BIOMECHANICS OF SINGLE LEG SQUAT IN PHYSICALLY ACTIVE FEMALES: INFLUENCE OF DYNAMIC KNEE VALGUS AND EXERCISE INTERVENTION

FARHAH NADHIRAH AIMAN BINTI SAHABUDDIN

UNIVERSITI SAINS MALAYSIA

2022

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by

FARHAH NADHIRAH AIMAN BINTI SAHABUDDIN

Thesis submitted in fulfilment of the requirements for the degree of Master of Science

February 2022

ACKNOWLEDGEMENT

To begin, praise and thanks to God, the Almighty, for His showers of blessings throughout my research work, which enabled me to successfully complete the research. I would like to express my sincere appreciation to my supervisor, Dr. Shazlin Shaharudin and co-supervisor, Sir Nurul Azuar Hamzah, for providing me with an opportunity to conduct this research and also gain important insight on writing journal and thesis preparation. They have taught me how to carry out research and present the results as thoroughly as possible. Furthermore, collaborating and studying under their supervision were a tremendous privilege and honor for me. Therefore, I am extremely grateful for what they have offered me and patience throughout research work and thesis discussion. I am extremely appreciative of my parents' love, prayers, concern, and sacrifices in educating and preparing me for my future. Additionally, I would like to convey my gratefulness to my aunt, Mrs. Zahratul Alwa Binti Ibrahim and grandmother, Mrs. Mariatul Kabtiah for their support and continuous devotion in preparing this dissertation successfully. And also, I would like to thank all of my siblings and family for their support and valuable prayers. Furthermost, I would like to express my deepest appreciation to my research partner, Nazatul Izzati Binti Jamaludin for endless support and motivation during ups and downs throughout this research. I would also like to express my heartfelt gratitude to my postgraduate colleagues for their constant encouragement throughout my Master journey. Finally, I want to express my sincere thanks to everyone who assisted me in any way throughout the research work.

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LIST OF ABBREVIATIONS

DKV	-	Dynamic Knee Valgus
SLS	-	Single Leg Squat
ACL	-	Anterior Cruciate Ligament
DLS	-	Double-Legged Squat
ASIS	-	Anterior Superior Iliac Spine
PFPS	-	Patellofemoral Pain Syndrome
DF ROM	-	Dorsiflexion Range of Motion
ROM	-	Range of Motion
FPPA	-	Frontal Plane Projection Angle
DVJ	-	Drop Vertical Jump
WHO	-	World Health Organization
USM	-	Universiti Sains Malaysia
JEPeM	-	Universiti Sains Malaysia's Human Research Ethics Committee

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BIOMEKANIK ‘SQUAT’ SEBELAH KAKI DALAM GOLONGAN WANITA YANG AKTIF FIZIKAL: KESAN VALGUS LUTUT DINAMIK DAN SENAMAN INTERVENSI

ABSTRAK

Valgus lutut dinamik (DKV) umumnya dikaitkan dengan kecederaan kaki tanpa-kontak, terutamanya dalam kalangan wanita. Justeru, Kajian 1 membandingkan pemboleh ubah kinematik anggota bawah badan di antara golongan wanita aktif fizikal yang mempunyai normal dan DKV berlebihan ketika SLS pada 45° dan 60° fleksi lutut. Tiga puluh empat wanita telah dibahagikan kepada dua kumpulan (DKV normal dan berlebihan) melalui ujian “drop vertical jump” (DVJ). Penilaian DKV untuk wanita adalah berdasarkan nilai normal FPPA lutut (7° sehingga 13°) (DKV normal), manakala (lebih daripada 13°) (DKV berlebihan). Ujian 3 Dimensi (3D) SLS (45° dan 60° fleksi lutut) yang dilakukan oleh peserta telah dirakam dengan sistem “Qualisys Track Manager” dan data kinematik dianalisis dengan menggunakan Ujian “Independent T”. Ketika 45º fleksi lutut, kaki dominant kumpulan DKV normal (4.493±3.25°, $t(32) = 2.371$, $p= 0.024$) menunjukkan sudut hadapan pinggul yang lebih besar berbanding kumpulan berlebihan DKV (1.426±4.23°). Tambahan pula, normal DKV memaparkan adduksi lutut (1.72±6.14°, $t(32) = 2.291$, $p= 0.029$) tetapi kumpulan berlebihan DKV mendemonstrasi abduksi lutut (-3.620±7.40°) ketika SLS. Semasa 60º fleksi lutut, kumpulan DKV normal melaksanakan lutut dominan secara adduksi (0.223±0.07°, $t(16.048) = 10.707$, $p=0.000$) tetapi abduksi dalam kumpulan berlebihan DKV (-4.478±1.81°). Ketika 60º fleksi lutut dengan kaki bukan dominan, kumpulan DKV normal melakukan ujian SLS dengan abduksi lutut (-1.127±0.89°, $t(21.410) =-6.863$, $p= 0.000$) manakala kumpulan DKV berlebihan melaksanakan SLS dengan adduksi lutut (0.635±0.57°). Malah, pinggul bukan dominan meg-abduksi (0.635±0.54°, t(21.567) = 6.225, p= 0.000) dalam kumpulan normal DKV manakala adduksi (-0.245±0.23°) dalam kumpulan DKV berlebihan. Oleh itu, wanita yang mempunyai DKV berlebihan mempunyai kinematik anggota bawah badan dan teknik mengawal pergerakan yang berbeza dengan wanita yang mempunyai normal DKV. Hasil dapatan menekankan kepentingan saringan DKV, serta rasional mencipta senaman intervensi untuk mengelak kecederaan tanpa kontak. Oleh itu, kajian 2 mengkaji kesan empat minggu senaman pinggul dan buku lali pada mekanik anggota bawah badan ketika SLS dalam kalangan wanita aktif fizikal. Tiga puluh enam wanita aktif fizikal dengan DKV berlebihan, e.g., lebih daripada 13° FPPA lutut) telah dibahagikan sama rata kepada tiga kumpulan: kumpulan HIP, ANKLE dan kawalan. Melalui 12 sesi selama empat minggu, kumpulan intervensi menjalani senaman berfokuskan pinggul (HIP) atau buku lali (ANKLE). Tiada sebarang intervensi yang diberikan kepada kumpulan kawalan. Seterusnya, mereka mendemonstrasi protokol ujian SLS yang sama seperti kajian 1 pada sebelum dan selepas intervensi. Ujian "two-way ANOVA" digunakan untuk menilai data. Ketika 45° fleksi lutut SLS, terdapat kesan interaksi yang signifikan dalam momen lutut (F(2,66) = 9.437, p=0.000) dan buku lali (F(2,66) = 16.465, p=0.000) bahagian sisi kaki dominan di antara kumpulan sepanjang intervensi. Manakala, terdapat kesan interaksi dalam sudut extensi pinggul kaki dominan (F (2,66) = 12.032, p=0.000) dan bukan dominan (F(2,66) = 3.618, p= 0.032) telah dikenal pasti semasa 60° fleksi lutut. Empat minggu intervensi berfokuskan bahagian pinggul telah memberi kesan kepada biomekanik anggota bawah badan ketika SLS terutamanya pada satah sisi. Justeru itu, menguatkan otot pinggul terutamanya "hamstring" dan "quadriceps", melalui senaman boleh membantu untuk meminimumkan DKV berlebihan dalam kalangan wanita aktif fizikal.

BIOMECHANICS OF SINGLE LEG SQUAT IN PHYSICALLY ACTIVE FEMALES: INFLUENCE OF DYNAMIC KNEE VALGUS AND EXERCISE INTERVENTION

ABSTRACT

Dynamic knee valgus (DKV) is generally associated with non-contact lower-limb injuries, particularly in females. Thus, Study 1 compares the lower limb joints kinematic among physically active females with and without excessive DKV during single leg squats (SLS) at 45° and 60° knee flexion. Thirty four females were enlisted and categorized into two groups (i.e., normal and excessive DKV) based on the results of the drop vertical jump screening test. A DKV evaluation is based on the average knee FPPA range which is 7° to 13° for females in normal DKV group, while those in excessive DKV group have more than 13° of knee FPPA range. The 3-Dimensional (3D) SLS test (45° and 60° knee flexion) executed by the participants were captured with a Qualisys Track Manager System and analysed the kinematic data using an independent T-test. During 45° knee flexion, the dominant leg of normal DKV group showed a higher hip adduction angle (4.49±3.25°, $t(32) = 2.371$, $p = 0.024$) than the excessive DKV group (1.426±4.23°). Moreover, the normal DKV group displayed knee adduction (1.72±6.14°, $t(32) = 2.291$, $p = 0.029$), but the excessive DKV group demonstrated knee abduction (-3.620±7.40°) during SLS with dominant leg. During 60° knee flexion, the normal DKV performed with adducted dominant knee (0.223±0.07°, $t(16.048) = 10.707$, $p=0.000$) but abducted in the excessive DKV group (-4.478±1.81°). During 60° knee flexion with the non-dominant leg, the normal DKV group demonstrate SLS test with abducted knee (-1.127±0.89°, $t(21.410) =-6.863$, $p = 0.000$) while adducted in the excessive DKV group (0.635±0.57°). Furthermore, the

non-dominant hip angle was abducted in the normal DKV group (0.635±0.54°, t(21.567) = 6.225, p= 0.000) but adducted (-0.245±0.23°) in the excessive DKV group during SLS. Therefore, females with excessive DKV had considerably different lower limb kinematics and movement control techniques than females with a normal DKV range. The findings emphasized the significance of DKV screening among physically active females, including the rationale for endorsing personalized exercise interventions to avoid lower limb non-contact injuries. Thus, the aim of Study 2 was to examine the effect of four weeks hip- and ankle-focused exercises on lower limb mechanics during SLS among physically active females. Thirty-six physically active females with excessive DKV, i.e., greater than 13° knee frontal plane projection angle (FPPA), were assigned equally to three groups: HIP, ANKLE, or control. Throughout 12 sessions across four weeks, the intervention groups underwent exercises focusing on either the hip (HIP group) or ankle (ANKLE group) musculatures. A training plan was not given to the control group. Next, all three groups demonstrated a similar SLS test protocol from study 1 (i.e., 45º and 60° of squat depths) were capture before and after intervention. A two-way ANOVA test was used to assess the data. During 45° SLS, there were interaction effects in the dominant knee (F (2.66) = 9.437, P = 0.001) and ankle (F (2.66) = 16.465, P = 0.001) sagittal moment between groups throughout four-weeks intervention. Meanwhile, the interaction effects in the hip extension angle for the dominant (F(2.66) = 12.032, P = 0.001) and non-dominant leg (F(2.66) = 3.618, P = 0.032) between groups were identified during 60° SLS after intervention. A four-week intervention of hip-focused exercises affected lower limb biomechanics during SLS, especially in the sagittal plane. Thus, strengthening hip muscles, particularly the hamstring and quadriceps, through exercise may help to minimise excessive DKV in physically active females.

CHAPTER 1

INTRODUCTION

1.1 Background Of Study

Powers, (2010) stated that the excessive dynamic knee valgus (DKV) was defined as a combination of hip internal rotation, knee valgus or tibial rotation angles, contralateral pelvic drop, and a shift in the centre of mass away from the stance limb induced by hip abductor weakness. These mechanisms of excessive DKV were related to non-contact injuries including anterior cruciate ligament (ACL) rupture, patellar dislocation and patellofemoral pain syndrome (PFPS) (Myer et al., 2015). Therefore, many previous studies have been carried out to modify internal joint loading for the prevention of lower extremity injuries. For instance, the preventive training programmes that were carried out by previous studies (Petersen et al., 2005; Baldon et al., 2014; and Verhagen et al.,, 2004) have shown their effectiveness in reducing the incidence of sports injuries, especially in the lower extremity. Meanwhile, Hewett et al., (2005) found the effectiveness of neuromuscular training in minimising knee valgus angles and improving single-leg stability and balance, which are fundamental in injury prevention.

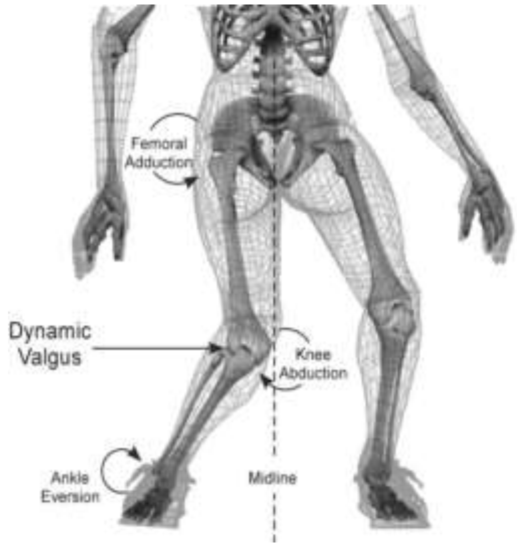

Figure 1.1 Dynamic Knee Valgus is defined as the position or motion of the distal femur toward and distal tibia away from the midline of the body. (Retrieved from http://davidpotach.com, 2015).

The single leg squat (SLS) is a common motion observed in sports such as running, cutting, pivoting, stopping, tackling and kicking (Claiborne et al., 2006; Munro et al., 2012). It is also an example of a functional movement test, and commonly used in rehabilitation, sports medicine and orthopaedic settings (Hattam et al., 2010). Correct performance of the SLS can provide an indication of knee function and assessment of recovery. Zeller et al., (2003) investigated the kinematics and muscular activities of nine men and nine women athletes during the SLS. Results showed that women exhibited more knee valgus, which was associated with greater ankle dorsiflexion and pronation, less trunk lateral flexion, and greater hip adduction, flexion, and rotation (Zeller et al., 2003). Rectus femoris muscle activation was also greater in women than men (Zeller et al., 2003). In the present study, the lower limb kinematics on three different planes (frontal, sagittal and transverse plane) during SLS test were compared within physically active females with and without excessive DKV. Then, in the study 2, the effects of hip- and ankle-focused exercise intervention was conducted among physically active females with excessive DKV to investigate the improvement of biomechanical patterns of the knee.

Deficits in the proximal hip strength or neuromuscular control may lead to a dynamic lower extremity valgus (Hewett et al., 2005). In a previous study, it was evidenced that targeting hip musculature activation and strength may aid in modifying dynamic lower extremity valgus, which may help to reduce the risk of future ACL injury and PFPS (Powers, 2010). Thus, the present study compared the effects of hip- and ankle- focused exercises training on lower limb mechanics during SLS test before and after exercise interventions.

Limited ankle dorsiflexion range of motion (DF ROM) has been reported as a possible cause to excessive knee valgus (Fong et al., 2011) and it has been linked to a harmful landing mechanics (Mason-Mackay et al., 2015). Other than that, the reduction in ankle DF ROM is one of the risk factors in some medical conditions, such as patellar tendinopathy (Backman et al., 2011). Interventions such as manual tibiotalar joint mobilisation and manipulation (Loudon et al., 2014) and static-stretching of gastrocnemius/soleus complex (Terada et al., 2013) are effective to improve the DF ROM and reduce the DKV, as well as neuromuscular control training composed of plyometric and agility exercises with the inclusion of feedback on movement quality (Ter Stege et al., 2014). Therefore, this study investigated whether the ankle training exercise can improve biomechanical patterns of DKV during SLS.

1.2 Problem Statement

One of the common functional movement tests used in rehabilitation, sports medicine and orthopaedic setting is SLS. The measurement in SLS includes Frontal Plane Projection Angle (FPPA) at knee joint, which can detect DKV. DKV is the degree of inward movement of the knee because it provides information on the knee function and assessment of recovery (Kianifar et al., 2017). Identifying DKV during SLS will provide further insight into the risk of injury. To the best of our knowledge, there were no previous studies have investigated the comparison of the lower limb kinematics particularly during SLS on three different planes (frontal, sagittal and transverse) among physically active females with and without excessive DKV. The lower limb mechanics of those with and without DKV should be compared since those with DKV were more prone to have lower limb injuries. Moreover, the kinetic chain of excessive DKV during SLS is not clearly understood whether it is affected from the proximal to distal (top-down kinetic chain) or from distal to proximal (bottom-up kinetic chain). Several studies reported that the hip adduction, knee flexion and knee extension strength were significant predictors of the valgus in FPPA (Willson et al., 2011; Willson et al., 2006). Also, other studies observed that excessive DKV is associated with ankles and heels kinematics (Kagaya et al., 2015; Lima et al., 2018). However, studies that compare the effects of exercise intervention based on these kinetic chains on improving DKV during SLS remain unknown.

1.3 General and Specific Objectives

1.3.1 Study 1

The general objective of Study 1 is to compare the lower extremity joint kinematic during single leg squat at 45° and 60° among physically active females with and without DKV.

Specific objectives of Study 1 are:-

- To compare the kinematics of hip, knee and ankle joints during single leg squat at 45° on three different planes among physically active females with and without DKV.
- To compare the kinematics of hip, knee and ankle joint during single leg squat at 60° on three different planes among physically active females with and without DKV.

1.3.2 Study 2

The general objective of Study 2 is to compare the effects of hip- and ankle-focused exercises on lower limb mechanics during SLS among female athletes.

Specific objectives of Study 2:-

- To compare the effects of hip and ankle exercises on frontal plane kinetics and kinematics of lower limb (e.g., hip, knee and ankle joint) mechanics during SLS in female athletes.
- To compare the effects of hip and ankle exercises on sagittal plane kinetics and kinematics of lower limb (e.g., hip, knee and ankle joint) mechanics during SLS in female athletes.

- To compare the effects of hip and ankle exercises on transverse plane kinetics and kinematics of lower limb (e.g., hip, knee and ankle joint) mechanics during SLS in female athletes.

1.4 Research Question and Hypotheses

1.4.1 Study 1

Research questions:

Are there any significant differences for the hip, knee and ankle joints kinematics during single leg squat at 45° on three different planes between physically active females with and without DKV?

Null Hypothesis (H_O): There are no significant differences for kinematics of hip, knee and ankle joint during single leg squat at 45° on three different planes between physically active females with and without DKV.

Alternative Hypothesis ($\mathbf{H_A}$): There are significant differences for kinematics of hip, knee and ankle joint during single leg squat at 45° on three different planes between physically active females with and without DKV.

Are there any significant differences on kinematics of hip, knee and ankle joint during single leg squat at 60° on three different planes among physically active female with and without DKV?

Null Hypothesis ($\mathbf{H_O}$): There are no significant differences on kinematics of hip, knee and ankle joint during single leg squat at 60° on three different planes among physically active female with and without DKV.

Alternative Hypothesis ($\mathbf{H_A}$): There are significant differences on kinematics of hip, knee and ankle joint during single leg squat at 60° on three different planes among physically active female with and without DKV.

1.4.2 Study 2

Research questions:

Are there any significant effects of hip and ankle exercises on frontal plane kinetics and kinematics of lower limb (e.g; hip, knee and ankle joint) mechanics during SLS in female athletes?

Null Hypothesis (H_O): There are no significant effects of hip and ankle exercises on frontal plane kinetics and kinematics of lower limb (e.g; hip, knee and ankle joint) mechanics during SLS in female athletes.

Alternative Hypothesis ($\mathbf{H_A}$): There are significant effects of hip and ankle exercises on frontal plane kinetics and kinematics of lower limb (e.g; hip, knee and ankle joint) mechanics during SLS in female athletes.

Are there any significant effects of hip and ankle exercises on sagittal plane kinetics and kinematics of lower limb (e.g; hip, knee and ankle joint) mechanics during SLS in female athletes?

Null Hypothesis (H_O): There are no significant effects of hip and ankle exercises on sagittal plane kinetics and kinematics of lower limb (e.g; hip, knee and ankle joint) mechanics during SLS in female athletes.

Alternative Hypothesis ($\mathbf{H_A}$): There are significant effects of hip and ankle exercises on sagittal plane kinetics and kinematics of lower limb (e.g; hip, knee and ankle joint) mechanics during SLS in female athletes.

Are there any significant effects of hip and ankle exercises on transverse plane kinetics and kinematics of lower limb (e.g; hip, knee and ankle joint) mechanics during SLS in female athletes?

Null Hypothesis (H_O): There are no significant effects of hip and ankle exercises on transverse plane kinetics and kinematics of lower limb (e.g; hip, knee and ankle joint) mechanics during SLS in female athletes.

Alternative Hypothesis ($\mathbf{H_A}$): There are significant effects of hip and ankle exercises on transverse plane kinetics and kinematics of lower limb (e.g; hip, knee and ankle joint) mechanics during SLS in female athletes.

1.5 Significance of the Study

Findings from the study may provide insights on the lower limb kinematics and kinetics of three different planes (frontal, sagittal and transverse) that may affect non-contact injury mechanics related to SLS. Also, it may offer clinicians a basis for teaching athletes and coaches on how to improve athletes' dynamic knee alignments during sports practice, as well as to avoid non-contact injuries such as ACL and PFP. This study was conducted among females only as they have a higher risk of having ACL injuries than males (Krosshaug et al., 2007). Moreover, this study was done to identify how the four-week intervention training involving hip- and ankle-focused exercises may improve the knee's biomechanical pattern. Thus, the findings of the study can be applied in neuromuscular training and designed specific exercises to improve excessive DKV among female athletes.

1.6 Operational Definition

- University athletes: Athletes that participate in competitions at university level, for example Sukan Antara Desasiswa (SUKAD) in Universiti Sains Malaysia. In this study, we recruited athletes from handball, volleyball, frisbee, basketball, netball and badminton teams.
- Kinematics: A branch of classical mechanics that describes the motion of points, bodies (objects), and systems of bodies (groups of objects) without considering the mass of each or the forces that caused the motion. In this study, we focused on hip, knee, ankle joints angle.
- Kinetics: Analysis of forces and torques that causes motion. In this study, we focused on moment of the lower limb joints.
- Physically active: Participants involved in physical activity (e.g., sports, exercise) for at least 3 days per week, minimum 30 minutes per session (Haskell et al., 2007).

CHAPTER 2

LITERATURE REVIEW

2.1 Dynamic Knee Valgus

Researchers such as Boden et al., (2000); Krosshaug et al., (2007); Olsen et al., (2004) have investigated how to estimate lower limb joint angles by means of video-analysis of injury occurrence. From their analysis, the results shown that volleyball athletes frequently landed with a little flexed, adducted and internally rotated hip, while knee with minimal flexion and the externally rotated tibia. Those mechanisms of lower limbs had shown an evidence of a valgus knee collapse. Furthermore, Krosshaug et al., (2007) reported that females had a 5.3 times higher relative risk of sustaining a valgus collapse injury mechanism than males. The lack of a ‘‘neuromuscular spurt’’ in females has been suggested as a contributing factor to the female bias in ACL injury (Quatman et al., 2006). Figure 2.1 shows DKV or the ‘position of no-return’ (Hewett et al., 2005).

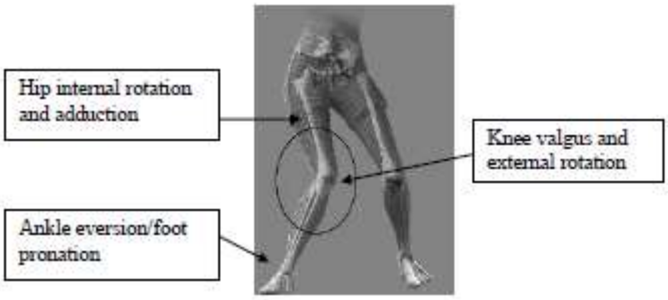

Figure 2.1 Dynamic knee valgus. (Adapted from Munro, 2012)

DKV is a biomechanical risk factor of lower limb injury and its attribution to non-contact injuries such as ACL tear and PFPS were consistently reported

(Herrington 2014; Kristianslund et al., 2014). Knee valgus occurs when there is a combination of motions in femoral and tibial, which can be affected by the proximal and distal joints of the knee, trunk, hip, and ankle (Rabin and Kozol, 2010). Deficiency of femoral control may cause excessive adduction and internal rotation, which can pressure the ACL (Hewett et al., 2006). Non-contact injuries usually occur during cutting, pivoting, landing, sudden deceleration prior to direction changes in sports and in any position and motion (Powers, 2010).

Regarding to Asperti et al., (2017), an injury was defined as an absent from sport for at least one practice or game. In spite of health benefits that offered in sports participation, injury incident in sports was considered as an economic burden (Öztürk, 2013). ACL injuries usually require an invasive surgery and rehabilitation which can be destructive to the athlete's career (Hewett et al., 2005; Mclean et al., 2005). Therefore, early detection of its risk is warranted for preventive actions.

Excessive DKV is typically associated with inadequate motor control of the muscle tissues proximal to the knee joint (Carroll et al., 2021). Individuals with severe DKV during single-limb standing activities have been found to have altered activation patterns of the hip abductors and adductors (Mauntel et al., 2013) as well as varied strength measurements of the hip extensors, lateral rotators, and abductors (Stickler et al., 2015 & Bell et al., 2008). Clinical therapy approaches for DKV that emphasise hip-focused neuromuscular control and strength training are based on this "top-down" principle (Ford et al., 2015).

DKV could also be caused by foot and ankle limitations. This "bottom-up" approach to DKV could be linked to atypical foot posture (Powers, 2003), such as talonavicular bulge variations, increased/decreased medial arch height, or excessive calcaneal inversion/eversion. Abnormal foot posture has been linked to proximal musculoskeletal dysfunction such as low back pain, knee pain, and hip pain by influencing the biomechanics of the lower extremity during weightbearing (Reilly et al., 2009; Gross et al., 2007; Ferrari et al., 2012). Yet, the evidence for a correlation between ankle dorsiflexion and MKD, on the other hand, is still not conclusive (Carroll et al., 2021).

When compared to top-down or bottom-up kinetic chains, open- or closed-kinetic chain exercises have different definitions. An open kinetic chain workout is one in which the distal part of the end is not fixed but instead free space (Fagan and Delahunt, 2008), allowing for a motion segment to be isolated (Cabral et al., 2008). Furthermore, it is often assumed that this sort of exercise does not involve any weight bearing (Lacerda Nobre, 2012). Closed kinetic chain exercises (Sousa et al., 2007), which include multi-joint movements with a fixed distal extremity, are frequently related with weight bearing (Fagan and Delahunt, 2008). The compression force increases and decreases the tibia-femoral compressive forces near patellofemoral the extension during these exercises, resulting in greater articular (Fehr et al., 2006; Sousa et al., 2007) and lower shear load of the tibia, the compression force increasing and decreasing the tibia-femoral compressive forces near patellofemoral the extension (Fleming et al., 2005). According to Fagan and Delahunt (2008), proprioception plays a role in the selection of these exercises because it is thought that the feedback is more efficient due to the compressive forces of the body and foot contact with the ground, and that the exercises reproduce functional movements that are commonly performed in daily life (Fehr et al., 2006; Fagan and Delahunt, 2008).

2.2 Single Leg Squat

Single leg squat (SLS) is commonly used in clinical setting to assess faulty movement patterns of trunk, pelvis and lower extremity (Khuu et al., 2016). SLS can be easily conducted in field setting as an early screening for those at higher risk for ACL tear and PFPS, which commonly occurs in sports. SLS is the most feasible test to implement because the rest of the lower limb functional assessments require multiple tasks, which are impractical for large group examination (Ugalde et al., 2015). Moreover, SLS which requires lower limb balance and control is crucial because it imitates various manoeuvres in sports such as running, cutting, pivoting, stopping, tackling and kicking (Claiborne et al., 2006; Munro et al., 2012). It was shown that high risk of knee injuries is related to these non-contact manoeuvers (McLean et al., 2005). Previous study (Craig et al., 2014) stated that the squat depth was restricted to approximately 60° (Claireborne et al., 2006 and Bittencourt et al., 2012) to avoid increased joint forces associated with increased ROM which might worsen the symptoms of knee pain in individuals with PFPS (Bland et al., 2010).

DKV or inward movement of knee due to the altered hip, knee and ankle kinematic (Munro et al., 2012) is one of the important aspects being observed during SLS test (Kianifar et al., 2017). This was acknowledged in the Ageberg et al., (2010) study, that reported the knee valgus position in 2-D during mini SLS was followed by a more medial tibia and thigh position, but a greater internal hip rotation in 3D during knee-medium-to-foot position of SLS. It was proposed that the 2-D method could be used to scan and test the excessive valgus of the knee during SLS (Hewett et al., 2005; Mclean et al., 2005 and Nagano et al., 2008). Furthermore, the real movement (in 3-D) of the knee-medial-to-foot position during SLS was a greater internal rotation of the hip (about 11°) relative to the position of the knee-over-foot (about 5°) (Ageberg et al., 2010). In other words, the presence of a knee-medial-to-foot position during mini SLS is mostly seen as an increased internal movement of the hip. Therefore, the frontal plane of the knee valgus may not be indicative of the 3-D valgus of the knee. As explained by Willson and Davis, (2008) from a frontal view during SLS, the FPPA was a negative indicator when the knee sign was medial towards a line from the ankle marker to the thigh. If the knee marker was laterally drawn from the ankle marker towards the thigh marker, the FPPA was positive. Negative value for FPPA showed knee valgus, knee excursion to the middle line of the body and positive values for FPPA represented knee varus.

2.3 Effects of Exercise Intervention on Dynamic Knee Valgus: a Systematic Review

This section has been published:

Sahabuddin, F. N. A., Jamaludin, N. I., Amir, N. H., & Shaharudin, S. (2021). The effects of hip- and ankle-focused exercise intervention on dynamic knee valgus: a systematic review. *PeerJ*, 9,e11731. https://doi.org/10.7717/peerj.11731

Abstract

Background. A range of non-contact injuries such as anterior cruciate ligament tear, patellar displacement and patellofemoral pain syndrome can be induced by disordered

knee joint loading from excessive dynamic knee valgus (DKV). Previous systematic reviews showed that DKV could be modified through the influence of hip strength and ankle range of motion. There was also a narrative review that investigated hip-focused neuromuscular exercise intervention on DKV. Therefore, the purpose of this systematic review was to examine the effects of exercise intervention which involved either top-down or bottom-up kinetic chains on minimizing DKV in male and female adults and adolescents, with and without existing knee pain.

Methodology. Electronic searches were conducted in SAGE, Science Direct, SCOPUS, and Pubmed. The search strategy consisted of the medical subject headings (MeSH) and the free-text search keywords, synonyms and variations of 'exercise intervention,' 'knee alignment,' 'dynamic knee valgus' that were merged via the Boolean operator 'AND and 'OR'. The search was conducted on full-text journals which documented the impact of the exercise intervention program involving either the bottom-up or the top-down DKV mechanism on the kinematics of the knee. Besides, the range of the intervention program must be at least one week with two or three sessions per week. This review also considered both men and women of all ages with a healthy or symptomatic knee disorder. The registration of the present review is pending at PROSPERO. The risk of bias of included studies were assessed by Cochrane risk assessment tool.

Results. Eight studies with a total of 289 participants (male= 79, female= 210; adults= 153, adolescents= 136) which met the inclusion criteria were included in this review. Five studies showed the significant effects of the exercise intervention program (range from two weeks to ten weeks) on reducing DKV. The exercises training in these five studies focused on muscle groups directly attached to the knee joint such as hamstrings and gastrocnemius. The remaining three studies did not show significant improvement in DKV after the exercise intervention (range between eight weeks to twelve weeks) probably because they focused on trunk and back muscles instead of muscles crossing the knee joint.

Conclusion. Exercises intervention focusing on specific knee-joint muscles is likely to reduce DKV rather than training load and volume. The results can help athletes and coaches to resolve DKV by including an effective exercise program which could minimize the knee valgus and ultimately preventing the lower limb injuries.

Introduction

Dynamic knee valgus (DKV) is defined as a body position in which the knee collapses from excessive valgus, excessive internal-external rotation, or both conditions (Krosshaug et al., 2007). DKV can be caused by the hip abductor weakness that entails internal rotation of the hip, excessive frontal knee alignment or tibial rotation angles and contralateral pelvic drop (Powers, 2010). Disordered knee joint loading from excessive DKV can trigger a spectrum of injuries such as anterior cruciate ligament (ACL) tear, patellar displacement, and patellofemoral distress (Myer et al., 2015).

The two types of kinetic chains play a major role in the mechanisms of DKV, namely top-down (proximal origin) and bottom-up (distal origin) kinetic chains (Jamaludin et al., 2020). A top-down kinetic chain occurs when the hip and trunk muscles alter the kinematic patterns at the distal joints (Snyder et al., 2009). On the contrary, a bottom-up kinetic chain involves the influence of ankle musculature and foot structures on knee joint motions (Khamis and Yizhar, 2007). Several studies have reported that the strength of hip adduction, knee flexion, and knee extension were the key indicators of valgus in the FPPA (top-down kinetic chain) (Willson et al., 2011; Willson, Ireland and Davis, 2006). In addition, recent studies also observed that excessive DKV could be associated with foot-ankle strength as well as its range of motion (ROM) and kinematics (bottom-up kinetic chain) (Kagaya, Fujii and Nishizono, 2015; Lima et al., 2018). Previous studies aimed to find the sources of excessive DKV and the internal joint loading to prevent lower extremity injuries such as ACL strain (Nessler, Denney and Sampley, 2017). Several other studies also presented evidence on how preventive training programs could minimize the occurrence of non-contact lower extremity injuries (Petersen et al., 2005), knee or ACL injuries (Hewett et al., 1999), and ankle injuries (Verhagen et al., 2004).

A systematic review by Lima et al., (2018) evaluated the association between ankle dorsiflexion, which involved bottom-up kinetic chain and DKV in intervention and non-interventional studies. By including the non-interventional study, the results of the review might not be related to the impact of exercises on reducing DKV. Meanwhile, a systematic review by Dix et al., (2018) investigated the association between hip muscle strength (top-down kinetic chain) and DKV in asymptomatic females. Similarly, the review did not investigate the effects of exercises that contribute to the hip muscle strength in reducing DKV. A narrative review by Ford et al., (2015) provided details on a hip-focused neuromuscular exercise intervention to improve DKV. However, narrative reviews did not cover and discussed on specific patient populations, in-depth methodological approaches, and adaptations that should be a concern in some of the exercises addressed. In contrast, a systematic review was meant to explore, select and critically review the findings of previous literature from the explicit methodology. To the best of our knowledge, there has been no systematic review that focused on the effects of exercise intervention on DKV mechanisms either in top-down or bottom-up kinetic chain. It is crucial to investigate further on how the exercises training program may improve the mechanism of knee mechanics. Therefore, this systematic review aims to determine the influence of exercise intervention on improving DKV.

Methods

This review was conducted in compliance with the recommendations of the Preferred Reporting Items for Systematic Reviews (PRISMA) (Liberati et al., 2009).

Search Strategy

Two researchers individually screened through four medical databases, namely SCOPUS, SAGE, Pubmed, and Science Direct from database inception until November 2020. The search technique consisted of medical subject headings (MeSH) and free text search keywords, synonyms, and variations to retrieve all relevant articles. Three phrases were merged for searching databases using the Boolean operator 'AND' and ‘OR’: i.e. 'exercise intervention,' 'knee alignment,' 'dynamic knee valgus'. The reference lists of all the included manuscripts and authors' files were also reviewed to identify any further relevant studies.

Study Selection

The titles and abstracts of the retrieved studies were downloaded into Mendeley (version 1.19.4, Mendeley, London, United Kingdom). Two independent reviewers scanned all abstracts for eligibility and any duplicates were removed. Full texts were obtained for abstracts that fulfilled the inclusion criteria. In the event of any ambiguous details, the corresponding authors of the studies were contacted via e-mail. Any disagreement between the two investigators would be resolved by discussing with a third investigator so that a consensus could be reached. A schematic diagram of the study selection is shown in Figure 2.2.

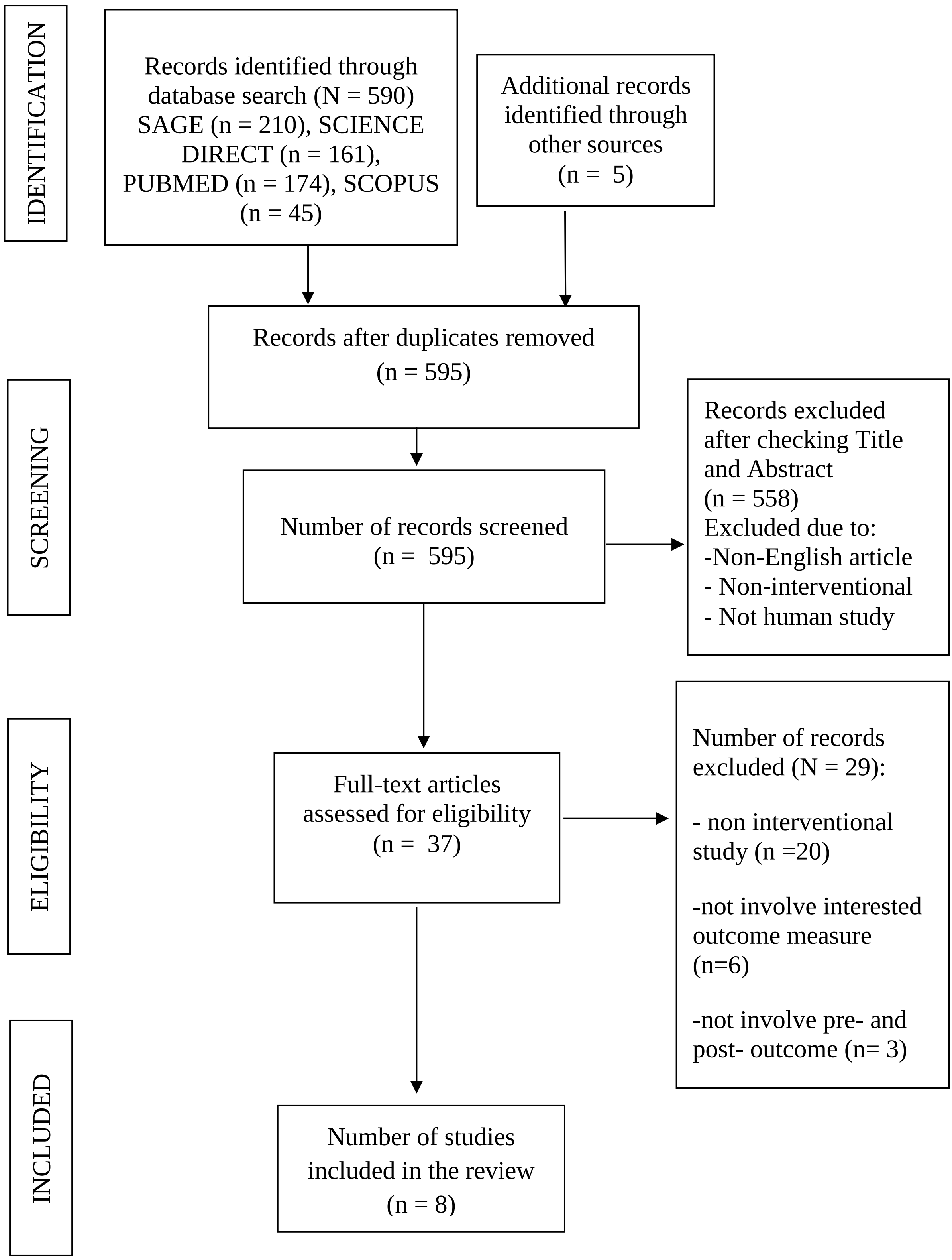

Figure 2.2 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analyses) flow chart of the included studies.

Inclusion and Exclusion Criteria

To be eligible for inclusion, the studies were obliged to notify the impact of the exercise intervention program that involved either the bottom-up or the top-down DKV mechanism on kinematics of the knee. The duration of the intervention program must be at least one week with two or three sessions per week. Men and women of all ages with a healthy or symptomatic knee condition were included. There was no limitation on the date of publication but only papers published in English were included. Only human interventional studies presented in full-text journals that discussed DKV or knee alignment were included in this review. Other research designs such as meta-analyses, systematic reviews, case reports and series, cross-sectional studies, concept papers, editorials, opinions, and *in vitro* research were excluded. Seminar, poster presentations, reviews, case studies, editorials, letters, and abstract-only texts were also excluded.

Data Extraction

For every included study, two researchers extracted the information. The data were synthesized and tabulated based on the first authors' surname, date of publication, sample size, mean ages, type of activity level, participants, the period of intervention, type of activities, group allocations, methods of outcome assessment, functional tasks, and outcomes (Table 2.1).

Table 2.1 Characteristics of included studies.

Study	Population (age, level of physical activity, status and measurement of knee valgus)	Program duration, session per week	Groups		Test	Outcome Measure
Sheerin, Hume and Whattman, 2012	n=19 (11 male, 8 female), 9 to 14 years old (11.54 ±1.34 years) Healthy youth athletes, competitive sports. Presence of DKV was determined based on knee abduction angle from pre-intervention	-8 weeks -3 times per week	Control group (n=10): Open and closed kinetic chain upper limb strengthening exercises:- -low pulley row and over-head pull-down with a resistance band, -bicep curls -lying chest press -front and side shoulder raises -overhead press with small hand-weights -triceps dips from a bench.	Experimental group (n=9) Similar training as control with additional functional weight bearing exercises:- -side lying hip abduction -double leg squats -crab walking - standing hip abduction -single leg squat -jump squats -jumps squats with rotation 90º and 180º -Broad jump (forward deep hold, single leg) -double leg landing	Treadmill-based assessment of running gait with 3D analysis (while wearing shoes)	Differences in pre- to post-intervention changes between control and experimental groups: -trivial for the right knee (-0.3°) -large detrimental increase in left knee valgus angle (1.9°)

Table 2.1 Continued.

Baldon et al., 2014	n=31 females 18-30 years old (ST= 22.7±3.2, FST= 21.3±2.6) Diagnosed with Patellofemoral Pain Syndrome (PFPS), recreational athletes (athletic activity for at least 3 times per week) DKV status was based on diagnosed of PFP.	8-weeks -3 times per week Duration: ST= 75-90 minutes per week FST= 90-120 minutes per week	ST (n=16) -Quadriceps and lateral retinaculum, hamstrings, soleus, gastrocnemius, and iliotibial band stretches exercise -straight leg raise in supine seated knee extension (90º-45 º of knee flexion) -leg press (0º-45º of knee flexion) -wall squat (0º-60 º of knee flexion) -step-ups and step-downs from a 20-cm step -single leg standing on the unstable platform.	FST (n=15) Transversus abdominis and multifidus muscle training exercise -lateral and ventral bridge -trunk extension on the Swiss ball -Isometric hip abduction/ lateral rotation in standing - hip abduction/ lateral rotation/ extension in side-lying - hip extension/ lateral rotation in prone - hip abduction/ lateral rotation with slight knee and hip flexion in side-lying - pelvic drop in standing - hip lateral rotation in closed kinetic chain - single-leg deadlift - single leg squat - forward lunge - prone knee flexion - seated knee extension (90º-45º of knee flexion) -single-leg standing on unstable platform.	Single Leg Squat test with depth squat at least 60° of knee flexion	-significant reduction of knee abduction moment after 8-weeks of intervention in FST only.

Table 2.1 Continued.

			The strengthening exercises performed by both groups were based on a 1-RM, pain not higher than 3/10 of 10-cm VAS scale. Loads were progressed across 8-weeks of intervention when patients perform without excessive knee pain, fatigue and muscle pain 48 hours after training session.			
Barendrecht et al., 2011	N=80 Age (years): -AAVA (NMT = (15.6±1.5) and RT = (15.6±1.5)) -BAVA (NMT = (14.9±1.3) and RT = (15.2±1.3)), The status of DKV divided into two groups (AAVA and BAVA) based on drop-jump test.	-10-weeks -2 sessions per week	NMT AAVA (n=27) BAVA (n=22) -usual handball training and standard warm-up. -balance and coordination exercises on a wobble board and a mat -strength and plyometric exercises	RT AAVA (n=22) BAVA (n=9) -performed standard warm-up and the usual handball training only.	Test: Drop jump test (2D) from 30-cm height with double leg landing. The highest jump of 2 trials was measured.	Linear Regression analysis showed that in the NMT groups (AAVA and BAVA groups), initial minimum normalized knee distance predicted 59% of the variance in pre- to post-test for knee flexion angle.