RELATIONSHIP BETWEEN ISOKINETIC LEG STRENGTH AND KNEE FRONTAL PLANE PROJECTION ANGLE DURING SINGLE LEG SQUAT AMONG MALE JUNIOR ATHLETES

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Abstract

Background: Those with increased dynamic knee valgus are vulnerable to increased risk of non-contact knee injuries. However, studies on the top down kinetic chain of lower limb mechanics during dynamic motions such as single leg squat (SLS) among trained males were scarce.

Objective: The objective of the study was to evaluate the relationship between isokinetic hip and knee strength and frontal plane projection angle (FPPA) of the knee joint during SLS.

Methods: Thirty-two male junior athletes (twelve cyclists, ten runners and ten squash players) were screened for excessive dynamic knee valgus (DKV) prior to participation. Only those within the normal value of DKV were included. Their hip and knee isokinetic strength in sagittal plane were evaluated at 60º/s of angular velocity for both legs using dynamometer. Two dimensional knee FPPA was evaluated during SLS at 60º of knee flexion. Pearson correlation was evaluated between knee FPPA during SLS and isokinetic leg strength.

Results: Correlations between knee FPPA and hip and knee isokinetic strength were not statistically significant except between knee flexion peak torque/body weight (r = -0.35, p = 0.05) and hamstring to quadriceps ratio (r = -0.39, p = 0.03) of non-dominant leg.

Conclusions: Isokinetic hip and knee strength and knee FPPA during SLS was correlated only for non-dominant leg during SLS among male junior athletes. DKV during SLS may be reduced through strengthening the muscles around hip and knee joints.

Keywords: *Dynamic Knee Valgus, Kinematics, Muscular Strength, Top Down Kinetic Chain, Youth Athletes*

Introduction

Weakness of thigh and hip muscles is thought to be an underlying mechanism for excessive knee valgus motion during dynamic movements (1). Dynamic knee valgus (DKV) is a dynamic alignment consisting of hip adduction, hip internal rotation, knee abduction and ankle eversion (2, 3). Those with increased DKV is vulnerable to increased risk of knee injuries including patellofemoral pain syndrome (PFPS) and anterior cruciate ligament (ACL) strain (4). DKV can be evaluated through functional tasks such as single leg squat (SLS) and drop landing. It was shown that knee frontal plane projection angle (FPPA) measured during SLS is associated with three-dimensional (3D) knee kinematics during dynamic motions comprising mostly sagittal plane such as running (5). Additionally, SLS is a common clinical test used to examine lower extremity alignment and identify faulty movement patterns of trunk, pelvis, and lower extremity (6). Moreover, SLS resembles common motions in sports such as running, soccer and hockey (7).

Decreased hip strength has been associated with increased frontal plane knee excursion during SLS (8). Specifically, isometric hip abductor strength was correlated to frontal plane knee motion during SLS (9). On the other hand, negative correlation was found between isokinetic hip abduction peak torque and knee valgus during SLS whereby weak hip muscle strength has been associated with a larger medial knee displacement during SLS (7). Almeida et al. (10) noted that two dimensional (2D) knee FPPA during SLS is correlated to the knee, hip and trunk strength in women with and without PFPS. Furthermore, a low correlation was observed between hip strength and frontal plane hip and knee angles and joint motions during running and jumping (11).

It has been suggested that musculature around the knee joint (i.e., hamstrings and quadriceps) plays a substantial role in affecting knee valgus motion (12). Moreover, McLean et al. (13) showed that the 2D knee valgus angles were inherently influenced by hip and knee joint rotations in all three dimensions. Overall, there is a trend that hip and knee strength may affect the knee mechanics during landings. However the relationship between isokinetic lower limb strength evaluated at sagittal plane and knee mechanics during SLS at 60° knee flexion is not known. Moreover, previous studies on this regard emphasised on females instead of adolescent male athletes. Therefore, the purpose of the current study was to evaluate the relationship between isokinetic hip and knee strength in sagittal plane and knee valgus during SLS in state level male junior athletes.

Materials and Methods

Study design

The current study was a cross-sectional study. Thirty-two state-level male junior athletes (twelve cyclists, ten runners and ten squash players) voluntarily participated in the current research. The participants aged between 13-18 years (average age: 15.37 ± 1.21 years) with normal body mass index (BMI) (i.e., 18.50-24.99 according to World Health Organisation) and free from any musculoskeletal injury at the time of data collection. Only participants with normal DKV evaluated using 2D drop vertical jump screening test (4) were included in the study. The protocol of the study was approved by research ethical committee from a local research university (USM/JEPeM/17020106) and was conducted in compliance with Declaration of Helsinki. Informed consent and assent forms were collected from participants and their guardian prior to their participation.

Study procedure

Before the tests, participants were advised to have enough sleep (at least six hours) the night before, and had their meal and avoided caffeine at least two hours before the tests. Their body weight (kg) and height (m) were measured with a digital medical scale (Seca 769, Hamburg, Germany) while their body fat percentage was evaluated using Omron HBF-375 Body Fat Analyzer (Seca 796, Hamburg, Germany). For warm up session, they cycled on an ergometer at 60 RPM with 50 watts for five minutes. Then, isokinetic hip and knee strength tests at the sagittal plane were conducted for both lower limbs using a dynamometer (Biodex 3 Multi-joint Testing and Rehabilitation System, Shirley, NY, USA). Isokinetic strength was determined by peak torque which was normalised to each participant's body mass (PT/BW). Peak torque is a valid and reliable parameter to measure maximal strength (14, 15). The hamstring to quadriceps ratio (H:Q) and hip extensor to hip flexor ratio were calculated to determine the ratio between agonist and antagonist muscles of the knee and hip joints, respectively.

For isokinetic hip extension and flexion test, participants laid supine on a table, which was put in front of and perpendicular to the dynamometer (16). The sagittal plane of the hip joint was aligned with the axis of the dynamometer and straps were used to stabilise the pelvis, trunk, and contralateral thigh. Next, familiarisation was conducted prior to data collection. Participants performed maximal concentric hip flexion and extension for two sets of five repetitions at angular velocity of 60^o/s. The test started with hip flexion from its neutral position (16). A one-minute rest interval was provided between the sets.

For isokinetic knee extension and flexion test, participants were seated with the hip flexed at 90°. The support lever was secured between the lower third and upper two-thirds of the tested leg while the dynamometer axis of rotation was aligned to the knee rotation axis (16). Participants were strapped in the testing position after the depth of seat, the height of dynamometer, and the length of support lever were adjusted. After a familiarisation session, the test started with knee extension from 90° flexion (16). Two sets of five repetitions of knee flexion-extension test were carried out at 60^o/s of angular velocity with one minute rest interval between the sets (7).

Upon completion of the isokinetic strength tests, SLS test was carried out. The SLS test followed the protocol described by Stickler and colleagues (17). Prior to the test, leg dominance was determined as the leg with which the participants would kick a ball (18). Initially, participants warmed up by cycling on an ergometer (Cybex Inc., Ronkonkoma, NY, USA) with 50 Watts at 60 RPM for five minutes. Then, goniometer was used to determine 60^o knee flexion during double-leg squat (17). At the level of the participant's ischial tuberosity, an adjustable plinth was set to indicate the desired squat depth (17). Next, markers were put at their anterior superior iliac spine (ASIS), tibia condyles and the centrepoint between the lateral and medial malleoli (17). The investigator demonstrated the test procedure. Then, participants were given time to practice the SLS prior to the actual trials.

Participants were required to put their hands on their hips and stand on one limb (i.e., stance leg), while the opposite limb flexed to 90^o. Then, they performed a 60^o knee flexion squat with the stance leg and then returned to the standing position. Five trials of SLS were conducted.

The speed of SLS was controlled by using a metronome which indicated 5 seconds for lowering and 5 seconds for returning to standing position (17). Participants were ensured to touch the plinth during each SLS trial with their buttocks to denote 60^{o} knee flexion squat. They must keep the opposite limb away from the ground and restraint any support from the upper limb (17). The test was repeated with the non-dominant leg as stance leg.

A digital camera (SONY HDR-CX240, Japan) was placed at the front of the participant to capture his motion during SLS test. The camera was placed directly in front of the participant with its height aligned to the participant's pelvis (17). The knee FPPA is the intersection of a line created between the knee markers and ASIS and another line formed between the ankle and knee markers (4). Two-dimensional video analysis (Kinovea Software 0.7.10 version 2) was applied to determine knee FPPA during SLS, which was clinically feasible, and reliable (4). Moreover, 2D knee FPPA is valid as compared to 3D analysis (13).

Data distribution was checked using Shapiro-Wilk test. Pearson correlation coefficients were calculated to determine the relationship between knee FPPA at 60° SLS and isokinetic hip and knee strength. The strength of correlation coefficients was based on classifications by Portney and Watkins (19). The significance level was set at $p \leq 0.05$. Data analysis was performed using statistical software (SPSS version 22, Chicago, IL).

Results

All participants were within normal values of DKV during screening test (5.3° ±1.6). The physical characteristics of participants are presented on Table 1. Knee FPPA at standardised peak knee flexion (60°) during SLS was not significantly different across legs (p = 0.99) and sports (p = 0.84). Table 2 and 3 present the knee and hip isokinetic strength of dominant and non-dominant legs and its correlation to knee FPPA during SLS.

Table 1: Physical characteristics of participants (N = 32)

Physical characteristics	Mean (SD)
Weight (kg)	55.08 (6.20)
Height (cm)	165.00 (7.19)
Body Mass Index (BMI) (kg/m^2)	20.40 (1.79)
Body fat percentage (%)	18.53 (6.51)
^{a}Dominant knee FPPA during SLS (°)	8.14 (4.17)
^{a}Non-dominant knee FPPA during SLS (°)	7.80 (4.41)

^{a}knee FPPA at standardised peak knee flexion (60°) during SLS

Table 2: Knee and hip isokinetic strength of dominant leg and its correlation to knee FPPA during SLS (N=32)

Variables	Mean (SD)	*r*	*p*-value
Knee extension (PT/BW)	256.40 (48.30)	-0.04	0.82
Knee flexion (PT/BW)	127.58 (30.71)	-0.13	0.49
Ratio knee flexor:knee extensor (H:Q)	0.50 (0.10)	-0.13	0.49
Hip extension (PT/BW)	164.79 (52.02)	-0.12	0.51
Hip flexion (PT/BW)	162.70 (30.36)	-0.04	0.85
Ratio hip flexor: hip extensor	1.06 (0.29)	0.13	0.48

Table 3: Knee and hip isokinetic strength of non-dominant leg and its correlation to knee FPPA during SLS (N=32)

Variables	Mean (SD)	*r*	*p*-value
Knee extension (PT/BW)	252.41 (49.22)	-0.19	0.30
Knee flexion (PT/BW)	121.27 (32.59)	**-0.35***	**0.05**
Ratio knee flexor:knee extensor (H:Q)	0.48 (0.08)	**-0.39***	**0.03**
Hip extension (PT/BW)	173.73 (48.84)	-0.25	0.17
Hip flexion (PT/BW)	160.49 (29.42)	-0.33	0.07
Ratio hip flexor: hip extensor	0.98 (0.24)	0.23	0.20

* significant at $p \leq 0.05$

Discussion

There were no statistically significant correlations between knee FPPA during SLS and hip and knee isokinetic strength except for knee flexion PT/BW (r = -0.35, p = 0.05) and H:Q ratio (r = -0.39, p = 0.03) of non-dominant leg among male junior state-level athletes with normal DKV. This means that increased knee flexor strength (i.e., hamstring) and H:Q ratio may reduce knee FPPA during SLS on non-dominant leg. Moreover, the H:Q results indicated an imbalance of muscular strength between hamstring and quadriceps particularly at the non-dominant leg which may augment the lower limb injury risks and osteoarthritis following ACL strain (20).

Quadriceps and hamstrings are crucial in regulating valgus motion and knee loading during landing manoeuvre (21). Specifically, it has been shown that increase in quadriceps and hamstrings strength may reduce frontal plane moments during drop landings (22). In a biomechanical study of single-leg forward-jump task, higher peak knee valgus angle was observed among individuals with greater hamstrings and lateral quadriceps activity compared to those with greater medial quadriceps activation (12).

Balance of the muscular strength is quantified as the torque ratio between the antagonists and agonists (16, 23). Previous study showed that the average value for the knee H:Q ratio among healthy volunteers was about 60% tested at angular velocity of 30º/s to 60º/s (16). The common H:Q peak torque ratio of healthy population ranges from 50% to 80%. The value is dependent on the tested angular velocity and knee angle (24). The knee H:Q ratio obtained from our study on non-dominant leg was 42% for squash players, 50% for cyclists and 52% for runners. However, investigations on the association between hip muscles strength imbalance and injuries among athletes are scarce (25).

Muscular strength imbalance between the knee extensors and knee flexors is frequent in patients with anterior knee pain (26). Poor hip control may cause the hip to adduct during weight-bearing motions (1). Following this top-down kinetic chain, the femur will rotate internally thus the knee is positioned as valgus (1). This mechanism is known as DKV and a risk factor for non-contact knee injuries particularly among females (1).

Basketball players showed significantly greater knee FPPA of their right leg during a drop jump, but no differences were observed across legs during single leg landing task (27). It was noted that knee valgus moment during cutting was greater at the dominant leg than non-dominant leg (28). However, our study revealed that there was no statistically significant difference of knee FPPA during SLS at dominant versus non-dominant leg. Further prospective research is needed to ascertain the potential effects of limb dominance on ACL injury risk. At the moment, no studies had shown that injury rates were affected by limb dominance (3, 29).

Several studies on dynamic tasks (i.e., running, cross-cutting, and side-step cutting manoeuvres) showed that women demonstrated greater knee valgus angles compared to men (3, 30, 31). Moreover, female athletes demonstrated a higher incidence of ACL injuries than male athletes (32-34). On the other hand, our participants were male state-level junior athletes which may explain the lack of significant correlations. However, at the moment, studies on SLS biomechanics in junior male athletes are scarce.

Study limitation

2D knee FPPA can be influenced by other motions at transverse and frontal planes. Hence, more negative knee FPPA values will be observed among those who squat with greater hip internal rotation, which cannot be quantified by using 2D motion analysis alone. Although 2D analysis is a valid and reliable tool to evaluate dynamic knee valgus (11, 34), more kinematics and kinetics data in three planes could be obtained through 3D analysis for detailed explanation regarding DKV during SLS. Studies regarding male junior athletes are scarce, hence comparisons with our findings are not possible. Moreover, isokinetic strength test on ankle joint may be included because it was shown previously that decreased strength and range of motion at the ankle joint might cause knee valgus during squatting (35). Furthermore, only participants with normal range of DKV were included in the present study which may explain the lack of significant correlations.

Conclusion

There were no statistically significant correlations between knee FPPA and hip and knee isokinetic strength except for knee flexion peak torque/body weight (PT/BW) and H:Q ratio of non-dominant leg among male junior athletes with normal DKV. Precautions need to be taken to reduce the risk of knee injuries especially at the non-dominant leg among male junior athletes. Coaches and athletes may apply SLS test with 2D motion capture to screen their athletes from possible risks of lower limb injury. Excessive DKV during SLS may be reduced through strengthening the muscles around hip and knee joints.

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Competing interests

The authors declare that they have have no competing interests.

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