SEX DIFFERENCES IN SPORTS MEDICINE
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This book is dedicated to my parents, Bill and Kristine, for their endless encouragement. To my husband Chris and my children, Nathaniel and Emersyn, for their support and love. And finally, to my sports medicine colleagues, for our shared passion in caring for athletes of all kinds.

—Ellen Casey, MD

I dedicate this book to my parents, Cecilia and Jae Rho, who came from a culture and a generation that placed limits on women in sports and in medicine. Throughout my life, I have inherited many wonderful things from my parents, but they never passed these limitations on to me. In fact, they have always encouraged me to go beyond where I can see.

—Monica Rho, MD

To my best friends—Gayle, Hannah, Aaron, and Jenny.

—Joel Press, MD
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The title of this book nearly became *Gender Differences in Sports Medicine*. Before embarking on this book, we used the terms *sex* and *gender* interchangeably. However, “gender” refers to the phenotype that comprises psychosocial, cultural, and behavioral factors, whereas “sex” refers to the genotype of the chromosomal complement present in cells, hormonal profiles, and sex organs. This book is aimed at addressing the biology behind the differences of men and women in sports medicine, which is why the preferred term we use in our title and in our chapters is “sex differences.”

The theme of this book may immediately engender some feeling that the book is going to address one sex being superior to the other in the arena of sports medicine. In creating this book it is not our intent to add to the “battle of the sexes” or to determine superiority between them. *Sex Differences in Sports Medicine* is written for the sports medicine clinician who wants to take his or her approach to the next level of personalized care. A PubMed search on sex or gender differences in the musculoskeletal system reveals very little literature prior to the late 1990s. Before that time little thought was given to sex-specific differences in researching the musculoskeletal system. Since that time, and with the overwhelming effects of Title IX legislation increasing female participation in sports, there has been a noticeable shift in musculoskeletal research acknowledging sex disparity. We have been interested in these differences for many years. Inherently, when we treat men and women in our offices we attempt to utilize sex-specific approaches to their sports-related injuries. However, there has been no singular source of collected information on the sex-specific differences in sports medicine in textbook form.

A few years ago we created an academic symposium entitled “The Active Female Across the Lifespan.” This course focused on the ever-changing female musculoskeletal system and how it impacts risk of injury and response to treatment of active females at key maturational phases. We invited nationally renowned speakers to the Rehabilitation Institute of Chicago, who eloquently explained the female musculoskeletal system. Educationally, the symposium was outstanding. However, as the directors of this course we could not help but notice that less than 5% of our course participants were male. We learned a significant lesson during the development of this course—in order to engender true understanding of sex-specific differences, you can neither focus on nor alienate one sex. Isolating one sex from the other tends to automatically segregate your audience. There are textbooks focused on topics relevant to the “female athlete.” The intention of this book is to present the sex-specific differences of both men and women in order to provide sports medicine clinicians a well-rounded understanding of these issues.

We would like to thank all of the authors who contributed to this book. We have had a tremendous amount of support from them to make this a truly one-of-a-kind textbook. We asked for their creativity in creating the outline of their chapters, their diligence in presenting the most current research findings, and their dedication in synthesizing this information for mass consumption. Our authors share our common goal, which is to educate other clinicians about these sex-specific differences so that we can provide better care to our athletes. We hope that you, our readers, will take this information and incorporate it into your everyday clinical practice.

Ellen Casey, MD  
Monica Rho, MD  
Joel Press, MD
INTRODUCTION

Ever since humankind crawled out of the primordial soup or Adam and Eve came to be in the Garden of Eden, men and women have existed side by side. Although they both evolved over the same time period and were exposed to similar climate and evolutionary forces, differences in their structural makeup exist. Anatomic changes have occurred to serve various evolutionary needs. Man, originally, was felt to be the hunter/gatherer while women were needed to raise the offspring and protect them as they grew. Over the centuries their roles have evolved as well as their overall activity levels. Ultimately, humans began to be engaged in physical activity, not only for survival, but for recreation and sport. The loads placed on the musculoskeletal system during sports and physical activity can have different and varying effects on men and women owing to numerous muscle, bone, and connective tissue differences. Understanding some of these differences may be a key to understanding the evaluation and treatment of many sports-related musculoskeletal disorders.

The only difference between male and female skeleton models is that the female has a more rounded pelvis, but in reality there are many subtle differences between male and female skeletons (1). First of all, bones develop at different rates in males and females. The bones in a female body mature earlier than those in the male body. Note the tallest person in the class picture in kindergarten is often a girl. Female bones complete their development around age 18, while male bones continue to mature until around age 21. This is part of the explanation behind the difference in the average size of male and female bones—because the male bones continue to grow and develop longer, they also become larger (on average) and have more pronounced corners. Thus the jawbone is generally larger and more pronounced in males and the brow is taller (1). Male skeletons also generally have longer, thicker bones in the arms, legs, and fingers. Women have a much broader pelvic bone than men to facilitate parturition. The effects of these subtle differences will be reflected on in later chapters on the sports-related injuries.

Besides skeletal differences, changes in ligament and cartilage can vary between men and women, at least in part due to hormonal differences. Ligamentous laxity in general has been found to be greater in women and may explain issues of ankle instability, shoulder instability, and anterior cruciate ligament (ACL) injuries that occur more often in women (2). Cartilage changes are also noted to be different between the sexes and osteoarthritis of the knee develops more frequently in women compared with men (2). In asymptomatic women between ages 50 and 79 years, MRI studies showed that women lose cartilage in the tibia at four times the annual rate of men (2). More recent studies have shown sex-specific differences in peak torque, muscle stiffness, and musculoarticular stiffness of the knee joints in a young active population where females demonstrated less normalized peak torque, relaxed muscle stiffness, and contracted musculoarticular stiffness. These observed differences may contribute to higher knee injury incidence and prevalence in females when compared to males (3). There is also literature that suggests that there are sex-specific responses of knee extensor torque to maximal-effort contractions (4) and differences in leg stiffness (5).

To better understand the sex differences between men and women as they relate to sports injuries, we first need to understand the background of sports participation of men and women. Men and women have not equally participated in sports and recreational activities over mankind’s life span. History shows that women were actually engaged in some sport three millennia ago. Homer (c. 800 BC) relates the story of Princess Nausicaa playing ball with her handmaids next to a riverbank on the island of Scheria: “When she and her handmaids were satisfied with their delightful food, each set aside the veil she wore: the young girls now played ball; and as they tossed the ball...” (Homer, lines 98–112) (6). The second-century BC grammarian...
Agallis attributed the invention of ball games to Nausicaa, most likely because Nausicaa was the first person in literature to be described playing with a ball. It took thousands of years before women were involved in any sort of play activities that were more than recreational (7).

In 1874, as women were beginning to gain access to higher education, Dr. Edward Clarke published Sex in Education, Or, A Fair Chance for Girls, which sparked tenacious and acrimonious debate about the capacity of women for physical activity (6). Ultimately, in the late 1800s and early 1900s, women began to form informal athletic clubs that involved tennis, croquet, bowling, and archery. Early college sports for women were largely intramural (within colleges between students). Finally, the confluence of numerous movements, including passage of the Nineteenth Amendment allowing women to vote, the war effort of women in World War II as demonstrated by “Rosie the Riveter,” the Civil Rights Act of 1964, feminist activism of the 1960s and 1970s, and the formation of associations for women’s athletics led to the evolution of Title IX and its passage in 1972 (6). Title IX gave women the right to participate in sports on a plane equal to men. The impact on female participation in athletics has been dramatic (8). Increased participation also carries with it an increased number of athletes exposed to potential injuries. As women’s participation in sports has been brought closer to levels observed in men, differences in injury types and frequencies need to be addressed.

For many years the debate as to the susceptibility of the different sexes to specific injuries has been clouded by reporting of actual number of athletes participating in sports, injury mechanisms, definitions of injuries, and the number of exposures to possible injuries (9–11). A retrospective study by Sallis et al. of patterns of injuries between men and women, which looked at over 3,700 athletes, spanning 15 years, showed that except for some minor sex differences in total injuries for two sports (swimming and water polo) and several differences in total injuries by anatomic location, very little difference exists in the pattern of injury between men and women competing in comparable sports (12). Wolf et al. also showed no significant relationship between occurrence of injury and gender in Division 1 collegiate swimming (13). Similar findings were noted in gymnastics (14) and cross-country skiers, swimmers, long-distance runners, and soccer players (15). However, although injury rates are similar between men and women for many sports, the anatomic locations of these injuries can vary. Arendt and Dick showed significantly higher anterior cruciate ligament injury rates in both basketball and soccer in females compared with males (16). Sallis’s retrospective review also confirmed several differences in total injuries by anatomic location. Understanding some of these gender-specific issues related to sports injuries can help the sports medicine clinician address prevention, evaluation, diagnosis, and rehabilitation of sports injuries.

Men and women have evolved over the centuries to be very active in recreational and sporting activities. Patients of both sexes come to our clinics every day with various sports-related injuries. Often they will have specific issues that need to be evaluated with a good understanding of sex-related nuances and differences. It is the purpose of this book to provide an in-depth look at the musculoskeletal system and tease out some of the many sex-related issues that affect our patients in hopes of providing better care for them.

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SEX DIFFERENCES IN SPORTS MEDICINE
INTRODUCTION

Injuries of the elbow, wrist, and hand are common in the athletic population. Approximately 25% of all sports injuries involve injuries to the elbow, forearm, and wrist (1). Sex differences associated with the anatomy and biomechanics of elbow, wrist, and hand structures have been reported in the literature. These differences can have implications in various traumatic and overuse injuries seen in athletes. To understand and treat injuries of the musculoskeletal system, it is important to first understand the “normal” functioning of the involved body part among different populations, such as males and females. This can help providers identify risk factors for injury in order to optimize treatment and/or injury prevention. This chapter provides an overview of gender and sex differences in elbow, wrist, and hand anatomy and biomechanics and looks specifically at various injuries in which sex differences have been reported in the literature.

ANATOMY AND BIOMECHANICS

Elbow

The elbow joint involves three articulations: the proximal radioulnar joint, the ulnohumeral joint, and the radiocapitellar joint. It has two degrees of freedom: flexion-extension and pronation-supination. Stability of the elbow joint is accomplished primarily by the congruity of the articular surfaces, the capsule, as well as the ligament complexes. Myotendinous units that cross the joint also provide dynamic stability.

Normal elbow range of motion (ROM) is approximately 0° to 150° of flexion and 80° of pronation and supination (2). Golden et al. evaluated 600 elbows (300 participants) of healthy children and adolescents and found females to have greater total ROM, greater flexion, and greater extension than males (3). Chapleau et al. demonstrated similar findings of greater elbow ROM in females compared with males in an adult population (4).

The elbow has a relative valgus alignment, formed between the long axis of the humerus and the long axis of the ulna when in full extension and supination, called the carrying angle. This angle is approximately 5° to 10° (2). Numerous studies have demonstrated an increased carrying angle in females (5–11). This difference has often been considered to be a secondary sex characteristic. Not all studies, however, have noted this difference. Beals conducted a radiographic study of the carrying angle in 422 patients and found no real differences in males and females (12). The author suggested that the clinical observation of an increased carrying angle in females may be explained by increased joint laxity, allowing for a greater degree of extension (Figure 3.1).

An increased carrying angle, when combined with the significant valgus and extension forces generated in overhead throwing motions, can lead to stress injuries of the elbow. Continued valgus stress can cause ligament damage, formation of olecranon tip osteophytes, loose bodies, articular damage, flexor-pronator tendonitis, ulnar neuritis, and medial epicondylitis or apophysitis (13).

Wrist

The wrist consists of the distal ulna, distal radius, eight carpal bones, and the bases of the metacarpals. It is divided into three primary joint regions: distal radioulnar, radiocarpal, and midcarpal. It has two primary degrees of freedom: flexion-extension and radial/ulnar deviation. Normal wrist palmar flexion is 75° to 80° and normal dorsal extension is 75° to 85° (2). Normal radial deviation is 20° to 25°; normal ulnar deviation is 35° to 40° (2). Allander et al. analyzed wrist joint ROM in 517 females and 203 males, all ranging in age from 33 to 70, and found
that females had significantly larger ROM in the wrist than males (14).

The relative length of the ulna in relation to the radius at the level of the wrist is called ulnar variance (Figure 3.2). Ulnar variance may be positive (ulnar projects distally), negative (ulnar projects more proximally), or neutral (both the ulnar and radial articular surfaces are the same length).

Ulnar variance has been associated with various pathological states. Positive ulnar variance has been associated with ulnar impaction syndromes and triangular fibrocartilage complex (TFCC) injury. Negative ulnar variance has been associated with Kienbock’s disease, avascular necrosis of the scaphoid, and scapholunate dissociations.

Goldfarb et al. assessed ulnar variance in the adolescent population and found that young adolescent boys demonstrated a greater degree of negative ulnar variance compared with young adolescent girls (15). Nakamura et al. measured ulnar variance in 325 normal wrists, consisting of 203 males and 122 females ranging in age from 14 to 79 years (16). The study found that males had a lower mean value (i.e., greater degree of negative ulnar variance) in all age groups compared with females.

**Hand/Fingers**

The skeletal anatomy of the hand consists of phalanges, metacarpal bones, and carpal bones. These 27 bones serve as attachment and insertion sites for muscles and ligaments that can produce a vast array of movements and tasks through complex interactions (17).

Mallon et al. assessed the ROM of fingers in young healthy adults. The study found that females showed an increased amount of both active and passive extension at all joints on all digits (18).

**Overarm Throwing Kinematics**

The position of the hand, shoulder, and elbow during overarm throwing all play a role in the amount of stress experienced across the elbow. Van den Tillaar and Cabri investigated the throwing velocity and kinematics of overarm throwing in elite female and male handball players (19). The analysis consisted of maximal joint angles, angles at ball release, maximal angular velocities of the joint movements, and maximal linear velocities of the distal endpoints of segments and their timing during the throw. No major differences in kinematics were found, except for the maximal endpoint velocities of the hand and wrist segment (19). The authors conclude that male and female handball players throw with the same technique, and differences in throwing velocity are generally not the result of changes in kinematics in the joint movements.

The perception that sex alone causes suboptimal throwing mechanics appears false. “Throwing like a girl” may simply be an immature throwing mechanic and not a specific gender-related anatomic or physiologic finding (20). Multiple studies have reported that the pace of developing a mature throwing mechanic may be delayed in females compared with males (21,22). While gender has generally been a reasonable predictor when evaluating throwing velocity, if grouped by stages of development, gender explains no more than 2% additional variance (23). This finding is discussed in greater depth elsewhere in this textbook, in Chapter 4 on upper limb mechanics: throwing.
Swing Kinematics

The golf swing is a complex movement utilizing the whole body in a coordinated fashion. Repeated motion can result in injury in both professional and amateur golfers. Female golfers have been found to have twice as many wrist injuries as males (24). Zheng et al. compared the golf swing kinematics between 25 female and 25 male professional golfers (25). Significant differences were found in the maximum angular velocity of both wrists, the maximum angular velocity of the right elbow extension, and the timing when the maximum left wrist angular velocity occurred. These velocity differences may account for the difference in wrist injury incidence.

SELECTED INJURIES/PATHOLOGY

Reported sex differences in specific injuries/pathology of the elbow, wrist, and hand are somewhat limited in the literature. However, the injuries described in the following sections have been found to have differing incidence in males and females.

Valgus Extension Overload

Valgus extension overload (VEO) is a constellation of symptoms and pathology seen with overarm throwing athletes as a result of high repetitive stresses generated by overarm throwing motions. There is increased incidence of VEO in males, given the high association with baseball pitchers. With each pitch, the elbow joint is subject to a valgus torque reaching an average of 64 Nm, of which approximately 50% is taken up by the ulnar collateral ligament (UCL) (26). Overhead sports requiring similar motions, such as a tennis serve, football pass, or volleyball spike, can also produce tensile forces to the medial elbow. The valgus carrying angle of the elbow, which can be increased in females, may predispose the medial elbow to overuse injuries.

A valgus torque of 45 Nm is generated at the elbow during underhand softball pitching (27). Although a smaller magnitude of force is exerted on the softball pitcher’s elbow compared with a baseball pitcher, Barrentine et al. suggest that the underhand throwing motion in softball may not be as safe from overuse injuries as previously thought (27).

Ulnar Neuropathy

Compression at the Elbow/Cubital Tunnel

At the level of the elbow, the ulnar nerve enters the ulnar groove formed between the medial epicondyle of the humerus and the olecranon process of the ulna. Distal to this groove, the ulnar nerve travels under the two heads of the flexor carpi ulnaris muscle, known as the cubital tunnel (Figure 3.3). Ulnar neuropathy at the elbow may be caused by compression at the ulnar groove or at the cubital tunnel.

Ulnar neuropathy at the elbow is the second most common entrapment neuropathy of the upper extremity. Richardson et al. compared characteristics of patients with and without ulnar neuropathy at the elbow and found that men were more likely to have an ulnar neuropathy at the elbow than women (28). The study also found that more women with a body mass index (BMI) of less than or equal to 22.0 had ulnar neuropathy at the elbow when compared to women with a BMI greater than 22.0, suggesting that thin women are at increased risk for ulnar neuropathy.
at the elbow, presumably due to susceptibility to external compression. This trend was not seen among men. The authors suggested that any mechanical protective effect of an increased BMI in males may be offset by increased forearm muscle mass and grip strength that produce greater pressures over the ulnar nerve (28).

Contreras et al. also looked at sex differences and their relationship to ulnar neuropathy at the elbow (29). They found significantly larger (2 to 19 times greater) fat content on the medial aspect of the elbow in women compared to men. In addition, the tubercle of the coronoid process was approximately 1.5 times larger in men. These two anatomical findings suggest two mechanisms by which the ulnar nerve may be predisposed to increased risk of compression in males compared to females.

There has been increased use of ultrasound in the evaluation of nerves, including the ulnar nerve. Multiple studies have demonstrated increased cross-sectional areas and increased cross-sectional diameters in healthy males when compared with healthy females (30,31).

**Comprehension at the Wrist/Guyon’s Canal**

At the level of the wrist, the ulnar nerve enters a canal formed proximally/medially by the pisiform bone and distally/laterally by the hook of the hamate, called Guyon’s canal. In the canal, the nerve divides into the superficial sensory and deep palmar motor branches.

Ulnar neuropathy at the wrist/Guyon’s canal is much less common than ulnar neuropathy at the elbow. It is most commonly due to a ganglion cyst within Guyon’s canal that compresses the ulnar nerve. Women are three times more likely to be affected by hand and wrist ganglions than men (32). Ulnar neuropathy at the wrist/Guyon’s canal can also be associated with trauma and fractures.

**Olecranon Bursitis**

Olecranon bursitis is inflammation of the subcutaneous synovial-lined sac of the bursa overlying the olecranon process of the ulna. Annual incidence is approximately 10/100,000 and predominantly affects male patients (80%) aged 40 to 60 years (33). Most cases of nonseptic bursitis seen in athletes are posttraumatic or due to overuse.

**Lateral and Medial Epicondylosis**

Lateral epicondylosis, often referred to as tennis elbow, is a common cause of lateral elbow pain. It is an overuse syndrome affecting the wrist extensors, particularly the extensor carpi radialis brevis tendon. The literature is mixed regarding incidence of lateral epicondylosis between males and females. Several studies note an increased incidence in females (34–36). Other studies note equal incidence in males and females (37–39).
Medial epicondylitis, often referred to as golfer's elbow, is a common cause of medial elbow pain. It is less common than lateral epicondylitis. It is an overuse syndrome affecting the wrist flexors. There appears to be equal incidence in males and females (38–40).

**Triangular Fibrocartilage Complex**

TFCC consists of the articular disc, the meniscus homologue, the dorsal and palmar radioulnar ligaments, the ulnolunate and ulnotriquetral ligaments, and the extensor carpi ulnaris tendon sheath. The TFCC plays a key role in stabilization, rotation, translation, and loading transmission to the wrist and acts as an essential pivot point (41). It is prone to injuries because of its anatomical location and involvement in rotation and load bearing. Positive ulnar variance is associated with degeneration of the TFCC, while negative ulnar variance is associated with less degenerative wear (41).

**Mallet Finger**

Mallet finger, also known as baseball finger, is a deformity caused by rupture of the extensor tendon after sudden passive flexion of the distal interphalangeal joint when the finger is extended. Peak incidence has been found to vary between sexes, occurring in young to middle-age men and in older women (42).

**Boxer’s Fracture**

Boxer’s fracture is a fracture of the metacarpal neck/shaft that may be seen after a person strikes a wall or another person with poor technique. It may occur at any digit but is commonly seen in the fifth digit. Gudmundsen and Borgen reviewed 271 fifth metacarpal fractures and found 48% were related to aggression, with males comprising 93.1% of the aggression group as well as 70.2% of the nonaggression-related group (43).

**CONCLUSION**

Significant sex differences exist in the anatomy and biomechanics of the elbow, wrist, and hand. In addition, various injuries have higher incidence in males or females. Knowledge of these differences can provide greater understanding of the musculoskeletal system and can help providers optimize their treatment of elbow, wrist, and hand injuries in athletes.

**Summary of Sex Differences in the Elbow, Wrist, and Hand**

<table>
<thead>
<tr>
<th>Anatomy/Biomechanics</th>
<th>Sex Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow ROM</td>
<td>Increased in females (3–4)</td>
</tr>
<tr>
<td>Wrist ROM</td>
<td>Increased in females (14)</td>
</tr>
<tr>
<td>Finger ROM</td>
<td>Increased in females (18)</td>
</tr>
<tr>
<td>Carrying angle</td>
<td>Increased in females (5–11)</td>
</tr>
<tr>
<td></td>
<td>No difference (12)</td>
</tr>
<tr>
<td>Negative ulnar variance</td>
<td>Increased in males (16)</td>
</tr>
</tbody>
</table>

**Musculoskeletal Complaint**

<table>
<thead>
<tr>
<th>Sex Difference in Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>VEO</td>
</tr>
<tr>
<td>Ulnar neuropathy at the elbow</td>
</tr>
<tr>
<td>Ulnar neuropathy at the wrist</td>
</tr>
</tbody>
</table>

(continued)
Summary of Sex Differences in the Elbow, Wrist, and Hand (continued)

<table>
<thead>
<tr>
<th>Musculoskeletal Complaint</th>
<th>Sex Difference in Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olecranon bursitis</td>
<td>Increased in males (33)</td>
</tr>
<tr>
<td>Lateral epicondylitis</td>
<td>Increased in females (34–36) No difference (37–39)</td>
</tr>
<tr>
<td>Medial epicondylitis</td>
<td>No difference (38–40)</td>
</tr>
<tr>
<td>TFCC injury</td>
<td>Possibly increased in females due to association with positive ulnar variance</td>
</tr>
<tr>
<td>Boxer’s fracture</td>
<td>Increased in males (43)</td>
</tr>
</tbody>
</table>

ROM, range of motion; TFCC, triangular fibrocartilage complex; VEO, valgus extension overload.

REFERENCES


INTRODUCTION

Low back pain (LBP) is a widely prevalent condition, with documented lifetime prevalence rate as high as 90% (1). Most cases of acute LBP are self-limiting, although recurrence may occur in 60% to 73% of people (2). Not only is LBP problematic for the general population, it can be debilitating or even career ending for a professional athlete. During sports, athletes have considerable loads placed on their spines throughout a dynamic range of motion (ROM), which may predispose them to spine injuries. Therefore, it is not surprising that LBP is the most common reason that athletes miss a game (3), with up to 20% of all sports-related injuries involving the spine (4). Sports with high prevalence of LBP include gymnastics, weightlifting, swimming, tennis, volleyball, and football (5–7).

Studies on sex differences as related to the spine remain largely inconclusive. Frequently it is difficult to separate the sex influences on spine pathology from the influences of specific sports or activities that have a gender preference. An example would be gymnastics, in which males and females compete in different activities. Therefore, the results of studies evaluating rates of spine pathology associated with specific sporting events could be due to the event or the sex differences. This example epitomizes how determining the exact contribution of gender differences in injury rates can be challenging. However, there are many other sports such as basketball that are played by both sexes and help facilitate comparisons between genders.

Despite these difficulties, some studies have found distinctions between the sexes. Female athletes are more likely to suffer from LBP as compared to males (4,5,7). According to NCAA Injury Surveillance Data from 1997 to 1998, female athletes were twice as likely to sustain low back injuries compared to males (7). Low back injury was the most common injury in women’s volleyball and gymnastics, second most common in women’s soccer, and third most common in women’s basketball (7). This chapter reviews supported data on sex differences as they relate to anatomical and pathological conditions and offers potential insights where data are limited. We start by reviewing anatomical and alignment differences between the sexes, then offer insights and data on gender differences in spine pathology among several common spine disorders.

SPINE ANATOMY

The spinal column has multiple functions. It must offer osseous protection of the contained spinal cord and nerve roots. It must also offer significant stability to allow load transfer between the upper and lower limbs. In addition to these stabilizing features, the spine has a segmental multi-planar motion that is crucial for mobility. This combination of stability and segmental mobility results in unique demands on the spinal column. As such, the spine, especially the lumbar spine, is predisposed to great stress, putting it at risk of acute injury and repetitive overuse injuries. In assessing pathology in the spine, it is important to note that distinct gender differences exist in the spine anatomy secondary to sexual dimorphism. These differences are likely due to the load-bearing adaptations necessary for the accommodation of bipedal pregnancy.

Bony Anatomy

Although some minor variations in numbering exist, the vertebral column typically consists of 7 cervical vertebrae, 12 thoracic vertebrae, and 5 lumbar vertebrae along with the fused sacrum and coccyx. Vertebrae consist of a vertebral body anteriorly and laminae, spinous process and transverse processes posteriorly connected by two pedicles. The superior articular process (SAP) and inferior articular
process (IAP) arise from the junction of the pedicle and lamina to join with the vertebrae above and below in the form of zygapophyseal joints (z-joints) as shown in Figure 5.1.

There are regional differences in the vertebrae. The cervical vertebrae have foramen in each transverse process to house the vertebral artery. The first two cervical vertebrae are further specialized to allow rotation with the first level (C1 or atlas) supporting the head and the second (C2 or axis) forming a tooth-like dens that serves as a pivot to allow lateral rotation. The C0-1 joint provides the most amount of flexion extension at approximately 25° while the C1-2 joint is responsible for 80° of axial rotation (9). The thoracic vertebrae have costal facets on the antero-lateral ends of the transverse processes for articulation with the ribs. The lumbar vertebrae are broader and heavier to help facilitate load transfers from the lower limbs through the pelvis to the upper body (10).

Studies have shown that vertebral width and disc-facet depth of male cervical vertebrae are greater, yielding more stable intervertebral coupling (11). Such differences in stability may partially explain the higher susceptibility to trauma-related neck pain that is found in females (12,13). Lumbar vertebrae bodies in females also have reduced cross-sectional areas (CSA) and volumes (14). This is true even when matched for age, weight, vertebral bone density, and vertebral body height (14). This difference confers an additional risk for vertebral fractures in females, as the smaller female vertebrae confer a 30% to 40% higher mechanical stress for equivalent applied loads even in the setting of comparable vertebral bone densities (15).

**Alignment**

Besides inherent differences in bony structure, there are also gender differences in alignment. Janssen and colleagues showed that the T1-L5 segments of the female spine are more dorsally inclined in the sagittal plane (16). Based on animal models, this dorsally directed shear load could predispose the female spine to reduced rotational stability (17). A comparative study of men and women with chronic LBP demonstrated that men exhibited earlier and greater lumbopelvic rotation ROM during hip medial rotation (18). Additionally, the study found a greater proportion of men reported an increase in LBP symptoms with hip medial rotation compared to women, suggesting that movement of the hip medial rotation may be more problematic for men than women with LBP. This could potentially increase risk of developing LBP in men who participate in rotational sports such as golf or tennis.

Pelvic incidence, defined as the angle between the line joining the hip axis and the center of the S1 end plate and the line orthogonal to the S1 end plate, is also higher in women. It has been shown that an abnormally high pelvic incidence upsets the spinal balance and is associated with higher rates of spondylolisthesis and increased likelihood of disease progression (19,20) and severity of scoliosis in the elderly population (21).

Lumbar lordosis is an important adaption for bipedalism. However, since pregnancy shifts the center of mass anteriorly, the female spine must have increased lumbar curvature and reinforcement to compensate for the increased bipedal obstetric load (22), as shown in Figure 5.2. Additionally breasts have been theorized to affect spinal alignment. Radiographic studies suggest that breast size can affect the thoracic kyphosis and lumbar lordosis angles (23), with larger breast sizes being associated with both increased thoracic kyphosis and lumbar lordosis, as shown by the difference in lordosis when comparing male to female vertebral columns in Figure 5.3. However, a study has shown that reduction mammoplasty does not seem to change the measurable thoracic kyphosis and lumbar lordosis angles (24).
FIGURE 5.2: With pregnancy, human females have to adapt with increased lumbar lordosis to accommodate the anterior-translated center of mass. (A) Nongravid female. (B) Gravid female without lumbar lordotic compensation. (C) Gravid female with lumbar lordotic compensation.

FIGURE 5.3: Male vs. female lumbar spine.
Joints, Ligaments, and Musculature

Spine mobility is maintained through the segmental intervertebral discs and a gliding movement of the paired synovial zygapophyseal joints. The cartilaginous nature of these joints may also provide shock absorption throughout the spine. Studies have shown that z-joint cartilage thickness is lower in females and the gap in the dorsal region is greater (25). Cervical z-joint shear and distraction motions in females were higher than that of males, providing a mechanism to explain why women may be more susceptible to whiplash injury (26). Studies have shown that disc height in women is higher than in men (27). Disc space narrowing is more frequent in women than men (28) while degenerative changes were observed more frequently in males (29).

Although spinous ligaments provide stability, the musculature is felt to be the primary stabilizer of the spine. In fact, it has been demonstrated that a cadaver with bones and ligaments intact but muscles removed will buckle under about 20 pounds (30). The anterior longitudinal and posterior longitudinal ligaments help to support the intervertebral discs. The intrinsic muscles of the back act primarily as extensors and rotators and help stabilize the spine. While gender variations in ligament and muscle activation have been documented in other joints and parts of the body (31–33), few available studies have described gender differences in spine ligament and musculature.

PATHOLOGY-SPECIFIC GENDER DIFFERENCES

Scoliosis

Scoliosis denotes pathological lateral curvature of the spine in the coronal plane. The four major types include congenital, neuromuscular, degenerative, and idiopathic scoliosis. Congenital scoliosis is associated with vertebral malformations; neuromuscular scoliosis is found in patients with trunk weakness associated with spina bifida, cerebral palsy, or neuromuscular disorders; and degenerative scoliosis results from traumatic or degenerative bone collapse secondary to osteoporosis. The prevalence of congenital, neuromuscular, and degenerative scoliosis shows little gender predilection apart from that associated with the primary condition.

Idiopathic scoliosis is however the most common etiology, accounting for 65% of structural scoliosis, and it affects adolescents during the growth spurt years (34). The exact pathophysiology is uncertain but it has been hypothesized that there is a complex interplay of defect in central control of growth as well as the spine’s inherent susceptibility to deformation. Researchers are looking into genetic, hormonal, collagen, and platelet-related causes (35). Interestingly, some studies report that athletes of certain sports have a higher incidence of scoliosis, most noticeably among female rhythmic gymnastic trainees (36,37), though it is not clear whether this is because of the demands of the sport or the particular gender predilections of the participants.

Regardless of exact pathophysiology, idiopathic scoliosis is much more common in females. The female-to-male ratio ranges from 1.5:1 to 3:1, with a 7.2:1 predilection in curves greater than 40° (38). While the reasons are still unclear, females may be more predisposed given that they go through relatively shorter and more rapid adolescent growth of the spine. Thus, they may be more predisposed to any defect in control of growth affecting the spine.

Timing of screening for scoliosis depends on age of adolescence. The American Academy of Orthopaedic Surgeons (AAOS), the Scoliosis Research Society (SRS), the Pediatric Orthopaedic Society of North America (POSNA), and the American Academy of Pediatrics (AAP) recommend that girls should be screened twice, at age 10 and 12, and boys once, at age 13 or 14, by the Adam’s forward bending test. The Adam’s test is a visual scoliosis screening tool performed with the patient bending forward at the waist with feet together, knees straight, and arms hanging freely. The examiner observes the patient from behind to look for asymmetric rise of one side of the rib cage next to the vertebral column. The peak rise of the convex side can be measured more objectively using a scoliometer, a specialized tool with a bubble level and angle measure to help determine the degree of curvature, as demonstrated in Figure 5.4 (39).

Given the predisposition of scoliosis in females, research from Norway has demonstrated that screening is cost saving when performed in girls only (40). Referral to a spinal deformity expert and x-rays should be considered if the Adam’s test is positive. Bracing should be initiated in patients with curves above 20° ± 5° Cobb who are still growing or demonstrating progression of deformity (41). Interestingly, males are less likely to respond to brace treatment and have been theorized to have more rigid spines (42).

Surgical intervention is usually considered when curves exceed 50°, are causing loss of pulmonary function, or are progressive (43). Fortunately, despite males having possibly more rigid spines, sex does not seem to affect outcomes of surgery for adolescent idiopathic scoliosis (44). Most experts advise a return to physical activity at the same level after surgery (36). A small study also showed that sports activity is not more restricted after surgical intervention than after nonoperative treatment; however, surgical and nonsurgical groups with scoliosis had reduced sport activity.
secondary to back pain as compared to matched controls without spinal disorder (45).

**Kyphosis**

The sagittal alignment of the thoracic spine displays a dynamic range and usually kyphosis naturally increases throughout life. Females exhibit significantly higher kyphosis after the age of 40 (46). This is often accompanied by decreased lumbar lordosis, and together the syndrome is termed lumbar degenerative kyphosis (47). In Takemitsu’s epidemiological study, 90% of subjects with the syndrome report significant LBP. There have been studies associating increases in thoracic kyphosis with higher spinal loads and trunk muscle forces (48). The resultant flat back has been associated with anomalous pelvic tilt (49). Higher thoracic kyphosis, as determined by occiput wall distance, has also been associated with shoulder pain and subacromial impingement (50). Treatment of excessive thoracic kyphosis includes physical therapy focusing on posterior kinetic chain strengthening and even surgical fixation in some cases (51).

A distinct entity of thoracic kyphosis is Scheuermann’s kyphosis, which is defined as the basis of anterior wedging of 5° or more of at least three adjacent vertebral bodies and typically occurs during adolescence (52). The prevalence of Scheuermann’s kyphosis ranges from 0.4% to 8.3% (53). While historically it was thought to be more prevalent in males (54), more recent studies have shown no gender predilection (35,55,56). Mild cases are treated symptomatically for back pain with exercise and anti-inflammatory medications while kyphosis greater than 45° requires bracing before progressing to surgery for curves greater than 75° (52). In regard to sports, some experts recommend more extension-biased sports such as gymnastics, swimming, and basketball while avoiding sports associated with repetitive flexion and heavy loading (57). Most authors recommend a rehabilitation program focusing on maintaining flexibility, strengthening the extensor muscles of the spine, and correcting any postural component of kyphosis (58).

**Spondylolysis and Spondylolisthesis**

Spondylolysis is a unilateral or bilateral defect in the pars interarticularis of the vertebra, most commonly found at the L5 level (59), as illustrated in Figure 5.5. The exact pathogenesis of lumbar spondylolysis remains controversial and is likely multifactorial. The most accepted mechanism...
is biomechanical stresses due to chronic low-grade trauma from repetitive flexion, extension, or rotation of the lumbar spine on a congenitally weak or dysplastic pars interarticularis (60,61). There are two main mechanisms of how the stress fracture occurs. The first is the “nutcracker” mechanism in which there is direct compression of the IAP of the cranial vertebra on the pars interarticularis of the caudal vertebra when the lumbar spine is in extension (62–65). The second mechanism is when the pars interarticularis fails in tension through a traction mechanism (62,63,66,67).

The incidence of asymptomatic spondylolysis has been estimated to be approximately 6% of the general population (59,66,69). Some studies have shown the positive association between spondylolysis and other diseases including spina bifida occulta (66,69–71), Scheuermann’s disease (72,73), and scoliosis (74). Numerous studies have reported a high incidence of lumbar spondylolysis among family members (up to 69%), which suggests a genetic predisposition to this condition (69,75–77).

The incidence is higher in athletes than in the non-athletic population (78–80). Most studies report 10% to 15% of adolescent athletes have been reported to have spondylolysis (59,81,82), especially those involved in sports with repetitive flexion/extension such as gymnastics, weight lifting, diving, and rowing (59). Most cases of spondylolysis are asymptomatic. In children and adolescent athletes, however, it is the most identifiable cause of back pain (59,67), usually manifesting as axial LBP that is exacerbated with lumbar hyperextension.

Spondylolysis is also more frequently found in males, with an incidence ratio of 2:1 (66,67,69), although spondylolisthesis affects females two to three times more frequently (59,67,83). Some have suggested that the increased incidence of males compared to females, as previously reported, might be a result of a time when females were not as active in sports as males. Fredrickson et al. refutes this claim; he reported an incidence of 2:1 ratio of boys to girls at age 6, at which activity levels of both sexes are similar (69). The etiology of this difference between males and females remains unknown, although the progression to spondylolisthesis may be due to differences in pelvic incidence between males and females.

Bilateral pars defects can result in the development of spondylolisthesis. Patients with known spondylolisthesis, bilateral pars defects, or possibly those presenting with unilateral pars defects at a young age, should be screened for the development or progression of a spondylolisthesis by intermittent standing spine films from a lateral view. This is especially critical during the adolescent growth spurt, as this condition can develop without any changes in symptomology.

Adolescent athletes with extension-biased pain and high suspicion of stress fracture of the pars interarticularis should be treated presumptively as spondylolysis. Treatment includes relative rest until pain free, with a gradual return to sports after correction of biomechanical abnormalities through physical therapy. These injuries typically require several months of rest and therapy before a full return to activities. Nonsteroidal anti-inflammatory medications are typically avoided as these medications may delay bone healing. Bracing is controversial; while it may limit activity it may also increase movement through the affected segment. Practitioners may also consider screening for vitamin D deficiency as a contributor to the pathology. However, there are no studies supporting sex-specific workup or management algorithm of spondylolysis in athletes.

**Intervertebral Disc Pathology**

Lumbar intervertebral discs degenerate not only with normal aging but also as a consequence of intrinsic and extrinsic factors. Although the exact cause and mechanism of disc degeneration is still under investigation, genetic link (84–86), obesity (87,88), smoking (89,90), and physical loading related to occupation and sports are associated with disc degeneration (91–94). Clinical manifestation of discogenic pain includes LBP typically associated with activities that increase intradiscal pressures, such as sitting, bending forward, coughing, and sneezing.

Some studies report sex differences in disc degeneration. Miller et al. analyzed 600 intervertebral discs excised from 273 cadavers and found male discs degenerated earlier than female discs and to a greater extent, most significantly in the second decade (95). In this study, nearly 40% of males had evidence of Grade II degeneration, as compared to no degeneration found in females. While the exact mechanism explaining the gender difference remains unclear, the author proposes several contributory factors including increased mechanical load on the male lumbar spine, greater CSA of male discs resulting in longer nutrient pathways, and differences in biochemical composition of the discs between males and females.

Kjaer et al. performed a cross-sectional cohort study on 439 thirteen-year-olds and found patterns of differences when results were stratified by gender (96). In boys, there was a statistically significant association in upper lumbar disc findings as compared to girls, with association found in the lowest lumbar spine segments. Additionally, there was a strong association between “seeking care” and disc protrusion/high intensity zone in girls, but not in boys. Despite
this literature on gender differences, there are no known implications for participation in sports.

Ankylosing Spondylitis

Ankylosing spondylitis (AS) is a progressive chronic inflammatory disease that affects the axial skeleton, with variable involvement of enthesis, peripheral joints, and, rarely, internal organs. Clinical features of AS include low back or buttck pain, peripheral joint pain, enthesitis, dactylitis, and/or progressively limited spinal mobility. Extra-articular comorbidities include acute anterior uveitis, psoriasis, inflammatory bowel disease, cardiovascular disease, and pulmonary disease.

Historically, it was thought that AS was found predominantly in males with sex ratios quoted as 10:1 (97). Recent studies, however, indicate the male-to-female ratio is closer to 2:1 (98). A suggested explanation for underestimation of female prevalence includes milder and less extensive clinical manifestations with less disabling symptomatology among females (99–101). Other possible explanations include slower development of radiographic findings in women, more peripheral arthritis in women leading to alternative diagnoses, and traditional regard of AS being a disease of men (101). Clinically, women with AS tend to have more neck and peripheral joint pain (98).

Radiographic differences between men and women have been studied, although no conclusive findings have been found. Some studies have found higher frequency of cervical spine involvement in females (102,103) and higher lumbar spine involvement in males. Other studies refute this claim showing no sex differences in cervical involvement despite higher frequency of cervical pain (104). Radiographic progression is more severe in males with AS than females (98,105). It has been suggested that radiographic severity was associated with males due to earlier diagnosis and therefore longer duration of disease. However, a study by Lee et al. correcting for age and duration of disease showed that males were still more likely than females to have increased levels of radiographic damage (98).

Special consideration should be given to athletes with AS. Over time, development of osteoporosis and ossification of the axial skeleton and ligamentous structures result in progressive rigidity, loss of lumbar and cervical lordosis, and altered biomechanical properties of the spine. Limitations in mobility and altered biomechanics may result in increased risk of spinal fractures, particularly in the cervical spine, even from low energy impact (106,107). While there are no set guidelines, Harper and Reveille recommend cautioning patients with AS to avoid sports at high risk of spinal injury, including football, ice hockey, wrestling, diving, skiing, snowboarding, rugby, cheerleading, or baseball (108).

CONCLUSION

Much remains to be learned about sex differences as related to the spine. While there are some studies that describe sex differences due to anatomical and pathological conditions, much of the evidence remains inconclusive. As described, there are anatomical differences in body anatomy and spinal alignment between males and females, although the exact implications of these differences remain unclear. There are more studies looking at gender differences in certain pathological conditions of the spine. There appears to be a gender predilection in spondylolysis, disc degeneration, and AS for males, and in scoliosis for females. While there may be a gender predisposition for certain pathological conditions, there is not a gender restriction based on anatomic or pathological cause as relates to sports. In general, more studies are needed to evaluate gender differences in relation to the spine.

Gender Predilection Based on Spine Pathology

<table>
<thead>
<tr>
<th>Spine Pathology</th>
<th>Sex With Higher Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scoliosis</td>
<td>Females (38)</td>
</tr>
<tr>
<td>Scheuermann’s kyphosis</td>
<td>No gender predilection (35,55,56)</td>
</tr>
<tr>
<td>Spondylolysis</td>
<td>Males (66,67,69)</td>
</tr>
<tr>
<td>Spondylolisthesis</td>
<td>Females (59,67,83)</td>
</tr>
<tr>
<td>AS</td>
<td>Males (97,98)</td>
</tr>
</tbody>
</table>

AS, ankylosing spondylitis.

REFERENCES

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