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Sex Differences in Common Sports Injuries

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Abstract

Common sports injuries include bone stress injuries (BSIs), anterior cruciate ligament (ACL) injuries, and concussions. Less commonly recognized are the specific sex differences in epidemiology, risk factors, and outcomes of these conditions by sex. An understanding of these factors can improve their clinical management, from prescribing appropriate prehabilitation to guiding postinjury rehabilitation and return to play. This narrative review summarizes the sex differences in the diagnosis and management of BSIs, ACL injuries, and concussions. Although BSIs are more common in female athletes, risk factors for both sexes include prior injury and relative energy deficiency in sport (RED-S). Risk factors in female athletes include smaller calf girth, femoral adduction, and higher rates of loading. Female athletes are also at greater risk for developing ACL injuries in high school and college, but their injury rate is similar in professional sports. Increased lateral tibial slope, smaller ACL size, and suboptimal landing mechanics are additional risk factors more often present in female athletes. Male athletes are more likely to have ACL surgery and have a higher rate of return to sport. Concussions occur more commonly in female athletes; however, female athletes are also more likely to report concussions. Male athletes more commonly sustain concussion through contact with another player. Female athletes more commonly sustain injury from contact with playing equipment. Managing post-concussion symptoms is important, and female athletes may have prolonged symptoms. An understanding of the sex-specific differences in these common sports injuries can help optimize their prehabilitation and rehabilitation.

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Introduction

Some of the most common sports injuries encountered by physiatrists include bone stress injuries (BSIs), anterior cruciate ligament (ACL) injuries, and concussions. It is well recognized that each of these injuries can be sustained by both sexes. More recently, research has focused on elucidating sex and gender specific differences in epidemiology, risk factors, and outcomes for sports injuries. Instead of a one-size-fits-all treatment approach, managing these conditions with an understanding of the sex-specific differences may help to optimize their individualized recovery [1].

Discussion of sex-specific factors for sports injuries refers to biological differences. Sex differences relate to factors including hormones, anatomy, or X and Y chromosome gene expression. Gender is associated with societal behaviors and cultural factors. In reality, it is not always easy to separate the impact of sex and gender on sports injuries as they are often intertwined. Intrinsic and extrinsic injury risk factors include the influence of hormones, neuromuscular control, biomechanics, anatomy, and societal differences in sports participation.

The significant increase in female sports participation in the United States has been largely attributed to Title IX legislation. This federal legislation in the United States in 1972 mandated equal access for women and men in educational programs, including sports, to receive federal funding. As female athletes became involved in more sports, injuries previously seen in male athletes became more prevalent in female athletes.

This piece highlights 3 common sports injuries and discusses what is known about sex differences in epidemiology and risk factors between the sexes for BSI, ACL injury, and concussion. The 3 injuries identified for review have some key overlapping features including risk factors. For example, altered landing mechanics and dynamic alignment are risk factors common to both ACL injury and BSI and are also treatment targets [2–4]. History of concussion has been associated with increased risk of lower limb injuries including ACL injury [5]. A practical framework for a sex-specific approach to the rehabilitation of these injuries is also described.

Methodology

The authors used consensus to determine the 3 sports injury topics with sufficient published data to support a discussion of differences in epidemiology, risk factors, treatment strategies, and outcomes between the sexes. Subsequently, a literature review using PubMed was conducted in June through September 2017 to identify key articles that describe the sex-specific differences in epidemiology, risk factors, and management of each injury. For BSI, the search terms included “stress reaction,” “stress fracture,” and “fracture.” For ACL injury, the search terms included “ACL injury” and “menstrual cycle.” For concussion, the search terms included “concussion” and “post-concussive syndrome.” Common search terms for all injuries included “athletes,” “females,” “males,” “injury prevention,” “sex differences,” “risk factors,” and “treatment outcomes.”

Bone Stress Injuries

BSIs are an overuse injury to bone from cumulative microtrauma. The injury occurs on a spectrum of disease severity, with early injuries often referred to as “stress reaction” and present without fracture line on imaging. Magnetic resonance imaging (MRI) is most commonly used to evaluate and grade injury severity, with early changes represented by bone marrow edema on T2 imaging and a stress fracture represented by both T2 and T1 changes and presence of fracture line [6]. A higher grade of BSI predicts a longer return to play for athletes of both sexes, and trabecular-rich sites (including the femoral neck and pelvis) require greater healing time [6]. Initial observation reported by Marx in 2001 identified trabecular-rich sites of BSI that were more commonly associated with low bone mineral density (BMD) in female athletes; the same association was recently reported in male athletes [7].

Epidemiology

Female athletes appear at higher risk for BSI than male athletes [8]. Running sports may have the highest rate of injuries for both sexes starting in high school, with athletic exposure rate of 10.62 and 5.42 for girl and boy cross-country runners, respectively. There is a 20% annual incidence of BSI in collegiate runners of both sexes [9].

Risk Factors

The most common risk factor for BSI is history of prior injury [10–12]. The concept of Relative Energy Deficiency of Sport (RED-S) describes how inadequate energy intake to meet demands of sport contributes to impaired bone health and injury risk in athletes of both sexes [13].

The Female Athlete Triad (Triad) describes the interrelationship of energy availability, menstrual function, and bone health [14]. The term RED-S expands on the concept of Triad [13]. Risk factors for BSI include Triad of late menarche (defined as age of menarche 15 years or older), participation in the lean sports of dance/gymnastics, low body mass index, less dietary calcium intake, reduced vitamin D intake, and BMD Z-score <–1.0 [10,11,15–17]. Additionally, the Female Athlete Triad Consensus Statement defines athletes at low-, moderate-, and high-risk categories based on cumulative risk factors [14]. These risk factors were independently assessed in a population of 323 female National Collegiate Athletic Association (NCAA) division-I athletes from 16 sports [12]. The sports of cross-country, gymnastics, lacrosse, and swimming and diving had the highest proportion of athletes in the moderate- to high-risk categories. The clinical significance was a 2.6- and 3.8-fold increased risk for BSI compared to low-risk category athletes. Cross-country runners had the highest magnitude of injury risk of all sports. Compared to low-risk athletes, there was a 4.0- and 5.7-fold increased risk for moderate- and high-risk category athletes. Multivariate regression also revealed that risk factors for BSI within the full population of athletes included older age, participation in cross-country, oligomenorrhea/amenorrhea history, and prior stress reaction/stress fracture. In addition, biomechanical and anatomical risk factors for BSI in female athletes have been described. This includes reduced calf circumference, high rates of loading, increased tibial free moment, and femoral adduction [3,18–20].

Compared to female athletes, known risk factors for BSI are limited in male athletes. Although ball sports participation is protective against BSI in female athletes without Triad risk factors [21], studies in male athletes and military suggests a reduced risk for BSI in those who participate in ball sports, particularly basketball [10,21,22]. Biomechanical studies to date have not clearly described the association of biomechanics including rates of loading and lower limb alignment and injury risk.

Management and Outcomes

The initial management for BSI is the same for both sexes. This includes activity modification and appropriate protected or non–weight bearing status to facilitate initial healing. Athletes should be advised to meet the 2010 Institute of Medicine guidelines for calcium and vitamin D intake [23]. Female athletes in elevated risk categories, including low body weight or recent weight loss, history of primary or secondary amenorrhea, concern for eating disorder/disordered eating, and/or low BMD, require further treatment including multidisciplinary team management to ensure biological risk factors are addressed for fracture healing [13,14]. Athletes of both sexes who meet the RED-S clinical assessment tool criteria for elevated risk require further treatment to ensure safe return to sport [13]. Unique to males, this may include measuring sex hormones of testosterone or other features suggestive of hypogonadal male [24]. For both female and male athletes, low sex hormones are recommended to be managed with nonpharmacological treatment [13,14].

Injury Prevention

Prehabilitation to prevent BSI should start at a young age for both sexes, and this includes meeting IOM recommendations for calcium and vitamin D intake, screening and management of the Triad/RED-S in sports, and encouraging multisport participation including ball sports at a young age [25,26]. Physical therapy is commonly prescribed to address impairments in strength that impact dynamic lower extremity alignment, including gluteal strengthening exercises to correct for femoral adduction [27,28]. Gait retraining can be prescribed to reduce rates of loading and improve lower extremity landing mechanics for both sexes [29]. Table 1 summarizes the sex-specific differences in epidemiology, risk factors, and outcomes for BSI.

ACL Injury

The ACL is a key knee stabilizer that prevents anterior translation of the tibia relative to the femur and also provides rotatory stability. Knee stability is important for many sports, and multidirectional land-based sports with cutting and jumping are more difficult to perform with an ACL-deficient knee.

Epidemiology

Approximately 200 000 ACL injuries occur annually, with >50% occurring in high school– and college-age athletes [30]. Significant short- and long-term morbidity is associated with this injury, including an 80% likelihood of developing knee osteoarthritis within 15 years of the injury [30–32]. The National Collegiate Athletic Association data demonstrates that a higher number of ACL injuries occur in male athletes because of football (53% of all

reported ACL injuries), but rate of ACL injury (injury per athletic exposure) was highest in women's gymnastics, basketball, and soccer [33]. Across all levels of play in basketball and soccer, female athletes are 2–8 times more likely to sustain an ACL injury than their male counterparts [34–38]. Most research investigating interventions to prevent injury have focused on noncontact ACL injuries that are sustained during sudden deceleration while landing or changing direction [2]. Noncontact ACL injury is a multifaceted event influenced by anatomical, neuromuscular, biomechanical, genetic, hormonal, and other risk factors. At the time of this publication, it remains unclear in the literature if female athletes are at increased risk of ACL injury because they are more likely to have the underlying risk factors, or if the risk factors are different in men and women, resulting in sex-specific injury mechanisms [4].

Risk Factors

Anatomical risk factors for an ACL injury include smaller ligament size [39], decreased femoral notch width [39], increased posterior-inferior slope of the lateral tibia plateau [40], increased knee and generalized laxity [41], and increased body mass index (BMI) [42,43]. Each of these factors is more likely to occur in female than male athletes [4]. Vacek et al. conducted a prospective study of high school and collegiate athletes, which demonstrated sex-specific patterns in anatomical risk factors. In females, increased laxity, elevated BMI, and a parent who sustained an ACL injury were predictive of injury, whereas in males, increased laxity, posterior knee stiffness, and navicular drop were predictive [43]. The main neuromuscular and biomechanical risk factors for an ACL injury are increased knee abduction, internal rotation, lateral trunk motion, and posterior center of mass [4]. Studies focused on sex differences in neuromuscular control have demonstrated increased knee abduction and increased quadriceps-to-hamstring ratio during landing in females [44]. Because injury risk, motor control patterns, and the hormonal milieu diverge between females and males around puberty [45], the link between female sex hormones and neuromuscular control has been studied. Further supporting the role of sex hormones as a risk factor is that receptors for these hormones exist in the ACL [46–48] and that ACL injuries occur more often in the follicular and preovulatory phases of the menstrual cycle [49,50]. Estrogen and relaxin likely act synergistically to modulate collagen turnover and cross-linking, which lead to increased ligamentous laxity, decreased ACL load-to-failure, and reduced tendon stiffness [48,51–55]. In a prospective study of collegiate athletes, relaxin concentration ≥6.0 pg/mL resulted in a 4-fold increase in ACL tears [56]. There is little information regarding how sex hormones affect ACL injury risk in men except that testosterone has been shown to stimulate collagen fibroblast production and may contribute to ACL strength [57,58]. Variants in genes involved in collagen formation, including *COL1A1*, have been linked to ACL injury [59]. The *COL5A1* is also associated with ACL injury, but only in females [60].

Management and Outcomes

Treatment options for patients with an ACL tear include rehabilitation, bracing, and surgical reconstruction. Reconstruction of the ACL is commonly performed in younger patients who want to return to cutting, pivoting sports [61]. In a large epidemiologic study examining ACL reconstruction in adult patients, men were more likely to undergo surgery than women

(26% versus 19%; $P < .001$) [62]. Unfortunately, both male and female athletes have low rates of return to their prior level of sports [63]. One study of Australian athletes demonstrated that only 55% play competitive sports after an ACL reconstruction, but that men are 1.5 times more likely to return to activity than women [64]. Some studies suggest that female athletes are at greater risk of graft failure [65] and contralateral ACL tear [66], whereas others identified no sex differences in subsequent injury [61]. There is limited consensus on definitive return-to-play criteria, and whether or not this needs to be different for male and female athletes needs further investigation [4].

In regard to post-traumatic knee osteoarthritis, men and women appear to have an equal risk of developing tibiofemoral osteoarthritis [67]; men are more likely to develop patellofemoral arthritis [68]. Women were more likely than men to undergo total knee arthroplasty in a study of patients 15 years after ACL reconstruction [69].

Injury Prevention

Prevention programs for ACL injuries are focused on neuromuscular training to optimize motor patterns during landing and cutting maneuvers [70]. Overall, the risk reduction of injury incidence is 75%–100% and the number needed to treat ranges from 5–187 athletes [71,72]. A systematic review in 2012 suggested programs resulted in a cumulative risk reduction for ACL injuries of 85% in males and 52% in females [72]. One of the injury prevention programs designed for soccer players, quickly being adopted by other sports, was created by the Fédération Internationale de Football Association (FIFA) Medical and Research Centre (F-MARC). This program, often referred to as FIFA 11+, encompasses 15 exercises with 3 subgroups: (1) Running and stretching, (2) core and lower limb strengthening, and (3) fast-paced, functional soccer movements like cutting F-MARC [73]. A systematic review regarding the efficacy of the FIFA 11+ program in injury prevention for soccer players demonstrated a 30% overall injury reduction in males compared to a 22% overall injury reduction in females [74]. It is worth noting that two-thirds of the studies reviewed included male soccer players, so the data are less robust for female soccer players using the FIFA 11+ at this time. Future research is needed to determine exactly which prehabilitation exercises should be included as well as the optimal timing, duration, and frequency of exposure. Furthermore, because a sex disparity exists in the risk of injury as well as the efficacy of injury prevention programs, sex-specific prevention programs need to be further investigated. Another potential injury prevention strategy in female athletes is to modify the hormonal milieu with hormonal contraceptives. A recent meta-analysis reported a 20% reduction in ACL injuries in women taking hormonal contraceptives [75], but further research is needed regarding the differential effect of hormonal type, concentration, and mode of delivery on the material properties of the ACL as well as risk of injury.

Table 1 summarizes the epidemiology, risk factors, and outcomes of ACL injury. A better understanding of the relative importance of each ACL injury risk factor, their interrelationships, and how this differs between males and females will allow physicians to better provide athletes with an individualized risk assessment and injury reduction plan.

Sports Concussion

A concussion is a form of traumatic brain injury (TBI) characterized by pathophysiological alterations affecting brain function resulting from biomechanical forces. Concussions are most commonly seen in collision and contact sports. Recent greater public attention to sports concussions has contributed to increased research on this topic and a significant increase in knowledge of sex-specific risk factors for this injury.

Epidemiology

Current research suggest that concussion rates are higher for female athletes compared to male athletes when examined on the basis of sports with comparable exposure types [76–80]. The relative risk of concussion in collegiate female athletes compared to male athletes has been reported to range from 53% higher in basketball and 83% higher in soccer to 265% higher in baseball/softball [80]. Additionally, higher rates of concussions are observed in female athletes despite competition rules designed to reduce the level of contact between players. Female lacrosse is a noncontact sport; however, the relative risk of concussion in females is 64% higher than in males [80]. Epidemiologic studies in high school athletes demonstrate a higher rate of injury in female athletes [76–79]. Limited research on recurrent concussion suggests that female athletes may also be at an increased risk for subsequent injury [80].

Confounding accurate measurement of differences in concussion incidence between the sexes is the increased rate of concussion reporting in females. End of season/career athlete reported nondisclosure rates of concussion range from 16%–42.9% in males to 5%–14.9% in females [81–86]. These findings are supported by a study demonstrating that the level of gender nonconformity in females influences nondisclosure rates, with female athletes who have higher levels of conforming to traditionally masculine norms reporting a greater level of intent to withhold disclosure of concussion-related symptoms from coaches and medical personnel [84].

Risk Factors

Several different factors have previously been cited to contribute to this sex and gender disparity in concussion incidence. In particular, females tend to have a reduced amount of neck girth and strength relative to head size and head-neck length compared to males [87–93]. This may reduce the overall stability and stiffness of the head-neck segment such that it is less able to absorb externally applied forces. Female athletes demonstrate increased amounts of head-neck segment accelerations and displacements compared to male athletes with a functionally applied external load, such as heading a soccer ball [87,88,94,95]. Furthermore, decreased neck strength has been associated with an increased risk for concussion, with every additional pound of neck strength reducing the odds of concussion by 5% in high school athletes [96].

Sex-based differences in hormonal milieu may also play a role in concussion risk, but the effect of different hormones remains unclear with few human studies published. Progesterone has been suggested to provide a protective effect, but that a sudden withdrawal

of progesterone has been posited as a risk factor [97,98]. One study found no effect of menstrual cycle phase on symptoms, neurocognitive function, or postural stability in nonconcussed individuals [98]. Furthermore, clinical trials using exogenous progesterone in more severe traumatic brain injury have demonstrated uneven results [99]. Estrogen has also been theorized to provide a protective effect after TBI, but studies evaluating this have primarily been in animal models [100].

Several epidemiologic and observational studies have noted sex-based differences in concussion risk for different types of play exposures. Although player-versus-player contact is the most common overall mechanism of injury for both sexes, male athletes at both the high school and collegiate levels tend to have a higher proportion of concussions resulting from player-versus-player contact, whereas female athletes tend to have a higher proportion of concussions resulting from playing equipment (eg, lacrosse stick, ball)-to-head and surface-to-head mechanisms [76–80,101–104]. These relationships hold both for sports that have the same rules of play (eg, soccer, basketball) and for those with sex-based differences in rules of play (eg, lacrosse, ice hockey).

Management and Outcomes

Some level of controversy exists regarding the clinical presentation of concussion based on sex. Studies indicate that females appear to have an increased number and severity of concussion symptoms both at baseline and after experiencing a concussion [105–109]. Additionally, some studies have suggested that there is a sex bias for the reporting of different symptoms, with females tending to report more neurobehavioral symptoms and males tending to report more cognitive symptoms [110]; however, it is unclear if these relationships are due to true sex differences or differences in willingness to report symptoms [111,112].

Females appear to have an altered trajectory of recovery from concussion. Although not universal, most studies have found an increased duration of time loss for female athletes following a concussion, and that females are at an elevated risk for postconcussive syndrome compared to males [109,113–116]. Females also receive interventions such as medications and school accommodations at higher rates compared to males [117]. It is worth noting that females may experience abnormal menstrual patterns in the wake of a concussion, with one study reporting an odds ratio of 5.85 of having an abnormal menstrual cycle within the first 4 months after a concussion compared to females with orthopedic injuries [118,119].

Although the treatment of concussed athletes should be approached on an individual basis, medical providers should be well-informed regarding potential sex-based differences when managing sports concussions. These considerations should be taken into account at all stages from prehabilitation to injury assessment and rehabilitation. Providers should have an understanding of sex-based differences in biomechanical and exposure-based risk factors when participating in sideline coverage for potential concussion events on the field. Providers should be mindful during initial evaluations of how typical symptom profiles may vary between the sexes in order to make a prompt and accurate diagnosis. Given the increased levels of symptom reporting and recovery duration in females, providers should include this information when educating the female athlete (and guardians if applicable)

regarding the athlete's projected recovery course and outcome in order to help manage expectations. Additional age-appropriate sex-specific content such as possibly temporarily altered menstrual cycles should be included. Although all athletes should be treated with the same level of due diligence, providers may be prompted to consider additional interventions in females aside from rest and progressive activity, such as school accommodations or use of medications, given their potentially higher risk for delayed return to play, postconcussive syndrome, and reported need for interventions.

Injury Prevention

Prehabilitation and rehabilitation measures should consider the role of neck strength, neck stiffness, and neuromuscular control for the prevention of concussion in both sexes; however, given that females have reduced neck girth and strength relative to head size and head-neck length compared to males, such interventions may be particularly applicable in the female athlete. It is notable that a recent study in male rugby athletes focusing on balance training, whole-body resistance training (including neck strength), plyometric training, and controlled landing and cutting motions decreased the relative risk of concussion by up to 59% [120]. Although this study was in male athletes, it does provide support for the role of neck strengthening in concussion prevention. However, it is possible that improved whole body neuromuscular control also allows athletes to better avoid contact and high-risk positions. Further studies are needed to better delineate the role of sex-specific concussion prevention measures and rehabilitation of athletes with concussions.

Summary

This review highlights that BSIs, ACL injuries, and concussion are commonly seen in athletes of both sexes, and presents their unique sex-specific epidemiology, risk factors, and injury outcomes (see Table 1).

The risk factors for BSI are better described in female athletes. Although the biological risk factor of Triad has been studied in female athletes, the more recent introduction of RED-S may create greater interest in understanding the role of energy availability and hormonal status in male athletes and how this contributes to injury. The biomechanical risk factors have been studied more commonly in female runners and military populations; further studies are needed to characterize the specific risk factors in male athletes.

Noncontact ACL injury is believed to result from an interplay of risk factors including anatomy, genetics, hormones, and neuromechanics. ACL injury prevention in both sexes primarily focuses on neuromuscular training to optimize motor patterns during landing and cutting maneuvers. Further studies are needed on the role of sex-specific interventions for injury prevention and rehabilitation of ACL injuries.

Although some variation in the literature exists, the majority of available data indicate that female athletes have an increased risk for concussion, report more symptoms, and have an extended recovery duration compared to male athletes. However, differences between sexes is confounded by sex-specific factors related to concussion and symptom reporting. Females also appear to be more at risk for concussion from contact with playing equipment compared

to males. Females tend to have reduced neck strength and stability compared to males, which may be a modifiable target for reducing concussion risk; however, interventional studies on neck strengthening and neuromuscular control are needed.

By accounting for sex differences, clinicians can optimize the individualized evaluation and management of injuries. The importance of targeting modifiable risk factors regardless of the sex of the patient, such as improving movement patterns, dynamic strength, and biomechanics for prehabilitation and rehabilitation is a unifying theme in the approach to these common sports injuries. Injury prevention is an important aim, and our review highlights the current knowledge for each injury by sex.

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Table 1

Summary of Sex Differences in Common Sports Injuries

Injury Type	Epidemiology	Risk Factors	Outcomes
Bone stress injury	Higher incidence in females [8]	In both males and females, history of fracture [10–12] or RED-S [13]. Female risk factors include Triad: low BMI, late menarche, low BMD [10,11,15–17]	Longer time for return to play for a given grade BSI in female athletes with Triad risk factors [6]
ACL injury	Increased incidence in females compared to males at high school and college level [30]	Female risk factors include increased posterior tibial slope [40], ACL smaller in size [39], increased generalized laxity [41], increased BMI [42,43], increased peak knee abduction angles during landing [44]	Males more likely to undergo ACL reconstruction surgery [62] and more likely to return to preinjury level of sport [64].
Concussion	Higher incidence in females [76–88]	Female risk factors include reduced neck girth and strength relative to head size compared to males [87–93]	Females report more symptoms postinjury and have higher rates of postconcussive syndrome [109,110]

RED-S = relative energy deficiency in sport; BMI = body mass index; BMD = bone mineral density; BSI = bone stress injury; ACL = anterior cruciate ligament.