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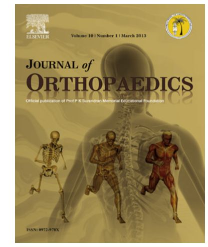

Editorial

The female ACL: Why is it more prone to injury?

Female athletes tear their anterior cruciate ligaments (ACL) at an alarmingly higher rate in certain sports including basketball, team handball, and soccer. The participation in sports by girls has increased dramatically, in recent times.[1] The rapidly increasing numbers of females participating impacts the number of injuries. However, the rates of ACL injuries in comparable sports of basketball and soccer have remained alarmingly high with change in male-to-female ratios over the last 10 years.[2] The incidence of female to male is 3.5 times greater in basketball and 2.8 times greater in soccer.[3] The typical mechanism of injury is a rapid but awkward stop and anticipation of lateral movements.[4] The ACL tears in 70 ms. Dynamic movement patterns are very important factors contributing to ACL injury.[5] The extrinsic or changeable factors are controlled by the player and coaches. The intrinsic differences between male and female athletes that would explain why women tear the ACL two to eight times more frequently than men.

1. Consensus statement

A consensus conference was held in Hunt Valley, Maryland, on June 10, 1999, sponsored by the American Orthopaedic Society for Sports Medicine (AOSSM), National Athletic Trainers' Association (NATA), National Collegiate Athletic Association (NCAA), and Orthopedic Research arid Education Foundation (OREF). The goal of the conference was to discuss anatomic, environmental, hormonal, and biomechanical risk factors for noncontact ACL injuries; specifically, what we know from the written information, areas for further research, and prevention strategies. From the written information and presentation of the twelve physicians and nine basic researchers at this retreat, a prevention booklet was published.[5,6] The categories of risk factors were anatomic, environmental, hormonal, and biomechanical. Neuromuscular factors appear to be the most important reason for the higher rate of ACL injuries in females compared to males.[6] The at-risk situations for noncontact ACL injuries appear to be deceleration, cutting or changing directions, and landing.[5] Prior to the injury, an awkward dynamic body movement and a perturbation event are usually observed. With this, quadriceps activation during eccentric contraction is a major factor in ACL injury during the at risk maneuver. Anatomic risk factors of the femoral notch and lower extremity alignment were discussed. Although there is much literature on the role of the femoral notch size in ACL injury, no consensus on the notch's role in ACL injury can be reached at this time. Identifying sports-specific at-risk motions and positions and encouraging athletes to avoid these at-risk situations when possible seems promising. Further, strategies for activating protective neuromuscular responses when at-risk situations are encountered is also a possible prevention strategy. There is a need to improve public and participant awareness for risk of ACL injury and the possibilities for prevention. We need to continue to define the specific neuromuscular, proprioceptive, and motor control factors associated with ACL injury. Although specific predictive and protective factors are determined, training and prevention programs should continue to be implemented, assessed, and improved. From this consensus conference, a monograph of prevention strategies has been published.[5]

2. Hormonal

Sex hormones have effects on numerous end organs, as evidenced by changes during menarche and menopause. Estrogen, progesterone, relaxin, and other sex hormones have cyclic effects. There is no consensus of the scientific community that sex hormones play a role in the increased incidence of ACL injury in female athletes.[6] One must understand the hormonal activities during the cycle and the hormonal effects during the cycle. In 1998, Wojtys et al.[7] reported on a series of 28 women, who were found to have more ACL injuries than expected during the ovulatory phase and fewer injuries during the follicular phase at a p-value of 0.03. However, reevaluation of these data led to the discovery that the results were not statistically significant but only showed a trend.[8] More recently, Wojtys et al.[9] have reported, on 69 females with acute ACL injuries studied within 24 h at four centers by menstrual cycle details and urinary hormonal levels. These results supported a significantly greater than expected percentage of ACL injuries during midcycle (ovulatory phase) and less than expected during the luteal or follicular phase.[9] Wojtys et al.[9] reported that oral contraceptives reduce the rate of ACL tear in the ovulatory phase.

However, no recommendations are being made to modify practices, activity level, or place females on oral contraceptive pills in the face of these results.[6] In the follicular stage, ACL injuries have been reported to be less by Wojtys. Myklebust[10] reported higher rates of ACL injury 1 week before menses and just after menses. Slauter Beck and Hardy also found higher ACL rates before and after menses.[11]

3. Anatomic differences

The lower extremity static alignment and measurements have not been predictive of ACL injuries.[1,12] Authors frequently slate that the female has a wider pelvis than the male. However, females have a narrower pelvis. Horton and Hall, found that males had a greater hip width by 3 cm and longer femoral length by 5 cm.[12,13] The ratios of hip width to femoral length were about equal – 0.73 in males and 0.77 in females. Ratios appear to be a more important measurement than absolute width.

4. Femoral notch

The ACL size and orientation determine width and shape of the femoral notch. Regardless of gender, smaller notches have been associated with increased rate of ACL injury. Most authors report that a smaller ligament is housed in a smaller notch. However, Muneta et al.[14] used measurements from Japanese knee cadavers to determine ACL cross-sectional area as it relates to notch dimensions.[14] The small notch knees did not have a thinner ACL in them. Anderson et al. by magnetic resonance imaging, notch width index between the sexes were not statistically significant. With adjustments for body weight, the size of the ACL in girls was found to be statistically smaller than in boys.[15] The question remains whether or not a smaller ligament is more apt to fail. It remains unknown whether a bigger ligament is stronger.

There are conflicting data about significant NWI differences between men-and women. Some studies have demonstrated that there are no gender-related differences in NWI,[14] whereas other studies have shown that there is a difference between male and female subjects.[15,16] The reason for the increased injury rate in women remains unclear; it is probably caused by a complex interplay between multiple variables.[17] Other studies suggest that the NWI and other morphologic parameters of the osseous intercondylar fossa may not be critical etiologic factors in the patient with a unilateral or bilateral ACL tear. Muneta et al.[14] suggested that if a narrow intercondylar notch contains a smaller ACL, this may explain why people with narrow notches have a higher incidence of ACL injuries but no significant correlation was found after dissecting cadaveric knee joints. Anderson et al.[15] evaluated 100 high school basketball players by MR imaging. They found no correlation between ACL and notch size; this suggested that the size of the ACL cannot be predicted from the size of the intercondylar notch. These data indicated that narrower ACL width might be indicative of reduced ACL strength, which could be more susceptible to injury.

The femoral notch-to-width ratio was 0.189 for noncontact injuries and 0.233 for contact. The normal was 0.231 ± 0.044.[18,19] Sheiboume et al.[20] reported on the relationship of the intercondylar width of the femur and ACL tears prospectively There was no statistically significant difference in notch width between height groups for men and women.[20] Women were found to have significantly narrower notches than men, with height and weight as co-variants. After ACL reconstruction with 10 mm autografts, there was no difference in graft tear pattern between the groups, men or women. Regardless of gender, individuals who possess smaller notch dimensions appear to be, at greater risk for injury than individuals with larger notches.[21] A template to position the knee during acquisition of notch views was suggested to reduce the variability. Analysis of the intercondylar notch has also been recorded by computed tomography[22] and by magnetic resonance imaging.[15] Magnetic resonance imaging scans have been analyzed for notch size and ACL volume. The ACL volume was also significantly smaller in females and there was indeed a significant correlation between femoral notch volume and ACL volume, that is, smaller notches housed smaller ACLs. There are conflicting data about whether femoral intercondylar notch stenosis is a predisposing factor for an acute ACL tear and whether there are significant topographic differences between men and women. Most authors have found a statistically significant smaller notch width index (NWI) in patients with bilateral or unilateral ACL ruptures when compared with normal knees.[14,15]

5. Neuromuscular

Gender differences in neuromuscular activation patterns have been reported to contribute, to ACL injury. Compared to males, females have been found to be less effective in stiffening their knee.[23] Maximum contraction of the knee musculature significantly decreased the anterior tibial translation in men and women comparing relaxed to contracted states. However, the percent increase in knee stiffness was significantly greater at the $p = 0.003$ level, with male percentages of 473% and females 217%.[23] Wojtys et al. have done excellent work on the comparison of neuromuscular performance in elite male athletes, female athletes, and nonathletic females.[24] Results of these tests revealed that the female athlete and controls demonstrated more anterior tibial laxity by arthrometry than male counterparts and less muscle strength and endurance. The female athletes take significantly longer to generate maximum hamstring torque during isokinetic testing than males. The muscle recruitment order in some female athletes was markedly different, and the quadriceps was recruited initially in response to anterior tibia translation instead of the hamstrings for initial knee stabilization.[24]

6. Core stability

It has long been understood that lack of control contributes to an individual getting into a position that allows for an ACL rupture. In recent years, the realization of proximal control dictating distal function has become increasingly apparent. One concept that has been closely linked to this has been the idea of ''core stability''. The ''core'' may be operationally defined as the abdominal, back extensor, and hip musculature strength/function that contribute to stability of the lumbo-pelvic-hip region complex where a person's center of gravity is located and all movement begins.[25] Richardson et al.[26] showed that the abdominal musculature role as a primary stabilizer of the internal and external obliques are the primary stabilizers of the trunk, and the transverses abdominus promotes lumbopelvic region stability of utmost importance for function. A study by Cresswell et al.[27] gave evidence that transverses abdominus is critically important to spine stabilization. Horak et al.,[28] when comparing movements of lower extremity to erector spinae function, identified a temporal relationship between biceps femoris and erector spinae reaction time latency.[28] Bouisset and Zattara[29] demonstrated that hip and lower extremity activation preceded onset of upper limb acceleration. An efficient core allows the length-tension relationship of functional agonist and antagonist to be maintained. Baratta et al.[29] have also shown that antagonists provide regulated stabilizing function to distraction forces generated by the agonist muscles. An efficient ‘‘core’’ provides for a stable base so the lower extremity can function with an optimal kinetic chain to reduce forces and dynamically stabilize against abnormal forces. If the extremity muscles are strong and the core is weak, not enough force will be created to produce efficient movements.[25] It is these inefficient movements and abnormal agonist/antagonist relationship from an unstable ‘‘core’’ that set the stage for injury.

ACL research retreat consensus statement: An ACL research retreat for gender bias was held in April 2001, with participants presenting their research in areas of neuromuscular, biomechanical, hormonal, and structural. Publication of this was done, and a consensus statement of what we know, what is still unknown, and where do we need to go was published in *Clinical Biomechanics*.[34] Multicenter prospective studies to look at the multiple factors contributing to the future in the biomechanical area is to develop are valid methods of kinematic measurements and develop functionally valid tests. In the hormonal area, although there are receptors for progesterone and estrogen on the ACL, there is no definitive information of whether cyclic hormonal change can cause structural change in the ACL properties. Future studies are heeded on the basic research in the area of ligament remodeling, influence of sex hormones on other ligaments, capsule, and muscle tendon structures. More valid methods of recording daily hormonal levels need to be established. In the structural factors, further studies on relationships and tests that measure structure as it relates to ACL injury across gender must be developed.

7. Summary

Physical movement classes should occur very early in life, teaching children to land safely and in control, similar to the cry of ‘‘get down, stay down’’ routinely heard during youth soccer. Similarly, specific strength training programs can address landing as well as foot movements during cutting in basketball. Coaches should issue stem warnings when athletes demonstrate a high-risk movement patterns such as one-leg landings, out-of-control baseline landings, or straight-leg landings. Therefore, prospective analysis is likely to be received more warmly by the athletes if the program is presented with an emphasis on performance improvement rather than injury prevention. With increased participation in these programs, multiple-center analysis will have the power necessary to determine which factors significantly predispose athletes to ACL injury. The future for injury prevention is bright. We must rise to the challenge.

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