

Change of Muscular Activity and Dynamic Stability of the Knee Joint Due to Excessive and Repetitive Jumping or Cutting by Female Athletes

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Abstract. [Purpose] Previous studies have reported that physical activity is increasingly being encouraged as an essential part of a healthy lifestyle; thus, sports and preventable injury are becoming an important public health issue. Using an isokinetic test, we evaluated muscular activities and dynamic stability of the knee joint of skilled female athletes. [Methods] The subjects were 42 females aged 24.5 ± 0.9 years old, weighing 61.5 ± 1.1 kg; they were 169.6 ± 1.3 cm in height and had a body mass index (BMI) of 18.2 ± 0.5 . We used a Biodex 3 System Pro® as the isokinetic dynamometer. [Results] The extensor in the dominant leg of the jumping group showed significantly higher strength than its counterpart in the cutting group. However, knee flexors showed no significant difference between groups. Furthermore, the H:Q ratios of the jumping group (ND: $45.4 \pm 2.3\%$, D: $45.0 \pm 1.2\%$) and the cutting group (ND: $48.1 \pm 1.9\%$, D: $51.5 \pm 1.6\%$) were lower than 60%. In addition, the ratio of dominance in the jumping group was significantly lower than in the cutting group. [Conclusion] These results suggest that skilled female athletes who perform excessive and repetitive jumping actions need to be more aware of their risk of developing anterior cruciate ligament (ACL) injury, and they need a more specific therapeutic program for this injury.

Key words: Muscle activity, Dynamic stability, Anterior cruciate ligament injury

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INTRODUCTION

Previous studies have provided strong proof of the health benefits of sports activities in developed countries^{1,2)}. People who achieve comparatively high exertion levels during exercise have a lower risk of developing diseases compared with those achieving only a low level of exertion. Physical exercise should help in the prevention and management of medical conditions such as hypertension, hyperlipidemia, obesity, diabetes mellitus, and cancer, in addition to the age-related decrease in muscular strength^{3,4)}. As a result, the number of young adults participating in sports activity, which is defined as a physical activity requiring vigorous bodily exertion, has risen dramatically⁵⁾. However, female athletes may exercise more without paying attention to the degree of damage such exercise can cause, and researchers agree that exercise could, in some cases, be more harmful than recreational for women⁶⁾. Skilled athletes may have a higher tolerance of pain, and may neglect limiting themselves to a suitable amount of exercise. This tendency would make them vulnerable to sustaining sport-related injuries⁷⁾. Attention to female injuries associated with sport and recreational activities is also viewed as an important health goal, because it has a significant social and economic impact⁸⁾. Consequently, a

comprehensive program for the prevention of sport injuries related to physical exercise is being highlighted as a major contribution to the maintenance of optimal health among individuals and society as a whole. However, sport injury problems still need to be elucidated^{9,10)}. In particular, female athletes suffer anterior cruciate ligament (ACL) injury at a 4- to 6-fold higher rate than male adults when jumping or cutting^{11, 12)}. Most ACL injuries in female athletes occur in a noncontact situation, typically during deceleration, pivoting, or landing tasks, which are often associated with high external knee joint loads^{13, 14)}. The ACL may potentially be harmed due to the impact of forces during landing (jumping) and twisting (cutting) sport movements, when the muscles of the knee joint cannot appositely and sufficiently dissipate the associated torques and forces. This is because the velocity of motion increases during flexion, and the forward momentum of the tibia increases to a point where augmented hamstring recruitment is required to limit not only extension rotation, but also anterior translation of the joint^{15, 16)}. It has been reported that significant positive alterations in muscular strength and active patterns of the knee joint can be achieved for female athletes through neuromuscular training, and previous studies have demonstrated that neuromuscular training has a positive effect on ACL

Table 1. General characteristics of participants

Group	No.	Age (yrs)	Height (cm)	Weight (kg)	BMI (%)
JG	21	24.5 ± 0.9	175.9 ± 1.7*	65.3 ± 1.5*	20.4 ± 0.8*
CG	21	23.8 ± 0.8	164.5 ± 1.0	58.5 ± 1.3	16.5 ± 0.2
Total	42	24.1 ± 0.6	169.6 ± 1.3	61.5 ± 1.1	18.2 ± 0.5

Mean ± standard error; *p<0.05. JG, jumping group; CG, cutting group; BMI, body mass index

injury rates in female athletes^{17, 18}). In other words, muscular activity and the H:Q ratio are related to the majority of factors involved in dynamic joint stability, which depends on both passive and active restraints¹⁹). Assessment of knee joint strength and muscular balance through a conservative H:Q ratio is closely correlated with injury prevention and performance enhancement^{20, 21}). Therefore, the H:Q ratio has been suggested as a possible screening tool for predisposition to injury²²). When the knee is injured, the H:Q ratio is often used as a rehabilitation index due to the importance of the flexor-extensor strength balance in overall knee stabilization¹⁷). A number of previous studies have concluded that sport-specific muscle balance is required because people with a greater percentage of fast twitch fibers, such as sprinters require greater muscle balance due to the impact of the exercise undertaken. On the other hand, an optimal sport-related leisure life requires a higher H:Q ratio, representing greater balance^{20, 23}). Previous research has examined the different influences and aspects of excessive and specific sports-related physical activity on muscular strength and dynamic joint stability during jumping (jumping group, JG) and cutting (cutting group, CG) in female volunteer volleyball and table tennis players^{11, 16}). These sports are representative of drastic jumping or cutting activity. Therefore, we hypothesized that these two experimental groups may exhibit significant differences in muscular strength and the H:Q ratio.

SUBJECTS AND METHOD

Forty-two volunteers who had no physical or psychological conditions provided their written informed consent to participation in this study (age: 24.1 ± 0.6 years old; weight: 61.5 ± 1.1 kg; height: 169.6 ± 1.3 cm; BMI: 18.2 ± 0.5) (Table 1). A survey was conducted to verify repetitive activities that may be dependent on exercise addiction, using the exercise addiction inventory–short form (JG: 18.4 ± 1.4, CG: 16.9 ± 0.8). A score of 13–23 was chosen to be indicative of a symptomatic individual, while a score of 0–12 was deemed to indicate an asymptomatic individual⁶). The Isokinetic Dynamometer Biodex 3 System Pro® was used to assess peak work variables, peak torque of the flexor and extensor of the knees normalized to body mass, and the agonist/antagonist ratio at 60°/second. Isokinetic assessments measure muscle contractions while the limb is moving at a constant and predetermined velocity. An isokinetic dynamometer applies an accommodative resistance along the whole range of the movement. Thus, an increase in the muscle power by the subject being evaluated produces an increase in the resis-

tance, but no increase in the velocity, similar to that which occurs in isotonic exercises. Volunteers performed a five-minute warm up on an ergonomic bicycle before beginning the isokinetic testing. For the measurements, each volunteer was seated on the dynamometer, with the chair positioned to provide 85° hip flexion, and the movement axis of the equipment was aligned to the side epicondyle of the femur. Volunteers were belt-stabilized around their trunks and thigh in order to inhibit compensatory movements. The magnitude of the movement was limited between 110° flexion and 0° extension, and 0° was defined as full extension. Before starting the test, volunteers performed three submaximal repetitions in order to become familiar with the procedures. The dominant (D) and non-dominant (ND) legs were determined by asking subjects which of their legs they would use to kick a ball the furthest. During the test, volunteers performed five maximal flexion and extension repetitions of the knee in the concentric mode at 60°/second velocity. An angular velocity of 60°/sec was chosen because muscle strength assessed at low velocities allows a higher number of motor units to be recruited, thus generating a better representation of the maximal work performed by the musculature assessed. The peak torque (peak TQ) and peak TQ/BW were adopted as the evaluation criteria. Peak torque is the muscular force output at any moment during a repetition, and peak TQ/BW is peak torque normalized to bodyweight. All volunteers received verbal encouragement during the tests²³). We also calculated the conventional H:Q ratio. This ratio was calculated according to its formal definition by dividing maximal isokinetic hamstring (knee flexor) strength by maximal quadriceps (knee extensor) strength at a given contraction mode and joint angular velocity⁸). Data are expressed as means ± SEM. The independent t-test was used for comparisons and data were analyzed using SPSS (v. 12.00). Values of p<0.05 were considered to be statistically significant.

RESULTS

Peak torques of maximal isokinetic knee extensors in the jumping group were significantly higher than in the cutting group. However, for peak TQ/BW, only the dominant extensor of the jumping group was significantly higher than that of the cutting group (Table 2). Peak torque of maximal isokinetic knee flexors in the jumping group were significantly higher than those in the cutting group. However, there were no significant differences for peak TQ/BW (Table 3). The H:Q ratios of the jumping group (ND: 45.4 ± 2.3%, D: 45.0 ± 1.2%) and cutting group (ND: 48.1 ± 1.9%, D:

Table 2. The muscular activity in knee extension

Group	Peak TQ (Nm)		Peak TQ/BW (%)	
	Ext-ND	Ext-D	Ext-ND	Ext-D
JG	184.7 ± 9.2*	186.4 ± 5.6*	278.5 ± 13.7	281.7 ± 9.3*
CG	147.2 ± 4.9	143.5 ± 5.4	252.2 ± 7.4	246.1 ± 8.5

Mean ± standard error; *p<0.05. JG, jumping group; CG, cutting group; BMI, body mass index; TQ, torque; BW, body weight; Ext, extension; ND, non-dominant; D, dominant

Table 3. The muscular activity in knee flexion

Group	Peak TQ (Nm)		Peak TQ/BW (%)	
	Flex-ND	Flex-D	Flex-ND	Flex-D
JG	80.5 ± 2.9*	83.5 ± 3.1*	121.5 ± 4.3	125.9 ± 4.6
CG	69.8 ± 2.4	73.0 ± 2.5	120.2 ± 4.4	125.3 ± 4.2

Mean ± standard error; *p<0.05. JG, jumping group; CG, cutting group; BMI, body mass index; TQ, torque; BW, body weight; Flex, flexion; ND, non-dominant; D, dominant

51.5 ± 1.6%) were lower than 60% (Table 4). The ratio of dominance in the jumping group was significantly lower than that of the cutting group.

DISCUSSION

Participation in sports also involves a risk of injury for all participants, from athletic to the recreational levels^{12, 24}. Prior studies have reported that sports injuries constitute 10–19% of all acute injuries seen in emergency departments, and the most common types are knee and ankle injuries²⁵. In addition, serious knee injuries, such as injuries to the anterior cruciate ligament, are a growing cause of concern for female sports players⁷. The highest incidences of ACL injury are seen in young adults playing pivoting and jumping sports such as football, volleyball, and basketball²⁶. In these sports, women are three to five times more likely to experience a serious knee injury than men^{11, 25}. Knee injury may be caused by diverse factors such as environmental, anatomical, and hormonal risk factors, but there is no conclusive evidence that any one single risk factor correlates directly with the higher incidence of ACL injury observed in female participants^{27, 28}. Therefore, the emphasis of ACL injury prevention has turned to biomechanical risk factors and the use of neuromuscular and proprioceptive intervention programs to address potential biomechanical deficits^{16, 29}. It has been confirmed by previous studies that neuromuscular training results in a reduction in knee ligament injuries, possibly because of biomechanical (decreased landing forces and adduction-abduction moments) and physiological effects (decreased estrogen levels and increased H:Q strength ratios)^{11, 17}. There is some controversy in the literature about the ability of the isokinetic test as a good predictor of sports performance, since several studies found no relationship between the isokinetic variables of the knee joint and the height reached by subjects in vertical jumping^{30, 31}. Nevertheless, isokinetic tests have been widely used in a

Table 4. The H:Q ratio of the non-dominant and dominant legs

Group	Non-dominant (%)	Dominant (%)
JG	45.4 ± 2.3	45.0 ± 1.2*
CG	48.1 ± 1.9	51.5 ± 1.6

Mean ± standard error; *p<0.05. JG, jumping group; CG, cutting group

great number of previous studies, as they supply objective, reliable, and reproducible values related to the muscle function of several joints^{32, 33}. Thus, isokinetic tests allow parameters related to muscle performance to be assessed, including strength, work, power, and imbalances between agonist and antagonist muscles^{34, 35}. In the present study, we found a significant difference between JG and CG in all peak TQ of the hamstring, but not for peak TQ/BW. Our subjects' physical characteristics were significantly different in terms of height, weight, and BMI. Because of such differences, a number of previous studies have used peak TQ/BW to evaluate physical performance^{21, 31}. Therefore, our results show that the strength of the hamstrings is not significantly influenced by specific sport performance such as jumping and cutting. However, this was not the case for the quadriceps, which not only showed significant differences between JG and CG in all peak TQ, but also a significant difference in the peak TQ/BW of the dominant knee joint. Since the knee extensor musculature is considered the major generator of strength for jumping^{21, 33}. Jumping is a complex multi-joint movement, common to many sports activities, and requires optimal muscle coordination which is obtained through relevant skill development¹⁸. In particular, jumping has been reported as one of the essential actions in volleyball^{21, 36}, and attaining the highest jumping height is defined as an important skill among elite athletes⁹. As a result, it is commonly observed that specific training programs and activities for sport-related physical activities can induce peculiar neuromechanical

adaptations that are commonly considered as signs of acquisition or improvement of a specific movement skill¹⁸). When quadriceps activation without sufficient strength of the hamstrings is reduced to provide the net flexor moment required to perform the movement safely, insufficiency in strength and activation of the hamstrings may directly limit the prospect for muscular co-contraction to protect ACL ligaments. This potential absence of muscular control of the joint may have led to quadriceps dominance in JG²⁹). The appearance of co-contraction patterns during sport-specific tasks that load the knee joint in the frontal plane suggests that they may work to stabilize the knee during dynamic tasks as well²⁸). The agonist of the ACL is the hamstring, while the antagonist is the quadriceps, and the quadriceps increases the strain on the ACL in the lower half of the knee flexion range (0–45°)¹⁴). Therefore, dynamic anterior-posterior stability, as well as abduction-adduction, and internal-external rotational stability during multi-planar movements, is contingent on hamstring co-activation resisting anterior translation and tibial rotation resulting from quadriceps contraction, and is potentially dependent on the H:Q ratio^{15, 31}). In other words, previous studies have concluded that balancing the medial-to-lateral H:Q ratio in women may help them to resist abduction loads on the knee, thereby diminishing the risk of ACL injury²⁸). However, evaluations of sports-related physical activities such as jumping and cutting, and comparisons and analyse of changes of lower extremity strength using isokinetic devices for elite female athletes has been less well documented^{20, 32}). Consequently, we investigated the H:Q ratio of the knee joint of the dominant and non-dominant legs of elite female athletes who not only had similar competitive levels, but also took part in excessive and repetitive jumping or cutting. Some previous studies have argued that differences in H:Q ratios may be due to the level of competition. Sports such as volleyball, soccer, basketball, softball, and team handball require similar movements, including running, jumping, cutting, deceleration, and acceleration, to effectively perform the activity¹⁷). Meanwhile, the risk of injury while playing racket sports (table tennis, badminton, and tennis) is distinct from that of volleyball, soccer, or others²). Racket sports also have specific sport-related movements, but the area vulnerable to injury in these sports is dissimilar in terms of the part of the knee joint used^{2, 37}). In particular, the precise movements required in table tennis do not involve explicit jumping, providing a comparison for the muscular activities and recruitment of the agonist and antagonist in the knee joint of volleyball players. A number of previous studies have reported that female volleyball players performed better in all tests and were more resistant to fatigue than non-jumper subjects^{34, 38}). Furthermore, volleyball players showed reduced co-activation of knee flexor/extensor muscles^{30, 36}). Our results suggest a neural adaptation of the motor control scheme to training¹⁸), because the demand imposed on the knee joint through the practice resulted in specific muscle adaptations that may have generated strength imbalances in static and dynamic actions acting on this joint³⁵). The H:Q ratio of the jumping group was significantly than that of the cutting group in the dominant knee joint. It is possible

that the jumping group has significantly different in biomechanical factors related to the knee joint compared to the cutting group, which did not perform specific jumping activities excessive and repetitive sport-related physical activity. Numerous tests and training programs based on scientific evidence should be used to monitor the sport performances of female athletes, and the results of these evaluations should be used to adjust training techniques in an attempt to prevent trauma and overuse injuries. This research had a limitation in that the results. Therefore, further multidimensional research is needed, along with multidirectional experimentation and analysis.

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