Oversized young athletes: a weighty concern

M P McHugh

Correspondence to:
Dr M McHugh, Nicholas Institute of Sports Medicine and Athletic Trauma, Lenox Hill Hospital, 130 East 77th Street, New York, NY 10075, USA; mchugh@nismat.org

Accepted 11 October 2009
Published Online First
27 November 2009

ABSTRACT

The prevalence of overweight and obesity in children and adolescents is increasing worldwide, with a corresponding decline in physical fitness and general physical activity level. Overweight and obese adolescents are more than twice as likely to be injured in sports and other physical activities compared with non-overweight and non-obese adolescents. Obese adolescent athletes are more than three times as likely to sustain an ankle sprain compared with normal weight adolescent athletes. At the societal level, promoting physical activity for children and improving dietary habits are key strategies for lowering the prevalence of overweight and obesity. The increased risk of injury associated with being overweight or obese may in part be due to low physical activity level. Promotion of physical activity for children can provide neuromuscular training that may be beneficial in decreasing injury risk associated with general play and sports participation. For lower-extremity injuries, specific neuromuscular training interventions, such as balance training, have great potential in reversing the increased injury risk associated with overweight and obesity. Finally, the injured overweight young athlete may have a more prolonged recovery period than non-overweight young athletes. Early aggressive treatment of swelling with physical modalities, prolonged non-weight bearing, limited period of immobilisation and regular repetitive passive joint motion are indicated for the overweight young athlete with a lower-extremity joint injury.

Obesity is a worldwide epidemic affecting adults and children. Quantifying the extent of the problem in individuals less than 18 years old is difficult because obesity definitions and terminology vary in children and adolescents.[1] For example, in the USA, Centers for Disease Control (CDC) criteria have been used to categorise children as overweight and at risk of overweight based on a body mass index (BMI) that is at or above the 95th percentile (overweight) or between the 85th and 95th percentile (at risk of overweight) for age and gender of a reference group.[2–5] By contrast, the International Obesity Task Force (IOTF) uses the terms obese and overweight to categorise children and adolescents whose BMI is above normal, and individuals are categorised based on discrete BMI cut-off points.[6] For the purposes of consistency, the terms overweight and obese will be used here, even when a particular reference used the terminology at risk of overweight and overweight.

It is clear from numerous studies that the prevalence of obesity is increasing in children and adolescents. Using the IOTF classification, the prevalence of obesity in 6–17-year-olds in the USA has increased from less than 5% in 1965 to 10–15% in 2005, while the prevalence of being overweight or obese has increased from approximately 15% to 35%.[7 8] A prevalence of 10–15% for obesity and 35% for overweight or obese in 6–17-year-olds in the USA in 2005[7] is higher than 2006 values reported for the European Union, where the obesity prevalence was 7%, and the overweight and obese prevalence was 30% in 5–18-year-olds.[8] Lobstein and Jackson-Leach[7] noted that the prevalence of overweight and obese children in the USA is among the highest in the world.

The increasing prevalence of obesity in children and adolescents has occurred in parallel with a decrease in physical activity and exercise[9] and a decline in cardiorespiratory fitness.[10] Most alarming in this trend is the decline in provision of physical education. From 1991 to 2001, the percentage of 14–17-year-old students in the USA attending regular physical education classes dropped from 42% to 32%.[9] Similarly, the percentage of ninth- to 12th-grade students in Canada enrolled in physical education classes decreased from 70.3% in 1999 to 60.3% in 2005.[11] Decreasing rates of participation in physical education classes has occurred, while the number of students participating in organised sports has likely increased. For example, during the 1971–1972 school year, an estimated 4 million individuals participated in high school sports in the USA, while by 2005–2006, this number had increased to 7.2 million (80% increase).[12]

The purpose of this review is to examine the evidence for obesity being a risk factor for sports injury in children and adolescents, and whether low physical fitness and limited prior exposure to physical activity are compounding factors. Mechanisms by which obesity might contribute to increased injury risk and potential interventions to reduce injury risk are discussed.

Search strategy

A Medline database search was used to identify relevant articles examining the relationship between obesity and injury risk. The terms "obese," "obesity," "overweight" and "BMI" (or "body mass index") were combined with "injury," "risk," "physical activity" and "sport." The search was limited to non-review papers. Papers specific to children, adolescents and young adults were further examined for relevance.

IS OBESITY A RISK FACTOR FOR INJURY?

Most studies examining the effect of obesity on injury risk in children and adolescents use BMI as the criterion measurement.[3–5 13–17] The use of BMI may be an issue in sports involving large subjects whose muscular development is well above normal for their age and height. In sports such as American football and rugby, a high BMI does not necessarily reflect excessive adiposity. However, Gomez *et al*[18]

reported a correlation coefficient of 0.8 for per cent body fat (%BF) and BMI in high school American football linemen. Since linemen are the heaviest athletes in that particular sport, these findings indicate that BMI for the most part does reflect adiposity in these large athletes.

A total of 13 studies that directly or indirectly addressed the role of obesity in injury risk for children and adolescents were reviewed (table 1). Five studies were specific to injuries occurring in American football[3–5 18 22] Four studies included injuries occurring in all activities, not specifically in sports,[13–15 17] and one study included students involved in any high school sport[16] The remaining three studies were on military recruits[19–21] where, because the ages of the subjects were 18–22 years, and the basic training setting replicates the stress of sports training, these findings have some relevance for injury risk in young athletes.

Of the 13 studies listed in table 1, nine did not differentiate between types of injuries,[3 4 13 14 16 19–22] one examined all injuries and a subgroup of lower-extremity injuries,[18] two studies focused on ankle sprains[5 17] and one study was specific to dental injuries.[14] Seven studies included male and female subjects while six studies included only male subjects (five on American football, one on military recruits). Of note, only five of the 13 studies cited in table 1 used exposure-based measurements of injury occurrence for examining the effects of BMI.[5 18 20–22]

Eleven of the 13 studies listed in table 1 showed some evidence that either a high BMI or a high %BF was associated with increased risk of injury. For subjects categorised as overweight, obese or in a high-BMI group, the increase in injury risk ranged from 1.4 to 3.9 times the risk for the respective control group. Both studies that found no effect of BMI on injury risk involved 8–15-year-old boys playing American football.[3 4] Interestingly, in one of these studies, a low BMI was associated with increased risk in the youngest players (9–10 years old)[3] indicating that undersized athletes in a physical sport may be at increased risk of injury in the youngest age groups for competition. Studies on older children playing American football (14–19 years old) showed increased injury risk associated with a high BMI.[5 18 22] Kaplan *et al*[22] found obese players to be 2.3 times more likely to sustain an injury than non-obese players. Gómez *et al*[18] found that obese linemen (BMI>29) were 2.7 times more likely to sustain a lower extremity injury than linemen with lower BMIs. Tyler *et al*[5] found that obese players were 3.9 times more likely to sustain non-contact ankle sprains than players with normal BMIs. It appears that the effect of obesity on injury risk in American football may be more apparent in adolescents than in younger athletes.

Of the seven studies that included male and female subjects, two found gender-specific effects. Chau *et al*[15] found an increased injury risk for obese girls but not for obese boys. Additionally, the risk associated with obesity in girls was not specific to sports participation but included non-sports physical activities. In contrast, for military recruits, male subjects in the upper quartile for BMI and %BF had an increased risk of injury, while female recruits did not.[21]

Of the four studies that addressed specific injuries, two showed an increased risk of sustaining an ankle sprain in obese subjects,[5 17] one found an increased risk of lower extremity injuries in obese subjects and specifically cited ankle and medial collateral ligament sprains,[18] and one showed an increased risk of traumatic dental injuries in obese subjects.[14] Gomez *et al*[18] found an increased risk for lower-extremity injuries in American football linemen with higher BMI and %BF. The incidence of lower extremity injury for players above and below various BMI and %BF cut-off points was graphed, and in general, injury incidence was at least twice as high in the players with higher BMI or %BF. The authors noted that the incidence of both ankle sprains and medial collateral ligament sprains was higher in higher-fat groups but did not report the specific injury incidences or magnitude of difference between groups. Tyler *et al*[5] found that the incidence of non-contact ankle sprains for obese high school American football players was 3.9 times higher than for players with a normal BMI. Zonfrillo *et al*[17] found that the prevalence of obesity in patients presenting to a paediatric emergency department with an acute ankle sprain was higher than the prevalence of obesity in patients presenting with fever, headache or sore throats with an adjusted odds ratio of 3.26. Lastly, Petti *et al*[14] reported a prevalence of dental injuries of 31% in obese 6–11-year-olds compared with 20% for non-obese children. However, this effect of obesity was not specific to sport but related to a difference in injuries related to indoor play. The results are pertinent to the discussion of obesity and sports injuries because the study noted that prior exposure to injury risk activities, including sports, was actually protective. The authors noted that the non-obese subjects were more active and theorised that they were better adapted to avoid injuries when involved in physical activity.

Direct consequences of increasing rates of childhood obesity on the incidence of paediatric orthopaedic conditions have been documented. For example, the percentage of overweight 13–15-year-old children in Scotland increased from 15% in 1981 to approximately 27% in 2001.[23] Obesity is a known risk factor for slipped capital femoral epiphysis, and not surprisingly an increased incidence has been noted in Scottish children over the same time period with an incidence of 3.78 per 100 000 children in 1981 increasing to 9.66 in 2000.[23]

PROPOSED INJURY MECHANISMS

Six of the studies listed in table 1 discussed potential mechanisms for the effect of obesity on injury risk (table 2). For acute traumatic injuries, there was some consensus suggesting that impairments in postural control in obese subjects was the mechanism for increased injury risk.[5 14 15 17] In support of this conclusion, previous studies have shown that obese children have poor postural control compared with non-obese children.[24 25] Furthermore, in high school American football players, balance training has been shown to eliminate the increased risk of sustaining an ankle sprain associated with the combination of a high BMI and a previous ankle sprain.[26] It remains to be determined if balance training would be effective in reducing the risk of sustaining other types of injuries in obese athletes. However, this type of intervention has been effective in reducing a range of injuries, including but not limited to ankle sprains, in various populations of athletes.[27–29 31]

Impaired postural control in obese children may be due to the challenge of controlling a disproportionately large body mass in activities that require rapid alterations in direction of movement such as occur in most sports. This challenge is compounded by poor physical fitness and low physical activity level. With respect to physical fitness, in weight-bearing activities the obese athlete may have either inadequate strength relative to body mass to safely control body movements or a low cardiorespiratory fitness which may induce fatigue leading to impaired postural control. With respect to physical activity level, a lower prior general physical activity level in obese athletes may compromise neuromuscular control when sports activities are undertaken. The neuromuscular and motor learning adaptations that occur with a high level of physical activity during development may be invaluable to children when they become involved in organised sports.

Table 1 Effects of body mass index (BMI) or body fat percentage (%BF) on injury risk in children and young adults

Subjects	Age (years)	N	Type of Injury	Effect of BMI or %BF	Comments	Reference
All children	9 to 17 ♂♀	2363	All injuries	Obese versus non-obese OR 1.42 (1.13 to 1.79) p = 0.003	Retrospective recall of injuries in previous year; injury prevalence 44.3% in obese versus 35.9% in non-obese; injuries in sport and non-sport activities combined	Bazelmans *et al*[13]
All children	6 to 11 ♂♀	938	Dental injuries	Obese versus non-obese OR 1.45 (1.08 to 1.94) p = 0.01	Retrospective comparison of evidence of prior dental injury in obese (30.8% injured) versus non-obese (20% injured; prior exposure to high risk activities (eg, sport) was protective	Petti *et al*[14]
All children	5 to 19 ♂♀	180	Ankle sprains	Obese* versus normal weight OR 3.26 (1.86 to 5.72) p<0.001	Case control study of prevalence of obesity in emergency department cases (ankle sprain) versus control (fever, headache, sore throat); 36% of ankle sprain group were obese versus 20% in control group	Zonfrillo *et al*[17]
All children	11 to 18 ♂♀	3294	All injuries	♀Obese versus non-obese OR 2.61 (1.16 to 5.91) p<0.05	Prospective comparison of injuries occurring at school in obese versus non-obese girls and boys; ♂no effect of BMI on injury risk; ♀effect not specific to sport	Chau *et al*[15]
American football	15 to 18 ♂	152	Ankle sprains	Overweight* versus normal weight OR 2.01 (0.5 to 8.5);	Prospective comparison of injuries per 1000 exposures in normal weight (0.52 injuries), overweight (1.05) and obese (2.03) football players; risk increased 19 fold with combination of obesity and previous ankle sprain	Tyler *et al*[5]
				Obese* versus normal weight OR 3.9 (1.0 to 15.1); linear effect p = 0.04		
American football	15 to 18 ♂	98	All injuries	Obese* versus non-obese OR 2.3 (CI not reported) p<0.05	Prospective comparison of injuries per player per season in obese (0.53 injuries) versus non-obese (0.23); body mass >90 kg versus <90 kg OR 2.5	Kaplan *et al*[22]
American football	8 to 15 ♂	653	All injuries	None	Prospective comparison of overweight and obesity prevalence in injured players (40.6%) versus the total sample (42.6%); no definition of injury, no measure of exposure	Malina *et al*[4]
American football	9 to 14 ♂	678	All injuries	None	Prospective study of injury incidence (total 10.4 per 1000 exposures); BMI compared between injured and uninjured players in each age group; injured 9–10 years old had lower BMI (p = 0.05)	Malina *et al*[3]
American football	14 to 19 ♂	215	Lower extremity injuries	BMI⩾30 versus <30 OR 2.7†	Prospective comparison of injuries per 1000 h across BMI cut-off points (total injuries 5.7); only linemen studied, mean BMI 30.7, %BF 25.7%	Gómez *et al*[18]
				%BF⩾25 versus <25 OR 2.0† (CI not reported) p<0.05		
High school athletes	14 to 19 ♂♀	2721	All injuries	BMI 50–90th pct versus 10th pct OR 1.52 (1.06 to 2.17)‡	Retrospective recall of prior injury compared across BMI groups; 65.7% of subjects reported an injury in prior year; BMI>90th percentile no effect	Rose *et al*[16]
Military recruits	18 (SD 3) ♂♀	1210	All injuries	Overweight* versus normal weight OR 1.48 (1.12 to 1.96)	Retrospective comparison of injury prevalence between normal weight, overweight and obese subjects; most obese subjects played American football	Billings[19]
				Obese* versus normal weight OR 3.44 (1.94 to 6.09) p<0.05		
Military recruits	95% 18 to 22 ♂	912	All injuries	Upper BMI quintile versus Middle quintile RR 1.91 (1.27 to 2.87) p<0.01	Prospective comparison of injuries per 100 conscript-months in BMI quintiles; BMI higher in older subjects, results not directly applicable to children	Heir and Eide[20]
Military recruits	21 (SD 4) ♂	310	All injuries	♂ upper BMI quartile versus 2nd quartile RR 3.4 (1.3 to 9.4) p = 0.02	Prospective comparison of injury prevalence across BMI quartiles (Q1 25.8%, Q2 9.4%, Q3 13.8%, Q4 32.3% injured); ♂%BF upper quartile RR 2.4 p = 0.09; ♀no effect of BMI or %BF	Jones *et al*[21]
	20 (SD 3) ♀					

*The terms "overweight" and "obese" are used here instead of the terms "at risk of overweight" and "overweight," which were used in the original reference (see earlier introductory section for explanation and definitions).
†Values estimated from figures.
‡Values averaged from reported data for subgroups.
OR, odds ratio; Pct, percentile; RR, relative risk (95% CIs in parentheses).

Table 2 Proposed mechanisms by which obesity increases injury risk

Predominant injury	Proposed mechanism
Dental injury	Poorly adapted to "trauma-predisposing behaviour" due to low physical activity level[14]
Acute Traumatic	Impaired postural control; moods disorders[15]
Overuse Injuries	Higher relative musculoskeletal strain during weight bearing activities for subjects with higher BMI[20]
Overuse and acute injuries	Poor physical fitness and low prior physical activity level[21]
Ankle sprains	Inability to control momentum during changes in direction[5]
Ankle sprains	Impaired balance ability[17]

POTENTIAL PREVENTIVE MEASURES

Reducing injury risk for overweight and obese young athletes may be achieved by interventions that address three specific areas, weight loss, improved physical fitness and improved neuromuscular coordination/postural stability. With respect to weight loss interventions, the primary approach is a combination of diet, exercise and behaviour modification, with pharmacological and surgical treatments being more extreme approaches.[30] Diet, exercise and behaviour modification may be more successful in the overweight young athlete compared with the non-athlete given the potential higher level of motivation if the weight loss intervention is seen as a strategy to improve athletic performance. Similarly, achieving improvements in physical fitness may be easier in overweight young athletes than in non-athletes, since there will be specific fitness requirements for particular sports. However, intervention studies aimed at reducing risk of injury in overweight athletes are lacking.

From a practical perspective, an effective intervention to reduce injury risk in overweight and obese young athletes might be to introduce balance training as part of individualised training. McHugh *et al*[26] trained high school American football players deemed to be at risk of sustaining an ankle sprain on a rubber stability pad. The stability training was targeted at players who were overweight or who had a history of previous ankle sprains. The training was incorporated into the players' weight training programme by adding a dedicated balance training station. In other sports such as volleyball, balance boards have been placed at the side of the court for players to train on during breaks in practice.[31] Not only are these types of balance training interventions effective at reducing injuries but also they are inexpensive to implement and have a high compliance. A balance training intervention for overweight and obese young athletes may be effective in reducing the increased risk of injury associated with a high BMI without having to address the wider societal issues of excessive adiposity, poor cardiorespiratory fitness and low physical activity.

LONG-TERM CONSEQUENCES OF INJURY

The increased risk of injury in obese and overweight children and adolescents may be compounded by a more prolonged recovery. Timm *et al*[32] found that long-term ankle morbidity after an acute ankle injury was much more prevalent among children with a higher BMI. Obese and overweight children were more than twice as likely to have persistent swelling and pain. Approximately 33% of overweight and obese children had persistent swelling and pain compared with only 15% of children with lower BMIs. Marchi *et al*[33] previously reported that more than 20% of children sustaining acute ankle sprains can be expected to have permanent sequelae associated with the injury (permanent defined as problems persisting at 12-year follow-up). Increased morbidity following acute injury in overweight and obese children has the potential to create a vicious cycle; injury risk is increased by the combination of a high BMI, poor cardiorespiratory fitness and low physical activity, recovery is compromised by being overweight, prolonged recovery further decreases fitness, and the forced relative inactivity further increases BMI.

Considering that obesity and low cardiorespiratory fitness are risk factors for many chronic illnesses, such as heart disease and diabetes, forced inactivity due to the prolonged effects of injury in obese children may have dire consequences. Therefore, interventions that focus on the specific rehabilitation needs of overweight young patients are critical. In this regard, aggressive early management of swelling may be an important target for treatment. Persistent inflammation following joint injury has deleterious effects on articular cartilage.[34] Overweight and obese children have persistent swelling and pain following ankle injury,[32] and this might reflect a prolonged inflammatory response to injury. Considering that obesity is a strong risk factor for the development of osteoarthritis[35] and that childhood obesity is associated with elevations in systemic inflammatory markers such as C reactive protein and interleukin-6 (IL-6),[36 37] effective management of postinjury joint inflammation may be more important in overweight young patients with acute joint injuries. Physical modalities for controlling joint swelling, such as cryotherapy and electrical stimulation combined with compression and elevation, may need to be applied more frequently or for longer durations for the overweight patient. Additionally, progression of weight bearing or other joint compressive loading may need to be delayed. However, it may be equally important to avoid prolonged joint immobilisation in order to avoid deleterious effects on articular cartilage.[38] Furthermore, immobilisation has been shown to have a proinflammatory effect, while continuous passive motion has been shown to have an anti-inflammatory effect.[39] Therefore, for joint injuries, such as ankle sprains, overweight and obese patients may benefit from (1) increased provision of supervised physical therapy emphasising modalities that control swelling, (2) longer periods of non-weight-bearing with slower progression of partial weight-bearing and (3) continuous passive motion or other low load cyclic joint motion.

Growth and development in the overweight young athlete

An additional concern for the overweight young athlete is that being overweight is associated with elevations in systemic inflammatory markers[36 37] and that proinflammatory cytokines can inhibit anabolic hormones associated with growth and development.[40] In non-obese wrestlers, intense training results in elevations in inflammatory cytokines and depression of anabolic mediators.[41 42] These effects are reversed when intense training ceases.[42] The effect of obesity on the anabolic hormonal response to exercise and training in children has not been studied extensively. Acute exercise-induced elevations in growth hormone are attenuated in obese children versus normal weight children,[43] but it is unknown if such effects impair adaptations to exercise training.

FURTHER RESEARCH

Large-scale prospective studies are needed to quantify the relationship between obesity and injury risk in youth sports. Studies with sufficient sample size and diversity can quantify sports-, gender- and injury-specific effects. Additionally, time-based measures of athletic exposures are needed to accurately document injury incidence, and as a basis for analysing risk

What is already known on this topic

- The prevalence of overweight and obesity is increasing in children and adolescents, while physical activity and cardiorespiraory fitness are decreasing.
- The long-term health consequences of overweight and obesity are well recognised; however, the associated injury risks are not well documented.

What this study adds

- Overweight and obese children and adolescents are at increased risk of sustaining an injury during sport or physical activity compared with normal weight children and adolescents.
- Increased risk of injury has been attributed to impaired postural control secondary to excessive body mass relative to height.
- Stability training may be an effective intervention to decrease the injury risk associated with overweight and obesity.

factors and injury-prevention interventions. Once the magnitude of the problem is established for a particular sport and particular types of injuries, specific injury-prevention interventions can be designed and tested. The possibility that overweight young athletes have a protracted recovery from injury and are at increased risk for residual symptoms needs to be examined.

Conclusions

Based on a growing volume of diverse literature, it appears that overweight and obese adolescents are at increased risk of injury in sports and general physical activity. The exact mechanism of increased risk has not been established, but a general consensus is that impairment in postural stability is an important factor. Balance training is a viable intervention to reduce the injury risk associated with being overweight or obese.

Competing interests: None.

Provenance and peer review: Commissioned; externally peer reviewed.

REFERENCES

1. **Flegal K,** Tabak C, Ogden C. Overweight in children: definitions and interpretation. *Health Educ Res* 2006;**21**:755–60.
2. **Ogden C,** Carroll M, Flegal K. High body mass index for age among US children and adolescents, 2003–2006. *JAMA* 2008;**299**:2401–5
3. **Malina R,** Morano P, Barron M, *et al*. Incidence and player risk factors for injury in youth football. *Clin J Sport Med* 2006;**16**:214–22.
4. **Malina RM,** Morano PJ, Barron M, *et al*. Overweight and obesity among youth participants in American football. *J Pediatr* 2007;**151**:378–82.
5. **Tyler T,** McHugh M, Mirabella M, *et al*. Risk factors for noncontact ankle sprains in high school football players. *Am J Sports Med* 2006;**34**:471–5.
6. **Cole T,** Bellizzi M, Flegal K, *et al*. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ* 2000;**320**:1240–3.
7. **Lobstein T,** Jackson-Leach R. Child overweight and obesity in the USA: prevalence rates according to IOTF definitions. *Int J Pediatr Obes* 2007;**2**:62–4.
8. **Jackson-Leach R,** Lobstein T. Estimated burden of paediatric obesity and co-morbidities in Europe. Part 1. The increase in the prevalence of child obesity in Europe is itself increasing. *Int J Pediatr Obes* 2006;**1**:26–32.
9. **Brownson RC,** Boehmer TK, Luke DA. Declining rates of physical activity in the United States: what are the contributors? *Annu Rev Public Health* 2005;**26**:421–43.
10. **Wedderkopp N,** Froberg K, Hansen HS, *et al*. Secular trends in physical fitness and obesity in Danish 9-year-old girls and boys: Odense School Child Study and Danish substudy of European Youth Heart Study. *Scand J Med Sci Sports* 2004;**14**:150–5.
11. **Centers for Disease Control and Prevention (CDC)**. Participation in high school physical education—Ontario, Canada, 1995–2005. *MMWR Morb Mortal Wkly Rep* 2007;**56**:52–4.
12. **Comstock RD,** Knox C, Yard E, *et al*. Sports-related injuries among high school athletes—United States, 2005–06 school year. *Morb Mortal Wkly Rep* 2006;**55**:1037–40.
13. **Bazelmans C,** Coppieters Y, Godin I, *et al*. Is obesity associated with injuries among young people? *Eur J Epidemiol* 2004;**19**:1037–42.
14. **Petti S,** Cairella G, Tarsitani G. Childhood obesity: a risk factor for traumatic injuries to anterior teeth. *Endod Dent Traumatol* 1997;**13**:285–8.
15. **Chau N,** Prédine R, Aptel E, *et al*. School injury and gender differentials: a prospective cohort study. *Eur J Epidemiol* 2007;**22**:327–34.
16. **Rose MS,** Emery CA, Meeuwisse WH. Sociodemographic predictors of sport injury in adolescents. *Med Sci Sports Exerc* 2008;**40**:444–50.
17. **Zonfrillo MR,** Seiden JA, House EM, *et al*. The association of overweight and ankle injuries in children. *Ambul Pediatr* 2008;**8**:66–9.
18. **Gómez JE,** Ross SK, Calmbach WL, *et al*. Body fatness and increased injury rates in high school football linemen. *Clin J Sport Med* 1998;**8**:115–20.
19. **Billings CE.** Epidemiology of injuries and illnesses during the United States Air Force Academy 2002 Basic Cadet Training Program: Documenting the Need for Prevention. *Mil Med* 2004;**169**:664–70.
20. **Heir T,** Eide G. Age body composition, aerobic fitness and health condition as risk factors for musculoskeletal injuries in conscripts. *Scand J med Sci Sports* 1996;**6**:222–7.
21. **Jones BH,** Bovee MW, Harris JM 3rd, *et al*. Intrinsic risk factors for exercise-related injuries among male and female army trainees. *Am J Sports Med* 1993;**21**:705–10.
22. **Kaplan TA,** Digel SL, Scavo VA, *et al*. Effect of obesity on injury risk in high school football players. *Clin J Sport Med* 1995;**5**:43–7.
23. **Murray AW,** Wilson NI. Changing incidence of slipped capital femoral epiphysis. *J Bone Joint Surg Br* 2008;**90**:92–4.
24. **Deforche BI,** Hills AP, Worringham CJ, *et al*. Balance and postural skills in normal-weight and overweight prepubertal boys. *Int J Pediatr Obes* 2009;**4**:175–82.
25. **D'Hondt E,** Deforche B, Bourdeaudhuij ID, *et al*. Childhood obesity affects fine motor skill performance under different postural constraints. *Neurosci Lett* 2008;**440**:72–5.
26. **McHugh MP,** Tyler TF, Mirabella MR, *et al*. The effectiveness of a balance training intervention in reducing the incidence of noncontact ankle sprains in high school football players. *Am J Sports Med* 2007;**35**:1289–94.
27. **Wedderkropp N,** Kaltoft M, Lundgaard B, *et al*. Prevention of injuries in young female players in European team handball: a prospective intervention study. *Scand J Med Sci Sports* 1999;**9**:41–7.
28. **Tropp H,** Askling C, Gillquist J. Prevention of ankle sprains. *Am J Sports Med* 1985;**13**:259–62.
29. **Myklebust G,** Engebretsen L, Braekken IH, *et al*. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med* 2003;**13**:71–8.
30. **Durant N,** Cox J. Current treatment approaches to overweight in adolescents. *Curr Opin Pediatr* 2005;**17**:454–9.
31. **Bahr R,** Lian O, Bahr IA. A twofold reduction in the incidence of acute ankle sprains in volleyball after the introduction of an injury prevention program: a prospective cohort study. *Scand J Med Sci Sports* 1997;**7**:172–7.
32. **Timm NL,** Grupp-Phelan J, Ho ML. Chronic ankle morbidity in obese children following an acute ankle injury. *Arch Pediatr Adolesc Med* 2005;**159**:33–6.
33. **Marchi AG,** Bello DD, Messi G, *et al*. Permanent sequelae in sports injuries: a population based study. *Arch Dis Child* 1999;**81**:324–8.
34. **Green DM,** Noble PC, Bocell JR, *et al*. Effect of early full weight-bearing after joint injury on inflammation and cartilage degradation. *J Bone Joint Surg Am* 2006;**88**:2201–9.
35. **Powell A,** Teichtahl AJ, Wluka AE, *et al*. Obesity: a preventable risk factor for large joint osteoarthritis which may act through biomechanical factors. *Br J sports Med* 2005;**39**:4–5.
36. **Retnakaran R,** Hanley AJ, Connellyl PW, *et al*. Elevated C-reactive protein in Native Canadian children: an ominous early complication of childhood obesity. *Diabetes Obes Metab* 2006;**8**:483–91.
37. **Visser M,** Bouter LM, Mquillan GM, *et al*. Low-grade systemic inflammation in overweight children. *Pediatrics* 2001;**107**:E13.
38. **Vanwanseele B,** Lucchinetti E, Stüssi E. The effects of immobilization on the characteristics of articular cartilage: current concepts and future directions. *Osteoarthritis Cartilage* 2002;**10**:408–19.
39. **Ferretti M,** Srinivasan A, Deschner J, *et al*. Anti-inflammatory effects of continuous passive motion on meniscal fibrocartilage. *J Orthop Res* 2005;**23**:1165–71.
40. **Cooper DM,** Nemet D, Galassetti P. Exercise, stress, and inflammation in the growing child: from the bench to the playground. *Curr Opin Pediatr* 2004;**16**:286–92.
41. **Nemet D,** Kim HS, Cooper DM. Effects of intense exercise on inflammatory cytokines and growth mediators in adolescent boys. *Pediatrics* 2002;**110**:681–9
42. **Nemet D,** Pontello AM, Rose-Gottron C, *et al*. Cytokines and growth factors during and after a wrestling season in adolescent boys. *Med Sci Sports Exerc* 2004;**36**:794–800.
43. **Eliakim A,** Nemet D, Zaldivar F, *et al*. Reduced exercise-associated response of the GH-IGF-I axis and catecholamines in obese children and adolescents. *J Appl Physiol* 2005;**100**:1630–7.