

**Long term joint consequences of sporting activity: preventing and
managing osteoarthritis in the athlete**

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Introduction

In an Olympic year, attention inevitably turns to the sporting achievements of elite athletes. However, after the glory of competition fades, athletes can be left to deal with the musculoskeletal effects of years of intense sporting participation. This narrative review will provide a brief perspective on the possible long-term joint consequences arising from sport, specifically the development of osteoarthritis (OA), and discuss strategies to prevent and manage OA in athletes. While the focus will be on elite athletes, given the limited research in this population, research pertaining to other levels of sporting participation will be included. Furthermore, as the bulk of research involves the knee, this joint will be the primary focus.

Risk of osteoarthritis from sport

In the athlete, an increased risk of OA could be due to injury to the joint stabilizing or load-bearing structures and/or to repeated biomechanical stress (Figure 1). This section pertains both to injuries that can be sustained during sport as well as OA risk simply from participation. Before briefly discussing the link between OA and sport, it must be highlighted that in many epidemiological investigations, the link is based on detection of radiographic OA features, rather than on the presence of symptomatic OA (combination of symptoms and radiographic OA). This is an important consideration given that radiographic features are not well correlated with symptoms and osteophytes (typically the first radiographic feature identified) may not be a deleterious

finding but may represent an effort to promote joint stability. In essence, it is the relationship between sport and symptomatic OA that is most clinically meaningful.

Joint injury

Acute injuries are common in sport particularly at the knee and ankle joint and in sports involving pivoting, jumping and tackling such as football, volleyball, gymnastics, handball, ice hockey, netball and basketball.

Joint injury including joint contusion, intra-articular fracture, ligamentous injuries and dislocations have been found to increase the risk of OA. It has been consistently shown that injury to the anterior cruciate ligament (ACL) and in particular, concomitant meniscus damage, significantly increases the risk of incident radiographic and symptomatic knee OA ^{1,2} (Figure 2).

While there are less longitudinal data at other joints, an estimated 55-78% of ankle OA can be attributed to prior trauma, such as fractures and severe ligament sprains ^{3,4}. In one study, a combination of chronic lateral ankle instability with intensive volleyball playing was suggested as possibly increasing the risk of ankle OA ⁵. Thus while ankle sprains are common sporting injuries generally believed to be benign and self-limiting, they can in fact have long-term adverse consequences.

Another condition that is seen in active individuals and may contribute to OA is femoroacetabular impingement (FAI). This involves abutment between the

proximal femur and the acetabular rim which can cause hip labral injury, groin pain and functional limitations in the young sports person. A recent systematic review concluded that the limited available evidence suggests it can also lead to hip OA in the longer term ⁶. Whether participation in high-level sport during youth predisposes to the development of FAI is contentious with reports of a higher prevalence of FAI in collegiate football players ⁷ but not soccer players ⁸ compared with the general population.

There are several mechanisms underpinning the increased risk of OA following joint injury. First, mechanical damage to the articular surface, osteochondral unit or meniscus at the time of injury initiates a cascade of progressive tissue damage including cell death, inflammation and matrix degradation ⁹. Second, injury can change the biomechanics of the joint and neuromuscular function. For example, injury-induced gait changes during walking and running can increase the loads and/or shift the normal load bearing regions of the knee joint to areas less well adapted to withstand load ¹⁰.

Sports participation

The literature suggests that the risk of subsequent OA from sports participation may relate to the intensity of participation, the performance level (elite versus recreational) and, as discussed above, the concomitant presence and/or likelihood of joint injury ¹¹⁻¹³.

Whilst there is some evidence suggesting an increased risk of OA with athletic activity this has not been adequately disentangled from joint injury. ***In this light, there is no good evidence supporting a deleterious effect of exercise on joints in the setting of normal joints and moderate physical activity.*** In contrast, elite sport participation may be associated with an increased risk of OA compared with non-elite participation depending on the type of sport ¹⁴. In a large study of 2049 internationally competitive male athletes and 1403 healthy controls over a 21 year follow-up, Kujala et al ¹¹ reported increased risk of hospital admission for hip, knee and ankle OA in the athletic group. Ice hockey players, wrestlers and weight-lifters were at highest risk whereas participants in endurance sports, basketball, track and field, boxing and throwing sports were not at increased risk. In a recent cross-sectional study of 709 former male elite athletes and 1368 controls, a higher prevalence of knee OA and rate of joint arthroplasty was found in athletes in both impact (soccer, handball and ice hockey) and non-impact (eg. canoeists, distance runners, weight lifters) sports compared with controls ¹⁵. Knee injury explained the increased risk in the impact sports but not in the non-impact sports. A higher prevalence of hip OA was only seen in the impact athletes ¹⁵. Nevertheless, there are conflicting results in the literature with other studies failing to support a relationship between vigorous sport and OA ¹⁴. As most of the studies have methodological limitations and generally provide low-level evidence, a connection between participation in athletic activities and development of OA, independent of joint injury, remains to be definitively proven.

Sports injury prevention

Given the strong established link between joint injury and subsequent development of OA, a focus on injury prevention in athletes is vital. This is especially applicable for sports where joint and ligament injuries are common.

There is high quality biomechanical and randomized controlled trial evidence to support the effectiveness of targeted neuromuscular exercise programs to prevent knee and ankle ligament injuries, particularly in women^{16,17}. Indeed neuromuscular exercise can reduce the risk of ACL injury by as much as 60%. These programs are simple and can easily be incorporated into training regimens. They typically emphasize correct landing techniques and control of upper body, trunk and lower body position, balance, agility, functional strengthening and plyometric activities (Figure 3). Neuromuscular exercise programs have generated widespread support from eminent international organizations including the IOC (International Olympic Committee) and FIFA (International Federation of Association Football) and have now been disseminated in a number of countries with success in reducing the national injury burden.

Other interventions can also reduce the risk of ankle ligament sprains. A systematic review showed that ankle taping or bracing confer a 50% reduction in the risk of ankle sprain, especially after an initial ankle injury¹⁷. In collegiate baseball and softball, contact with a fixed base contributes to ankle sprains,

and bases that release or break away upon impact reduce lower extremity injury rates ¹⁸.

Sports injury management

Injury management must balance the need for short-term return to competition with the athlete's longevity in the sport as well as long-term joint health and well-being. Injury management requires appropriate rehabilitation, judicious use of surgery, and education of the athlete and coach. The potential role of biologic agents in treating acute joint injuries to prevent long term OA is of current research interest.

Rehabilitation

Following musculoskeletal injury, patterns of abnormal functioning of the motor, sensory, pain and psychological systems exist. For example, following arthroscopic partial meniscectomy, muscle strength deficits have been found to exist up to six months post operatively ¹⁹. Similarly, following ACL reconstruction, aberrant hip and knee joint kinematic profiles are present during jumping which could influence future injury risk ²⁰. Rehabilitation, optimally, should seek to identify and address deficits in these systems as well as identify and correct other factors that predispose athletes to re-injury. While the focus in elite sport is towards a speedy return to practice and competition, delaying the time to return may facilitate tissue healing, allow better rehabilitation to restore function and reduce the risk of re-injury. Physical therapy that includes appropriate exercise to improve muscle

strength, endurance and power, muscle flexibility, motor control and coordination of muscle and joint actions, sport specific skills and general fitness is important. Other physical modalities that are adjunctive to exercise and in the main used to improve healing and overcome pain include joint and soft tissue manipulation, braces and taping and electrophysical agents.

Surgery

Surgery may be considered for some joint injuries and must be a judgment between the athlete and the surgeon taking into account the athlete's disability, sporting activity and level, their short- and long-term goals and expectations together with the evidence about surgical outcomes.

Reconstruction of the injured ACL is a common procedure in athletes. While it is necessary to allow return to high-level sport, a recent randomized controlled trial found that a strategy of rehabilitation plus early ACL reconstruction was not superior in terms of clinical outcomes to rehabilitation plus optional delayed ACL reconstruction in recreational athletes ²¹. Cohort studies suggest that ACL reconstruction does not reduce the likelihood of future OA irrespective of the graft type ^{1,22}.

Given the well known detrimental consequences of meniscal removal, preservation and repair techniques are advocated for the athlete whenever possible. However, while research suggests that the method of management of meniscal tears appears to have little impact on OA prevalence ¹, further high quality research is required. Meniscal replacement surgery may be an

option for athletes with substantial loss of meniscal tissue and degenerative symptoms although the procedure is still in its infancy²³. Clinically, athletes need to be aware that rehabilitation after meniscal repair or replacement is very slow and restrictive compared to partial meniscectomy.

The management of symptomatic focal cartilage defects in younger sporting individuals remains problematic. Although there are several surgical treatment options available such as microfracture, autologous chondrocyte implantation, and osteoarticular transplantation, none are ideal. A recent systematic review found 11 studies evaluating articular cartilage repair in athletes of which only one was a randomized controlled trial²⁴. The overall rate of return to pre-injury level of sports was relatively low, only 66%. While the results showed better clinical outcomes after cartilage repair or restoration with outcomes deteriorating over time following microfracture, the authors concluded that there is little high-level evidence to support one procedure over another²⁴.

Open and arthroscopic surgery is often used to manage FAI with case series consistently showing symptomatic and functional improvement over the longer term²⁵. However, whether surgical correction of the anatomic contributors to FAI reduces the potential increased risk of hip OA is not currently known.

Education and advice

Following a joint injury, clinicians should counsel the athlete about their increased likelihood of future OA, irrespective of the method of managing the

injury. This allows athletes to make informed decisions about return to sport as well as plan future management. In the less competitive athlete, a change to low impact sports/exercise or a reduction in intensity may be considered. On return to competitive sport following injury, athletes are at increased risk of re-injury. Thus appropriate involvement in prevention activities especially neuromuscular training is important. Information should be provided about joint load-reducing interventions as outlined below. Sports people should also be made aware that the onset of pain subsequent to a joint injury may indicate early OA. Proactive management in the early stages may help slow the progression of symptomatic OA.

Biologic and other therapies

Biochemical abnormalities within the joint precede radiological OA by many decades and may represent targets for early pharmacological intervention. This may be especially applicable in post-traumatic joint injuries where deleterious intra-articular processes are initiated immediately following the injury exacerbated by the joint response to injury including hemarthrosis and inflammation. Biologic interventions to minimize chondrocyte damage and matrix degradation and to facilitate anabolic processes are the subject of research⁹ but are not yet used in clinical practice.

Platelet-rich plasma therapy involving the application of autologous plasma and platelet-derived proteins to influence inflammation, angiogenesis, or extracellular matrix synthesis, can be applied by local injection or during surgical joint procedures. However, despite its widespread use, especially in

elite athletes, and apparent safety, there is little scientific evidence to support its clinical efficacy in treating sports injuries²⁶. While platelet-rich plasma therapy is currently permitted for use in elite athletes, specific purified or recombinant growth factors (eg, insulin growth factor-1, vascular endothelial growth factor, platelet-derived growth factor) are prohibited by the World Anti-Doping Agency.

Other adjunctive treatments used in sports medicine with the supposed aim of improving healing include hyperbaric oxygen therapy, extracorporeal shock wave therapy, prolotherapy and intramuscular injection of Botulinum toxin. Currently there is no high level evidence supporting the benefits of any of these therapies. Given this, clinicians and patients should consider the potential side effects of these unproven therapies in order to make an informed decision about their use.

Management of osteoarthritis in the athlete

Given that sports injuries are typically sustained by adolescents and young adults, the development of symptomatic OA 10-20 years later means that many affected individuals are young, aged in their 30s and 40s (the so called 'young patients with old joints'). Although there is limited research directed at the management of OA in these younger patients, conservative interventions play a key role. It is also preferable to additionally target athletes who are at risk of developing symptomatic OA (those with prior joint injury).

Load-modifying strategies

We suggest that the clinician advise the athlete of strategies known to reduce joint load given that increased joint loading plays a role in the development²⁷ and progression of OA²⁸. Furthermore, higher knee load during walking has been reported in people who have had an ACL and/or meniscal injury compared with age-matched uninjured controls^{29,30}.

Interventions that have been shown to lower joint loads in biomechanical studies include shock absorbing insoles which reduce impact loads at heel strike, wedge insoles, variable-stiffness sole shoes and unloader knee braces^{31,32}. The latter may be particularly useful for individuals who wish to continue with sporting activity.

Activity modification is advisable with avoidance, or at least a reduction of, high impact, twisting sports and repetitive loading such as running. The athlete should be encouraged to participate in low impact activities such as cycling, swimming and deep-water running. If the athlete wishes to continue running, attention to the running surface is important to minimize load.

Muscle strengthening

Strengthening the quadriceps muscle may be important particularly in former athletes who become deconditioned with reduced sporting involvement.

There is some evidence to suggest that quadriceps muscle weakness could increase the risk of knee and hip OA disease development, possibly more so

in women. A study of over 2000 individuals found that compared with the lowest tertile, the highest tertile of adjusted isokinetic knee extensor strength protected against development of incident symptomatic whole knee OA³³. Thus a program of lower limb muscle strengthening with attention to the quadriceps should be recommended.

Weight control

Being overweight or obese increases the risk of knee OA onset³⁴ although such a relationship is less evident for hip OA. During gait, body weight is transferred to the knee with substantial leverage such that with each additional kilogram of body mass increases the compressive load over the knee by roughly 4 kilograms³⁵. Thus maintaining an optimal body weight is important. While this is generally not an issue in elite athletes, weight loss may be relevant particularly in former athletes who may find that their weight increases over time as they become less active. Referral to a dietitian can assist the individual to achieve healthy eating patterns.

Pharmacologic or dietary agents

There are currently no pharmacologic agents with convincing structural disease-modifying efficacy for people with existing joint damage and most have been tested in mid- to late-term OA rather than early OA. Promising therapies are being developed for new OA targets with clinical trials predominantly testing pro-anabolics (growth factors/hormones), with a modest selection of anti-catabolics (IL-1, IKK (IB kinase) and iNOS inhibitors) as well as cell therapy (using primarily mesenchymal stem cells from either bone

marrow or adipose tissue)³⁶.

The most commonly used dietary supplement for OA is glucosamine. In higher quality trials, effects of glucosamine on pain are generally similar to those of placebo with industry-independent trials showing smaller effects than commercially-funded trials³⁷. Evidence for a possible structure-modifying effect is still controversial. The use of nutritional supplements, such as glucosamine, for the management of osteoarthritis is not recommended by recent American College of Rheumatology guidelines³⁸.

Summary

Athletes who have sustained a joint injury are at an increased risk of subsequent OA. There is no good evidence that moderate sporting activity in the presence of normal joints predisposes to OA. Whether high-level participation in sport, particularly impact type sports, is associated with OA is unclear as it is difficult to disentangle the confounding effect of joint injury. Attention to strategies that prevent joint injury in athletes is paramount to reduce the burden of OA. Optimal injury management is needed to minimize the onset and extent of joint symptoms in athletes. Management of OA in athletes requires attention to load-reducing strategies, activity modification, muscle strengthening and weight control (Figure 1).

REFERENCES

- 1 Lohmander, L. S., Englund, P. M., Dahl, L. L. & Roos, E. M. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. *Am J Sports Med* 35, 1756-1769 (2007).
- 2 Oiestad, B. E. *et al.* Knee function and prevalence of knee osteoarthritis after anterior cruciate ligament reconstruction: a prospective study with 10 to 15 years of follow-up. *Am J Sports Med* 38, 2201-2210 (2010).
- 3 Valderrabano, V., Hintermann, B., Horisberger, M. & Fung, T. S. Ligamentous posttraumatic ankle osteoarthritis. *The American journal of sports medicine* 34, 612-620 (2006).
- 4 Horisberger, M., Valderrabano, V. & Hintermann, B. Posttraumatic ankle osteoarthritis after ankle-related fractures. *J Orthop Trauma* 23, 60-67 (2009).
- 5 Gross, P. & Marti, B. Risk of degenerative ankle joint disease in volleyball players: study of former elite athletes. *Int J Sports Med* 20, 58-63 (1999).
- 6 Harris-Hayes, M. & Royer, N. K. Relationship of acetabular dysplasia and femoroacetabular impingement to hip osteoarthritis: a focused review. *PM R* 3, 1055-1067 e1051 (2011).
- 7 Kapron, A. L. *et al.* Radiographic prevalence of femoroacetabular impingement in collegiate football players: AAOS Exhibit Selection. *The Journal of bone and joint surgery. American volume* 93, e111(111-110) (2011).
- 8 Johnson, A. C., Shaman, M. A. & Ryan, T. G. Femoroacetabular Impingement in Former High-Level Youth Soccer Players. *The American journal of sports medicine* (2012).
- 9 Anderson, D. D. *et al.* Post-traumatic osteoarthritis: improved understanding and opportunities for early intervention. *Journal of orthopaedic research : official publication of the Orthopaedic Research Society* 29, 802-809 (2011).
- 10 Andriacchi, T. P., Briant, P. L., Bevill, S. L. & Koo, S. Rotational changes at the knee after ACL injury cause cartilage thinning. *Clin Orthop Relat Res* 442, 39-44 (2006).
- 11 Kujala, U. M., Kaprio, J. & Sarna, S. Osteoarthritis of weight bearing joints of lower limbs in former elite male athletes. *BMJ* 308, 231-234 (1994).
- 12 Lievense, A. M. *et al.* Influence of sporting activities on the development of osteoarthritis of the hip: a systematic review. *Arthritis Rheum* 49, 228-236 (2003).
- 13 Vignon, E. *et al.* Osteoarthritis of the knee and hip and activity: a systematic international review and synthesis (OASIS). *Joint Bone Spine* 73, 442-455 (2006).
- 14 Papavasiliou, K. A., Kenanidis, E. I., Potoupnis, M. E., Kapetanou, A. & Sayegh, F. E. Participation in athletic activities may be associated with later development of hip and knee osteoarthritis. *The Physician and sportsmedicine* 39, 51-59 (2011).
- 15 Tveit, M., Rosengren, B. E., Nilsson, J. K. & Karlsson, M. K. Former Male Elite Athletes Have a Higher Prevalence of Osteoarthritis and

- Arthroplasty in the Hip and Knee Than Expected. *Am J Sports Med* (2011).
- 16 Hubscher, M. *et al.* Neuromuscular training for sports injury prevention: a systematic review. *Medicine and science in sports and exercise* 42, 413-421 (2010).
- 17 Verhagen, E. A. & Bay, K. Optimising ankle sprain prevention: a critical review and practical appraisal of the literature. *Br J Sports Med* 44, 1082-1088 (2010).
- 18 Sendre, R. A., Keating, T. M., Hornak, J. E. & Newitt, P. A. Use of the Hollywood Impact Base and standard stationary base to reduce sliding and base-running injuries in baseball and softball. *The American journal of sports medicine* 22, 450-453 (1994).
- 19 Glatthorn, J. F., Berendts, A. M., Bizzini, M., Munzinger, U. & Maffiuletti, N. A. Neuromuscular function after arthroscopic partial meniscectomy. *Clinical orthopaedics and related research* 468, 1336-1343 (2010).
- 20 Delahunt, E. *et al.* Hip and knee joint kinematics during a diagonal jump landing in anterior cruciate ligament reconstructed females. *J Electromyogr Kinesiol* (2012).
- 21 Frobell, R. B., Roos, E. M., Roos, H. P., Ranstam, J. & Lohmander, L. S. A randomized trial of treatment for acute anterior cruciate ligament tears. *N Engl J Med* 363, 331-342 (2010).
- 22 Holm, I., Oiestad, B. E., Risberg, M. A. & Aune, A. K. No difference in knee function or prevalence of osteoarthritis after reconstruction of the anterior cruciate ligament with 4-strand hamstring autograft versus patellar tendon-bone autograft: a randomized study with 10-year follow-up. *Am J Sports Med* 38, 448-454 (2010).
- 23 McDermott, I. Meniscal tears, repairs and replacement: their relevance to osteoarthritis of the knee. *British journal of sports medicine* 45, 292-297 (2011).
- 24 Harris, J. D., Brophy, R. H., Siston, R. A. & Flanigan, D. C. Treatment of chondral defects in the athlete's knee. *Arthroscopy* 26, 841-852 (2010).
- 25 Kemp, J. L. *et al.* Hip arthroscopy for intra-articular pathology: a systematic review of outcomes with and without femoral osteoplasty. *Br J Sports Med* (2011).
- 26 Engebretsen, L. *et al.* IOC consensus paper on the use of platelet-rich plasma in sports medicine. *Br J Sports Med* 44, 1072-1081 (2010).
- 27 Amin, S. *et al.* The relationship between cartilage loss on magnetic resonance imaging and radiographic progression in men and women with knee osteoarthritis. *Arthritis & Rheumatism* 52, 3152-3159 (2005).
- 28 Bennell, K. L. *et al.* Higher dynamic medial knee load predicts greater cartilage loss over 12 months in medial knee osteoarthritis. *Ann Rheum Dis* 70, 1770-1774 (2011).
- 29 Butler, R. J., Minick, K. I., Ferber, R. & Underwood, F. Gait mechanics after ACL reconstruction: implications for the early onset of knee osteoarthritis. *Br J Sports Med* 43, 366-370 (2009).
- 30 Sturnieks, D. L. *et al.* Knee strength and knee adduction moments following arthroscopic partial meniscectomy. *Med Sci Sports Exerc* 40, 991-997 (2008).

- 31 Pollo, F. E., Otis, J. C., Backus, S. I., Warren, R. F. & Wickiewicz, T. L. Reduction of medial compartment loads with valgus bracing of the osteoarthritic knee. *Am J Sports Med* 30, 414-421 (2002).
- 32 Radzimski, A. O., Mundermann, A. & Sole, G. Effect of footwear on the external knee adduction moment - A systematic review. *Knee* (2011).
- 33 Segal, N. A. *et al.* Effect of thigh strength on incident radiographic and symptomatic knee osteoarthritis in a longitudinal cohort. *Arthritis Rheum* 61, 1210-1217 (2009).
- 34 Reijman, M. *et al.* Body mass index associated with onset and progression of osteoarthritis of the knee but not of the hip: the Rotterdam Study. *Ann Rheum Dis* 66, 158-162 (2007).
- 35 Messier, S. P., Gutekunst, D. J., Davis, C. & DeVita, P. Weight loss reduces knee-joint loads in overweight and obese older adults with knee osteoarthritis. *Arthritis Rheum* 52, 2026-2032 (2005).
- 36 Matthews, G. L. & Hunter, D. J. Emerging drugs for osteoarthritis. *Expert Opin Emerg Drugs* 16, 479-491 (2011).
- 37 Zhang, W. *et al.* OARSI recommendations for the management of hip and knee osteoarthritis: Part III: Changes in evidence following systematic cumulative update of research published through January 2009. *Osteoarthritis Cartilage* 18, 476-499 (2010).
- 38 Hochberg, M. C. *et al.* American College of Rheumatology 2012 recommendations for the use of nonpharmacologic and pharmacologic therapies in osteoarthritis of the hand, hip, and knee. *Arthritis Care and Research* 64, 465-474 (2012).

Figure 1: Diagram of the relationship between sport and osteoarthritis with areas for clinical intervention to reduce the burden of disease highlighted

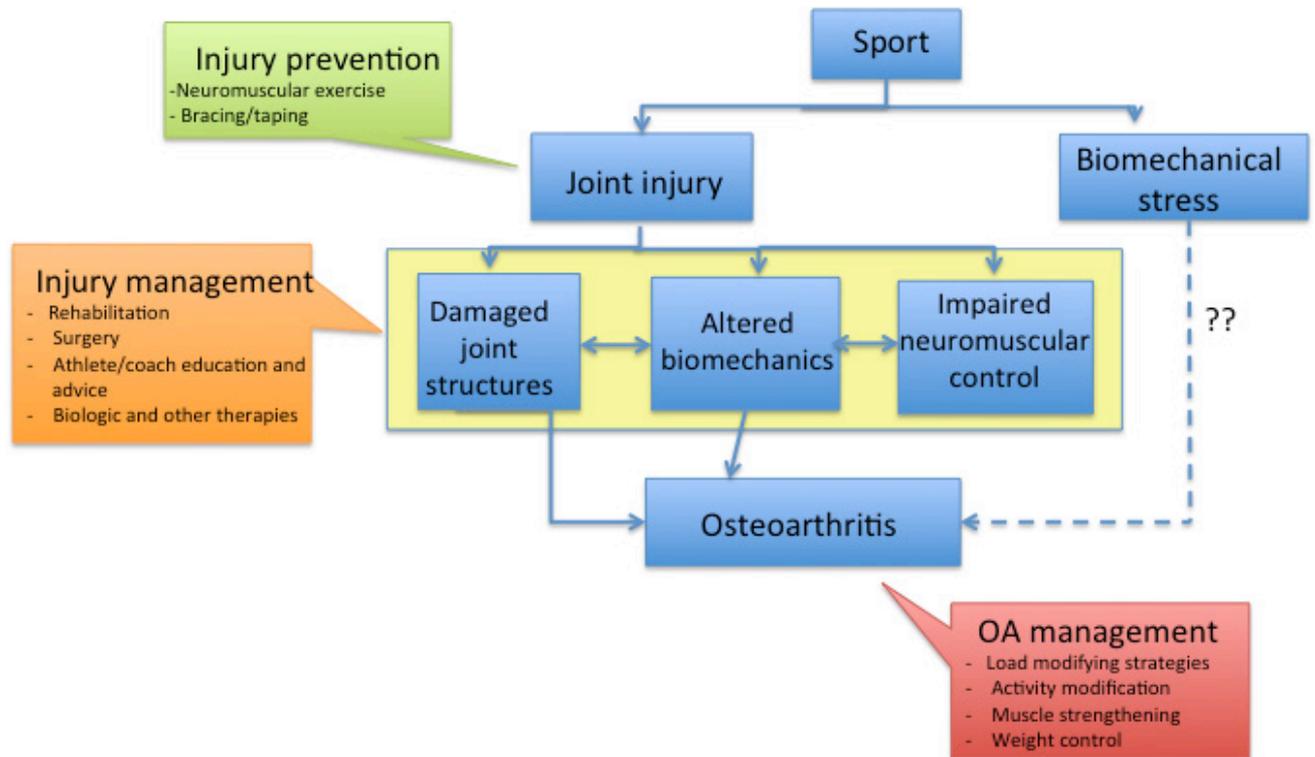


Figure 2a: Scattergram of the proportion of individuals with radiographic osteoarthritis plotted against time after anterior cruciate ligament injury or reconstructive surgery. Each data point represents a data set from 1 of 127 individual publications. Symbols: ● represents nonsurgical treatment; ▼ represents primary suture or enhancement; ■ represents reconstruction by autograft; ◆ represents reconstruction by synthetic graft or allograft.

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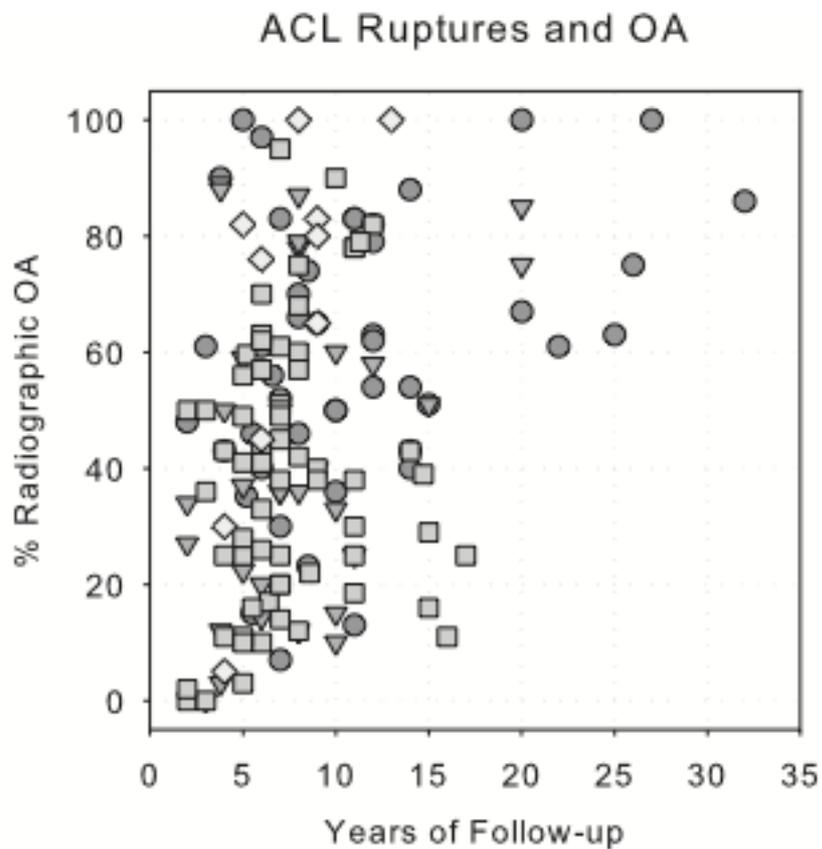


Figure 2b: Scattergram of the proportion of radiographic osteoarthritis plotted against time after diagnosed or treated meniscal lesion. Each data point represents a data set as reported in 1 of 41 individual publications. Studies shown here contain isolated meniscus lesions only. Symbols: ● represents total or subtotal meniscus resection; ▼ represents partial meniscus resection; ■ represents meniscus repair.

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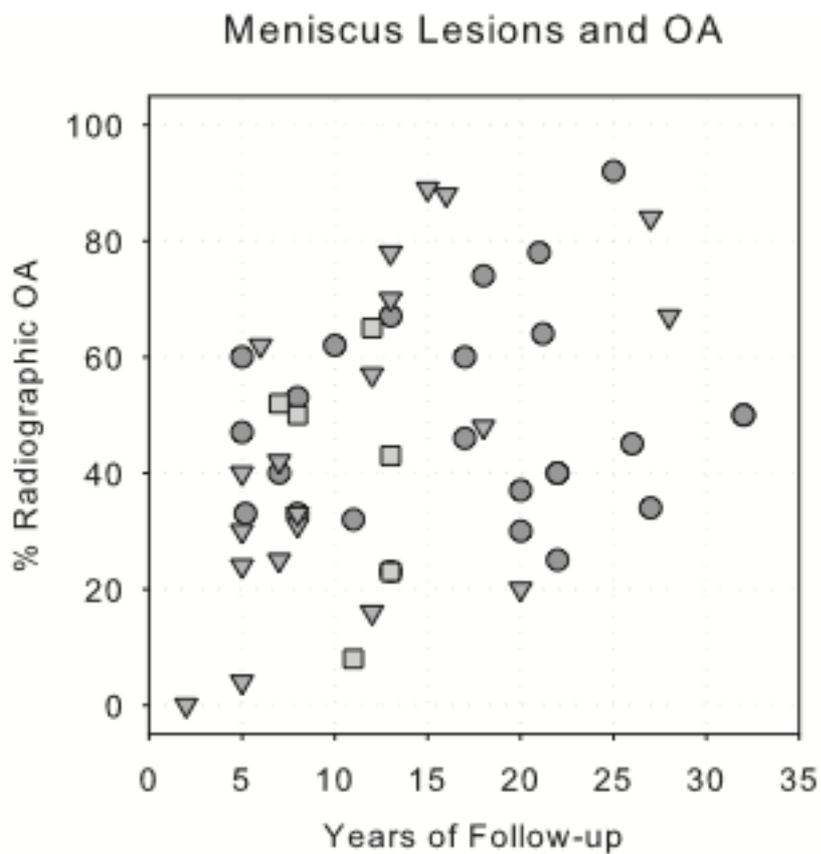


Figure 3: One of the aims of neuromuscular training programs is to teach correct landing positions. The incorrect position on the right demonstrates the hip internal rotation, hip adduction, pelvic drop and knee valgus alignment that are associated with an increased risk for damage to the anterior cruciate ligament. The position on the left shows the correct alignment of the body with knee positioned over the foot.

