THE MECHANISM OF DYNAMIC KNEE VALGUS AND THE CONCURRENT VALIDITY AND RELIABILITY DURING SINGLE LEG SQUAT IN PHYSICALLY ACTIVE FEMALES

NAZATUL IZZATI BINTI JAMALUDIN

UNIVERSITI SAINS MALAYSIA

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by

NAZATUL IZZATI BINTI JAMALUDIN

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LIST OF SYMBOLS

°	Degree of knee flexion
r	Correlation of linear correlation
p	A measure of the probability that an observed difference could have occurred just by random chance

LIST OF ABBREVIATIONS

SLS	Single leg squat
DLS	Double leg squat
FPPA	frontal plane projection angle
DKV	Dynamic knee valgus
DF-ROM	Dorsiflexion range of motion
ACL	Anterior Cruciate Ligament
PFP	Patellofemoral Pain
2-D	Two-dimensional
3-D	Three-dimensional
IPS	Institut Pengajian Siswazah
USM	Universiti Sains Malaysia

LIST OF APPENDICES

MEKANISMA BIOMEKANIK ANGGOTA BAWAH BADAN DAN KEBOLEHPERCAYAAN DAN KESAHAN SERENTAK SEMASA 'SQUAT' SEBELAH KAKI DALAM KALANGAN POPULASI WANITA YANG AKTIF SECARA FIZIKAL

ABSTRAK

"*Dynamic knee valgus* (DKV)" atau pergerakan lutut ke dalam yang berlebihan semasa bergerak adalah disebabkan oleh perubahan kinematik sendi pinggul dan pergelangan kaki. Nilai DKV yang berlebihan semasa melakukan pergerakan merupakan faktor utama berlakunya kecederaan pada bahagian bawah badan terutamanya dalam kalangan wanita, ujian *"single-leg squat"* (SLS) boleh digunakan bagi tujuan kajian. Namun, kajian mengenai mekanisma dan rantaian kinetik pergerakan semasa melakukan SLS masih berkurangan. Justeru, tujuan utama kajian ini adalah untuk mengenalpasti mekanisma biomekanik kaki yang merangkumi rantaian kinetik atas ke bawah (pengaruh otot pinggul terhadap pergerakan sendi lutut) dan rantaian kinetik bawah ke atas (pengaruh otot buku lali terhadap pergerakan sendi lutut) dalam kalangan wanita yang aktif. Tujuan kedua kajian ini adalah untuk menilai kesahihan kaedah 3-D dan 2-D bagi menilai kinematik lutut semasa SLS pada dua sudut "*squat*" dan kebolehpercayaan data yang diambil dalam sehari dan antara hari dengan menggunakan kaedah yang sama. 34 orang wanita yang aktif direkrut bagi menjalani ujian saringan dan dibahagikan kepada dua kumpulan iaitu kumpulan yang mempunyai normal nilai DKV dan lebih nilai DKV. Seterusnya mereka menjalani ujian SLS pada dua kedalaman "*squat*" iaitu lutut bersudut 45° dan 60°. Ujian SLS yang sama diulangi

kali kedua terhadap setiap peserta untuk memeriksa kebolehpercayaan dua kaedah tersebut dalam masa sehari dan antara hari direkod menggunakan kamera digital pada satah hadapan dan sisi, serentak dengan kaedah 3-D. Hal ini bertujuan untuk menilai kesahihan dua kaedah yang digunakan. Selepas itu, ujian "*Weight-Bearing Lunges*" dilakukan untuk menilai julat pergerakan pergelangan kaki (ROM). Ujian statistik "*Pearson Correlation*" digunakan untuk menilai perhubungan antara kekuatan otot pinggul, pergelangan kaki dan julat pergerakan pergelangan kaki dengan kinematik lutut semasa melakukan SLS pada kedua-dua sudut. "*Intraclass Correlation Coefficient* (ICC)" digunakan sebagai indikator bagi ujian kebolehpercayaan dalam sehari dan antara hari terhadap kedua-dua kumpulan. "*Bland-Altman Plot*" dan "*Pearson correlation*" digunakan untuk menilai kesahihan dua jenis kaedah bagi menilai sudut lutut pada satah hadapan. Bagi kumpulan normal DKV, terdapat perhubungan relevan antara kekuatan "*hip adduction*" kaki dominan (r=-0.51, p=0.04), dan "*hip extension*" kaki bukan dominan (r=-0.56, p=0.02) dengan sudut lutut semasa SLS. Untuk kumpulan yang mempunyai nilai DKV yang berlebihan, perhubungan relevan dapat dilihat antara kekuatan "*hip abduction*" kaki bukan dominan dan sudut lutut (r=-0.53, p=0.03). Seterusnya, perhubungan relevan antara sudut pergelangan kaki dominan (r=0.51, p=0.04) dan jarak pergelangan kaki dominan (r=-0.53, p=0.03) dengan sudut lutut dalam kumpulan normal DKV, dan antara sudut pergelangan kaki bukan dominan semasa lenturan lutut 45° (r=0.51, p=0.04) dan sudut pergelangan kaki bukan dominan semasa lenturan lutut 60° (r=0.50, p=0.04) dengan sudut lutut dalam kumpulan yang mempunyai lebih nilai DKV. Kemudian, kaedah 2-D dan 3-D yang menilai sudut lutut dalam satah hadapan semasa lutut bersudut 45° dan 60° didapati sahih untuk kedua-dua belah kaki bagi kumpulan normal DKV. Walaubagaimanapun, kaki bukan dominan sahaja menunjukkan perhubungan relevan antara kaedah 2-D dan 3-D semasa lenturan lutut bersudut 60° dilihat sahih bagi kumpulan lebih nilai DKV.

THE MECHANISM OF DYNAMIC KNEE VALGUS AND THE CONCURRENT VALIDITY AND RELIABILITY DURING SINGLE LEG SQUAT IN PHYSICALLY ACTIVE FEMALES

ABSTRACT

Excessive dynamic knee valgus (DKV) or inward movement of the knee during motions is due to the altered kinematics of hip (i.e., top-down kinetic chain) and ankle (i.e., bottom-up kinetic chain) joints. Excessive DKV during motions is a major predictor of lower limb injuries, particularly in females, and can be measured using single leg squat (SLS) tests. However, its mechanism and kinetic chain during SLS are unknown. Therefore, the primary goal of the current study was to elucidate the mechanism of DKV, which include top-down (i.e., influence of hip musculature on motions at knee joint) and bottom-up kinetic chain (i.e., influence of ankle musculature on motions at knee joint), among physically active females. The secondary goal is to examine the validity of 2-Dimensional (2-D) and 3-Dimensional (3-D) motion capture methods in evaluating knee angle during SLS at two squat depths and the within-and between-days reliability of these methods. 34 participants went through screening test and divided into two groups (i.e., normal DKV and excessive DKV group). Then, 3-D knee kinematics (i.e., joint angle) during SLS test at 45° and 60° of knee flexion were observed. The same SLS test was repeated to examine within-and between-days reliability. The motions were captured simultaneously by digital cameras in frontal and sagittal planes with 3-D infrared cameras to examine the validity between the both methods in evaluating knee angle. Weight-Bearing Lunges Test was conducted to evaluate their ankle range of motion (ROM). Ankle and Hip Isokinetic Strength was tested at 180°/s angular velocity in ankle dorsiflexion, plantarflexion, inversion and eversion and hip flexion, extension, abduction and adduction for both legs. Pearson correlation was used to examine the relationships between hip, ankle strength and ankle ROM and knee kinematics during SLS at both angles. Intraclass Correlation Coefficient (ICC) was used as indicator for within-and between-days reliability test of both groups. Bland-Altman Plot and Pearson correlation were used to illustrate the validity of 2-D and 3-D motion capture methods. Normal DKV group shows significant relationships between dominant hip adduction strength ($r=-0.51$, $p=0.04$), non-dominant hip extension strength ($r=-0.56$, $p=0.02$) and knee angle during SLS. Significant relationship was noticed between non-dominant hip abduction strength and knee angle during SLS ($r=-0.53$, $p=0.03$) in excessive DKV group. Next, there were significant relationships between dominant ankle angle ($r=0.51$, $p=0.04$) and distance ($r=-0.53$, $p=0.03$) with knee angle in normal group, and between non-dominant ankle angle during 45° knee flexion ($r=0.51$, $p=0.04$) and non-dominant ankle angle during 60° knee flexion ($r=0.50$, $p=0.04$) with knee angle in excessive DKV group. Next, both methods of evaluating knee angle at both squat depths are shown valid for both legs in normal group. However, the methods are valid only for non-dominant leg during SLS at 60° knee flexion for excessive DKV group. Thus, both groups demonstrated the influence of the top-down and bottom-up kinetic chains on knee kinematics during SLS, with distinct muscle groups being emphasised in each group. Besides, SLS is a valid and reliable test for 2-D and 3-D methods of studying knee angles at squat depths of 45° and 60° knee flexion for participants with normal and excessive DKV groups.

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Excessive dynamic knee valgus (DKV) is an abnormal lower extremity movement pattern that visually characterised by excessive lower extremity medial movement during weight-bearing activity (Schmidt et al., 2019). An excessive value of knee frontal plane projection angle (FPPA) during dynamic tasks is proposed to be linked to chronic aberrant loading of the subsequent joints (Wyndow et al., 2016). Excessive DKV during motions is a major predictor of lower limb injuries in sports, particularly in females (Schmidt et al., 2019). Specifically, excessive DKV during jump-landing motions was observed as a strong predictor for lower limb injuries (Lesinski et al., 2017).

Increased movement of DKV can cause excessive stress to the knee or hip joint and lead to patellofemoral or chronic hip joint pain over time. For example, when hip adduction increases, hip internal rotation, and knee eternal rotation can increase the dynamic quadriceps angle (Powers, 2010) thereby increasing laterally directed stresses. Moreover, individuals with and without patellafemoral pain (PFP) can be discriminated by the values of their knee FPPA (Willson et al., 2008).

There are two types of the kinetic chain that are related to DKV which are bottom-up and top-down kinetic chains. These two kinetic chains may affect knee motions, especially during sports activities. A top-down kinetic chain indicates that changes of the proximal joints such as the hip and trunk may cause dynamic instability during motion as it had complex interaction with lower extremities' muscles (Dix et al., 2019). For example, decrease in gluteal strength may predispose patients to knee valgus collapse during pivoting and cutting motions, whereas weak hamstrings may cause increase in anterior tibial translation (Wetters et al., 2015). Previous studies on the treatment of excessive DKV emphasised a specific kinetic chain. For instance, Neamatallah et al., (2019) studied top-down kinetic chain by conducting an isokinetic hip strength test and a functional task (i.e., single-leg squat test) in 34 healthy males and females. They found that hip and knee kinetic and kinematic variables were associated with DKV as shown by gluteal muscle strength and EMG activity (Neamatallah et al., 2019). Besides, Stickler and friends (2015) also studied top-down kinetic chain by conducting an isometric test using a dynamometer for strength test for trunk and hip and a functional task (i.e., single-leg squat, SLS). 2-dimensional motion analysis software was used to analyse the frontal plane projection angle (FPPA). They found that hip abductors, hip external rotators, hip extensors, and core musculature gave impact on strengthening the FPPA during a single squat (Stickler et al., 2015).

On the other hand, the bottom-up approach indicates the influence of the distal joint (i.e., ankle joint) on the motions of the knee joint. For instance, knee motion during SLS was observed to be affected by ankle range of motion (ROM) and its muscular strength (Wyndow et al., 2016) and foot positions (Ishida et al., 2014). Ishida and friends (2014) studied the bottom-up kinetic chain by performed DKV at knee flexion angle at 30° in three toe directions (neutral, toe-out, and toe-in) among 16 females. They found that the knee rotates externally during dynamic knee valgus, and the knee rotation is affected by toe direction. Other than that, Hoch and friends' study also convey a bottom-up kinetic chain among 15 physically active persons with chronic ankle instability (CAI). From this study, they found that individual with less dorsiflexion ROM performed more erect landing posture and greater ground reaction force GRF (Hoch et al., 2015).

There were lack of informations from the previous studies such as the reliability and validity of using 2-D and 3-D motion analysis methods between participants with normal and excessive DKV. In the current study, excessive DKV group and normal DKV group were separated because we want to know whether knee motion is influenced by knee alignment or not and what the significance difference shown between both group results from the functional task that we had done.

The mechanism and kinetic chain during SLS, among those with a normal range of DKV is also not available. Narrowing to which more significant mechanism that contributes to DKV would be important. Elucidating the mechanism of DKV during this common motion (i.e., SLS) was crucial to prevent injuries that were costly in terms of time absent from sports, financially and psychologically. Hence, this study was conducted to elucidate the mechanism of DKV in both kinetic chains, top-down (i.e., the influence of hip musculature on motions at knee joint), and bottom-up kinetic chain (i.e., the influence of ankle musculature on motions at knee joint) among the physically active females.

Concurrent validity of 2-D and 3-D motion analysis of lower limb kinematics during SLS is crucial because although 3-D motion capture is considered the "gold standard" for recording and analysing kinematics, 2-D video analysis may be a more practical, cheaper and portable option for kinematic assessment during pre-participation screenings. Therefore, a study conducted to assess the concurrent validity of both motion analysis need to be done. Schurr and friends (2017) found out that moderate to strong relationships were observed between the 2-D video camera and 3-D motion capture analyses at all joints in the sagittal plane, and the average mean difference was comparable to the standard error of measure with goniometry among 36 healthy adults. However, their study did not separate people with excessive and normal dynamic knee valgus. Therefore, the results might be messed up with people who already had abnormal knee alignment.

To address the gaps in previous studies related to SLS biomechanics, we conducted a screening test to evaluate the degree of DKV among the participants. Those with excessive DKV exhibit larger knee FPPA which is more than 14°. Females with normal DKV should be within the range of 7°-13° knee FPPA (Munro et al., 2012). Then, 3-D motion capture of SLS, top-down (i.e., hip strength) and bottom-up tests (i.e., ankle strength and ROM) were conducted to evaluate the mechanism of DKV and its relationship to SLS. These tests were conducted among physically active females with normal and excessive DKV. For validity test 3-D and 2-D (Digital Camera) motion capture of SLS were done concurrently.

DKV is due to the altered kinematics of hip (i.e., top-down kinetic chain) and ankle (i.e., bottom-up kinetic chain) joints. Excessive DKV during motions is a major predictor of lower limb injuries, particularly in females, and can be measured using single leg squat (SLS) tests. The primary goal of the current study was to elucidate the kinetic chains of DKV (i.e., the mechanisms of DKV). The secondary goal is to examine the validity of 2-Dimensional (2-D) and 3-Dimensional (3-D) motion capture methods in evaluating knee angle during SLS and the within-and between-days reliability of these methods. We hypothesized that at the end of this study, there are significant relationship observed between hip and ankle strength and ankle ROM with knee angles for objectives one. While for objective two we also hypothesized that there is significant reliability (within- and between-days reliability) and concurrent validity (2-D and 3-D methods) of lower limb kinematics during SLS among physically active population.

1.2 Problem Statements

Non-contact lower limb injuries (i.e., ACL tear, patellofemoral pain syndrome) are caused by excessive DKV. DKV is a kinetic chain motion whereby excessive frontal and transverse plane motions at the hip and core (i.e., top-down kinetic chain) or ankle strength and range of motion (i.e., bottom-up kinetic chain) may cause medial motion of the knee joint. Therefore, it is crucial to understand the DKV mechanism (i.e., its kinetic chains) specific to a motion in order to prevent injuries from the source instead of treating the symptom. SLS is a common sporting motion that can be used as a valid and reliable screening method in the active population. Despite being studied regularly in non-contact injury mechanisms, studies that investigated DKV in physically active population seldom differentiate those participants with normal and excessive DKV. Moreover, the top down and bottom up kinetic chain of DKV during SLS was not compared across those individual with normal and excessive DKV. Additionally, despite its popularity as a clinical test, the reliability and validity of SLS at different angle

(45° and 60°) and within-and between-days were not known among population with normal and excessive DKV which understate its usability.

1.3 General and Specific Objectives

General Objective:

To investigate the top-down and bottom-up of dynamic knee valgus during single leg squat and the reliability and validity of lower limb kinematics during single leg squat among physically active population

Specific Objectives:

1.3.1 Study 1

Specific objectives of Study 1 are:-

- To determine the relationship between hip musculature strength and kinematic of lower limbs during single leg squat among physically active females.
- To determine the relationship between ankle musculature strength and its range of motion and kinematic of lower limbs during single leg squat among physically active females.

1.3.2 Study 2

Specific objectives of Study 2:-

- To examine the within-day and between-days reliability of lower limb kinematics during single leg squat among physically active females.

- To examine the concurrent validity of 2-D and 3-D motion analysis of lower limb kinematics during single leg squat among physically active females.

1.4 Research questions and Hypotheses

1.4.1 Study 1

Research questions:

(1) What is the relationship between hip and ankle musculature strength and kinematic of lower limbs during single leg squat among physically active females?

(2) Is top-down and bottom-up persist in those with normal and excessive dynamic knee valgus?

Hypothesis (1)

Null Hypothesis (H_0): There are no significant relationship between hip musculature strength and kinematic of lower limbs during single leg squat among physically active population.

Alternative Hypothesis (H_A): There are significant relationship between hip musculature strength and kinematic of lower limbs during single leg squat among physically active population.

Hypothesis (2)

Null Hypothesis (H_0): There are no significant relationship between ankle musculature strength and its range of motion and kinematic of lower limbs during single leg squat among physically active population.

Alternative Hypothesis (H_A): There are significant relationship between ankle musculature strength and its range of motion and kinematic of lower limbs during single leg squat among physically active population.

1.4.2 Study 2

Research questions:

(1) What is the reliability within-day and between-days of 3-D motion analysis of lower limb kinematics during single leg squat in those with normal and excessive dynamic knee valgus?

(2) What is the concurrent validity of 2-D and 3-D motion analysis of lower limb kinematics during single leg squat in those with normal and excessive dynamic knee valgus?

Hypothesis (1)

Null Hypothesis (H_0): There are no significant within-day and between-days reliability of lower limb kinematics during single leg squat among physically active population.

Alternative Hypothesis (H_A): There are significant within-day and between-days reliability of lower limb kinematics during single leg squat among physically active population.

Hypothesis (2)

Null Hypothesis (H_0): There are no significant concurrent validity of 2-D and 3-D motion analysis of lower limb kinematics during single leg squat among physically active population.

Alternative Hypothesis (H_A): There are significant concurrent validity of 2-D and 3-D motion analysis of lower limb kinematics during single leg squat among physically active population.

1.5 Significance of the Study

Findings of the present study may help athletes to understand the influence of their hip and ankle joints characteristics (i.e., strength, ROM) on the knee motions during dynamic tasks. The knowledge may reduce the risks of non-contact injuries which are common in physically active females with excessive DKV. As injuries are costly to athletes in terms of medical cost, psychological and absence from sports participation, preventive measures are deemed crucial. Additionally, the outcomes from the research provided the validity and reliability of 2D motion analysis of SLS test among physically active population.

1.6 Operational Definition

Table 1.1 Operational definition

Abbreviations	Operational Definition
Dynamic Knee Valgus (DKV)	The combination of hip adduction, hip internal rotation, knee flexion, knee external rotation, knee abduction, ankle inversion, and ankle dorsiflexion observed during dynamic motions (i.e., single leg squat, drop vertical jump). Excessive is an individual who exhibit larger knee FPPA. The normal range of knee FPPA for females is 7°-13°.
Single leg squat (SLS)	The single leg squat is a squat movement that's performed on a single leg. It adds a balance and stability challenge to the traditional squat. In this study, we tested SLS at 45° and 60° of knee flexion, while the other leg was extended to the front.
Kinetic chain	Is a linkage of body segments performing movements together to generate force summation.
Bottom-up kinetic chain	Kinetic chain at the distal part of a joint that may influence the motions of the subsequent proximal joint (eg: motions at ankle influence motions at the knee).
Top-down kinetic chain	Kinetic chain at the distal part of a joint that may

Table 1.1 Continued

	influence the motions of the subsequent proximal joint (eg: hip-knee strength).
Kinematic	The movements of points, bodies, and systems of bodies are defined in this branch of classical mechanics without taking into consideration the mass of each or the forces that induced the motion. The angle of the knee joint in the frontal plane was the subject of this research.
Reliability within day	In simple terms, research reliability is the degree to which the research method produces stable and consistent results. In this study, reliability within the day was obtained by captured 3-D motion for the first and second sessions. The gap for each session was at least 4 hours.
Reliability between days	In simple terms, research reliability is the degree to which the research method produces stable and consistent results. In this study, reliability between days was obtained by capture 3-D motion third session within a week.
Validity	Validity means findings were truly represented the phenomenon claimed to be measured. In this study, we claim to have a valid result between 2-D and 3-D motion captured. Concurrent means, two or more

Table 1.1 Continued

	things happened at the same time, which refers to videos taken in 2-D and 3-D were taken at the same time.

CHAPTER 2

LITERATURE REVIEW

2.1 Relationship of hip strength and dynamic knee valgus (DKV) during SLS: A systematic review

A top-down kinetic chain shows that changes in proximal joints such as the strength of hip and trunk musculature can cause dynamic instability during movement due to the complex interaction between the joints and the muscles of the lower extremities (Agel et al., 2016). For example, decreased gluteal strength predisposes individuals to dynamic knee valgus (DKV) during pivoting and cutting motions, whereas weak hamstrings can cause increased tibial anterior translation (Araujo et al.,2017). External moments of force on the hip joint during the loading phase of walking, jumping or landing will cause flexion, adduction, and internal rotation moments known as DKV (Powers, 2010).

A similar systematic review was performed by Cashman et al., (2012) regarding the potential relationship between the strength of hip-abductor or external-rotator and knee-valgus kinematics among asymptomatic subjects during the performance of dynamic activities. According to the review findings, there was no robust evidence to show that healthy subjects with poor hip abductors and perhaps weak external rotators would exhibit increased knee valgus. Symptomatic patients were not included in this current study because of the possible confounding factors in determining the effect of intensity on kinematics due to the underlying process of pain avoidance, reward, and inhibition. As for this present review, we recruited both asymptomatic and symptomatic patients because we aimed to clarify all the possible causes that might influence the knee kinematics according to the different participants' criteria. Recently, Dix et al. (2019) conducted a systematic review on top-down kinetic chains during movement tasks among healthy females. They discussed the relationship between hip strength and DKV, similar to the objective of this current study. However, they only included studies that recruited asymptomatic/healthy females. Their emphasis on women was possibly due to the higher tendency for DKV (Cashman,2012), a higher prevalence of ACL (Clairborne et al., 2006), and other lower limb injuries (Dix et al., 2019, Grimaldi & Fearon, 2015) in females than in males. Thus, we have widened the inclusion criteria to encompass both genders. Additionally, both previous systematic reviews (Cashman, 2012; Dix et al., 2019) did not include patients in their reviews. Therefore, different groups of people (i.e., healthy adults or patients) with any conditions related to the knee were included in this study. The primary goal of the current review was to look at the relationship between hip strength and DKV in varied dynamic activities in healthy adults and patients.

2.1.1 Methods and materials

This systematic review was performed in compliance with the guidelines of the Preferred Reporting Items for Systematic Review (PRISMA) (Liberati et al.,2009).

Search Strategy

Four medical databases, namely Science Direct, Scopus, SAGE, and PubMed, were searched from database inception until November 2020 by two independent researchers. A search strategy composing of free text search words, synonyms, and combinations was used to gather all the relevant articles. Three concepts were combined for the search in databases using the Boolean operator 'AND': (1)'hip strength', 'hip muscle strength; (2)'dynamic knee valgus', 'knee alignment', 'knee stability', 'knee deviation', 'knee mobility'; (3)'top-down kinetic chain'. The terms within these definitions were merged using the Boolean operator 'OR'. In order to characterise the different studies, the reference list in the included manuscripts and personal files of the authors were checked thoroughly. Other sources related to this review were also obtained via manual searching of the references in the selected studies.

Study Selection

The titles and abstracts found using the search strategy were downloaded into Mendeley Software (version 1.19.4, Mendeley, London, UK) after the database search was completed. Duplicates were removed and all abstracts were screened for inclusion by two independent reviewers. Full texts were obtained when necessary. The corresponding author of the article was contacted via e-mail in the event of confusing details. Another investigator was invited for a discussion if there was any dispute between the two investigators before reaching a consensus. Figure 2.1 shows the flow chart of the search process and study selection.

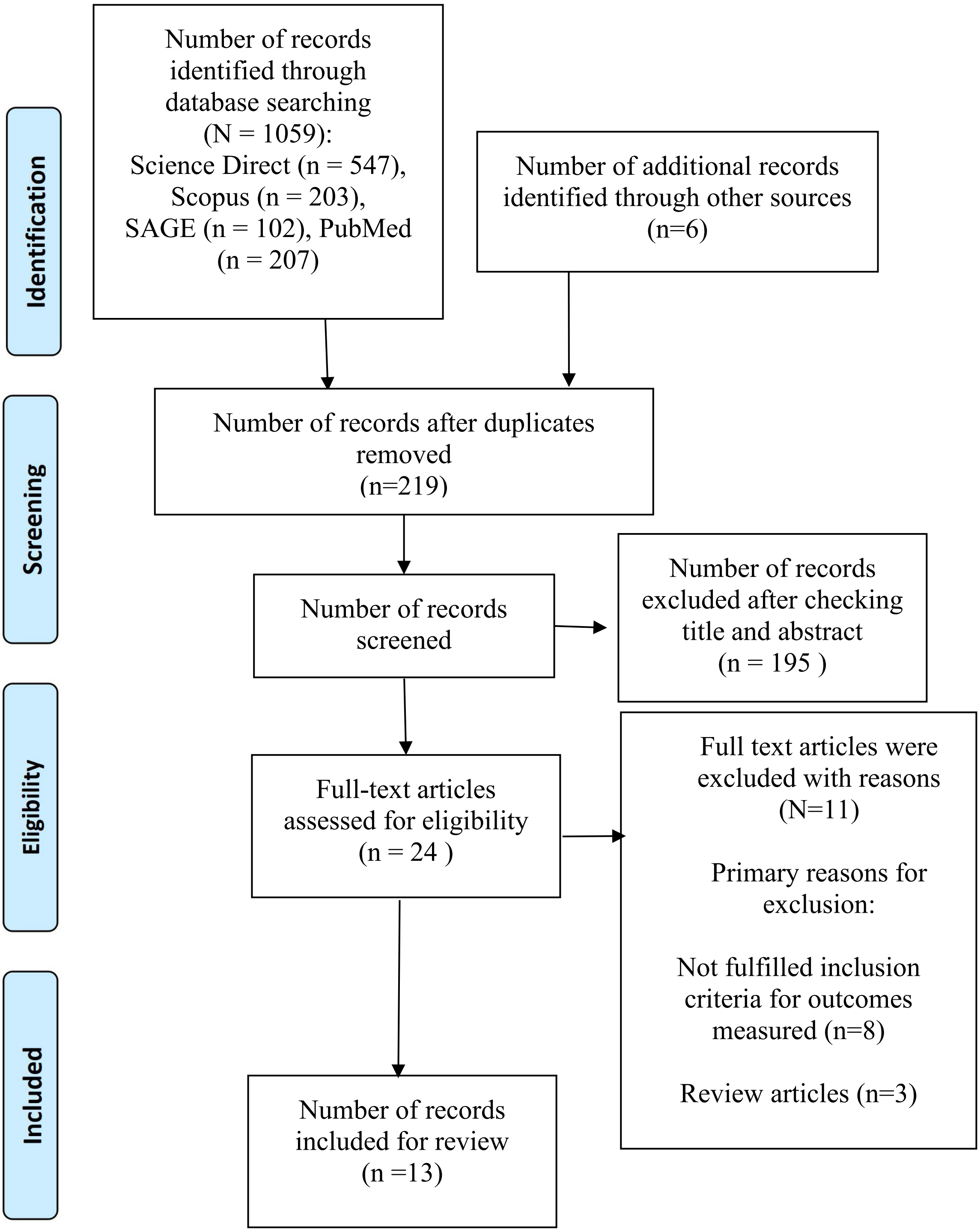

Figure 2.1 PRISMA (Preferred Reporting Items for Systematic Reviews) flow chart of electronic search

Inclusion and Exclusion Criteria

Studies must record the relationship between at least one outcome measure for hip strength and one outcome measure for the frontal plane knee angle during any motion in order to be considered. Healthy adults or patients with normal and excessive DKV were considered for the review. Only studies with full-text papers published in English were included. No limitations were imposed over the date of publication. Furthermore, there was also no restriction on the type of test used to evaluate the outcome measure as long as the outcomes were in line with the objectives of this review. Cross sectional and cohort studies as well as randomised controlled trials were included whereas case-control studies were excluded.

Data Extraction

The findings of the included papers were extracted by two reviewers. Table 2.1 summarises the findings from the studies included. The data are grouped by first author names, publishing dates, sample sizes, mean ages, background of participants, hip variables and measurement method, functional tasks and final outcomes.

2.1.2 Results

Characteristics of Included Studies

A total of 1,059 articles were obtained from the database search. Following the screening, only seven articles fulfilled the inclusion criteria and were included in the review (Neamatallah, Herrington, & Jones, 2020; Soares et al., 2019; Araujo et al., 2017; Stickler, Finley, & Gulgin, 2015; Malloy et al., 2015; Hollman et al., 2009; Clairborne et al., 2006). Following manual hand search, another six papers were identified (Schmidt, Harris-Hayes, & Salsich, 2019; Nilstad et al., 2015; McCurdy et al., 2014; Baldon et al., 2011; Norcross et al., 2009; Thijs et al., 2007). Thirteen studies with a total of 733 subjects (male=146, female=587), (healthy=644, patients=69) met the inclusion criteria. Table 2.1 outlines the characteristics of all the included studies.

To assess the association between hip muscle strength and the angles of knee valgus, five studies used the Single Leg Squat as their functional task, namely Neamatallah et al., (2020), Stickler at al., (2015), Clairborne et al., (2006), Baldon et al., (2011) and Schmidt et al., (2019). All these five cross-sectional studies showed that both variables were significantly correlated whereby increase hip strength may minimised knee valgus. Four studies (Hollman et al., 2009; Malloy et al., 2015; Schmidt et al., 2019; Stickler et al., 2015) used isokinetic and isometric testing of hip strength to assess the healthy female (Hollman et al., 2009; Malloy et al., 2015; Schmidt et al., 2019; Stickler et al., 2015) and male (Hollman et al., 2009; Schmidt et al., 2019; Stickler et al., 2015) adults.

Table 2.1 Hip systematic review

Study	Sex & Age	Sample size	Background of participants	Hip variable and measurement method	Dynamic knee valgus measurement method	Tasks	Outcomes
Neamatallah et al., (2020)	17 M 26.9±3.8 years 17 F 25.7±4.5 years	34	Physically active M and F	Isokinetic hip muscle strength, concentric and eccentric contractions Isokinetic dynamometer (Biodex system 4)	3D kinematics motion analysis	Single-leg Squat (SLS): at least 45°of knee flexion and no greater than 60°.	Knee abduction angle and moment were inversely correlated with hip abduction concentric strength (r=-0.50, p=0.02) and hip extension eccentric strength (r=-0.5, p=0.04).
Soares et al., (2019)	25.6 ± 6.8 years	35	Sedentary F with patellafemoral pain (PFP)	Hip muscle strength Handheld dynamometer (Lafayette IC)	3D kinematics motion analysis	Single leg hop test (SLHT)	A weak correlation was found between the knee extensor strength and knee ROM in the SLHT propulsion in sagittal plane (p=0.04, r=-0.336).

Table 2.1 Continued

Schmidt et al., (2019)	23.3 ± 2.4 years	47	20 F with PFP 14 F with chronic hip joint pain 13 F Control group	Pain:100-mm visual analog scale	3D kinematics motion analysis	Single leg squat	Hip adduction and contralateral pelvic drop were greater in those with chronic hip joint pain compared to those with PFP. Greater knee external rotation (r=0.47, p=0.04) was correlated with greater knee pain in those with PFP. Greater hip adduction (r=0.53, p=0.05) and greater hip internal rotation (r=0.55, p=0.04) were correlated with greater hip pain in those with chronic hip joint pain.
Araujo et al., (2017)	26.5 ± 3.8 years	36	Sedentary F experimental group (n=18), control group (n=18) -8-week of hip strengthening exercises	Hip passive torque:medial rotation,concentric and eccentric torque of hip lateral rotators Isokinetic dynamometer	3D kinematics motion analysis	Step-down task	Knee kinematics in transverse plane and frontal plane did not significantly modified after intervention ($p \geq 0.069$, main effect). Meanwhile, hip muscle performance and passive properties, revealed

Table 2.1 Continued

			-three session per week				significant effects for group x condition interaction for maximum concentric work of lateral rotators, maximum eccentric work of lateral rotators, and resting position.
Stickler et al., (2015)	24.0 ± 2.6 years	40	Physically active F	Peak isometric force using dynamometer (MicroFET2, Hoggan Health Industries). Isometric testing: sidelying plank test, hip abduction, hip extension and hip external rotation	2D video analysis for knee frontal plane projection angle (FPPA) during single leg squat	Single leg squat at depth of 60° knee flexion	All 4 strength tests (hip abductor, hip external rotation, hip extension & side-lying plank) showed that hip strength were significantly correlated with the knee FPPA, ranging from r=0.396 to r=0.466.
Malloy et al., (2015)	19.4 ± 0.8 years	23	F,National Collegiate Athletic Association division I soccer	Maximal isometric hip abduction and external rotation strength	3D kinematics motion analysis with force plates	Unanticipated Single-Leg Landing (SLL) tasks that consisted of	Greater hip external rotator strength was significantly associated with greater peak knee internal rotation moments (r=0.41,

Table 2.1 Continued

			players	Hand-held dynamometer		either: (a)SLL+hold (b)SLL+side cut, Or (c)SLL+forward run and cutting tasks	p=0.048) during unanticipated SLL and cutting tasks.
Nilstad et al., (2015)	21 ± 4 years	279	F, Norwegian elite soccer players	Hip abductor strength Handheld dynamometer	3D kinematics motion analysis	Drop jump task	Anatomical characteristics explained 11% of the variance in peak knee valgus angles (p<0.001), with height and static knee valgus being significant predictors. No significant correlation between peak knee valgus angle and hip abductor strength for both legs (dominant leg=p=0.085, non-dominant leg=0.581).
McCurdy et al., (2014)	20.9 ± 1.62 years	26	F, healthy subjects with athletic experience	Isometric hip extension, external rotation, and abduction strength were measured using a handheld	Hip and knee mechanics were measured using 3D electromagnetic sensors during bilateral (60 cm) and unilateral	Drop jump	The strongest correlations were found between squat strength and knee valgus (-0.77 ≤ r ≤-0.83) After controlling for squat strength, hip external rotation strength and

Table 2.1 Continued

				dynamometer. Free weight was used to measure the bilateral squat strength and a modified single-leg squat strength.	drop jumps (30 cm).		unilateral knee valgus (r=-0.41), hip abduction strength and bilateral knee valgus (r=-0.43), and knee flexion strength and bilateral hip adduction (r=-0.57) remained significant. Eccentric knee flexion strength and unilateral knee internal rotation was the only significant correlation for eccentric strength(r=-0.40).
Baldon et al., (2011)	16 M,16 F 21.8 ± 2.8 years	32	M and F recreational athletes	Eccentric hip abductor assessed using isokinetic dynamometer	3D lower limb kinematics (contralateral pelvis depression/ elevation and anterior/ posterior rotation, femur abduction /adduction and lateral/ medial rotation, and knee abduction/	Single leg squat	-Women and in overall sample show positive relationship between eccentric hip abductor torque and coronal plane knee movements (r=0.61, p=0.01) and (r=0.49, p=0.00) -Men show no correlation between these variables.

Table 2.1 Continued

					adduction)		
Norcross et al., (2009)	22 M, 25 F 21.3 ± 2.0 years	47	M and F, healthy individuals	Isometric and eccentric peak torque of the hip abductors measured using isokinetic dynamometer	3D Knee kinematics were assessed by electromagnetic motion capture system	Lateral step down test	Isometric hip abduction was significantly and negatively correlated with frontal plane knee angle (r=-0.372, p=.011)
Hollman et al., (2009)	24.0 ± 2.6 years	20	Physically active F	Hip strength was measured using handheld dynamometer	2D FPPA of hip and knee joints	Single-leg step-down	Hip-adduction angles (r=0.755, p=0.001) and hip-abduction strength (r=0.455, p=0.022) were correlated with knee FPPA.

Abbreviations: M=male; F=f emale; 3-D=three dimensional; 2-D=two dimensional; FPPA=frontal plane projection angle; LL=lower limb; WB=weight-bearing; NWB=non-weight bearing; DF=dorsiflexion; ROM=range of motion