided: number of years at élite level: mean 13y (range 4-23y); mean training hours per week 14h (5-25); mean hours of strength training per week 5 (1-12); javelin throws per week mean 190 (60-500); ball and shot throws per week mean 422 (120-1200)	Shoulder Elbow	Shoulder: Major injuries 19%, pain 24% (dominant), lack of internal 67% and external rotation 19%, cranialisation of humeral head 65%, labrum injury 65%. Positive association between duration of elite participation and degenerative changes in glenoid. Training with weights >3kg led to higher risk of shoulder OA. No correlation with other parameters. Elbow: No intraarticular injuries. Pain in 14%. Osteophytes and sclerosis 100%, joint space narrowing 38%, cysts and calcifications 67%. Joint space narrowing more frequent in athletes who trained with weights >3kg (p=0.07).	Main risk factors not controlled and likely influencing OA rates.	No control group. Definition and report of radiological changes not much detailed. Most radiological changes alone have poor direct relationship with actual OA.	Javelin throws were not associated with increased risk of shoulder and elbow OA, but weight train may be related to shoulder OA.
Rogers et al., 2002	Case-control, Level III evidence	415 cases (men 306, women 109) with diagnosis of hip/knee OA at follow-up compared to 1995 controls (men 1521, women 474).	Walking, treadmill, cycling, swimming, aerobic, weight train, running, racquet sports, soccer, basketball	Not detailed. Sports categorized in low and moderate/high joint stress	Hip Knee	Activities associated with moderate/high joint stress were associated with the lowest risk of hip/knee OA in both men and women: men OR 0.62 (0.43-0.89); women OR 0.24 (0.11-0.52).	Analysis adjusted for age, BMI, history of knee or hip injury, and years of follow-up.	Minimum follow-up of only 2 years. Minimum exposure to sports of only 3 months. Controls not exposed to sports Combination of moderate and high joint stress activities. Hip/knee OA not disclosed	Physical activity in terms of sports may reduce the risk of hip/knee OA, especially in women.

Author	Type of study	Study / Patient characteristics	Exercise	Exposure to sport	Joints	Results	Confounding factors considered	Observations	Conclusions
Schmitt et al., 2003	Case-control, Cross-sectional study, Level III evidence	40 men ex-élite high jumpers retired at least 10 years earlier, mean age 42 (SD 5.4), BMI 23 (2.4), years of retirement 16 (5), and 40 age-, sex-, and BMI-matched controls. Clinical and radiological ankle OA	High jumpers	Duration of career mean 10y (SD 3), training 18h/week (8), strength training 5h/week (2), jumps per week 716 (317), sports after retirement 4h/week (3)	Ankle	Worst functional scores for athletes performing a higher number of jumps. The more jumps during active phase, the worse radiological scores (r=0.4; p=0.01). No differences in radiological ankle OA between athletes and control. No radiological differences between takeoff and swinging leg. No correlations of outcomes with training history	Main risk factors not controlled Probable influence of ankle injury on risk of OA.	Participation 81 % Subjects may have participated in other sports after retirement Statistics for radiology not reported because of small sample size	Ankles of former elite jumpers have not increased risk of clinical and radiological OA.
Schmitt et al., 2004	Case-control, Level III evidence	19 male ex-élite javelin throwers (mean age 52y, range 40-59) and 22 male ex-élite high jumpers (47y, range 42-57) compared to correspondent age, sex, and BMI-matched controls. Follow-up mean 19y (range 10-28) after retirement from competitive sports. Duration of sports career: javelin 13y (4-23); Jumpers 11y (5-17).	Javelin throwers, high jumpers	Training (h/week): javelin 14 (5-25), jumpers 17 (8-28). Strength train (h/week): javelin 5 (1-12), jumpers 5 (2-10). Sports activity (h/week): javelin 5 (2-12), jumpers 5 (1-15)	Hip	Javelin throwers: hip OA was 3 times greater compared to age-, and BMI-matched controls: OR 6.1 (2.1-17). High jumpers: hip OA was 2.5 times greater than age-, and BMI-matched controls: OR 3.3 (1.1-9.5). OR of pooled sample 4.4 (2.1-9.1).	None of athletes had heavy labor, were regular smokers or had chronic disease. Analysis not adjusted for occupational exposure and joint injury.	Controls have also participated in sports, although to a lesser degree and not at competitive level. Athletes have participated in other sports after retirement.	Javelin throwers and high jumpers have an increased risk of hip OA.
Shepard et al., 2003	Cross-sectional, Level III evidence	68 ex-elite soccer players mean age 44y (range 32-59) and 136 age-, sex-matched controls	Soccer	Playing career mean 16y (range 5-25); Number of matches 474 (range 1-850)	Hip	13% soccer players had hip OA (none reported to have hip injury during career) vs 1.5% hip OA in controls (p<0.001); OR 10.2 (2.1-48.8)	Age-, sex-, injury-adjusted analysis BMI not controlled Occupation not controlled (assumed subjects fully dedicated to soccer)	Cross-sectional: hip OA in controls in the subsequent years unknown	Elite soccer increases the risk of hip OA
Szoeke et al., 2006	Cohort study, Level II evidence	224 women assessed for hand and knee OA 11y after inclusion in a prospective study. Radiological OA.	General physical activity	Not detailed. Baseline: 25% daily physical activity, 20 no physical activity; Follow-up: 40% daily physical activity, 13% no physical activity	Knee hand	Overall OA 56%: 21% knee OA, 44% hand OA. Physical activity not associated with hand OA. Physical activity at ages 20-29y associated with higher risk of knee OA (p=0.03): daily exercise 10 times greater (0.3-13.1), exercise 2-6 times a week 8 times greater (0.3-13.1), once a week 7 times greater (0.1-7.3), and few times per month 1.8 times greater (0.04-4).	Controlled for age, BMI, hormone use and smoking. Occupational load and joint injuries not controlled.	Participation 51 % Subjects exposed to many sports. Intensity not reported Sports not reported. Sports involving hand use not known.	High physical activity was associated with knee, but not hand, OA.

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Thelin et al., 2006	Case-control, Level III evidence	778 cases with knee OA and 695 controls; mean age 62.6y (range 51-70)	Soccer, Track & field, cross-country ski, ice hockey, tennis, orientation	Not reported; Most recreational level Cases 9% competition level; controls 6%	Knee	Knee OA only associated to soccer (OR 1.56 (1.12-2.17)), ice hockey (OR 1.89 (1.17-3.04)), and tennis (OR 2.01 (1.07-3.77)) in men. After adjusting for smoking, BMI, occupation, heredity and injuries, no sports increased the risk of knee OA compared to controls, even further adjusting for sports at competition level	Age, sex, smoking, BMI, occupation, injuries controlled	Larger non-response rate in controls 15.7% vs cases 5.7% Low number of subjects at competition level	Sports-related knee OA is explained by knee injuries rather than exposition to sports itself
Elleuch et al., 2008	Cross-sectional, Level III evidence	50 ex-elite male soccer players mean age 49.2y (range 45-55); 50 male controls mean 47.8y (45-58) Clinical and radiographic knee OA	Soccer	Mean 14h (range 9-18) training/week élite Mean participation soccer 17y (range 14-24); in élite 10y (5-15)	Knee	Overweight 80% soccer / 64% controls (n.s.) Axis deviation 58% soccer / 50% controls (n.s.) Radiographic OA 80% soccer / 68% controls (n.s.); Soccer had worst K-L OA (p=0.05) Knee pain 15% soccer / 50% controls (p=0.004) Functional impairment greater in controls p<0.05	Age, sex, BMI, controlled Knee injuries excluded History of occupation not reported; 46% of ex-soccer players were sports-related teachers	Small sample OA in soccer is influenced by other risk factors (although similarly distributed in controls)	Soccer similar risk of knee OA compared to controls Controls worst function if OA
Frobell et al., 2008	Case series (soccer players), cross-sectional, Level IV evidence	188 active amateur soccer players (123 men, 65 women) mean age 21.6y (SD 3.7) Clinical knee OA (KOOS questionnaire)	Soccer	Not reported; soccer at amateur level Tegner Activity Scale score 9	Knee	Age, sex, BMI had no influence on KOOS Injury significantly associated with worst KOOS Lower divisions higher scores for symptoms Mean (SD) score pain 93.5 (10), symptoms 88 (13), ADL 96 (8), Sports 88 (16), QOL 88 (17)	43% had minor and/or severe knee injuries. Within the group of soccer, controlled by age, sex, BMI, and injuries; not controlled by occupation	No control group 80% response rate Radiographic OA, and OA later in life unknown	Young active players have high scores in KOOS, but worst if injured
Dahaghin et al., 2009	Case-control, Level III evidence	480 cases with knee OA (mean age 57y SD 12y) vs 490 controls without knee OA (mean age 46y SD15y) (p<0.00001); 70% women in cases, 65% in controls; BMI 30 cases, 27 controls (p<0.00001)	Running, Body-building, Soccer, Volleyball, Others	Not reported	Knee	Participation in sports: 32% cases, 40% controls After adjusting for age, sex, BMI, sports did not increase risk of OA: running OR 1 (0.63), Body-building OR 0.97 (0.93-1.48), Soccer/volleyball OR 0.97 (0.67-1.39), Others OR 1.09 (0.7-1.7). Cycling more risk in men only OR 2.6 (1.4-4.7)	Age, sex, and BMI-adjusted History of knee injuries not reported	Subjects exposed to different sports Minimum exposure to sports = 6 months Low participation in sports in both groups	Sports participation does not increase the risk of knee OA

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Juhakoski et al., 2009	Cohort study, Level II evidence	840 subjects with no hip OA at baseline (mean age 42y, range 30-72), evaluated 22 years later. Clinical hip OA.	Many not detailed physical activities and sports	Not detailed.	Hip	At 22 years, hip OA 4.9% men, 5.1% women. Adjusted risk of hip OA from physical activity: irregular exercise OR 1.2 (0.5-2.9), regular exercise OR 1.1 (0.4-2.8).	Adjusted for age, sex, BMI, education, occupational load, smoking, alcohol, and hip injury	Participation 63% Small number of patients with hip OA. No radiographs used Subjects exposed to different sports Sports not specified	Leisure time physical activity did not increase the risk of hip OA.
Verweij et al., 2009	Cohort study, Level II evidence	1678 subjects with no knee OA at baseline (mean age 68y, SD 8), evaluated 12 years later. Clinical knee OA.	General physical activity	Not reported. Physical activity reported in terms of muscle strength, intensity (low, medium, high), mechanical strain, turning actions	Knee	Knee OA 28%. Subjects with more current physical activity (minute/day) = more knee OA. High mechanical load and low muscle strength associated with higher knee OA: HR 1.43 (1.15-1.77) and 1.3 (1.01-1.68).	Adjusted for age, sex, region of living, education, lifetime physical work, BMI, depression, and physical activity. Knee injuries not controlled.	Radiographs not performed. Excluded patients were older, less active, more men, with lower education, more depressed than those included. Questionnaires only asked for 2 sports. Physical activity assessed at 12y, but not throughout the period. Sports not detailed.	Older adults performing activities with low muscle strength and high mechanical strains had an increased risk of knee OA.
Vrezas et al., 2010	Case-control, Level III evidence	295 male cases with knee OA and 327 male controls, aged 25-70y Radiographic knee OA	Running, cycling, swimming, soccer, ball games, gymnastics, weight lifting, body building	Cumulative hours in each sport Level of sport not reported	Knee	Running, swimming, body-building, weight lifting: not increase risk of knee OA Cycling: increases risk with more cumulative hours of exposure: OR 3.7 (1.7-7.8) if >7000h Soccer: if 1660-4000h of exposure, OR 2 (1-3.8); if 4000-7800h of exposure OR 2.2 (1-5). Ball games (hand, volley, basketball: >2100h OR 4 (1.8-8.9) Gymnastics: 400-2200h OR 3.2 (1-9.8)	Age, sex, BMI, occupation, running-adjusted History of joint injury not reported	61% cases and 55% controls participated Mild OA not included Participation in only one sport by same subject not known Effects of joint injury on knee OA not known	High exposure to cycling, soccer, and ball games increases the risk of knee OA
Krajnc et al., 2010	Case series, Level IV evidence	40 ex-professional soccer players mean age 49y, BMI 26 Radiographic knee OA	Soccer	Mean duration of soccer career 18.9y (SD 3.8); duration of professional career 11.3 (SD 4.2)	Knee	Knee injuries: 60% retired because of injuries, 35% being knee injuries; mean 1.95 acute (moderate/severe) knee injury; 28% no injuries Knee OA: 57.5% non-dominant leg, 42.5% dominant leg	Age, sex, BMI, occupation and injuries not controlled because was not the purpose of the study	87% participation No control group Excludes initial stages of knee OA	Approximately half of ex-élite soccer players had knee OA

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Ratzlaff et al., 2011	Cohort study, Level II evidence	2918 subjects with no hip OA at baseline (mean age 61y, SD 7, mean BMI 27) evaluated for lifetime hip joint force. Self-reported physician-diagnosed hip OA	Many sports and physical activities; not detailed	Details on exposure collected but not reported in a disclosed way; use of cumulative peak force index (new tool)	Hip	Hip OA in 6% of subjects. Highest quintile of lifetime cumulative physical activity (HR 2.32 (1.31-4.12)) and high hip forces from 35-49y associated with hip OA. Sports participation were not associated with hip OA.	Controlled for age, sex, weight, height, ethnicity, hip injury, occupational physical load, education. Hip injury in 3.1%.	Participation 76% Only 2 years of follow-up Lifetime exercise assessed retrospectively	Lifetime physical activity was not associated with hip OA.
Wang et al., 2011	Cohort study, Level II evidence	39023 participants evaluated for hip and knee OA at baseline and physical activity exposure (mean age 58y Hip and knee OA with need of joint replacement.	Many sports and physical activities; not detailed	Details not reported; classified as vigorous, less vigorous, and walking, each for none, 1-2 times/week, and >3 times/week. Also total activity	Hip Knee	Knee replacement 1.4%, Hip replacement 1.2% Knee: Total activity level high HR 1.47 (1.09-1.96), vigorous activity HR 1.44 (1.02-2.04), less vigorous and walking HR not significant Hip: Risk of OA requiring joint replacement not increased in any parameter.	Adjusted for age, sex, BMI, country of birth, occupational physical activity, education, alcohol, and smoking (occupational load collected with not many details) Joint injuries not controlled.	Exposure to physical activity obtained at a single point in time and only for last 6mo No differentiation between different types of exercises	Increasing levels of physical activity may increase the risk of knee, but not hip OA

y, years; OA, osteoarthritis; PF, patellofemoral; LCL, lateral collateral ligament; kg, kilograms; n.s., non-significant; 1MTTP, first metatarsophalangeal joint; TF, tibiofemoral; THR, total hip replacement; BMI, body mass index; OR, odds ration reported as mean (95% confidence interval); vs, versus; RR, relative risk; WL, weight lifters; h, hours; PR, prevalence ratio reported as mean (95% confidence interval); SD, standard deviation; ROM, range of motion; K-L, Kellgren-Lawrence radiological classification of osteoarthritis; HRQOL, health-related quality of life; TKR, total knee replacement; KOOS, knee injury and osteoarthritis outcome score; ADL, activities of daily living; QOL, quality of life; HR, hazards ratio.

Table 2. Summary of studies evaluating the risk of osteoarthritis after exposure to sports.

Prevention of osteoarthritis may be categorized as primary, when measures aimed to avoid the onset of osteoarthritis are applied, or secondary, when measures aimed to avoid the progression of existing osteoarthritis are applied (Neogi T & Zhang Y, 2011). Increasing age, female sex, obesity, and prior knee injury are the risk factors with clearer relation with the incidence of osteoarthritis (Neogi T & Zhang Y, 2011).

Obesity is one of the most important modifiable risk factors. It is essential to prevent weight gain at young ages, as it was found that obesity in young individuals would evoke a greater risk of developing osteoarthritis in the future than becoming obese later in life (Gelber AC et al., 1999; Kohatsu ND & Schurman DJ, 1990). Weight reduction may decrease the risk of acquiring osteoarthritis (Felson DT et al., 1992). Felson and colleagues found that a decrease in body mass index of 2 units or more (weight loss of approximately 5,1 kg) over the 10 years before their current examination decreased the odds for developing osteoarthritis by over 50% (odds ratio, 0.46; 95% confidence interval 0.24-0.86; P = 0.02). Among women with a high risk for osteoarthritis due to elevated baseline body mass index (greater than or equal to 25), weight loss also decreased the risk (for 2 units of body mass index, odds ratio, 0.41; P = 0.02). Weight gain was associated with a slightly increased risk, which was not statistically significant (Felson DT et al., 1992). Once weight loss is achieved, maintaining a body mass index about 25 kg/m^2 or below would reduce osteoarthritis of the population by 27% to 53% (Felson DT, 1998; Helminen HJ, 2009). In obese patients, the principle of training referred to progression takes special relevance. If an obese patient wished to decrease weight, a rapid increase in physical activity would likely result in joint damage. It is recommended to begin with important diet modifications along with non weight-bearing exercises, until weight is decreased and the musculoskeletal system is adequately prepared. This may be accomplished by performing activities such as swimming or stationary cycling without resistance. After some weeks with non weight-bearing exercise and weight reduction through diet, a slow progression to weight-bearing activities may be initiated, but again, with caution. It would be recommended to begin with activities such as fast walking or slow jogging instead of playing tennis or volleyball. Failing to apply these principles may in turn induce a further damage to the articular cartilage.

One of the most important aspects to prevent osteoporosis is adequate lifestyle during childhood (Mark S & Link H, 1999; Nikander R et al., 2010). Bone strength at loaded sites can be increased in children but not in adults (Nikander R et al., 2010). Therefore, it is essential to promote healthy lifestyle in young subjects, based on adequate weight-bearing exercise combined with needed supplements of calcium, vitamin D, and sun, if possible.

Occupational physical loading may be sometimes preventable. Felson estimated that eliminating squatting, kneeling positions, and carrying heavy loads during work would reduce 15% to 30% the prevalence of osteoarthritis in men (Felson DT, 1998). This is sometimes difficult because of job demands. However, it should be understood that failure to take preventive measures at work will result in lower worker musculoskeletal health. In addition to creating a personal impairment, the company will have high economic costs when health problems develop in their employees. Measures as simple as offering easy prevention programs for those positions at risk, using adequate shoes, changing positions in the company for those jobs with higher physical demands, or increase routine physician's examination to detect preventable risk factors may in turn improve employees' health, reduce sick leaves, and prevent long-term consequences on both the company and the employee.

The risk of developing osteoarthritis in a subject with prior knee injury is increased 4-fold (Blagojevic M et al., 2010). This is, with obesity, one of the most important modifiable risk factors. History of joint injury may have primary and secondary preventive measures. In patients willing to participate in sports, it is essential to first provide the subject with adequate musculoskeletal health. The individual must understand that to do sports one must be in shape, and not use sports to get in shape. It is first crucial to offer adequate preventive programs based on muscle strengthening, aerobics (to decrease weight or prevent its increase), and plyometric (exercise through stretch-shortening cycles) and neuromuscular training aimed to improve proprioception and, in general, afferent somatosensory system (Alentorn-Geli E et al., 2009a; 2009b; Griffin LY et al., 2006; Myer GD et al., 2005; 2006; 2008; Roos EM et al., 2011). A clear example of potential preventive strategies for knee osteoarthritis would be the prevention of anterior cruciate ligament tears (Alentorn-Geli E et al., 2009a; 2009b; Griffin LY et al., 2000; 2006; Molloy MG & Molloy CB, 2011). Preventing joint injuries would additionally reduce the prevalence of osteoarthritis by approximately 14% to 25% (Felson DT, 1998; Helminen HJ, 2009). Based on the presented literature, the prevalence of osteoarthritis in middle-aged, obese individuals with prior knee injury is as high as 41% to 78%, demonstrating the relevance of preventive measures.

Whether or not a consequence of joint injury, muscle weakness and disorders of the neuromuscular system may have implications in osteoarthritis. Segal and colleagues assessed whether knee extensor strength or hamstring:quadriceps ratio predicted the risk for incident radiographic tibiofemoral and incident symptomatic whole knee osteoarthritis in adults aged 50 to 79 years (Segal NA et al., 2009). This longitudinal cohort of over 2000 individuals and demonstrated that subjects with greater knee extensor strength were protected against the development of incident symptomatic whole knee osteoarthritis in both sexes, with an adjusted odds ratio of 0.5 to 0.6. Hamstring:quadriceps ratio was not predictive of incident symptomatic knee osteoarthritis in either sex. Neither knee extensor strength nor the hamstring:quadriceps ratio was predictive of incident radiographic knee osteoarthritis (Segal NA et al., 2009). Therefore, providing the patient with adequate muscle strength and adequate neuromuscular control may prevent the development of symptoms of knee osteoarthritis.

Overall, exercise and sports participation do not place the subject at greater risk of osteoarthritis, except in those subjects with other risk factors who participate in sports with high impact and torsional loads (Buckwalter JA & Martin JA, 2004). Sports participation increases the risk of suffering from any ligament, cartilage or menisci injury that would induce osteoarthritis. Therefore, preventive programs are more needed to decrease the risk of injury in people participating in sports than for the participation in sports itself. In fact, it was shown that running protected against osteoarthritis (Lane NE et al., 1987; Wijayaratne SP et al., 2008; Willick SE & Hansen PA, 2010), although this finding was not consistent in all studies perhaps because of the influence of other risk factors poorly controlled. Of notice, sports and exercise can really change the properties of articular cartilage in children and adolescents by increasing its volume (Jones G et al., 2003). Thus, the prevention of osteoarthritis begins in children, as for osteoporosis. It was hypothesized that sports and exercise in children not only increase the volume of articular cartilage, but also its strength and resistance (Helminen HJ et al., 2000). This would be accomplished by strengthening the collagen network of cartilage that would prevent osteoarthritis later in life (Helminen HJ et al., 2000). Of special interest is the case-control study reported by Manninen and colleagues

(Manninen P et al., 2001). They demonstrated that some types of exercise (e.g., cross-country, skiing, walking and swimming) were associated with a decreased risk of knee osteoarthritis requiring knee arthroplasty in women but not men. Rogers and colleagues also found a protective effect of exercise on the development of hip and knee osteoarthritis, especially among women (Rogers LQ et al., 2002).

Investigation of potential preventive strategies to decrease the risk of osteoarthritis needs further development. There is a clear lack of studies dealing with long-term consequences of preventive programs on the incidence and progression of osteoarthritis. The incidence and prevalence of osteoarthritis is rising instead of decreasing (Zhang W, 2010). Therefore, further studies are warranted.

7. Discussion

The disease known as osteoarthritis is the most common form of arthritis (Lawrence RC et al., 2008). It has been estimated that 27 million United States adults aged 25 years or more have clinical osteoarthritis of either the hand, knee, or hip joint in 2008 (around 8.6%), an increase from 21 million in 1995 (Lawrence RC et al., 2008). Such a high prevalence and increase in the incidence of osteoarthritis may be likely related to aging of the population and rising prevalence of obesity (Neogi T & Zhang Y, 2011). This suggests how important the prevention of osteoarthritis is. Knowledge of the risk factors for osteoarthritis is of great relevance to implement adequate preventive strategies for a highly debilitating disease with a clear impact on the patient's quality of life (Guccione AA et al., 1994). This chapter has reviewed the principal risk factors for osteoarthritis. It has been described that older age, female sex, obesity, osteoporosis, occupation, sports activities, previous trauma, muscle weakness or dysfunction, proprioceptive deficit, lower limb malalignment, leg-length inequality, and genetic factors may increase the risk of osteoarthritis (Bosomworth NJ, 2009; Felson DT et al., 2000; Hunter DJ & Sambrook PN, 2002; Neogi T & Zhang Y, 2011). Age, sex, and genetic factors are non-modifiable, whereas the others may be modified by an appropriate intervention. The strongest risk factors are older age, obesity, and history of joint injury. The strongest modifiable risk factors are obesity, history of joint injury, and occupational physical load (Felson DT, 1998; 2000; Hunter DJ & Sambrook PN, 2002). The risk of osteoarthritis in obese subjects and individuals with history of joint injury would be 6-to-8-fold and 4-to-5-fold, respectively (Blagojevic M et al., 2010; Gelber AC et al., 2000; Hart DJ & Spector TD, 1993; Hunter DJ & Sambrook PN, 2002). The estimated decrease of the incidence of knee osteoarthritis by decreasing weight, preventing joint injury, and avoiding occupational risk factors was 27% to 52%, 25%, and 15% to 30% in men, respectively (Felson DT, 1998). In women, by decreasing weight and preventing joint injury, the incidence of knee osteoarthritis was reduced 27% to 52% and 14%, respectively (Felson DT, 1998). Additionally, the reduction of weight would decrease the incidence of hip osteoarthritis around 26% in both males and females (Felson DT, 1998).

Combination of risk factors multiplies the risk of osteoarthritis, thus increasing even more the relevance of preventive strategies. The fact that individuals will have their specific risk factors highlights the need for individualized preventive programs, where each factor is treated in accordance with the subject's characteristics and the type of physical activity that he/she wishes to practice. In patients with older age or increased weight who wish to participate in sports, it would be desirable to first lose weight and undergo a conditioning phase where non-impact exercise or sports are played (flat cycling, fast walking, and

swimming) (Bliddal H & Christensen R, 2009). Once weight is decreased (in combination with diet) or after some weeks of a conditioning phase (in old non-obese patients), the subject may be better prepared to participate in more intense sports. Failing to do this progression may increase the risk of joint damage. In athletes, preventive strategies are very important to prevent long-term disability due to osteoarthritis because this population has a high risk of joint injury.

This chapter was focused on the review of the exposure to sports and exercise as potential risk factors for osteoarthritis. Overall, sports and exercise participation may not be considered an independent risk factor, but instead, would increase the risk of osteoarthritis if accompanied by other risk factors. There is a popular belief that participation in sports is good for health, and this is generally true. However, there are some exceptions. Running would not increase the risk of osteoarthritis in healthy joints. In fact, it has been demonstrated by some authors that running may be protective (Lane NE et al., 1987; Manninen P et al., 2001). High impact and torsional loads coming from the participation of many sports may increase the risk of osteoarthritis, whether or not associated with previous joint injuries. In general, running would be more protective against osteoarthritis than sports participation with more actions than just straight-ahead running. It was found that adult human articular cartilage had a potential to adapt to loading changes by increasing the glycosaminoglycan content (Roos EM & Dahlberg LE, 2005; Tiderius CJ et al., 2004), but may be damaged at high impact loads (Wilson W et al., 2006). Patients with existing osteoarthritis should be encouraged to attain a minimum individualized physical activity and keep as active as possible to delay the progression of degeneration and improve pain, disability and quality of life (Bosomworth NJ, 2009; Dunlop DD et al., 2011). It is likely that exercise interventions are underused in the management of established knee osteoarthritis symptoms (Bosomworth NJ, 2009).

A pooled analysis of all studies reviewed in Tables 1 and 2 is very complex. There are considerable variations in the results of these publications. This may be explained by differences in the outcomes, assessment methods, length of follow-up, exposure to risk factors, influence of confounding factors, demographic characteristics of the sample, or whether clinical or radiographic osteoarthritis was considered. The existing literature is very heterogeneous and this may difficult the elaboration of conclusions. In addition, many of the reviewed studies have reservations regarding the employed methodology. In fact, studies included in the systematic review performed by Lievense were scored in average only a 44.6% (range 0% to 77%), with 0% being worst quality and 100% highest quality (Lievense AM et al., 2003). The authors claimed for more prospective cohort investigations (Lievense AM et al., 2003). The presence of a control group is also crucial to prevent the influence of other risk factors, most importantly, ageing. Most adequate control subjects would be those completely comparable to athletes except for their absolute sedentary lifestyle. This would ensure that differences in osteoarthritis are explained by the exposure to exercise. However, finding completely sedentary controls is very difficult because almost all humans have been relatively active at some point in their life. Also, an investigator can not place a subject to a group that has to be sedentary because of ethical reasons. Most studies presented in this chapter are case-control or cross-sectional (Level III-evidence). It should be recognized that performing adequate at least Level II-evidence studies would be more appropriate to investigate causal-effect relationships and would lower risk of bias. However, prospective longitudinal cohort studies are much more expensive and time consuming than case-control or cross-sectional, especially if we consider that follow-up should be long to know the real

effects of risk factors on articular cartilage. The use of retrospective studies may evoke in recall bias when self-assessed questionnaires are administered to subjects to assess past exposure to exercise and sports. The obtained information is usually pretty exact in professional athletes, but this is not the case for most individuals who were involved in the presented articles. In addition, self-assessments may depend on the level of education, which was not reported in many of the studies.

A major concern regarding many of the reviewed studies is the nature of sports pursued. It was suggested that the risk of osteoarthritis in sports and exercise in subjects without other risk factors may depend on the type of physical activity (Buckwalter JA, 2003; 2004). Sports with high impact and torsional loads would have a risk not comparable to other physical activities such as running or swimming. Many studies included subjects involved in different types of physical activity, thus preventing the elaboration of reliable recommendations for each one. In other words, if a group of patients exercised through different activities (jogging, tennis, cycling or soccer) and the risk of osteoarthritis is increased, that does not mean that running or cycling would be related to an increase in the risk of osteoarthritis. Moreover, many studies have not even detailed the physical activities in which the subjects were involved. In addition, volume, frequency, intensity and duration of training are not commonly reported in most of the studies. With the exception of some studies related to running (in which exact information on the exposure was provided), most of the studies in sports do not report the different parameters of training. For example, exposure to soccer may substantially differ between subjects performing 2 training sessions per week and subjects performing 5 sessions per week, and the same applies for intensity, duration and volume. It should be noticed that reporting the parameters of training would be very difficult if prospective studies are not conducted, as most subjects would not exactly know the above mentioned parameters. In contrast, a strong point of most of the presented publications is the fact that long-term follow-up was reported. Also, efforts to control potential confounding factors were made by the authors in most of the publications. Any study aimed to investigate the influence of sports and exercise in osteoarthritis may have a bias if the presence of other risk factors is not avoided.

Further studies are clearly needed to understand the genetic predisposition to osteoarthritis, the interaction between genetics and environmental factors, and the exact characterization of the risk of osteoarthritis depending on volume (in each session, season, and the whole life), frequency (number of sessions per week), intensity (in terms of velocity of running, percentage of strength with respect to the maximal repetition, etc…) and duration of training (of each session, and the total number of years exposed to training). A promising area would be investigation of the role of hormones, and their genetic regulations, on the development of osteoarthritis. As most studies deal with lower extremity, sports with predominance for upper extremity and their risk of osteoarthritis of the involved joints needs to be further investigated. Considering that osteoarthritis has a high personal and economic cost, and that the prevalence is not decreasing but increasing (Zhang W, 2010), it is crucial to investigate on preventive measures, either as primary, secondary, or even tertiary.

8. Conclusions

- The principal risk factors for osteoarthritis include: older age, female sex, obesity, osteoporosis, occupation, sports activities, previous trauma, muscle weakness or

dysfunction, proprioceptive deficit, lower limb malalignment, leg-length inequality, and genetic factors.

- The strongest modifiable risk factors for osteoarthritis are obesity, occupational physical load, and history of joint injury.
- Participation in running and sports with minimal impact and torsional loads may not be independent risk factors for osteoarthritis; that is, may not cause osteoarthritis in the absence of other risk factors.
- Participation in sport with high impact and torsional loads increases the risk of osteoarthritis, especially in subjects with prior joint injury.
- Presence of a combination of risk factors multiples the risk of osteoarthritis.
- Subjects at higher risk of osteoarthritis are overweight women with prior joint injury who wish to participate in sports with high impact and torsional loads, and non professional athletes of these kind of sports with prior joint injury who additionally work on physically heavy jobs.
- Preventive strategies for osteoarthritis should be based on weight loss, neuromuscular training, occupational modifications, and regular exercise.
- Avoiding sports with high impact and torsional loads and perform other types of exercise may better prevent osteoarthritis and may also be useful to treat already existing osteoarthritis.

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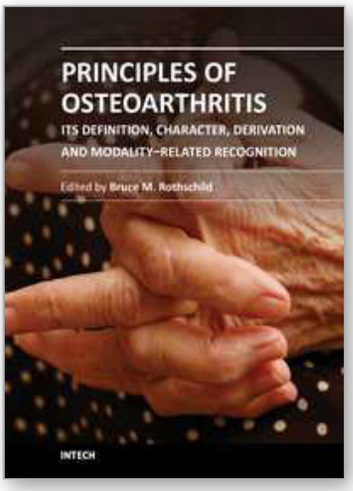

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This volume addresses the nature of the most common form of arthritis in humans. If osteoarthritis is inevitable (only premature death prevents all of us from being afflicted), it seems essential to facilitate its recognition, prevention, options, and indications for treatment. Progress in understanding this disease has occurred with recognition that it is not simply a degenerative joint disease. Causative factors, such as joint malalignment, ligamentous abnormalities, overuse, and biomechanical and metabolic factors have been recognized as amenable to intervention; genetic factors, less so; with metabolic diseases, intermediate. Its diagnosis is based on recognition of overgrowth of bone at joint margins. This contrasts with overgrowth of bone at vertebral margins, which is not a symptomatic phenomenon and has been renamed spondylosis deformans. Osteoarthritis describes an abnormality of joints, but the severity does not necessarily produce pain. The patient and his/her symptoms need to be treated, not the x-ray.

How to reference

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InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

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