BJSM Online First, published on November 22, 2013 as 10.1136/bjsports-2013-092790


# Total body fat percentage and body mass index and the association with lower extremity injuries in children: a 2.5-year longitudinal study

Eva Jespersen,[1] Evert Verhagen,[2] René Holst,[3] Heidi Klakk,[1] Malene Heidemann,[4] Christina Trifonov Rexen,[1] Claudia Franz,[1] Niels Wedderkopp[1,5]

[1]Centre for Research in Childhood Health, Institute of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark
[2]Department of Public and Occupational Health, EMGO+ Institute for Health and Care Research, VU University Medical Centre, Amsterdam, The Netherlands
[3]Biostatistical Research Unit, Institute of Regional Health Research, University of Southern Denmark, Odense, Denmark
[4]Hans Christian Andersen Children's Hospital, Odense University Hospital, Odense, Denmark
[5]Department of Orthopaedic, Hospital of Lillebaelt, Institute of Regional Health Service Research and Centre for Research in Childhood Health, IOB, University of Southern Denmark, Odense, Denmark

**Correspondence to**
Eva Jespersen, Centre for Research in Childhood Health, Institute of Sports Science and Clinical Biomechanics, University of Southern Denmark, Campusvej 55, 5230 Odense M, Denmark; ejespersen@health.sdu.dk

Accepted 26 October 2013

**To cite:** Jespersen E, Verhagen E, Holst R, *et al*. *Br J Sports Med* Published Online First: [*please include* Day Month Year] doi:10.1136/bjsports-2013-092790

## ABSTRACT

**Background** Overweight youths are generally recognised as being at increased risk of sustaining lower extremity injuries in sports. However, previous studies are inconclusive and choices for measuring overweight are manifold.

**Objective** To examine two different measures of overweight, body mass index (BMI) and total body fat percentage (TBF%), as risk factors for lower limb injuries in a school-based cohort.

**Study design** A longitudinal cohort study.

**Methods** A total of 632 school children, baseline age 7.7–12.0 years, were investigated. Whole body dual energy x-ray absorptiometry scans provided measures of TBF%. Measures of BMI were obtained by standard anthropometric methods. Musculoskeletal complaints were reported by parents answering weekly mobile phone text messages during 2.5 years. Injuries were diagnosed by clinicians. Leisure time sports participation was reported weekly using text messaging.

**Results** During 2.5 years of follow-up, 673 lower extremity injuries were diagnosed. Children being overweight by both BMI and TBF% showed the highest risk of sustaining lower extremity injuries (IRR 1.38 (95% CI 1.05 to 1.81)). Children who were overweight using BMI and TBF% showed the highest risk of sustaining lower extremity injuries (IRR 1.38 (95% CI 1.05 to 1.81)).

**Conclusions** The risk of lower extremity injuries appeared to be increased for overweight children. When comparing two different measures of overweight, overweight by TBF% is a higher risk factor than overweight by BMI. This suggests that a high proportion of adiposity is more predictive of lower extremity injuries, possibly due to a lower proportion of lean muscle mass.

## BACKGROUND

Injuries sustained in sports and leisure time activities have been established as a leading cause of the paediatric injury burden in Western countries.[1–5] These induce high direct and indirect costs for children and parents and may cause short-term disability, absence from school and/or physical activity (PA), lost enthusiasm for participating in PA and long-term consequences such as osteoarthritis.[6–11]

Both intrinsic and extrinsic risk factors have previously been investigated and some attention has been shown to body weight and body composition as a potentially modifiable risk factor on sport injury risk.[12 13] The importance is emphasised as overweight and obesity is affecting an increasing proportion of children globally.[14] Hence the paradox is that while PA is associated with numerous health benefits, including lowering the levels of overweight and obesity,[15] overweight might at the same time cause a rise in injury rates as the prevalence of overweight and obesity increases.

Overweight youths are generally considered as being at increased risk of sustaining lower extremity injuries in sports, due to a corresponding increase in the forces that joints, ligaments, tendons and muscular structures must endure.[16–18] However, findings in studies on the association between body composition and injuries are inconclusive and choices of measures of body composition have been varied, such as height and weight, lean muscle mass, body fat content and most commonly body mass index (BMI).[18]

Overweight and obesity should be defined as excess body fat. The most widely used measurement to define obesity is BMI. It is an indicator of overweight and obesity from a population perspective, but has limitations on an individual level and is only a proxy measurement of body fat.[19] The association between BMI and total body fat percentage (TBF%), especially in athletes, has been shown to be lower than in non-athlete controls.[20–23]

Moreover, the common use of BMI as a criterion measurement may be an issue when it involves physically active children. A high BMI might in that case be an expression of a high proportion of lean muscle mass, rather than overweight or 'unhealthy' weight. TBF% is a measure of adiposity and in the area of sports it has been shown to be a more precise measure for classification of overweight.[21–24]

Different mechanisms by which overweight increases the risk of injuries have been proposed. These include a relatively higher musculoskeletal strain and impaired postural control when controlling for a disproportionately large body mass in sport activities that require rapid alterations during changes in direction.[16] Poor physical fitness and low PA levels among overweight young people add to this risk.[15 16] Based on this, overweight caused by a high proportion of TBF% appears to be a more obvious risk factor than overweight caused by a high proportion of lean muscle mass. Overweight, defined by measures of TBF%, possibly associates differently with PA-related injuries than overweight defined by measures of BMI.

The objective of this study was to examine two different measures of overweight, BMI and TBF%, as risk factors for lower limb injuries in school children, followed for 2.5 years in a longitudinal setting, while considering the potential confounding effects of gender, age, fitness levels and exposure times in physical education (PE) and leisure time sports participation.

## MATERIAL AND METHODS

### Setting

Data from the Childhood Health, Activity, and Motor Performance School Study Denmark (CHAMPS Study-DK) August 2008 to July 2011 were used.[25] This investigation is a large prospective controlled school-based study in Denmark using the design of a natural experiment to evaluate the effect of increased levels of PE on childhood health in general.[26]

### Participants

All boys and girls from preschool to fourth grade in 10 public schools participating in the CHAMPS Study-DK also agreed to participate in the registration of musculoskeletal pain and injuries. The study was kept open, with the possibility for new children to enter. Owing to the novel data collection method of automated mobile phone text messaging, the schools were included gradually in order to allow for a phasing-in process.

A subsample of children attending second to fourth grade (age range 7.7–12.0 years) was invited to a dual energy X-ray absorptiometry (DXA) scan providing TBF% in 2008. Children were examined at baseline and at a 2-year follow-up. Height and weight were assessed at the same time points. Data on injuries and participation in organised sport were recorded from November 2008 to June 2011.

### Measurements

#### Musculoskeletal pain and injuries

Weekly information on musculoskeletal pain and injuries was measured using mobile phone text messaging. Each week, parents answered a text message asking questions on the presence or absence of musculoskeletal pain. A report of pain elicited a telephone consultation, to distinguish children with trivial complaints from those in need of clinical examination.

Physiotherapists, chiropractors or a medical doctor clinically examined the children during the coming fortnight and a standard medical record was performed. Injuries were diagnosed using the International Classification of Diseases (ICD-10), WHO.[27] If needed, the child was referred for further examination, such as X-ray, ultrasound or MR scans, or to consulting specialist doctors. Information on children being treated elsewhere during the study period, for example, emergency department, general practitioner, was collected concurrently to get a complete data collection on injuries in this cohort.

#### Physical activity

Weekly amount of PE was 4.5 h for children in sport schools and 1.5 h for children in normal schools, corresponding to three and one double lesson per week, respectively. Pupils at sport and normal schools were therefore assigned three and one sport exposure units per week, respectively. Leisure time sport was also assessed using text messaging, by parental reports on how many times the child had participated in leisure time sport activities during the past week.

#### Total body fat percentage

TBF% was measured by DXA (GE Lunar Prodigy, GE Medical Systems, Madison, Wisconsin, USA), ENCORE software (V.12.3, Prodigy; Lunar Corp, Madison, Wisconsin, USA).

TBF% was calculated for each participant from the equation: ((FM (g) × 100)/total body weight (g)). Cut-offs to classify children as normal weight or overweight were defined using the cardiovascular health-related and gender-related TBF% standards according to Williams *et al*.[28] The cut-off for overweight boys was ≥25 TBF% and a similar cut-off for girls was ≥30 TBF%.

#### Body mass index

Weight was measured to the nearest 0.1 kg on an electronic scale (Tanita BWB-800S, Tanita Corporation, Tokyo, Japan). Height was measured to the nearest 0.5 cm using a portable stadiometer (SECA 214, Seca Corporation, Hanover, Maryland, USA).

BMI was calculated as (weight (kg)/height$^2$ (m)). BMI classifications for normal weight, overweight and obese were defined using age-specific and sex-specific cut-offs as recommended by the International Obesity Taskforce recommendations.[29] Dichotomised categories were made for weight classes as normal weight or overweight/obese (hereafter referred to as overweight) for easier comparison with the dichotomous variable of normal weight versus overweight as described above.

#### Fitness level

Fitness was assessed by the Andersen test. This is a 10 min intermittent running test to estimate maximal oxygen uptake and indicate aerobic fitness.[30] The test was carried out indoors in 20 m running lanes marked by cones. Children were urged to run as quickly as possible for 15 s, then stopped for the next 15 s and this pattern was repeated for 10 min. The total distance measured in metres was the test result. The validity and reliability of this field test were tested and described thoroughly for the age group of our cohort in a study by Ahler *et al*.[31]

### Statistical methods

Data from the text messaging system and data on diagnosed injuries were analysed using STATA V.12.0 (StataCorp, Texas, USA).

Excessive levels of pain and the number of injuries were reported during the start-up-phase. This is possibly explained by the novelty of the study and the method. Observations from the first 4 weeks relative to the time of inclusion were therefore excluded.

The risk of getting injured according to absolute levels of baseline BMI and TBF% were explored. Furthermore, the potential effect of children changing body composition through the 2.5 years of injury surveillance was evaluated by a logistic regression using variables with 'no change', 'change to elevated BMI or TBF%' and 'change to normal BMI or TBF% values' as categories.

Concerns about children being underweight were addressed, as injury patterns could possibly be different in this group.[20 32] For this reason, the prevalence of underweight was determined in the baseline population, using the recommended cut-offs.[33 34] An initial analysis excluding the group of underweight children did not change the estimates of risk of injury or the estimated effect of other covariates. Underweight children were therefore not considered different from normal-weight children regarding the risk of injury. Hence, they were categorised as normal-weight children.

The calculation of incidence rates accounted for the total exposure expressed in 1000 athletic exposure units. These comprised the PE exposures and the participations in leisure time sport.

A multilevel mixed-effects Poisson regression was used to estimate the incidence-rate ratios (IRR) with BMI and TBF% as the

**Table 1** Sample characteristics in numbers (%) and means (±SD) measured by gender during 2.5 years of follow-up

| | Girls | Boys |
|---|---|---|
| Numbers | 321 (50.8%) | 311 (49.2%) |
| Age at baseline | 9.6 (0.9) | 9.6 (0.9) |
| Range | 7.9–11.6 | 7.7–12.0 |
| Baseline BMI | 16.7 (2.1) | 16.6 (2.1) |
| Baseline TBF% | 23.0 (7.4) | 17.1 (7.4) |
| Weekly exposure in PE and sports | 3.9 (1.3) | 3.9 (1.4) |
| Fitness level at baseline (metre) | 892.7 (89.2) | 967.8 (99.8) |
| Lower extremity injuries | | |
| Number of lower extremity injuries | 336 | 337 |
| Number of children with lower extremity injuries | 178 (55.5%) | 179 (57.6%) |

BMI, body mass index; PE, physical education; TBF%, total body fat percentage.

primary risk factors. BMI and TBF% were used as dichotomised variables (0=normal values, 1=elevated values) in separate regression analyses. For identification of groups of potential clinical interest, the four combinations of normal and elevated BMI with normal and elevated TBF% were likewise tested in a regression analysis, with normal BMI and normal TBF% being the reference groups.

Finally, BMI and TBF% were tested as continuous variables and used for illustrating the adjusted risk of lower extremity injuries in relation to the two measures of body composition.

The explanatory variables included gender, age, PE/leisure time sport and fitness levels. Classes and schools were used as random effects. The multilevel random effects model reflects the hierarchical sampling structure and was chosen to allow for potential variation between schools and between classes within schools and to ensure correct modelling of the variances. The number of weeks each child participated was included as an exposure term in the model.

Potential patterns for the missing values in injury data were addressed by a logistic regression analysis controlling for gender, age, school type and leisure time sports effects. Missing values because of practicalities concerning changed or wrong mobile numbers were dropped for analyses.

## RESULTS

A total of 632 children, aged 7.7–12 years at baseline, participated at baseline and the follow-up DXA scan and in the registration of musculoskeletal injuries. The mean baseline BMI was 16.6 (±SD 2.1) and TBF% was 20.1% (±SD 8.0). A total number of 673 lower extremity injuries were diagnosed during the 2.5 years of follow-up. Some children experienced more than one injury; the range was from zero and up to eight episodes of lower extremity injuries. The range of participation time in injury registration was 1–113 weeks, with 98.1 weeks being the mean value. Dropouts were due to children moving away from the municipality or changing to a non-project school, but were counterbalanced by new children moving to project schools. Fifteen children dropped out because answering SMS questions every week was too bothersome. An average weekly response rate of 96% was recorded during the study period of 113 weeks. A total number of 62 001 observations were recorded and 2502 (4%) were missing. The analysis of missing data did not show any patterns when looking at gender, age, school type and leisure time sports. The mean weekly sport exposures units in PE and leisure time sport were 3.9 (±SD 1.3) and fitness level at baseline had a mean of 930 8 m (±SD101.9). Differences in gender are presented in table 1.

The injury rates per 1000 athletic exposures showed a trend, albeit not significant, towards higher risk for children being overweight, whether defined by BMI or by TBF%. Injury rates, 95% CI and gender differences are described in table 2.[28 29]

The multivariate and multilevel adjusted IRR estimates by different measures of overweight are summarised in table 3. Overweight children were generally at higher risk of sustaining lower leg injuries, by BMI: 1.28 (95% CI 0.98 to 1.66) and by TBF% 1.34 (95% CI 1.07 to 1.68), the latter being statistically significant.

Looking at the four combined groups of body composition, children with elevated BMI and TBF% showed the highest risk of sustaining lower leg injuries: 1.38 (95% CI 1.05 to 1.81) relative to children having a normal BMI and a normal TBF% (figure 1).

The possible effect of children changing body composition during the 2.5 years of injury surveillance was also accounted for in the adjusted analysis; it did not explain the risk of lower extremity injuries, and nor did it influence the estimated effects of other covariates.

Gender and age did not influence the risk, whereas the time participating in PE and leisure time sport and fitness level explained some of the lower extremity injury risk. The risk of injury significantly increased for each additional time a child participated in PE and leisure time sport from 0 to 6.5 weekly exposure units. For the 18 children with a mean of more than 6.5 exposures a week, the risk again decreased. A positive linear relationship was found between risk of lower extremity injuries and aerobic fitness.

The adjusted risk of lower extremity injuries in relation to the two measures of body composition measured on a continuous scale are illustrated in figure 2 for girls and boys. A positive linear relationship was found between risk of lower extremity injuries and the continuous values of TBF% and BMI across the full range.

**Table 2** Lower extremity injury rates by BMI/TBF% groups, overall and by gender

| Lower extremity injuries Injury rate (CI)* | BMI† | | TBF%‡ | |
|---|---|---|---|---|
| | Normal BMI | Overweight by BMI cut-offs | Normal TBF% | Overweight by TBF% cut-offs |
| Overall | 4.4 (4.1 to 4.8) | 5.3 (4.1 to 6.5) | 4.4 (4.0 to 4.7) | 5.2 (4.3 to 6.1) |
| Girls | 4.4 (3.9 to 4.9) | 5.1 (3.6 to 6.5) | 4.3 (3.8 to 4.8) | 5.2 (4.0 to 6.5) |
| Boys | 4.4 (3.9 to 4.9) | 5.8 (3.7 to 7.9) | 4.4 (3.9 to 4.9) | 5.1 (3.7 to 6.6) |

*Injury rate is per 1000 athletic exposures; values in parentheses are 95% CI.
†Age-specific and gender-specific cut-offs according to IOTF/Cole *et al*.[29]
‡Cut-offs boys ≥25%, girls ≥30% according to Williams *et al*.[28]
BMI, body mass index; TBF%, total body fat percentage.

**Table 3** Incidence-rate ratio estimates by different body composition measures, adjusted for age, gender, physical education/leisure time sport and fitness level

| | BMI IRR (95% CI) | TBF% IRR (95% CI) |
|---|---|---|
| Normal weight | 1.00 | 1.00 |
| Overweight | 1.28 (0.98 to 1.66) | 1.34 (1.07 to 1.68)* |

*Statistical significance based on p<0.05%.
BMI, body mass index; IRR, incidence-rate ratio; TBF%, total body fat percentage.

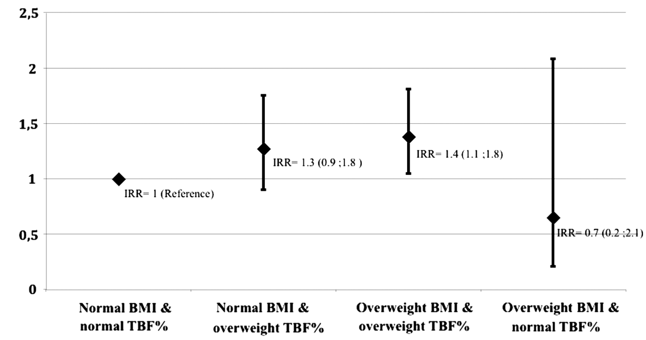


**Figure 1** Incidence-rate ratio estimates (95% CI) by four groups of body compositions, adjusted for age, gender, physical education/leisure time sport and fitness level (BMI, body mass index; IRR, incidence-rate ratio; TBF%, total body fat percentage).

## DISCUSSION

This study is the first to evaluate and compare two different measures of overweight as risk factors for lower extremity injuries in a school-based cohort of children. The risk of lower extremity injuries was observed to increase in overweight children. Being overweight measured by TBF% or a combination of elevated TBF% and BMI was more predictive than being overweight measured by BMI. This suggests that a high proportion of adiposity is more predictive of lower extremity injuries, possibly due to a lower proportion of lean muscle mass.

In contrast, Kaplan *et al*[35] found that body weight was a more powerful injury risk factor than adiposity, with no differences in injury risk between linemen and non-linemen in American football. This was shown in a study comparing different measures of body composition (body fat, BMI, weight, height) to injury risk in a group of 98 high school players with 28 injuries registered by trainers. This was reproduced in another American football study reporting injury rates by body fat, weight, BMI and lean body mass in high school football linemen,[36] whereas adiposity expressed as TBF% was a stronger predictor of the magnitude and type (overuse/traumatic) of musculoskeletal injuries in army cadets than BMI.[37] Direct comparisons may not be relevant because of differences in techniques to measure TBF%, injury registration methods, magnitudes of studies, ages and sports specific versus more heterogenic settings. Still, it is possible that in some sports, the effect of increased mechanical loading during weight bearing or collisions has a more pronounced effect than in other sports.

Injury patterns might also differ in relation to different injury types. Traumatic injuries provoked and/or aggravated by greater collision forces due to heavy weight could be argued to be independent of the muscle/fat distribution to a greater extent than overuse injuries, where the quality of tissue (eg, muscle strength and endurance) is important. The effect of overweight in relation to different injury types (overuse/traumatic), different diagnoses, different anatomical regions and different sports still needs to be clarified.

In this study, injury risk increased with increased participation in PE and leisure time sport. This is in accordance with the common understanding of the need to consider exposure time when estimating injury risk. Surprisingly, children with high fitness levels had a higher risk of sustaining lower extremity injuries. This is in contrast to earlier beliefs where lower fitness levels have been associated with muscle fatigue and subsequent injury.[38] A possible explanation could be that children with high aerobic capacities are also the children with the largest amount of exposure time. Even though analyses were carried out with adjustment for exposure time in terms of PE and leisure time sports, there may have been uncaptured exposure time in the most aerobically fit, as unorganised leisure time activity was unknown.

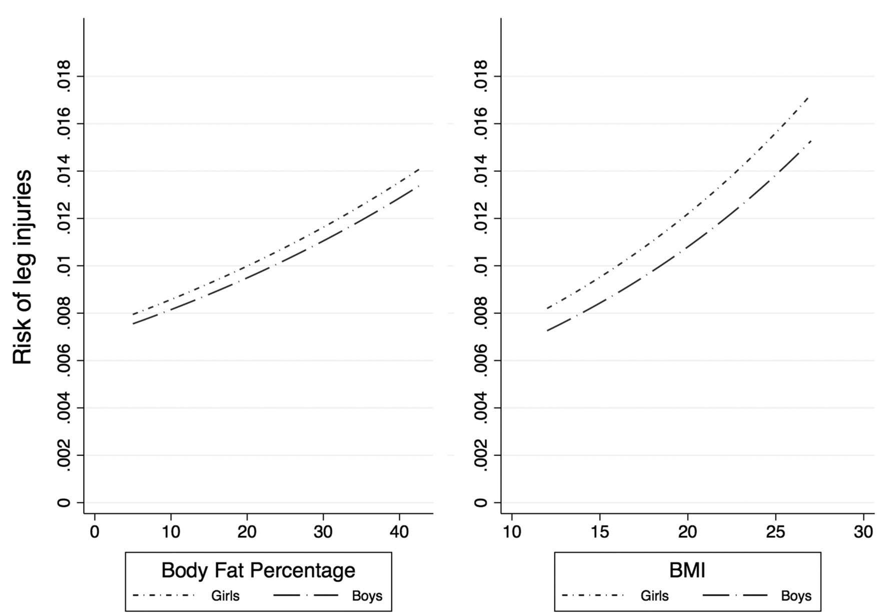


**Figure 2** Adjusted risk of lower extremity injuries by different measures of body composition in girls and boys (BMI, body mass index).

Cut-offs to classify children as normal weight or overweight were defined using cardiovascular health-related and gender-specific TBF% standards[28] and age-specific and gender-specific centiles from a pooled international dataset, linked to adult cut-offs for BMI classifications.[29] It can be questioned if these criteria have the same relevance in injury risk research, but they permit comparison across studies and contribute to a general evaluation of health risk among overweight children. The presentation of data in figure 2 does not suggest any obvious cut-off for a significant increase in risk of lower extremity injuries in relation to overweight. Specific overweight cut-offs for being at increased injury risk might be less important in the context of injury prevention, especially at an individual level where a more comprehensive screening of body composition involving an expression of TBF% would be more relevant.

## CONCLUSION

The risk of lower extremity injuries in a heterogenic cohort of schoolchildren was shown to increase in overweight children. When comparing two different measures of overweight, a body composition of proportionally high levels of TBF% is a higher risk factor than overweight as measured by BMI. This suggests that a high proportion of adiposity is more predictive of lower extremity injuries, possibly due to a lower proportion of lean muscle mass.

Increased levels of PE and leisure time sports participation and fitness were also associated with increased risk of lower extremity injuries.

### What are the new findings?

- This study is the first to evaluate and compare two different measures of overweight as risk factors for lower extremity injuries in a school-based cohort of children.
- Overweight children have an increased risk of lower extremity injuries.
- Overweight by measures of total body fat percentage is more predictive of lower leg injuries in children than overweight by measures of body mass index.

### How might it impact on clinical practice in the near future?

- Injury prevention in children and adolescents should involve a screening of body composition involving an expression of total body fat percentage. While dual energy X-ray absorptiometry scans are expensive and not feasible in most settings, a measurement method such as waist circumference is cheap and easy to obtain.
- Further research is needed into the proposed underlying mechanisms for overweight children being at increased injury risk. Previously suggested mechanisms have been poor postural control—leading to problems with balance and co-ordination, poor physical fitness—associated with muscle fatigue, and subsequent injury and low preparticipation physical activity levels—associated with impaired neuromuscular and motor learning.

**Acknowledgements** The authors wish to acknowledge K Froberg and LB Andersen, Centre for Research in Childhood Health, University of Southern Denmark. The authors would like to thank the participants and their parents and the participating schools, The Svendborg Project and the municipality of Svendborg. Finally, the authors wish to acknowledge the members of the CHAMPS Study-DK not listed as coauthors of this paper: T Junge and NC Møller.

**Contributors** NW was responsible for the overall study concept and design. HK and MH were responsible for the acquisition of the body composition data. EJ, CTR, CF and NW were responsible for the acquisition of injury data. EJ, EV, RH and NW were responsible for the analysis and interpretation of data. EJ drafted the manuscript. All authors took part in a critical revision of the manuscript. RH provided statistical expertise. NW obtained the funding.

**Funding** This study was supported by grants from The IMK Foundation, The Nordea Foundation, The TRYG Foundation—all private, non-profit organisations, which support research in health prevention and treatment, and TEAM Denmark, the elite sport organisation in Denmark, that provided the grant for the text messaging system.

**Competing interests** None.

**Ethics approval** Written informed consent was obtained from the child's parent, including verbal acceptance from the parent and the child prior to every clinical examination for diagnosing injuries and medical record keeping. All participation in the data collection was voluntary with the option to withdraw at any time. The study was approved by the Ethics Committee for the region of Southern Denmark (ID S20080047)

**Provenance and peer review** Not commissioned; externally peer reviewed.

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*Br J Sports Med* published online November 22, 2013
doi: 10.1136/bjsports-2013-092790

**Notes**