한국전문물리치료학회지 제9권 제4호
KAUTPT Vol. 9 No. 4 2002.

Gender Differences of Knee Angle in Landing From a Drop-Jump: A Kinematic Analysis

Yi Chung-hwi, Ph.D., P.T.
Dept. of Physical Therapy, College of Health Science, Yonsei University
Institute of Health Science, Yonsei University
Park So-yeon, M.Sc., P.T.
Dept. of Rehabilitation Therapy, The Graduate School, Yonsei University
Lee Sang-heon, B.H.Sc., O.T.
Dept. of Rehabilitation Therapy, The Graduate School, Yonsei University

국문요약

수직착지시 성에 따른 슬관절의 형상학적(kinematic) 자료 분석

이충휘
연세대학교 보건과학대학 물리치료학과 및 보건과학연구소
박소연
연세대학교 대학원 재활학과
이상헌
연세대학교 대학원 재활학과

이 연구의 목적은 수직착지시 성에 따른 슬관절 가동범위의 차이를 알아보는 것이다. 연구 대상자는 20대의 건강한 성인 48명(남자 25명, 여자 23명)이었다. 연구 대상자에게 40 cm 높이에서 한발로 뛰어내리도록 하고, 2차원 동작측정 기구인 CMS-HS를 이용하여 수직착지시 슬관절의 굴곡각도, 최대 슬관절 굴곡각도, 슬관절의 가동 범위, 각속도를 측정한 후, 남·여 두 집단간의 차이를 알아보았다. 이때 사용한 분석방법은 독립적인 두 표본 t-검정이었으며 축차적(stepwise) 다변량회귀분석을 이용하여 체중과 신장을 조절한 상태에서 남여 간에 차이가 있는지를 분석하였다. 그 결과 수직착지시 슬관절의 굴곡각도에서는 유의한 차이를 보이지 않았으나, 최대 슬관절 굴곡각도, 슬관절의 가동 범위, 각속도에는 유의한 차이가 있었다($p<.05$). 체중과 신장이 조절된 조건 하에서 여자는 수직착지시 최대 슬관절의 굴곡각도와 슬관절의 가동범위가 남자보다 작았다. 이러한 결과를 통하여 수직착지시 여자가 남자보다 슬관절 손상의 빈도가 높은 이유 중의 하나는 여자가 슬관절을 덜 굴곡시킴으로 인해 바닥의 충격을 더 많이 받기 때문이라는 가능성을 발견하였다.

핵심단어: 수직착지; 슬관절 굴곡; 운동형상학적 분석.

Introduction

There have been many documented instances of greater incidences of anterior cruciate ligament and patello-femoral injuries among the female athletic populations over the past 25 years as compared to their male counterparts participating in comparable sports such as basketball, volleyball, and soccer (Baker, 1998; Beim and Stone, 1995; DeHaven and Lintner, 1986; Engstrom et al, 1991; Feretti et al, 1992; Kaiser, 1998; Woodland and Francis, 1992).

Huston et al (2001) performed a study of 20 young height-matched subjects, 10 male, and 10 female that performed 3 jumps from 3 vertical heights. The largest gender difference in knee angle occurred at the highest jump height of 60 ㎝. Women were found to land with a significantly straighter knee angle than men at heights, 60 and 40 ㎝, thus exposing their knee joint to higher forces per unit body weight when landing from a jump than men do. Lafortune (1985) compared healthy and previously injured basketball players while rebounding basketballs. The noninjured athletes demonstrated greater flexion at the hip and knee joints during landing. Interestingly, previously injured athletes demonstrated less hip and knee flexion (Lafortune, 1985). Huston et al (2001) theorized that smaller knee flexion angle utilized by women during the impact phase of landing will also increase their vertical ground reaction forces and knee joint loads. Landing imposes forces on the body that must be absorbed primarily by the lower extremity (Caster and Bates, 1995). If loads become too great for the body to accomodate or if impact absorption fails, an injury will likely occur (Simpson and Kanter, 1997). These pathomechanics should be considered in the possible cause of the higher rates of knee injuries for women (Huston et al, 2001).

Several lines of evidence suggest the angle of knee extension on touchdown and impact with the ground will determine the magnitude of the ground impact force, and therefore, indirectly, knee loading. Although drop-landings have been studied extensively, a few studies have been done to examine gender differences (Huston et al, 2001; McNitt-Gray, 1993). Therefore, this study was conducted to compare the intial knee angle, maximum knee flexion angle, and angular velocity at the instant of impact for drop-landings between healthy men and women.

Methods

Subjects

Twenty-five healthy men (age, 24.6±2.2 yrs; height, 173.3±5.7 ㎝; weight, 71.5±8.2 ㎏) volunteers with ages ranging from 21~29 years and 23 healthy women (age, 23.0±3.8 yrs; height, 161.0±4.8 ㎝; weight, 57.5±10.3 ㎏) volunteered to participate as subjects in the study. They were free of injury or other physical impairment in the lower extremity at the time of testing. The age, height, and weight characteristics of the subjects are summarized in Table 1.

Table 1. Age, height, and weight characteristics of the subjects (N=48)

Variable	Male	Female
Age (yrs)	24.6±2.2*	23.0±3.8
Height (㎝)	173.3±5.7	161.0±4.8
Weight (㎏)	71.5±8.2	57.5±10.3

*Mean±SD

Test Protocol

Participants were instructed to perform three unconstrained jumps from 40 ㎝ high. The cmS-HS[1] measuring system was used to analyze the kinematic data. This system consists of a measuring sensor with stand, a basic CMS-HS unit, markers and a cable adaptor with 10 channels can be supplied for operation of individual markers. The measuring procedure is based on the determination of the spatial coordinates of miniature ultrasound transmitters. The sound pulse time between the transmitters and the three microphones integrated in the measuring sensor was measured. Active reflective markers were placed on the right side of the body at 3 sites: the lateral malleolus, the mid-thigh, and lateral femoral epicondyle (Figure 1).

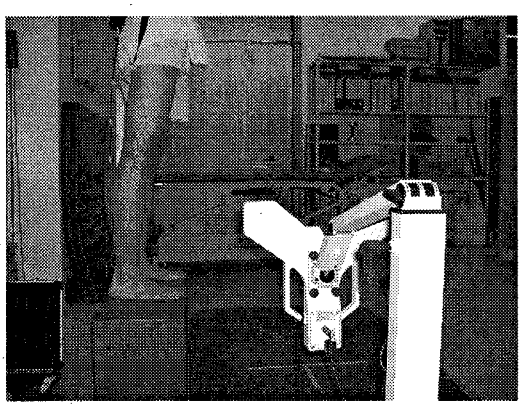

Fig 1. Experimental setting

In preparation for the jump, each participant was instructed to drop, not jump, from the raised platform onto the ground, attempting to land with their toes as close as possible to a mark on the floor 40 ㎝ from the platform, thus attempting to standardize the horizontal jumping distance of the participants. After landing, the subject returned to her normal standing position. The arms were not constrained during the landings and were generally put subjects' sides or waist for balance. Each subject practiced the data collection protocol prior to the time of data collection. The purpose of the practice sessions was to allow the subjects time to become comfortable with the data collection conditions. The subjects were asked to perform 3 landing trials.

1) Zebris Medizintechnik, GmbH. Isny. Germany.

Statistical Analysis

Knee joint angular position and velocity were calculated from the kinematic data. Independent t-tests were used to determine if difference existed between males and females for the intial knee flexion angle at the moment of impact, maximum knee flexion angle, and angular velocity at vertical drop-landing. The significant level for difference was set at $p<.05$. Stepwise multiple regression analysis was used to identify the most informative variable for prediction of range of motion change at knee joint during drop-landing. A dummy variable for gender was used.

Results

At 40 ㎝ height, the means of knee flexion angle at landing were 4.05±3.78 degrees for men and 5.45±4.86 degrees for women. Independent t-test revealed no significant difference between the two

Table 2. The kinematic data at landing (N=48)

	Male	Female	t	p
Knee flexion angle at landing (degree)	4.05±3.78*	5.45±4.86	-1.12	.267
Maximum knee flexion angle (degree)	48.16±4.57	42.74±6.47	3.37	.002
Knee flexion range** (degree)	43.64±4.63	37.40±6.23	3.95	.000
Angular velocity (degree/sec)	.26±.04	.23±.04	1.96	.056

*Mean±SD
**Maximun knee flexion angle - Knee flexion angle at landing

groups ($p>.05$)(Table 2).

After impact, the knee angle flexes as the vertical momentum of the body is arrested. The maximum knee flexion angle occurred an average of 167.46±29.24 msec (172.39±23.83 msec in men; 162.10±33.51 msec in women) after impact, in men. Men landed with 48.16±4.57 degrees of maximum knee flexion, whereas women landed with 42.74±6.47 degrees of maximum knee flexion. There were significant differences between genders in maximum knee flexion angles ($p<.05$)(Table 2).

With respect to the knee flexion range during landing, the means of the angle change were 43.64±4.63 degrees in men, 37.40±6.23 degrees in women, respectively. Independent t-test revealed significant difference between the two groups ($p<.05$)(Table 2).

Concerning the angular velocity, .25±.04 degree/sec for men, .23±.04 degree/sec for women, respectively. Independent t-test revealed significant difference between the two groups ($p<.05$)(Table 2).

To control the effect of gender, body weight, and height variables, a stepwise multiple regression for knee flexion range was performed. The regression model was obtained below(Table 3, 4)

Knee flexion range = 43.6−5.7×gender
if gender is 0, indicates male
if gender is 1, indicates female

Table 3. ANOVA output for regression analysis: Knee flexion angle and gender

Model	Sum of Squares	df	Mean Square	F	p
Regression	379.09	1	379.09	14.01	.001*
Residual	1217.54	45	27.06		
Total	1596.62	46			

*Predictor: gender

Table 4. Coefficients for regression analysis: Knee flexion angle and gender

	Unstandardized coefficients		Standardized coefficients	t	p
	B	Stander error	Beta		
Constant	43.645	1.040		41.953	.000
Gender	-5.692	1.521	-.487	-3.743	.001

To control the effect of gender, body weight, and height variables, a stepwise multiple regression for angular velocity was performed. The regression model was obtained below(Table 5, 6).

Angular Velocity = .257 -.024×gender
if gender is 0, indicates male
if gender is 1, indicates female

Discussion

There have been many theories as to the etiology of greater incidence of anterior cruciate ligament and patello-femoral injuries with females in the same sports. These factors include both extrinsic and intrinsic factors. Extrinsic factors include contact vs. non-contact mechanisms, muscle strength, conditioning, prior athletic experience and shoe-surface interface. Intrinsic factors include laxity of joints, anatomic limb variations, Q-angle, and dimensions of the intercondylar notch (Arendt et al, 1999; Feretti et al, 1992). Thus far, though, no one particular factor has been proven as the leading cause of increased numbers of anterior cruciate ligament and patello-femoral injuries in female athletes.

Our investigation set out to examine sex differences in kinematics in response to a

Table 5. ANOVA output for regression analysis: Angular velocity and gender

	Sum of Squares	df	Mean Square	F	p
Regression	.007	1	.007	4.638	.037*
Residual	.065	45	.001		
Total	.072	46			

*Predictor: gender

Table 6. Coefficients for regression analysis: Angular velocity and gender

	Unstandardized coefficients		Standardized coefficients	t	p
	B	Standard error	Beta		
Constant	.257	.008		33.774	.000
Gender	-2.4E-02	.011	-.306	-2.154	.037

single leg jump in non-athletic individuals. Past studies have quantified maximum knee flexion angles on impact, rather than the initial angle on touchdown, which is known to determine the maximum ground reaction force (Nigg, 1994). The results on maximum knee angle from the present study are, however, in agreement with result obtained from Dufek and Bates (1991). At a height of 59 ㎝, Dufek and Bates (1991) reported maximum knee flexion angles to be 77 degrees, whereas in this study, maximum knee flexion angles averaged 45.56 degrees. However, Dufek and Bates (1991) only examined three male participants as compared to our mixed participants population. Hewett et al (1996) reported that high school volleyball players' maximum knee flexion angles ranged from 69～72 degrees.

Amoroso et al (1997) have proposed that a gender difference exists in body configuration at the time of landing from a free-fall jump. However, body configuration is unlikely to affect the initial ground reaction force impulse which lasts for only 30 msec, because in this short time, the pelvis and super-incumbent body will not have started to decelerate.

Devita and Skelly (1992) demonstrated a change in the relative contribution of the ankle, knee, and hip joints to energy absorption between soft and stiff landing styles. Devita and Skelly (1992) determined that the hip, knee, and ankle absorbed 25, 37, and 37%, respectively, of the total energy absorbed during soft landings. When subjects consciously reduced joint range of motion to land stiff, the relative contribution of the lower extremity joints to total energy absorption was changed to 20, 31, and 50% for the hip, knee, and ankle joints, respectively.

Although energy absorption was not measured in this study, there were measured changes in the maximum angular velocity of knee flexion during landing. The maximum knee flexion angular velocity was, on average, about .25 degree/sec. A reduction in angular velocity could reflect a decrease in energy absorption based on the work-energy relationship. In landing, the angular velocity of the joints is reduced to zero at the end of the decent phase. A higher peak angular velocity reflects a greater angular kinetic energy of the rotating bodies. Greater negative work, in the form of a torque applied opposite to the direction of rotation, must be done to reduce the angular kinetic energy to zero. The source of the torque to decrease angular velocity at the knee is the eccentric activity in the quadriceps muscles.

This study provide evidence that the ground reaction force is likely to be greater in women per unit body weight than in men because women land with a straighter knee. Because anterior cruciate strain has been found to be greatest when the lower extremity is loaded in full knee extension, and anterior cruciate ligament strain significantly decreases with knee flexion. In the present study, the implication of a straighter in women than in men during landing is that landing with a straighter knee increase the likelihood of a knee injury. However, support of this interpretation will require application of an inverse dynamics analysis to measure the energy absorption during landings with knee extended and with knee flexed.

Given these findings, a review of the incidence and causes of these injuries among female athletes is in order, particularly in basketball, soccer, and volleyball. Such a review might suggest areas of further study that could help in treating anterior cruciate ligament injuries more effectively in female patients.

Conclusion

From the results obtained we conclude that women land with a straighter knee than men and landing with a straighter knee might increase the likelihood of a knee injury.

References

Arendt EA, Agel J, Dick R. Anterior cruciate ligament injury patterns among collegiate men and women. J of Athletic Training. 1999;34(2):86-92.

Baker MM. Anterior cruciate ligament injuries in the female athlete. J Women's Health. 1998;7(3):343-349.

Beim G, Stone DA. Issues in the female athlete. Orthop Clin North Am. 1995;26(3):443-451.

Caster BL, Bates BT. The assessment of mechanical and neuromuscular response strategies during landing. Med Sci Sports Exerc. 1995;27:736-744.

DeHaven KE, Lintner DM. Athletic injuries: Comparison by age, sport, and gender. Am J Sports Med. 1986;14(3):218-224.

Devita P, Skelly WA. Effect of landing stiffness on joint kinetics and energies in the lower extremity. Med Sci Sports Exerc. 1992;24:108-115.

Dufek JS, Bates BT. Biomechanical factors associated with injury during landing in jump sports. Sports Med. 1991;12:326-337.

Engstrom B, Forssblad M, Tornkvist H. Soccer injuries among elite female players. Am J Sports Med. 1991;19:372-375.

Feretti A, Papandrea P, Conteduca F, et al. Knee ligament injuries in volleyball players. Am J Sports Med. 1992;20(2):203-207.

Hewett TE, Stroupe AL, Nance TA, et al. Plyometric training in female athletes: Decreased impact forces and increased hamstring torques. Am J Sports Med. 1996;24:765-773.

Huston LJ, Vibert B, Ashton-Miller JA, et al. Gender differences in knee angle when landing from a drop-jump. Am J Knee Surg. 2001;14:215-220.

Kaiser DK. The incidence of ACL injury in female intercollegiate soccer players. Supplement to Journal of Athletic Training. 1998;7(3):343-349.

Lafortune M. Jumping mechanics and jumper's knee. Sports Science and Medicine Quarterly. 1985;2:2-4.

McNitt-Gray JL. Kinetics of the lower extremities during drop landings from three heights. J Biomech. 1993;26:1037-1046.

Nigg BM. Modeling. In: Nigg BM, Herzog W, eds. Biomechanics of the Musculoskeletal System. Chichester, United Kingdom, Wiley Inc, 1994:458.

Simpson KJ, Kanter L. Jump distance of dance landings influencing internal joint forces. I: Axial forces. Med Sci Sports Exerc. 1997;29:916-927.

Woodland L, Francis R. Parameters and comparisons of the quadriceps angle of college-aged men and women in the supine and standing positions. Am J Sports Med. 1992;20:208-211.