Review Paper:

Body Composition Role in Predicting Sports Injuries: A Systematic Review

Farahnaz Amirshaghaghi[1*], Parisa Pournemati[1], Shahrzad Zandi[2]

1. Department of Sports Physiology, Faculty of Physical Education, University of Tehran, Tehran, Iran.
2. Department of Health and Sports Medicine, Faculty of Physical Education and Sport Sciences, University of Tehran, Tehran, Iran.

Use your device to scan and read the article online

Citation Amirshaghaghi F, Pournemati P, Zandi S. Body Composition Role in Predicting Sports Injuries: A Systematic Review. Journal of Exercise Science and Medicine (JESM). 2019; 11(2):71-80. http://dx.doi.org/10.32598/JESM.11.2.3

http://dx.doi.org/10.32598/JESM.11.2.3

Article info:
Received: 10 Feb 2019
Accepted: 05 Jun 2019
Available Online: 01 Jul 2019

Keywords:
Body composition, Risk factor, Sports injury, Prevention

ABSTRACT

Introduction: This study aimed to review the literature on the role of body composition as a risk factor for injury in athletic people.

Methods: We searched articles in English in Google Scholar, Science Direct, PubMed, Web of Science, Scopus, ProQuest, and Cochrane Library databases without a time limit until 2020 using keywords related to “body composition” and “sports injury”.

Results: Based on the inclusion and exclusion criteria, 10 papers out of 1322 studies were comprehensively reviewed. It was found that body composition components are related to musculoskeletal injuries in the athletic population. Body mass index, weight, and bone density are found as risk factors in the development of sports injuries.

Conclusion: This systematic review provides preliminary evidence of the association between body composition and the prediction of injury in athletes. Defects in various aspects of body composition were recognized as potential risk factors for lower extremity injuries. Likewise, body composition should be considered in screening athletes.

Introduction

While physical activity is recommended as a beneficial healthy behavior, participation in sports and physical activities brings the risk of musculoskeletal injury [1]. Also, the costs of physical activity injuries are relatively high. In the Netherlands, for example, one in six injuries during sports generates indirect costs attributable to the inability to attend work, which is estimated to cost $525 million a year [2]. Injury is likely to happen when the stress exerted on a tissue exceeds its capacity to sustain that stress. Injury is the outcome of complex interactions between internal and external risk factors [3]. Striking a balance between absorbed and applied stress is usually essential for injury prevention programs. One of the most challenging issues in

* Corresponding Author:
Farahnaz Amirshaghaghi, PhD.
Address: Department of Sports Physiology, Faculty of Physical Education, University of Tehran, Tehran, Iran.
Tel: +98 (912) 4337828
E-mail: famirshaghaghi@ut.ac.ir

sports is injury prediction and it is considered as a key component of injury prevention because the successful detection of a risk predictor prepares the ground for the adoption of effective preventive measures. On the other hand, ensuring safety in sports and other forms of physical activity is a prerequisite for sustained engagement in sports and preservation of a healthy and active lifestyle. Accordingly, the prevention, reduction, and control of internal risk factors are major goals for sports specialists in particular and the society in general. A key factor in preventing sports injuries is identifying risk factors and causes of the injury [3].

Abnormal body composition is a known risk factor for many diseases, including cardiovascular disease [4], chronic kidney disease [5], and type 2 diabetes [6]. Musculoskeletal disorders associated with abnormal body composition are often attributed to elevated mechanical load [7], which by repeated micro-trauma in tissues can eventually cause acute and chronic damage. For example, one of the musculoskeletal injuries, tendon injury, is increasingly recognized as a major cause of complications in the labor force [8] as well as in the active [9] and inactive [9] people. Abnormal body composition may also be related to poor fitness (e.g. strength and endurance) and poor neuromuscular control, such as coordination and balance, which increases the risk of injury. Given the growing tendency to engage in any type of physical activity, it is essential to appreciate the predictors of sports injury so that proper interventions can be designed and adopted to decrease the risk of injury [3]. Therefore, the purpose of this systematic review is to look into the role of body composition as a risk factor for the prediction of sport injuries.

Materials and Methods

Criteria for selecting articles

After searching several databases, all identified articles were initially added to the Endnote software and the duplicates were removed. Afterward, all titles and abstracts were reviewed to identify articles relevant to the research topic. The inclusion criteria involved studies that predicted injury or examined risk factors, their study population had physical activity (athlete) or any sporting experiences (such as recreational, university, professional, etc. sports), their participants also had a history of lower or upper extremity injuries and at least one of the risk factors consisted of body composition or related components. The exclusion criteria covered research that failed to state the main idea, including review studies, expert opinions, and studies that were under current reviews such as annual meetings, Master's theses, and animal studies. The excluded articles were discussed by two researchers and any dispute was settled by the head of the group. After reviewing the abstracts, the full text of the articles was studied and categorized independently by two researchers for eligibility.

Search strategy

Articles in English were searched in databases of Google Scholar, Science Direct, PubMed, Web of Science, Scopus, ProQuest, Cochrane Library without time limit until 2020 using keywords such as "body composition", "waist circumference", "body mass index", "air-plethysmography chamber", "dual-energy x-ray", "DXA", "skinfold", "caliper", "fat-free mass", "total body fat", "lean body mass", "fat-free bone", "fat-free adipose tissue", "fat-free muscle", "waist-to-hip ratio", "lower extremity injuries", "upper extremity injuries", "sports injury", "risk factors", "prediction", "sport", and "prospective studies".

Many studies tend to use Body Mass Index (BMI) to assess body composition. Other assessments of body compositions such as waist-to-hip ratio and waist circumference are also employed to determine body composition. Modalities such as imaging and Dual-energy X-ray Absorptiometry (DXA) are rarely used in research due to their high cost. In light of the above, we utilized the above-discussed methods in this study without considering any restrictions in terms of time and language for studies. Articles not written in English or Persian were translated via Google Translate.

Data extraction

In the present study, the study topic was studied in several stages, and the findings were collected, analyzed, and interpreted according to PRISMA (the preferred reporting items for systematic reviews and meta-analyses) [10] (Figure 1). Results pertained to body composition and injury were extracted from the relevant studies.

Quality control

To evaluate the quality of the selected studies, the adjusted checklist of the Cochrane screening and diagnostic tests methods group (Cochrane methods) was used [11]. Two researchers evaluated the quality of articles and 11 items were reviewed [12].

The 11 items assessed in this paper were as follows: "study design" (1 for prospective and 0 for retrospective); "level of evidence" (5 for level 1, 4 points for level 2, 3 points for level 3, 2 points for level 4, 1 point for level 5); "selection criteria" (1 point for clear explanation of the inclusion and exclusion criteria); "setting" (1 point for presenting sufficient information to pinpoint setting); "demographic information" (1 point for assessing mean, median, and standard deviation, and reporting age and gender); "screening tool" (1 point for details of screening tool that enable duplication of the test as well as details of test device or instruments, and protocols of screening); "statistical analysis" (1 point if there are details on mean, median, standard deviation, confidence intervals and predictive value); "screening test's reliability" (1 point if reliability has been reported); "percentage missing" (1 point if all subjects have been measured or missing data or withdrawals have been reported); "outcome" (1 point for a clear definition of methods used for discussing outcomes); "confounders" (1 point for identifying and considering key confounders and prognostic factors in the design study). Hence, ideally, a total score of 16 could be attained. Given the absence of any guidelines on rating scores, we considered four categories: excellent quality (16 points), good quality (14–16 points), fair quality (10–13 points), and poor quality (<10 points).

Results

A total of 1322 articles were identified after searching the above keywords in different databases. Then, after removing duplicates (705 articles), 74 articles were opted for abstract review. Based on the inclusion and exclusion criteria, 22 full-text articles were obtained. Twelve articles were omitted from the review process because they did not meet our criteria [12]. Finally, 10 articles were selected for a comprehensive review (Figure 1).

The body composition components commonly used to predict injury in these articles were BMI, with other components such as waist circumference, waist-to-hip ratio, imaging, and DXA were rarely used in these studies. The BMI classification is primarily based on the recommendations made by the World Health Organization.

In articles examined in our review, a wide array of sports had been considered. As far as the demographics are concerned, research had chiefly focused on male athletes. Besides, studies often investigated team sports and individual sports received little attention. The bulk of research dealt with professional athletes and scant attention had been dedicated to amateur or non-professional athletes.

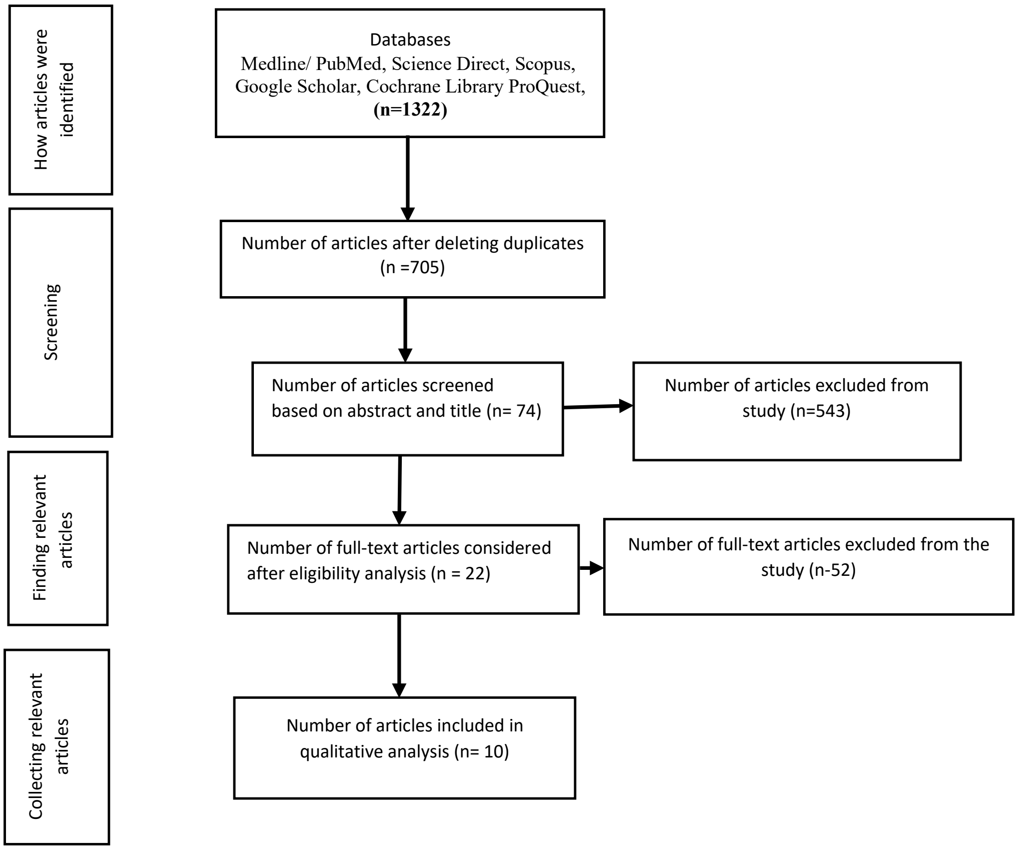

Figure 1. Results of the review process

In most research, a valid definition of injury had been presented, which usually describes an accident during sports and exercises that caused an athlete to stay away from training and competitions. The timeframe of the research covered the entire competition season.

Quality assessment results

The results related to the quality assessment are illustrated in Table 1. All studies were evaluated based on the adjusted quality index [11]. For most articles, the quality index score was higher than 14, indicating that the selected articles had desirable quality. The predictive role of body composition in sports injuries had been investigated in 10 articles (Table 2).

Discussion

Weight gain and BMI are associated with an increased risk of injury. In heavyweight players, body fat is potentially higher and they are less fit, which makes them more prone to injury. Given that lean muscle mass of athletes is relatively more massive than the general population, it is worth noting that BMI in the former group is a general yardstick of body mass to height ratio and does not provide a measure of body fat or body composition in particular [13].

In Gabbe et al. study [14], since 78% of the elite group under study were Australian professional football players, the elevated weight and BMI are likely related to the higher lean muscle mass. One clear limitation of this study is its failure to consider body composition [14].

A study by Fousekis et al. [21] revealed that players with elevated BMI (OR=8.16; 95% CI, 1.42-46.63; P=0.018) and elevated body weight (OR=5.72; 95% CI, 1.37-23.95; P=0.017) had a considerably higher risk of non-contact ankle sprains.

In Bennell et al. study [15], none of the risk factors investigated could predict stress fracture in men. Nonetheless, in female athletes, significant risk factors were low bone density, lower adipose tissue in the lower extremities, and unequal leg length. Multiple logistic regression indicated that menstrual age and leg circumference are the best independent predictors of a stress fracture in women. This bivariate model accurately assigned 80% of female athletes to groups with or without stress fracture. These results suggest the possibility of identifying female athletes who are more prone to this bone injury. Women experiencing stress fractures had a lower bone density and significant defects in the axial and appendicular skeleton. Low axial bone density could be a measure of risk factors for stress fractures, such as ovarian dysfunction or poor diet. On the contrary, bone density was unable to predict the occurrence of stress fractures in men. This could be ascribed to higher regional bone density in males compared to females. Female athletes suffering from stress fractures were less muscular than female athletes who did not have any fractures. Thus, this defect seems to be a regional phenomenon, because the total lean mass and hip circumference do not distinguish between the two groups. The muscle mass and stress fracture correlation can be explained by decreased regional bone density because both leg circumference and DXA of the lower limb lean mass were positively associated with tibial and fibula bone density (r=0.37 to 0.41). The second possible justification is that the ability to absorb muscle shock is a major factor to reduce forces applied to the bone [23]. The in vivo animal models have exhibited that muscle contraction increases bone strength and protects against fractures [24-26].

In Hadala et al. study [16], low-weight athletes were more likely to suffer chronic and recurrent injuries in lower extremities. Lack of weight loss during the competition was observed to be linked to the occurrence of injury. The thickness of subcutaneous fat is commonly analyzed to assess nutritional status and physical changes associated with the conditioning. These data illustrate that the nutritional behavior of athletes engaged in severe physical activity is inappropriate, or at least underestimated. Low levels of subcutaneous fat are retained in other aerobic exercises for many years [27, 28]. These attributes are not applied to the America's Cup sailors. Besides, these athletes are busy with heavy training courses for several years. One of the noticeable findings of the study [16] was that a thicker skinfold during competition leads to traumatic injuries and a higher chance of lower extremity injuries. Elevated BMI is observed in sailors with acute injuries.

Constant high body fat mass indicates that this parameter has not been properly oriented or at least underestimated in the team. The appropriate body fat assigned for elite athletes was previously estimated at 15%. For instance, Rico Sanz [29] expressed that the percentage of football players' body fat should be about 10%. The adverse effect of body fat on motor performance observed in these athletes has been reported in other sports methods [29, 30]. Maximizing the ratio of functional muscle mass to fat mass is a key factor in the recruitment of crew [31]. Between the 2004 and 2007 seasons, there was a statistically significant difference in

Table 1. The methodological quality of studies

Study	Design	Level of Evidence	Selection Criteria	Setting	Demographic Information	Screening Tool	Statistical Analysis	Reliability of Screening Test	Percentage Missing	Outcome	Confounders	Total Score (Max=16)
Grant et al. [13]	1	4	1	1	1	2	1	1	1	1	0	14
Gabbe et al. [14]	1	4	1	1	1	2	1	1	1	1	0	14
Bennell et al. [15]	1	4	1	1	1	2	1	1	1	1	1	15
Hadala et al. [16]	1	4	0	1	1	2	1	1	1	1	1	14
Twitchett et al. [4]	1	4	0	1	1	2	1	1	1	1	0	14
Gaida et al. [17]	0	2	1	1	1	2	1	1	1	1	0	11
Kemper et al. [18]	1	4	1	1	1	2	1	1	1	1	1	15
Jespersen et al. [19]	1	4	1	1	1	2	1	1	1	1	1	15
Henderson et al. [20]	1	4	1	1	1	2	1	1	1	1	1	15
Fousekis et al. [21]	1	4	1	1	1	2	1	1	1	1	1	15

Journal of
Exercise Science and Medicine

muscle mass [16]. Physiologically, this represents a positive change because muscle strength is proportional to muscle size [32]. Larger muscle mass can be beneficial, especially in sailors in the high-intensity group. A large muscle mass will generate more power [31, 33]. An increase in muscle mass suggests a higher muscle cross-sectional area, and consequently higher strength and power in those limbs. The data on muscle mass of different groups of athletes in this study confirms this hypothesis. The total muscle mass is associated with the type and site of the injury. A lower increase in muscle mass appears to contribute to injuries caused by the overuse of the upper extremities.

The study by Kemper et al. [18] indicates the relative risk for a monthly increase in BMI. The results of this study showed that a 0.3 kg/m^2 increase in this index is associated with a 1.61 higher possibility of injuries in adolescent athletes. In previous studies, a large increase in BMI was also observed in adolescent athletes [34]. When interpreting the association between higher BMI and injury in adolescent athletes, it is important to note whether this improvement is greater than expected of normal growth and maturity [35]. The link between diminished BMI and injury occurrence was not significant in this study, but BMI reduction could be significant. Trainers and medical staff need to keep an eye for high BMI reduction in young football players [36]. Players with a low fat percentage are subjected to a greater risk for injury (OR=1.81).

Twitchett et al. [22] found that the time a ballet dancer needs to reduce or adjust her level of activity for injury is significantly longer in individuals with lower body fat percentages. Another study on this group of athletes reported that other criteria such as lower BMI prolong the time required to recover from an injury [37]. The low body fat may be associated with several factors, but it is known that dancers tend to limit their diets, especially calorie intake [38]. Factors such as energy, fatty acids, proteins, and vitamins influence collagen synthesis and wound healing [39, 40]. Hence, a limited diet may partly explain the association between longer recovery time and lower body fat percentage.

In Gaida et al. study [17], individuals with unilateral tendinopathy had a higher waist-to-pelvic ratio than that in the controls, indicating a larger distribution of abdominal fat than gluteus femoral fat [41]. The distribution of human fat is controlled by a complex interaction of hormones, which is particularly affected by the female sex hormones (estrogen and progesterone) [42]. This study suggests hormonal changes due to gender disparity in the incidence of injuries such as patellar tendinopathy.

In Jespersen et al. study [19], a comparison can be drawn between the criteria that determine body com-

Table 2. Characteristics of the included studies

Study	Subject Characteristics Population	No. of Subjects	Sex (M/F)	Mean±SD Age (y)	Outcome Measure	Injury Definition Criteria for the Definition of Injury	Study Results
Grant et al. [13]	Division I University hockey players	79	79/0	20.2±1.6	Body fat percentage was measured based on the bio-electrical body composition	They defined injury as any events that can directly hamper the participation of an athlete in on-ice activity for at least one day.	The possibility of injury for a player with a BMI ≥25 kg/m^2 was 2.1 times (95% CI, 1.1-3.8) more than that of a player with a BMI <25 kg/m^2
Gabbe et al. [14]	Australian football clubs players	174	174/0	N/A	Body mass index	Injury of an elite player that leads to the missing of at least one game	Body weight was an independent predictor of hamstring injury in players ≥25 years of age. Risk ratio=1.07 (1.01-1.15)
Bennell et al. [15]	Track and field athletes	101	58/53	20.4±2.1	Total bone mineral content, soft tissue composition, and regional bone density were measured by dual-energy X-ray absorptiometry and anthropometric methods.	The diagnosis of stress fractures were based on positive results on clinical examination, CT scan, and triple-phase isotope bone scan.	None of the risk factors assessed could predict the stress fractures incidence in men. In female athletes, nonetheless, there were significant risk factors such as a low lean mass in their lower limb, low bone density, leg length discrepancy, and a low-fat diet.
Hadala et al. [4]	America's Cup yachting crew	61	61/0	29.5±8.17	BMI, body weight, skinfold thickness, fat, muscle and limb body	An injury during a scheduled sailing or training that leads to pain, tissue damage, or disability, and requires treatment from the medical staff	Crew members with overuse injuries showed significantly lower skinfold thickness and also lower muscle mass percentage. Athletes suffering from more than one injury had lower weight in both. Athletes with injuries at the upper extremity had the lowest weight, the lowest skinfold thickness, the lowest muscle mass also, and the lowest body fat weight.
Twitchett et al. [22]	Elite dancers	30	0/30	19.0±0.7	Body density, body weight, fat percentage were measured using a caliper, standard weighing scales, and related formula	Dance-related injury as a physical disorder caused by stress or other factors related to performance, training, rehearsal, touring, or other conditions of dance life, which influences the ability to fully engage in ordinary dance training, or physical activities	Body fat percentage was linked to the time a dancer was obliged to adjust activity as a result of injury (r=-0.614, P=0.026).
Gaida et al. [5]	National Basketball League and the Australian Basketball Association clubs	39	0/39	21.0±3.0	They measured body composition by a dual-energy X-ray. Also, the lean body mass and total regional fat were measured by a body scan.	Ultrasound examination of both patellar tendons. Tendons were treated as pathological if both longitudinal and transverse scans revealed a hypoechoic lesion.	The waist to hip ratio was higher in athletes with unilateral patellar tendinopathy. Also, the tibia length was longer relative to stature in these athletes.

Study	Subject Characteristics Population	No. of Subjects	Sex (M/F)	Mean±SD Age (y)	Outcome Measure	Injury Definition Criteria for the Definition of Injury	Study Results
Kemper et al. [18]	Elite soccer players	101	101:0	N/A	Fat percentage, body mass index, fat-free mass index, growth in height were measured.	Any physical complaint originating from the football match or training, whether it needs medical attention or leads to absence from football activities	≥0.6 cm growth in a month (P=0.03; 95% CI: 1.06–2.52; OR=1.63), ≥0.3 kg/m^2 increase in BMI over a month (P=0.03; 95% CI: 1.04–2.49; OR=1.61) and the low-fat percentage
Jespersen et al. [7]	Preschool to fourth-grade schools attending the CHAMPS Study-DK	632	311:321	9.6±0.9	Weight and height and total body fat were measured by dual-energy X-ray	Injuries were recorded using the International Classification of Diseases (ICD-10) of WHO.	Children that were considered overweight in terms of BMI and TBF% were most susceptible to the lower extremity injuries (IRR 1.38; 95% CI: 1.05 to 1.81). Children who were assumed to be overweight according to BMI and TBF% were highly susceptible to lower extremity injuries (IRR 1.38; 95% CI 1.05 to 1.81).
Henderson et al. [8]	English Premier League soccer players	36	36:0	22.6±5.2	Lean mass	Hamstring injury described any injury that hampered the player from participating in general training for 48 h or more	Lean mass had no significant effect on the overall model (P=0.068). At the practical scale, 95% CI for its inclusion was on the verge of unity (0.71–1.01), showing that athletes with lower lean mass are more prone to injury.
Fousekis et al. [21]	Professional soccer teams	100	100:0	N/A	Body mass index, body weight	An ankle sprain that leads to the missing of at least 1 practice session or game by the player and was registered by the medical staffs of each club.	In players with elevated body mass index (95% CI, 1.42-46. 63; OR=8.16; P=0.018), and body weight (95% CI, 1.37-23.95; OR=5.72; P=0.017) the risk of a noncontact ankle sprain was significantly higher.

BMI: Body Mass Index; N/A: not available; OR: odds ratio; RR: risk ratio; TBF: total body fat

Journal of Exercise Science and Medicine

position in relation to injury. The results revealed that the risk of injury in the lower extremities in overweight children is higher. By comparing the two different measures of obesity, the percentage of total body fat (TBF%) is found a higher risk factor than obesity identified by BMI. This finding shows that a high ratio of adipose is a good predictor of lower extremity injuries, which could be attributed to a lower ratio of lean muscle mass. On the contrary, Kaplan et al. [43] stated that bodyweight is a stronger risk factor than adiposity for injury.

This fact has been demonstrated in a study that compared different body composition criteria (BMI, body fat, height, and weight) to injury risk in a group of 98 high school players suffering from 28 injuries recorded by trainers. Another study on American footballers has reported the rate of injury by weight, body fat, lean body mass, and BMI in high school footballers [44]. The results of this research revealed that obesity expressed as a percentage of Total Body Fat (TBF) provides a solid prediction of BMI concerning the extent and type (overuse/traumatic injury) of musculoskeletal injuries in military staff [45]. A direct comparison may not be possible due to disparity in TBF measurement techniques, injury recording methods, study values, age, and specific exercise in diverse settings.

Still, in some sports, the impact of the elevated mechanical load during weight-bearing or impact may be more noticeable than in other sports. Injury patterns may also vary relative to different types of injury. It can be argued that traumatic injuries caused by the severe impact due to overweight of muscle/fat distribution are stronger than over-use injuries, where tissue quality (e.g., endurance and muscle strength) is of paramount importance.

Conclusion

In general, abnormal body composition may be associated with the prediction of injury, and strength of prediction for body composition criteria are variable. Hence, trainers are recommended to use body composition factors in pre-participation assessment to prevent injury.

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Authors' contributions

All authors have contributed equally to this article.

Conflict of interest

The authors declared no conflict of interest.

References

[1] Blair SN. Effects of physical activity on cardiovascular disease mortality independent of risk factors. In: Leon AS, editor. Physical activity and cardiovascular health: A national consensus. Champaign: Human Kinetics; 1997. https://books.google.com/books/about/Physical_Activity_and_Cardiovascular_Hea.html?id=OsS71Nf3R7UC

[2] Schmikli SL, Backx FJ, Kemler HJ, Van Mechelen W. National survey on sports injuries in the Netherlands: Target populations for sports injury prevention programs. Clinical Journal of Sport Medicine. 2009; 19(2):101-6. [DOI:10.1097/JSM.0b013e31819b9ca3] [PMID]

[3] Meeuwisse WH. Predictability of sports injuries. Sports Medicine. 1991; 12(1):8-15. [DOI:10.2165/00007256-199112010-00002] [PMID]

[4] Romero-Corral A, Montori VM, Somers VK, Korinek J, Thomas RJ, Allison TG, et al. Association of bodyweight with total mortality and with cardiovascular events in coronary artery disease: A systematic review of cohort studies. The Lancet. 2006; 368(9536):666-78. [DOI:10.1016/S0140-6736(06)69251-9]

[5] Chalmers L, Kaskel FJ, Bamgbola O. The role of obesity and its bioclinical correlates in the progression of chronic kidney disease. Advances in Chronic Kidney Disease. 2006; 13(4):352-64. [DOI:10.1053/j.ackd.2006.07.010] [PMID]

[6] Smith SR, Lovejoy JC, Greenway F, Ryan D, deJonge L, de la Bretonne J, et al. Contributions of total body fat, abdominal subcutaneous adipose tissue compartments, and visceral adipose tissue to the metabolic complications of obesity. Metabolism. 2001; 50(4):425-35. [DOI:10.1053/meta.2001.21693] [PMID]

[7] Pottie P, Presle N, Terlain B, Netter P, Mainard D, Berenbaum F. Obesity and osteoarthritis: More complex than predicted!. Annals of the Rheumatic Diseases. 2006; 65(11):1403-5 [DOI:10.1136/ard.2006.061994] [PMID] [PMCID]

[8] Walker-Bone K, Cooper C. Hard work never hurt anyone: Or did it? A review of occupational associations with soft tissue musculoskeletal disorders of the neck and upper limb. Annals of the Rheumatic Diseases. 2005; 64(10):1391-6. [DOI:10.1136/ard.2003.020016] [PMID] [PMCID]

[9] Kujala UM, Sarna S, Kaprio J. Cumulative incidence of achilles tendon rupture and tendinopathy in male former elite athletes. Clinical Journal of Sport Medicine. 2005; 15(3):133-5. [DOI:10.1097/01.jsm.0000165347.55638.23] [PMID]

[10] Liberati A, Altman DG, Tetzlaff J, Mulrow C, Tzsche PC, Ioannidis JPA, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. Journal of Clinical Epidemiology. 2009; 62(10):e1-34. [DOI:10.1016/j.jclinepi.2009.06.006] [PMID]

[11] Devillé WL, Buntinx F, Bouter LM, Montori VM, De Vet HC, Van der Windt DA, et al. Conducting systematic reviews of diagnostic studies: Didactic guidelines. BMC Medical Research Methodology. 2002; 2(1):9. [DOI:10.1186/1471-2288-2-9] [PMID] [PMCID]

[12] Dallinga JM, Benjaminse A, Lemmink KA. Which screening tools can predict injury to the lower extremities in team sports? Sports Medicine. 2012; 42(9):791-815. [DOI:10.1007/BF03262295] [PMID]

[13] Grant JA, Bedi A, Kurz J, Bancroft R, Gagnier JJ, Miller BS. Ability of preseason body composition and physical fitness to predict the risk of injury in male collegiate hockey players. Sports Health. 2015; 7(1):45-51. [DOI:10.1177/1941738114540445] [PMID] [PMCID]

[14] Gabbe BJ, Bennell KL, Finch CF. Why are older Australian football players at greater risk of hamstring injury? Journal of Science and Medicine in Sport. 2006; 9(4):327-33. [DOI:10.1016/j.jsams.2006.01.004] [PMID]

[15] Bennell KL, Malcolm SA, Thomas SA, Reid SJ, Brukner PD, Ebeling PR, et al. Risk factors for stress fractures in track and field athletes: A twelve-month prospective study. The American Journal of Sports Medicine. 1996; 24(6):810-8. [DOI:10.1177/036354659602400617] [PMID]

[16] Hadala M, Vera P, Barrios C. Anthropometry profile and its influence on injury pattern in America's cup racing crew. Journal of Sports Medicine Doping Studies. 2012; S5:001. [DOI: 10.4172/2161-0673.S5-001]

[17] Gaida JE, Cook JL, Bass SL, Austen S, Kiss ZS. Are unilateral and bilateral patellar tendinopathy distinguished by differences in anthropometry, body composition, or muscle strength in elite female basketball players? British Journal of Sports Medicine. 2004; 38(5):581-5. [DOI:10.1136/bjsm.2003.006015] [PMID] [PMCID]

[18] Kemper GL, Van Der Sluis A, Brink MS, Visscher C, Frencken WG, Elferink-Gemser MT. Anthropometric injury risk factors in elite-standard youth soccer. International Journal of Sports Medicine. 2015; 36(13):1112-7. [DOI:10.1055/s-0035-1555778] [PMID]

[19] Jespersen E, Verhagen E, Holst R, Klakk H, Heidemann M, Rexen CT, et al. Total body fat percentage and body mass index and the association with lower extremity injuries in children: A 2.5-year longitudinal study. British Journal of Sports Medicine. 2014; 48(20):1497-502. [DOI:10.1136/bjsports-2013-092790] [PMID]

[20] Henderson G, Barnes CA, Portas MD. Factors associated with increased propensity for hamstring injury in English Premier League soccer players. Journal of Science and Medicine in Sport. 2010; 13(4):397-402. [DOI:10.1016/j.jsams.2009.08.003] [PMID]

[21] Fousekis K, Tsepis E, Vagenas G. Intrinsic risk factors of noncontact ankle sprains in soccer: A prospective study on 100 professional players. The American Journal of Sports Medicine. 2012; 40(8):1842-50. [DOI:10.1177/0363546512449602] [PMID]

[22] Twitchett E, Brodrick A, Nevill AM, Koutedakis Y, Angioi M, Wyon M. Does physical fitness affect injury occurrence and time loss due to injury in elite vocational ballet students? Journal of Dance Medicine & Science. 2010; 14(1):26-31. https://www.ingentaconnect.com/content/jmrp/jdms/2010/00000014/00000001/art00004

[23] Paul IL, Munro MB, Abernethy PJ, Simon SR, Radin EL, Rose RM. Musculo-skeletal shock absorption: Relative contribution of bone and soft tissues at various frequencies. Journal of Biomechanics. 1978; 11(5):237-9. [DOI:10.1016/0021-9290(78)90049-0]

[24] Nordsletten L, Ekeland A. Muscle contraction increases the structural capacity of the lower leg: An in vivo study in the rat. Journal of Orthopaedic Research. 1993; 11(2):299-304. [DOI:10.1002/jor.1100110218] [PMID]

[25] Nordsletten L, Ekeland A. Muscle contribution to tibial fracture strength in rats. Acta Orthopaedica Scandinavica. 1993; 64(2):157-60. [DOI:10.3109/17453679308994559] [PMID]

[26] Nordsletten L, Kaastad TS, Obrant KJ, Skjeldal S, Kirkeby OJ, Stokke O, et al. Muscle contraction increases the in vivo structural strength to the same degree in osteopenic and normal rat tibiae. Journal of Bone and Mineral Research. 1994; 9(5):679-85. [DOI:10.1002/jbmr.5650090513] [PMID]

[27] Tarnopolsky MA. Nutritional consideration in the aging athlete. Clinical Journal of Sport Medicine. 2008; 18(6):531-8. [DOI:10.1097/JSM.0b013e318187ac44] [PMID]

[28] Toth MJ, Beckett T, Poehlman ET. Physical activity and the progressive change in body composition with aging: Current evidence and research issues. Medicine and Science in Sports and Exercise. 1999; 31(suppl 11):S590-S596. [DOI:10.1097/00005768-199911001-00017] [PMID]

[29] Rico-Sanz J. Body composition and nutritional assessments in soccer. International Journal of Sport Nutrition and Exercise Metabolism. 1998; 8(2):113-23. [DOI:10.1123/ijsn.8.2.113] [PMID]

[30] Reilly T, Secher N, Snell P, Williams C, Williams C. Physiology of sports. England: Routledge; 2005. [DOI:10.4324/9780203013311]

[31] Neville V. America's Cup yacht racing is not just about the boat. Journal of Science and Sport in Exercise. 2008; 15:26-7.

[32] Drinkwater EJ, Pyne DB, McKenna MJ. Design and interpretation of anthropometric and fitness testing of basketball players. Sports Medicine. 2008; 38(7):565-78. [DOI:10.2165/00007256-200838070-00004] [PMID]

[33] Neville VJ, Molloy J, Brooks JH, Speedy DB, Atkinson G. Epidemiology of injuries and illnesses in America's Cup yacht racing. British journal of Sports Medicine. 2006; 40(4):304-12. [DOI:10.1136/bjsm.2005.021477] [PMID] [PMCID]

[34] Malina RM, Morano PJ, Barron M, Miller SJ, Cumming SP. Growth status and estimated growth rate of youth football players: A community-based study. Clinical Journal of Sport Medicine. 2005; 15(3):125-32. [DOI:10.1097/01.jsm.0000164287.42066.63] [PMID]

[35] Malina RM. Body composition in athletes: Assessment and estimated fatness. Clinics in Sports Medicine. 2007; 26(1):37-68. [DOI:10.1016/j.csm.2006.11.004] [PMID]

[36] Cerquides J, De Màntaras RL. Proposal and empirical comparison of a parallelizable distance-based discretization method. KDD, 1997 Aug 14. http://www.sciweavers.org/publications/proposal-and-empirical-comparison-parallelizable-distance-based-discretization-method

[37] Benson JE, Geiger CJ, Eiserman PA, Wardlaw GM. Relationship between nutrient intake, body mass index, menstrual function, and ballet injury. Journal of the American Dietetic Association. 1989; 89(1):58-63. https://europepmc.org/article/med/2909593

[38] Kaufman BA, Warren MP, Dominguez JE, Wang J, Heymsfield SB, Pierson RN. Bone density and amenorrhea in ballet dancers are related to a decreased resting metabolic rate and lower leptin levels. The Journal of Clinical Endocrinology & Metabolism. 2002; 87(6):2777-83. [DOI:10.1210/jcem.87.6.8565] [PMID]

[39] Fuhrman PM. Wound healing and nutrition. Topics in Clinical Nutrition. 2003; 18(2):100-10. [DOI:10.1097/00008486-200304000-00006]

[40] Greenway SE, Filler LE, Greenway FL. Topical insulin in wound healing: A randomised, double-blind, placebo-controlled trial. Journal of Wound Care. 1999; 8(10):526-8. DOI:10.12968/jowc.1999.8.10.26217] [PMID]

[41] Hopper DM, Hopper JL, Elliott BC. Do selected kinanthropometric and performance variables predict injuries in female netball players? Journal of Sports Sciences. 1995; 13(3):213-22. [DOI:10.1080/02640419508732230] [PMID]

[42] Björntorp P. The regulation of adipose tissue distribution in humans. International Journal of Obesity and Related Metabolic Disorders. 1996; 20(4):291-302. https://europepmc.org/article/med/8680455

[43] Kaplan TA, Digel SL, Scavo VA, Arellana SB. Effect of obesity on injury risk in high school football players. Clinical Journal of Sport Medicine. Official Journal of the Canadian Academy of Sport Medicine. 1995; 5(1):43-7. [DOI:10.1097/00042752-199501000-00008] [PMID]

[44] Gómez JE, Ross SK, Calmbach WL, Kimmel RB, Schmidt DR, Dhanda R. Body fatness and increased injury rates in high school football linemen. Clinical Journal of Sport Medicine. 1998; 8(2):115-20. [DOI:10.1097/00042752-199804000-00010] [PMID]

[45] Havenetidis K, Paxinos T. Risk factors for musculoskeletal injuries among Greek Army officer cadets undergoing Basic Combat Training. Military Medicine. 2011; 176(10):1111-6.[DOI:10.7205/MILMED-D-10-00448] [PMID]

This Page Intentionally Left Blank