Gender differences during landing and implications to anterior cruciate ligament rupture: A review

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Executive Summary

The understanding of human movement patterns as complex interaction of multiple segments, joints and reaction forces is important in order to study related sport movements and potential risk of injury. The most common lower limb injury in sports involving pivoting and landing is rupture of the anterior cruciate ligament (ACL), where females are 2 to 8 times more likely to sustain this injury than their male counterparts (12, 20). An ACL injury can be devastating to an athlete as it may result in a premature end of an athlete's career and increase risk of future development of osteoarthritis (18).

The purpose of this review is to:

1. Critically review the current body of knowledge regarding the neuromuscular and biomechanical differences between male and female landing strategies and further how they are correlated to ACL injuries.
2. Discuss the limitations of the current methodologies implemented to investigate this area of interest.
3. Provide alternative recommendations when developing training programs for athletes involved in landing sports such as volleyball.

Within the literature, there is a large amount of evidence regarding the neuromuscular and biomechanical differences between genders while landing. It has been suggested that weakness in the knee extensors (6, 17, 23), altered muscle activation patterns at both the hip and knee (8, 22, 26, 29), greater internal moments at the hip and knee (11, 13, 14) and finally greater knee flexion angles (17) are the main factors contributing to female athletes sustaining a greater amount of ACL injuries than male athletes involved in landing sports.

The methodologies used by investigators are inconsistent within the scientific community. The use of varying box heights (13.5 cm – 100 cm) and landing strategies (unilateral vs. bilateral) has led to an abundance of inconsistent results and conclusions. Other areas that need to be further explored include the neuromuscular and biomechanical demands occurring at joint segments during the take off and transition phases of the jump – landing sequence. As well, there is limited research examining trunk activation patterns and the differences found between genders. It is important for investigators studying the gender differences during landing and their correlation to ACL injury to acknowledge the gaps in methodologies. In turn, this will further expand the body of knowledge that exists and assist in a better understanding of ACL injuries in landing sports.

Strength and conditioning coaches, rehabilitation specialists and sport medicine practitioners have combined efforts to develop prevention programs to reduce the occurrence of ACL injuries. The rates of ACL injury, however, remain high (22). Research has shown that heavy resistance (10) and weightlifting style approach (4) are essential to include in a training program to address weak lower limb musculature and altered cocontraction patterns. Female athletes involved in landing

sports can benefit from this approach to reduce the risk of experiencing an ACL injury.

Abstract

Fundamental multijoint, movement patterns are the basis for sports and sport performance. The understanding of human movement patterns as complex interaction of multiple segments, joints and reaction forces is important for studying related sport movements and potential risk of injury. Female athletes participating in landing sports such as volleyball are more likely to sustain an anterior cruciate ligament (ACL) rupture in comparison to their male counterparts (20). The cost of an ACL injury include premature end of an athlete's career and increased risk of developing osteoarthritis later in life (18). This article will (1) critically review the current body of knowledge regarding the neuromuscular and biomechanical differences between male and female landing strategies and further how they are correlated to ACL injuries, (2) discuss the limitations of the current methodologies implemented to investigate this area of interest, and finally (3) provide alternative recommendations when developing training programs for athletes involved in landing sports such as volleyball. Presently, the frequency of ACL injury remains high, especially in female athletes (22), which suggests that these programs have not been successful at reducing the incidence of ACL injuries in landing sports.

Background

Human movement is accomplished via multiple muscle loading patterns of different magnitudes and directions acting upon limb segments to induce joint rotation (2). Multijoint tasks involve coordinated activation of synergistic muscles with different torque generating abilities (2). The joint mechanics of the lower limb have been of particular interest within the research community for injury prevention. The understanding of human movement patterns as complex interaction of multiple segments, joints and reaction forces is important in order to study related sport movements and potential risk of injury.

Volleyball requires jumping and landing sequences during practice and game situations that overtime may predispose an athlete to injury. A common lower limb injury in pivoting and landing sports is the rupturing of the anterior cruciate ligament (ACL) (12). ACL injuries can be devastating and may lead to premature ending of an athlete's career as well as increased risk of future development of osteoarthritis (18). Extensive evidence regarding the neuromuscular and biomechanical differences between males and females while landing has lead to the understanding of the higher frequencies of ACL injuries found in female athletes. Strength and conditioning coaches, rehabilitation specialists and sport medicine practitioners have combined efforts to develop and initiate prevention programs aimed at reducing the occurrence of ACL injuries. Despite efforts, such programs have not been successful and therefore, the need to develop alternative methods is crucial.

The purpose of this article is to critically review the current body of knowledge regarding the neuromuscular and biomechanical differences between male and female landing strategies and further how they are correlated to ACL injuries.

Limitations of the current methodologies implemented will also be discussed in order to sufficiently review and provide alternative recommendations when developing training programs for athletes involved in landing sports such as volleyball.

Incidence and mechanism of ACL injuries

The likelihood of female athletes suffering a non-contact ACL injury is 2 to 8 times greater than their male counterparts (20). Anatomically, the ACL is most vulnerable at 30 degrees of knee flexion, when the tibia moves anteriorly on the femur or when the femur moves posteriorly on the tibia and when the knee joint is in a valgus position. Furthermore, there are intrinsic and extrinsic factors contributing to the rupture of the ACL. The intrinsic factors include size and strength of ACL, knee laxity, hormonal fluctuations associated with menstruation, Q angle, malalignment of lower extremity, and size of intercondylar notch (9, 14, 23). Extrinsic factors, of which can be controlled, include landing strategy, muscular strength, skill level, agonist – antagonist cocontractions and motor unit recruitment (9, 14, 23). Undoubtedly, when considering the mechanism behind ACL injury, there are many factors that need to be explored.

Muscle activation patterns

Landing is a skilled, multi-joint task that requires optimal activation of lower limb musculature to be executed successfully (i.e. land with balance in a given area). Prior to landing, the lower limb reaches its largest excursion into extension, which is followed by simultaneous flexion of the hip, knee and ankle at the early part of the ground contact phase (19). During the latter part of the ground contact phase, only the hip and knee continue to flex (19). In order to stabilize the body upon landing, the hip and knee extend, with only minor movement at the ankle joint and the trunk remaining in a flexed position (19).

From the initial take off to the landing, there is a sequenced pattern of muscle activation that must be achieved in order to land safely. Literature indicates deviances in this activation pattern, particularly with respect to cocontraction patterns occurring at the hip and knee joints (8, 22, 23, 26, 29). Upon landing, cocontraction stabilizes the knee joint, and any alteration in this pattern increases the risk for potential injury (22). Investigators observed that females have a delayed and decreased activation of lateral hamstring and vastus lateralis during the preparatory phase of landing (8, 22). In addition, a study by Zazuluk et al. (29) found that females displayed a decrease in peak gluteus maximus activity, maximal voluntary contraction, and mean muscle activation upon landing. An optimal amount of agoist – antagonist contraction is required stabilize and prevent unnecessary stress on the active (i.e. muscles) and passive (i.e. ligaments) of the knee. Likewise, decreased activation of the lateral rotators at the knee and places the knee joint in a valgus position, thereby increasing vulnerability of the ACL.

Researchers have also observed that females have delayed peak knee extensor joint moment and greater quad activation in comparison to their male counterparts (6, 26). These findings suggest that females adapt different motor unit recruitment strategies to reduce tension produced by the knee extensors. The greater reliance on the force capabilities of the knee extensors and the plantar flexors to decelerate the body, requires compensation of additional muscles, such as the hip extensors, to absorb the forces of landing (6, 26). This larger dependence of the hip extensors increases posterior strain on the femur, and consequent strain on the ACL.

Weakness of the knee extensors has been attributed to ACL rupture in female athletes. Decreased knee extensor strength creates an erect landing posture and consequent stiffer landing mechanics (6, 17). This is unfavourable since stiffer landing mechanics are associated with shorter times to peak hip and knee flexion which are important for distribution of forces and control while landing (25). If the proximal muscles of the lower extremity are unable to dissipate forces upon landing, then they must be absorbed elsewhere (i.e. knee and ankle joints, distal musculature). The use of proximal musculature, such as the quadriceps, is essential for dissipating impact forces as their large cross sectional area, shorter tendons, and long muscle fibres, reduce the moment of inertia relative to the hip joint, allowing for more efficient movement of the leg and greater energy absorption by proximal musculature (30). Female athletes, however, are at a mechanical disadvantage if the knee extensors are weak, thereby resulting in greater risk of ACL injury.

Biomechanics

The study of biomechanics has allowed researchers to develop an in depth understanding of human performance in relation to the forces and torques that act on the body to create motion. Investigators have found that, females tend to display an array of biomechanical differences during landing which predispose them to ACL injury. Research has not precisely defined what an optimal landing consists of, however, they have found specific biomechanical deviances that female athletes display when landing.

A joint moment is the tendency of a force to cause rotation at a joint (21). The magnitude and direction of the force acting on a joint will determine the resultant action occurring at that particular joint (21). Extremity joint moments can have significant effect on control of landing and have been suggested to differ between genders. A study by Hart et al. (11), found that females displayed greater peak hip internal rotation compared to males. This finding suggests that females have poor hip control upon landing as a result of poor eccentric control of the hip external rotators and hip abductors. It has been observed that in the first 30 – 50 % of the landing phase, females display greater knee valgus angles than males (13). Hip extensors as well as abductors are important in preventing excessive valgus moment at the knee joint, by countering with an external moment at the hip. Therefore, if these muscles are not being utilized during the landing phase, the knee joint will be stressed as a result of the increased valgus moment occurring.

To fully understand landing and its relation to ACL injuries, the kinematics (describes the surface motion of a joint) of the distal segment of the lower limb must also be explored (21). Landing is a multijoint task involving action at the ankle, knee and hip; therefore, all components of the lower limb must be explored. A study by Kiriyama et al. (14), found that females had significantly less external shank rotation and greater peak shank internal rotation angles than males upon landing. Females tend to be unable to generate sufficient external moment to counter the internal moment because of reduced external rotator strength (14). Thus, the greater internal moment placed on the knee joint causes the ACL to be in a more vulnerable position.

Evidence suggests that greater knee flexion angles are another factor contributing to the increased number of ACL injuries sustained by females over males (17). A study by Lephart et al. (17), determined that females, in comparison to males, have significantly less knee flexion during landing due to weak knee extensors. Eccentric quadriceps contraction is essential upon landing, as this allow for an athlete to land in an optimal position with control. As discussed earlier, an erect landing posture and a lack of quadriceps strength leads to an uncontrolled and unstable landing strategy in addition to increasing the risk for ACL injury.

Quality of evidence

Inconsistencies in research methodologies used to investigate landing mechanics between genders, has contributed to discrepancies, in particular when drop boxes are used with different heights ranging from 13.5 cm to 100 cm. In a study of physical performance characteristics of junior national, state and novice volleyball players, investigators found that the average jump height was 45.7 cm for a female national players and 54.6 cm for a male volleyball player (7). Zhang et al. (30) investigated the impact of shock transmission and reduction in landing activities with varied mechanical demands (30 cm – 90 cm drop landings). They found an increased range of motion for the ankle, knee, and hip joints, increased peaks of the vertical ground reaction force, and greater eccentric muscle work completed by lower extremity joints, were increased with greater landing heights. The mechanical and neuromuscular response upon landing from different heights cannot be compared since the relative muscle contributions are unknown at different drop heights (2). Therefore, studies investigating the demands of landing must take into account drop height that reflects actual jump heights of volleyball players.

Landing strategies chosen by investigators have also lead to inconsistencies in research methodologies. Some studies have subjects land unilaterally on a “dominant limb” (6, 11, 14, 17, 22, 24, 25, 26, 29) while others require their subjects to land bilaterally (8, 13, 16). The determination of a dominant limb is inconsistent amongst the studies. One common way studies define dominancy as the leg used to kick a soccer ball (17, 22, 25, 29). However, landing from a jump and kicking a soccer ball are very different skills. It is more logical to define the dominant leg as the stance leg since it is bearing the majority of the weight and the demands placed on this leg during a soccer kick are similar to the demands of landing. Moreover, ground reaction force has been found to be 5 times greater than body weight upon landing (1). This force absorbed on a single limb in comparison to two would require greater strength and stabilization. Therefore, the mechanics and activation patterns upon landing will be skewed and non-representative of what actually occurs during a landing task.

Lastly, variability in the activity level of the participants, number of trials performed, rest period between landing trials, EMG measurement (surface vs. intramuscular), and the number of practice trials performed also affect task performance and statistical analysis in testing the validity and reliability of the data collected.

Implications for research

As previously mentioned, consistent methodology and valid research will contribute to a more definite understanding of gender differences upon landing and ACL injury. The deviances within the methodologies used by investigators have resulted in an abundance of unsound conclusions. It is an investigators responsibility to ensure their methodology is consistent and reproducible. This will in turn produce valid data that can be compared across the spectrum of studies investigating gender differences in landing strategies and the correlation to ACL injury.

With this in mind, the sequence of jumping and landing must be studied in its entirety to understand its relationship to ACL injury. All aspects of the takeoff phase, transition phase (period in the air where takeoff phase becomes the landing phase), and landing phase must be investigated. It is possible that injury may occur upon landing if the necessary postural adjustment and muscle activation patterns are not initiated during transition from takeoff to landing. The adjustments required during the transition phase to land a jump optimally must be acknowledged and compared between genders. As well, there is limited research on trunk activation patterns and the differences found between genders. Certainly, activation of trunk musculature is important for dynamic stability upon landing (16). Future research should explore this area more thoroughly as it can contribute to our current understanding of gender landing differences and ACL injury. Likewise, once all the components involved in landing have been fully understood using consistent methodologies does it become possible to draw conclusions as to why females suffer from ACL injuries more than their male counterparts in landing sports.

Implications for practice

Landing is a fundamental skill but also the leading cause of injury in volleyball, with blocking and spiking contributing to over 70% of injuries (3, 28). A study by Tillman et al. (27), found that on average elite female volleyball players performed 22 jump-landing sequences per game. However, the number of jump landing sequences performed by an athlete is dependent on the position (offense or defense) played and the amount of playing time. This study further found that almost all jumps were executed bilaterally, however nearly half of the landing sequences were completed unilaterally. The ground reaction forces generated upon landing, which have been shown to be five times that of an individual's body weight, must first be dissipated by proximal segments (i.e. ankle complex, leg musculature) followed by distal segments (i.e. knee and hip joints, musculature surrounding knee and hip joints) (1). If at any point during a landing sequence the impact forces are not transferred in this fashion, an athlete becomes at risk for injury.

Based on the literature explored in this review, a few suggestions can be made for strength and conditioning coaches designing and implementing programs for female volleyball players. As previously mentioned, the main contributors to poor landing mechanics are deficits in lower limb musculature strength and altered muscle activation patterns. Within a training program, an appropriate amount of stimulus is required to elicit strength adaptations and re-program flawed sequences in fundamental movement patterns. In addition, training specificity will ensures that any improvement in size, strength and or power can be translated to an improvement in athletic performance (15). Research has shown that 6 months of heavy resistance and explosive power training of leg extensors leads to increased EMG activity of agonists and decreased EMG activity of antagonists (10). Moreover, resistance training has the capacity to elicit adaptation to neuromuscular elements that are involved in the execution of movements and therefore has an effect on sport performance during a wide range of movement tasks (4). As well, weightlifting exercises such as the snatch and clean, are effective for developing rate of force, increasing coordination of limbs and trunk, and improving reactive strength (ability to rapidly reverse eccentric to concentric motion) (5). During the catch phase of the snatch or clean, rapid activation of agonist musculature in an eccentric manner is required to overcome the downward motion of the bar during the catch phase (5). Certainly, the demands of this type of movement are similar to the demands of landing. Therefore, both heavy resistance training and explosive type movements are essential to include in a training program for athletes, especially females involved in landing sports. They can lead to increases in strength of proximal muscles and re-program altered cocontraction patterns of musculature involved in landing tasks.

Summary

In conclusion, it is imperative to understand multijoint tasks with respect to human movement, as they are the fundamental basis for sport performance. Female athletes involved in landing sports such as volleyball, are more likely to sustain an ACL injury than their male counterparts as a result of an array of neuromuscular and mechanical factors. Research in this arena has yet to be successful in providing consistent research methodologies, resulting in an abundance of inconclusive findings. It is critical for strength and conditioning coaches and clinicians to have a sound understanding of multijoint muscle kinematics in order to design effective prevention programs. In turn, gaps within the literature have inhibited the development of successful prevention programs that address the unique needs of female athletes involved in landing sports, and consequently reduce rates of ACL injury.

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