Review Article

Sex-based Differences in Common Sports Injuries

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Abstract

The patient's sex plays an important role in mediating the risk for, and experience of, disease. Injuries of the musculoskeletal system are no exception to this phenomenon. Increasing evidence shows that the incidence, clinical presentation, and treatment outcomes for male and female patients with common sports injuries may vary widely. Stress fracture, which is associated with the female athlete triad, is a sports injury with known sex-based differences. Other common sports-related injuries may also have distinct sex-based differences. Understanding these differences is important to optimize each patient's musculoskeletal care.

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At the end of the 20th century, the National Institutes of Health (NIH) implemented a series of policy changes that substantially increased the proportion of females participating in NIH-funded clinical trials.[1] These changes have had the desired result of improving our understanding of sex-based differences that exist in clinical medicine. More recently, the NIH has focused on ensuring that preclinical trials include both male and female cells and animals in the laboratory.[1]

The musculoskeletal system is rife with sexual dimorphism. One example is that males have greater bone mass, greater muscle mass, and greater lean mass than do females. Various sex-based differences in injuries and diseases of the musculoskeletal system have been described, including differences in osteoporotic hip fractures and osteoarthritis of the knee and the carpometacarpal joint of the thumb.[2]

Most of the existing data regarding sex-based differences in the incidence of sports injuries are from the pediatric literature. One recent epidemiologic study of sports-related injuries (SRIs) in Canadian children and adolescents reported that males are more frequently injured during sports participation than females are. Males comprised 71% of SRIs in this study, reporting higher injury rates in 11 of the 13 sports investigated.[3] A more recent study of children aged 5 to 17 years in the United States described the type, location, and chronicity of SRIs as a function of sex.[4] The authors noted that females are more likely than males to have overuse injuries; for example, females are three times more likely than males to develop patellofemoral knee pain. Males are markedly more likely than females to sustain acute, traumatic injuries such as sports-related fractures.[4]

Mounting evidence exists supporting the concept that the incidence, clinical presentation, and functional outcomes for male and female patients with sports injuries may profoundly differ. By improving our understanding of these sex-based differences, orthopaedic surgeons may be better equipped to care for patients with common sports injuries and improve treatment outcomes. For example, the intraoperative choice of an anterior cruciate ligament (ACL) autograft is a notable factor in determining return-to-sport and reinjury rates, especially for adolescent females with high quadriceps to hamstring strength ratios. Investigating this and similar hypotheses in a systematic fashion may lead to the development of sex-specific treatment algorithms that may optimize clinical outcomes.

Here, we review the current literature on sex-based differences for five commonly occurring SRIs: stress fracture, ACL injuries, femoroacetabular impingement (FAI), shoulder instability, and concussion.

Stress Fracture

Since the implementation of Title IX in 1972, the number of females participating in sports has increased dramatically at all levels of play. Thus, the number of SRIs has also increased. One injury that first seemed to be particularly common in this population was stress fracture, often seen in the context of hormonal and dietary irregularities. When the Task Force on Women's Issues of the American College of Sports Medicine was assembled in 1992, the term "Female Athlete Triad (FAT)" was created to describe the interrelated pathologies of disordered eating, amenorrhea, and low bone mineral density (BMD); all three components had to be present simultaneously for a diagnosis of FAT.

In 2007, the American College of Sports Medicine updated the diagnostic guidelines, and FAT was redefined to include a constellation of abnormalities including those related to energy availability (EA), menstrual function, and BMD.[5] Each component is part of a spectrum ranging from normal to increasing degrees of pathology. The female athlete no longer must demonstrate pathology in all three components of the triad to be diagnosed with the syndrome.

Determining the true prevalence of FAT is difficult, especially as the definition continues to evolve. Studies have demonstrated low EA in up to 36% of female high school athletes,[6] 63% of endurance athletes,[7] and 77% in ballet dancers.[8] The same group of authors identified menstrual dysfunction in 54% of high school athletes, 60% of endurance athletes, and 36% of ballet dancers. In a study of female endurance athletes, Melin et al[7] reported that 45% had impaired bone health and 25% demonstrated all three components of the triad.

In 2014, Barrack et al[9] reported that 11% of adolescent female athletes in their study population had a bone stress injury secondary to FAT. This finding is particularly concerning because 90% of peak bone mass is accrued by adolescence; a normal adolescent female gains approximately 2% bone mass per year, whereas an amenorrheic female loses 2% per year. If young female athletes fail to maximize their bone mass during the normal period of accrual, they may have an increased risk for osteoporosis and associated fragility fractures later in life.[10] The most common musculoskeletal manifestation of the FAT is stress fracture, and females are at a greater risk of this complication. In a 2011 systematic review of the incidence of stress fracture in military and athletic populations, Wentz et al[11] reported stress fractures in 9.7% of female athletes compared with 6.5% in male athletes. In the military population, females fared worse than males, with a reported stress fracture incidence of more than three times that of males.

Acknowledging that athletes of both sexes might be at risk for impaired bone health resulting from nutritional and neuroendocrine abnormalities, the International Olympic Committee convened in 2014 and published a consensus statement titled, "Beyond the FAT—Relative Energy Deficiency in Sport (RED-S)."[12] The term "RED-S" is intended to be a broader and more comprehensive definition of pathology secondary to a relative energy deficiency that may occur in any athlete, irrespective of sex.[12]

Highlighting the fact that RED-S may affect both male and female athletes, Tenforde et al[13] examined components of this syndrome in male athletes. These authors noted that male athletes, like their female counterparts, may sustain bone stress injuries in the setting of nutritional

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and endocrine abnormalities. They suggested that hypogonadotropic hypogonadism (characterized in males by low serum testosterone levels with concomitant clinical symptoms, such as low BMD, reduced energy and stamina, oligospermia, and decreased libido) is analogous to the hypothalamic amenorrhea component of FAT. Tenforde et al[13] proposed that a subset of male athletes may present with a combination of low EA, hypogonadotropic hypogonadism, and low BMD, in which each component exists on a spectrum similar to that characterizing FAT.[13] In addition, just as has been reported for female athletes, male athletes who seem to be most at risk for developing RED-S commonly participate in sports emphasizing leanness, including aesthetic sports (eg, gymnastics), endurance sports (eg, running, cycling), and sports with a weight classification (eg, rowing, wrestling).[10,14]

A recent study on awareness of FAT among multispecialty physicians demonstrated that only 37% of physicians across disciplines had heard of the triad.[15] This highlights the importance of continued education for all athletes, coaches, and physicians about RED-S, including its signs, symptoms, and at-risk populations (both female and male), so that the potential negative consequences of RED-S on long-term reproductive and skeletal health can be mitigated.

Anterior Cruciate Ligament Injury

Abundant data exist demonstrating that female athletes are particularly vulnerable to ACL rupture; the incidence of noncontact ACL injuries is two to eight times higher in females compared with males participating in basketball, soccer, team handball, netball, and alpine skiing.[16] According to survey data obtained from the US National Collegiate Athletic Association, females who participate in collegiate basketball have more than a threefold increased risk of sustaining an ACL injury than their male counterparts; female collegiate soccer players have a similarly high relative risk of noncontact ACL injury (relative risk = 2.75).[16] Therefore, given the higher rate of sports participation among males, the absolute number of ACL injuries remains higher for this group than for female athletes.

Risk factors for ACL injuries have been classified as nonmodifiable (eg, anatomic, structural, hormonal) or modifiable (eg, neuromuscular, biomechanical). An expert consensus is that modifiable factors may be more important in explaining the higher incidence of noncontact ACL injuries among female athletes.[17]

One primary modifiable risk factor for ACL injury that has been shown to differ between the sexes is the landing pattern.[18] Females tend to exhibit valgus collapse and increased abduction moments at the knee, both of which are predictive of ACL injury. In addition, when performing a single mini-squat, females tend to exhibit an anteriorly rotated pelvis, contralateral pelvic drop, hip internal rotation and adduction, knee valgus, tibia external rotation, and foot pronation[19] (Table 1). Similarities can be observed between the single mini-squat and the mechanism of noncontact ACL injury, which seem to set up the female athlete for ACL rupture.

Table 1

Sex-based Differences Observed During Performance of a Mini-squat

Body Region	Male	Female
Back	Flat	Lordotic
Pelvis	Level; neutral	Contralateral drop; anterior tilt
Hip	No rotation	Internal rotation and adduction
Knee	Neutral	Valgus
Tibia	Neutral	External rotation
Foot	Flat	Pronation

Nonmodifiable risk factors for ACL injury also exist. For example, smaller notch dimensions may predispose individuals to ACL injury. However, a sex-based difference does not seem to exist in this respect.[20] Other studies that evaluate the role of bony architecture in ACL injury risk have reported that a shallow medial tibial plateau and steep tibial slopes are risk factors for ACL injury; these anatomic differences have not been shown to be sex dependent.[21] Sex-based differences in the osseous anatomy of the knee have been reported, including differences in femoral condyle shape, hip version, and the length of the femur compared with the pelvic width. To date, however, no causal relationship between these factors and ACL injury has been proven.

Another nonmodifiable risk factor that has been theorized to correlate with ACL injury is the changing levels of circulating sex hormones throughout the female menstrual cycle; however, data are insufficient to make any conclusive statement regarding menstrual cycle, laxity, and the risk of ACL injuries in females.[22]

Interestingly, Posthumus et al[23] demonstrated that genetics likely plays a role in ACL injury risk; the *COL5A1* gene (which codes for alpha chains of collagen) is associated with an increased risk of ACL injury in females.

In terms of treatment and outcomes for athletes with ACL injury, information on sex-based differences is lacking. Prospective studies investigating whether sex affects a surgeon's choice of graft for ACL reconstruction are needed. Similarly, little information is available on whether and how sex affects postoperative rehabilitation and return-to-play decisions. Brophy et al[24] found that in soccer players followed for 7 years after ACL reconstruction, females were more likely than males to require further ACL surgery and less likely to return to play. A 2014 meta-analysis of 13 studies demonstrated no difference in graft failure, contralateral ACL rupture, or patient-reported outcomes as a function of the patient's sex.[25] However, the authors of this meta-analysis concluded that more high-quality studies are needed.

The incidence of ACL injury remains markedly higher in female athletes than in male athletes, even after controlling for sport. In addition, sex-based differences have been identified for both modifiable and nonmodifiable risk factors for ACL injury. However, sex-based differences in treatment and outcomes of this injury have not, as yet, been clearly delineated. More research studies on potential sex-based differences in risk factors, treatment, and outcomes for athletes with ACL injuries are needed.

Shoulder Instability

Atraumatic Shoulder Instability

As the most mobile of the major joints, the glenohumeral joint depends on a combination of soft-tissue restraints, dynamic muscular forces, and bony morphology for stability. Owens et al[26] investigated the role of osseous anatomy in providing shoulder stability and found that a patient whose glenoid is tall and thin has a higher risk of instability than one whose glenoid is short and wide. Subsequent investigators have observed that glenoid morphology varies markedly by race and sex;[27,28] compared with males, females have markedly smaller glenoids, with higher inclination angles.[27] In addition, height-to-width ratios of glenoids markedly differ between males and females; the functional importance of this finding is that the glenoid is more oval in shape (tall and thin) in females and rounder in males.[28] These anatomic findings substantiate that females should have higher rates of shoulder instability than males because the glenoid morphology in females favors instability. The combination of innate osseous vulnerability, increased shoulder range of motion, and greater prevalence of generalized ligamentous laxity[30] in females likely contributes to the higher rates of atraumatic multidirectional shoulder instability seen in this population. Thus, although sex-based anatomic risk factors for shoulder instability are fairly well characterized, little information is available regarding sex-based differences in treatment and functional outcomes for patients with atraumatic shoulder instability.

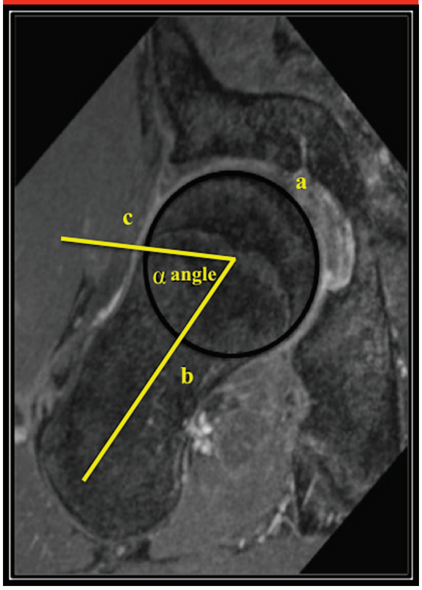
Traumatic Anterior Shoulder Instability

In the general population, the incidence of traumatic glenohumeral dislocations is relatively low, with 0.08 to 0.24 dislocations occurring per 1,000 person-years.[31] The incidence of traumatic shoulder instability is more than seven times greater in the military population, increasing to 1.69 per 1,000 person-years; most of these dislocations are observed in cadets.[31] Research on the incidence of traumatic shoulder instability as a function of the patient's sex has revealed that traumatic dislocations occur twice as often in males than in females.[32] In fact, Zacchilli and Owens[32] found that males are 2.6 times more likely to present to the emergency department with a shoulder dislocation than are females. Traumatic dislocations have also been found to have an inverse relationship with age and a direct relationship to activity level.[32]

In addition to males having an increased risk of initial traumatic shoulder instability relative to females, this population has also shown an increased risk of developing recurrent shoulder instability after an initial traumatic dislocation. In their investigation into the risk factors and functional outcomes for young patients with recurrent shoulder instability after an initial traumatic dislocation, Robinson et al[33] found that the mean time to the development of recurrent instability was 13.3 months, with the peak risk of recurrence at 24 months. Univariate analysis demonstrated that age, sex, generalized ligamentous laxity, participation in and intensity of sports, and return to contact sports were all contributing factors to the development of recurrent shoulder instability. However, after multivariate analysis, only male sex and younger age were independently predictive of recurrent instability. The risk of recurrent instability was lower for females of all age groups compared with their age-matched male counterparts.[33] Thus, although a variety of injury- and patient-related factors may contribute to the risk of recurrent shoulder instability, the risk is highest in athletic young males.[33]

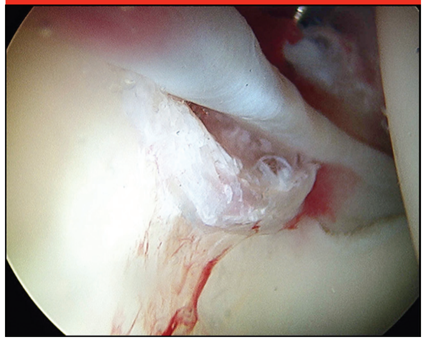
As yet, there has been little investigation into possible sex-based differences in the outcomes after surgical stabilization of the shoulder. In addition to this paucity of data, concern has been raised that the outcomes measures used in clinical research may not be valid for all patients: sex-based differences have been noted for the normalized scores of commonly used functional outcomes measures, such as the Constant-Murley score.[34] Methodologically sound, adequately powered studies that use validated, sex-neutral outcomes measures are needed to best understand how athletes' sex affects their risk of shoulder instability as well as its treatment and outcomes.

Figure 1



Radial reformatted MRI demonstrating the method of assessing the alpha angle in femoroacetabular impingement. It is measured by drawing a best-fit circle on the femoral head (**a**); a line from the center of the femoral head that bisects the femoral neck (**b**); and a line from the center of the femoral head to the location where the femoral head no longer follows a circular contour (**c**).

Figure 2



Intraoperative photograph of the hip demonstrating a labral tear extending into the chondrolabral junction. This pattern of injury is more commonly seen with cam lesions.

Femoroacetabular Impingement

FAI is a condition characterized by bony abnormalities around the hip that may cause labral tearing and damage to the articular cartilage, especially in young athletes.[35,36] Because the etiology of FAI is poorly understood, the effect of specific sports activities is unclear. Research has indicated that repetitive hip motion may lead to irregular bone formation, particularly in younger athletes as their physeal plates close.[37] Alternatively, athletes may have the same prevalence of radiographic FAI as the general population, yet become symptomatic because of increased stress through the hip.[36,38,39]

Sex-based differences in the acetabular and femoral morphology have been identified in patients with FAI.[40] Although pincer lesions occur equally in males and females, cam- or combined-type morphologies are more prevalent in males.[36] When cam morphology is present in patients with hip pain, males have larger alpha angles; in a recent study, Nepple et al[41] reported average alpha angles of 70.8° and 57.6° in symptomatic males and females, respectively (Figure 1). A study of large cohort of patients with symptomatic FAI assessed with CT suggested that females have increased femoral and acetabular anteversion with milder cam-type morphology, whereas males have more restricted motion and larger and broader cam-type morphology.[42] In addition to increased hip anteversion,[43-46] females also have a higher prevalence of acetabular dysplasia compared with males. In their recent series, Kapron et al[38] identified dysplasia in 21% of collegiate female athletes. This finding is relevant for surgical planning because overresection of a pincer lesion can result in instability.[47]

Symptoms of FAI and labral tears include intermittent anterior hip or groin pain, locking, and popping. Activities requiring hip flexion or pivoting often elicit symptoms in both male and female athletes.[36] Kapron et al[38] found that, in female athletes only, the response to impingement testing did not correlate well with the presence of radiographic FAI. On presentation, females reported worse function and decreased activity, despite a greater hip range of motion than that of males. Interestingly, this finding does not seem to correlate with the severity of the disease because males often have larger cartilage defects and labral tears[41] (Figure 2). Although females present earlier in the disease process than males do, males are more likely to undergo bilateral surgery within 2 years.[48]

Of note, symptoms of FAI can be seen in females with minimal bony abnormalities. This occurrence may be attributed to physiologic differences such as increased laxity, less muscle mass, and overall greater range of motion compared with males.[43,45] Awareness of alternate etiologies of pain, particularly in females, such as stress fractures, iliopsoas dysfunction, sacroiliac pathology, ovarian cysts, and endometriosis, is important. Management of confirmed FAI does not differ between males and females because a nonsurgical approach, including physical therapy, activity modification, and anti-inflammatory medication, is recommended as first-line treatment.[35,36] Typically, surgical intervention entails some combination of labral repair, acetabular osteoplasty, and femoral osteoplasty that can be conducted arthroscopically. Surgical techniques are not sex dependent; however, careful consideration of the underlying bony abnormalities is essential in determining appropriate resection.[35,36] Prognosis after surgery is favorable, with return to play reported in 73% to 92% of patients.[49,50] Markedly improved functional outcome scores after hip arthroscopy have been reported, with no difference between sexes in patients aged <45 years.[51,52]

Further investigation of sex-based differences in the clinical presentation, relevant anatomy, and surgical management of FAI is necessary to elucidate factors markedly associated with patient outcomes. For example, recognizing that females have higher rates of pelvic anteversion coupled with greater ligamentous laxity might suggest that surgical osteoplasty would be beneficial in this population, even in the setting of radiographically smaller impingement lesions. Rigorous scientific investigation that either confirms or refutes this type of clinical hypothesis is needed.

Concussion

Concussions sustained during athletic participation have become increasingly common; the CDC reported that 249,000 children (aged ≤19 years) were treated in an emergency department for sports-related concussion in 2009.[53] This new wealth of experience treating young athletes with concussions led some investigators to hypothesize that sex-based differences exist in both the incidence of and the symptomatology after a sports-related concussion.[54] In a recent study, Zuckerman et al[55] demonstrated a higher incidence of concussion in females participating in sports such as soccer, basketball, and lacrosse. Large epidemiologic studies have consistently found that female athletes sustain markedly more concussions than male athletes; in some studies, the number of concussions sustained by female athletes is double the number sustained by male athletes.[54,56] These differences are most commonly seen in sports such as basketball, soccer, and volleyball.[54,56] Some authors have additionally demonstrated that female athletes sustain more severe concussions than do males, with greater deficits in cognitive function reported and a longer recovery period required than their male counterparts.[57-59]

Why females seem to have a higher risk of sustaining a concussion compared with males remains uncertain. Several theories have been posited and primarily focus on anatomic and biomechanical differences: first, females typically have more slender necks and smaller heads compared with males and thus experience greater reactive forces when head trauma is sustained. Biomechanical studies have demonstrated that females can experience nearly 50% more head acceleration during head trauma than males.[54,60] Although it has also been theorized that a female's relatively weak neck musculature may provide less protection against concussion than a male's neck musculature, recent research suggests that dynamic cervical stabilization responses may play a larger role than neck strength in mitigating head impact severity.[61] Finally, in addition to the sex-based differences in anatomy and biomechanics that likely mediate an athlete's experience of concussion, hormonal differences between males and females may also play a role. Studies have shown that estrogen has differential effects on the brain after trauma, with animal studies suggesting a greater detrimental effect of estrogen in females.[54,62]

It has also been argued that the documented differences between the sexes with regard to concussion incidence and severity may simply be the product of reporting bias. Male athletes may be more likely than female athletes to hide concussions and fail to report them for fear of not being able to continue playing or to participate in sports.[63] Gender stereotypes may reinforce this behavior, with boys wanting to appear "manly" after sustaining a concussion and "toughing it out."

Much remains to be elucidated regarding sex-based differences in concussion incidence and severity. Ultimately, team physicians should have a high index of suspicion for concussion with any head trauma sustained in sports, regardless of the athlete's sex.

Summary

Sex-based differences are common in medicine, occurring at both the micro (cellular) and macro (whole organism) levels. Some sex-based differences in musculoskeletal medicine are fairly well characterized, such as those seen in patients with degenerative joint disease of the knee and fragility fractures of the hip. Despite these initial successes in advancing knowledge of sexual dimorphism in the field of orthopaedic surgery, research that strives to detect, describe, and delineate sex-based differences in musculoskeletal disease is a field of study that remains in its infancy, both at the bench and in the clinics.

Our review of the existing literature on sex-based differences in common sports injuries demonstrates the continued need for focused efforts at studying these differences because ultimately, a patient's sex will likely affect his or her clinical outcome. It is critical that we continue to enhance our understanding of the differences among patients and the role these differences play in mediating each patient's experience of, and treatment outcomes for, various musculoskeletal diseases—including stress fracture, ACL injury, shoulder instability, FAI, and concussion. Devising scientific studies that investigate sex-specific hypotheses (eg, do females with ACL injury have lower reinjury rates after quadriceps autograft reconstruction than males?) may lead to the development of evidence-based sex-specific treatment algorithms for various sports injuries and, ultimately, to improved musculoskeletal care for all athletes.

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