Physical Rehabilitation and the Challenge of Anterior Cruciate Ligament Injury in the Physically Active Female

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Abstract:

Rehabilitation professionals facilitate healthy movement and mobility in individuals seeking to engage in physically active lifestyles. The disparate rate of injury to the anterior cruciate ligament of the knee in physically active females in comparison to males serves as an excellent example of the challenges faced by rehabilitation professionals. The surgical reconstruction of the ligament and post-surgical rehabilitation has received a great deal of attention, but far less emphasis has been placed on the etiology and prevention of this disabling injury. This article addresses the impact of increased physical activity among females on ACL injury incidence, what is known and unknown about injury risk, and the importance of identifying strategies for prevention of injury to the ACL. One example of a research program that is exploring the potential risk factors for ACL injury in the physically active female is discussed.

Article:

For purposes of this paper, rehabilitation professionals will be defined as allied health care providers such as certified athletic trainers, physical therapists, strength and conditioning specialists, and the various medical specialties that comprise the sports medicine team. The objective of these professionals is to facilitate healthy movement and mobility in individuals seeking to engage in physically active every day lifestyles, including those participating in competitive athletics across the lifespan. Inherent in this objective is the need to develop scientifically based programs of injury prevention, evaluation, and rehabilitation. For these professionals to focus solely on physical rehabilitation does an injustice to the growing number of citiZens pursuing physically active lifestyles and the benefits that accrue from movement and mobility in every day living. One particular challenge currently faced by rehabilitation professionals is the epidemic of injury to the anterior cruciate ligament (ACL) of the knee among physically active females. This particular professional issue related to every day movement and mobility will be used to illustrate the importance of a comprehensive approach to physical rehabilitation. The paper will address the impact of increased physical activity among females on injury incidence, what is known and unknown about injury risk, and the importance of identifying strategies for prevention of injury to the anterior cruciate ligament of the knee. Finally, a research model that is exploring the relationship between sex hormones, knee stability factors, and ACL injury risk will be presented.

Increased Physical Activity Among Females and Epidemiology of ACL Injury

Opportunities for females to engage in sport and physical activity have increased significantly over the past three decades. In the 25-year period following passage of Title IX, the number of women participating in intercollegiate athletics surpassed 100,000, which represented a fourfold increase from 1971 to 1995. The number of girls participating in interscholastic athletics increased from 300,000 to 2.4 million from 1971 to 1996 (www.ed.gov/pubs/TitleIX, 1997). The total number of teams sponsored by NCAA institutions (men and women combined) increased 20.2%, from 12,447 in 1987-88 to 15,582 in 1997-98. At the same time, the total number of student-athletes rose 20.7%, from 268,776 to 338,866. Much of this increase can be attributed to the significant growth in women's intercollegiate sports. While the number of male teams and student-athletes rose only 12.0% and 12.3%, respectively, female athletic teams and student-athlete participation increased by 27.8% and 33.6%. During this ten-year span, three new women's sports were recognized (ice hockey, rifle, and water polo), and female participation in golf, rowing, skiing, and soccer increased over 50% (National Collegiate Athletics Association, 2004).

During this same period of time, rehabilitation professionals have been challenged to respond to a dramatic increase in the number of injuries to the anterior cruciate ligament (ACL) in physically active females (Arendt & Dick, 1995; Arendt, Agel, & Dick, 1999). It is estimated that 1 in 3,500 individuals in the general population will injure their ACL, with the majority of these injuries occurring in young adults (Miyasaka, Daniel, Stone, & Hirschman, 1991). The rate of injury to the ACL in physically active females is far greater. Indeed, females injure their ACL at a rate of 1.6 to 8.38 times that of males, depending on the age or sport under study (Arendt et al., 1999; Ireland, 1999). ACL injuries are particularly prevalent in high school and college women participating in basketball and soccer, with injury rates over three times greater in soccer and four to five times greater in basketball compared to males (Arendt & Dick, 1995; Arendt et al., 1999; Ireland, 1999; Powell & Barber-Foss, 2000). A review of NCAA injury surveillance data for a three-year period from 1999-00 to 2001-02 indicates 1 in every 40 female basketball players and 1 in 48 female soccer players will injure their ACL per season (National Collegiate Athletics Association, 2003). Of particular concern is that this increased rate of ACL injury in the female athlete has remained relatively consistent over the past 20 years, despite increased attention to strength and conditioning programs for female athletes over this time (Arendt & Dick, 1995; Arendt et al., 1999; Ireland, 1999). It is apparent that rehabilitation professionals have been unable to slow the epidemic of ACL injuries in physically active females, and this greater rate of female ACL injuries will to continue to grow as increasing numbers of females participate in sports.

Mechanism and Consequences of ACL Injury

The ACL is the primary stabilizing yet most frequently injured ligament in the knee. It provides the majority of passive restraint to anterior translation of the tibia on the femur, and together with the medial collateral ligament (MCL), restrains tibial rotation and valgus motion. The presence of mechanoreceptors in the ACL (SchultZ, Miler, Kerr, & Micheli, 1984) provides sensory feedback about changes in ligament length and tension and triggers a neuromuscular response that contributes to active joint stability (Fujita, Nishikawa, Kambic, Andrish, & Grabiner 2000; Solomonow et al., 1987).

The typical mechanisms of noncontact ACL injury are rapid deceleration, maneuvers requiring a sudden change of direction, and one-foot stopping and landing (Boden, Dean, Feagin, & Garrett, 2000) that exceed the capacity of the neuromuscular responses to protect the ligament. These maneuvers also frequently lead to what has been termed the "position of no return" (Ireland, 1999), which is loss of body control leading to tibial external rotation and a valgus stress to the knee.

Rupture of the ACL renders the joint unstable and unable to control the forces inherent to strenuous physical activity. Even with aggressive physical rehabilitation and knee bracing, return to sports requiring rapid deceleration, change of direction, and one-foot landing is nearly impossible. Inevitably, surgical reconstruction of the injured ACL and a prolonged period of several months of physical rehabilitation are required for return to preinjury levels of physical activity. The cost of this surgical intervention has been estimated at nearly one billion dollars per year (Griffin et al., 2000) and doesn't include costs for presurgical management or post-surgical rehabilitation.

Regrettably, even with reconstructive surgery, individuals sustaining ACL injury are at considerable risk for developing early onset osteoarthritis, requiring a return to the rehabilitation professional later in life. For example, a very high prevalence of osteoarthritis, pain, and functional limitations has been observed in female soccer players who had sustained an ACL tear 12 years earlier (Lohmander, Ostenberg, Englund, & Roos, 2004). This is particularly problematic in young active females who are at a much higher risk of sustaining an ACL injury and have a longer time to develop this disabling disease. Hence, preventing the initial trauma is an important goal for the rehabilitation professional, with an eye toward optimal joint health and physical activity across the lifespan.

Risk Factors for ACL Injury

A plethora of potential risk factors have been proposed for the higher rate of ACL injury in physically active females (Griffin et al., 2000). These factors can be categorized as environmental, anatomical, hormonal, and neuromuscular/ biomechanical. Among these factors, the most compelling appear to be of neuromuscular and biomechanical origin. Compared to males, females demonstrate preferential quadriceps activity (Huston & Wojtys, 1996; Malinzak, Colby, Kirkendall, Yu, Garrett, 2001; Shutlz et al., 2001), greater valgus angles (Ford, Myer, & Hewett, 2003; Hewett, Myer, & Ford, 2004; Zeller, McCrory, Kibler, & Uhl, 2003), and greater valgus/varus moments (Chappell, Yu, Kirkendall, & Garrett, 2002; Hewett, Stroupe, & Noyes, 1996; Malinzak et al., 2001; McLean, Neal, Myers, & Walters, 1999) during functional activity and testing conditions. Females also have greater joint laxity (Rozzi, Lephart, Gear, & Fu, 1999; Shutlz, Kirk, Sander, & Perrin, in press), altered muscle recruitment patterns (Huston & Wojtys, 1996; Shutlz et al., 2001), longer delays in muscle force generation (Moore, Drouin, Shutlz, & Gansneder, 2002), and decreased muscle stiffness (Granata, Padua, & Wilson, 2002; Wojtys, Ashton-Miller, & Huston, 2002) compared to males.

Female sex hormones have also been implicated as a potential risk factor for ACL injury (Moller-Nielsen & Hammar, 1989; Myklbust, Maehlum, Holm, & Bahr, 1998; Slauterbeck & Hardy, 2001; Wojtys, Huston, Boynton, Spindler, & Lindenfeld, 2002). These reports tend to point toward a higher rate of injury during the late follicular and menstrual phases of the

menstrual cycle. However, only two of these reports measured actual hormone levels to confirm cycle phase at the time of injury, which is important given the variability in magnitude and phasing of hormone levels across the menstrual cycle from one female to another. As such, the link between female sex hormones and ACL injury risk requires further study before definitive conclusions can be drawn. It is known that sex-specific hormones have a profound effect on collagen tissue and appear to significantly alter the metabolism and structure of the anterior cruciate ligament (Yu, Liu, Hatch, Panossian, & Finerman, 1999), and these factors are thought to contribute to increased knee laxity in females. Sex differences in knee laxity are cycle dependent, although the variation in hormone profiles between females (e.g., cycle length, hormone phasing, and concentration changes) lead to considerable differences in the relationship between the hormones with changes in knee laxity across the cycle (Shutlz et al., in press; Shutlz, Sander, Kirk, Johnson, & Perrin, 2004). Because of the role of the ACL, both as a passive restraint and active stabilizer of the knee, increased knee laxity may contribute to knee joint neuromechanical patterns that increase anterior shear forces, and the potential for valgus collapse of the knee during rapid deceleration, maneuvers requiring a sudden change of direction, and one-foot stopping and landing. Further research is needed to determine the impact of hormone dependent increases in knee laxity on knee joint neuromechancs and ACL injury risk.

Clinical Research on ACL Injury Risk

Rehabilitation professionals in research settings across the country are exploring the potential risk factors for ACL injury in physically active females. The following research agenda is examining sex hormones, knee stability factors, and ACL injury risk.

It has been determined that knee laxity changes across the menstrual cycle (Shutlz et al., in press; Shutlz, Carcia, & Perrin, 2004) and that knee laxity and lower extremity limb alignment effects muscle activation patterns in the healthy knee (Shutlz, Carcia, Gansneder, & Perrin, 2002; Shutlz, Carcia, & Perrin, 2004). Serum levels of estradiol, progesterone, and testosterone were assayed, and knee laxity was measured using a standard knee arthrometer in females across one complete menstrual cycle and compared with males who were tested once per week for four weeks (Shutlz et al., in press; Shutlz, Sander et al., 2004). Sex differences in estradiol and progesterone were menstrual cycle dependent, while differences in testosterone levels were present across all test days. Females had greater knee laxity than did males, and these differences were cycle dependent. The relationship between changes in hormone concentrations and changes in knee laxity was also evaluated, with the possibility of a time delay (hormone data shifted forward 0-8 days relative to knee laxity values) between these respective changes. The greatest variance in knee laxity was explained by the three hormones and their interactions when a time delay was considered. A substantial amount of inter-subject variability in menstrual cycle characteristics and the time delay at which this relationship was the strongest was found. This points to the complexity of predicting predisposition to ACL injury during certain phases of the menstrual cycle.

To examine knee joint neuromechanics in response to a weight-bearing perturbation, a lower extremity perturbation device (LEPD) was developed. The LEPD produces knee rotation and valgus angles that are representative of dynamic, functional activity (Shutlz et al., 2000; Shutlz et al., 2001). The model produces significant internal rotation of the tibia on the femur and valgus excursion of the knee, which are consistent with the ACL injury mechanism (SchmitZ, Shutlz,

Kulas, Windley, & Perrin, 2004). The model has been used to examine how sex, limb alignment, foot orthoses, and knee joint laxity influence neuromuscular control of the knee, to better understand what factors may contribute to reduced musculoskeletal stability (Rose, Shutlz, Arnold, Gansneder, & Perrin, 2002; Shutlz et al., 2002; Shutlz, Carcia, & Perrin, 2004; Shutlz et al., 2001). It was determined that females, in comparison to males, are more reliant on the quadriceps to stabilize the knee in response to the perturbation and that these differences may in part be attributed to sex differences in anatomical structure.

The next phase of this research program will be to determine the consequences of sex hormone-mediated increases in knee laxity on knee joint neuromechanics using the functional weight-bearing model. Once the relationships between sex, hormone-mediated knee laxity, and knee joint neuromechanics have been identified, future efforts will be directed toward a more detailed examination of their interactive impact on ACL injury risk using a prospective, epidemiological approach. This research agenda is only one of many currently investigating the challenge ACL injury in the physically active female presents for rehabilitation professionals.

Implications for the Rehabilitation Professional

Orthopaedic surgeons have developed sophisticated techniques for the surgical reconstruction of ACL injured knees, and rehabilitation professionals have aggressively sought to return patients to preinjury levels of physical activity in the minimum amount of time possible. Nevertheless, the emphasis has been on surgical intervention and rehabilitation strategies, while efforts toward ACL injury prevention have received far less attention. Moreover, the underlying causes for the increased rate of ACL injury in the physically active female remain a quandary. Expert consensus suggests sex differences in neuromuscular and biomechanical function are critical factors in the disparate injury rate in males and females. A great deal more needs to be learned about these and other factors before effective preventive interventions can be developed and tested for their efficacy. Rehabilitation professionals are challenged to place an equal if not greater emphasis on injury etiology and prevention if healthy movement and mobility are to be achieved for physically active females and others across the lifespan.

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