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2D Single-legged Dynamic Knee Valgus assessments Methods: Evaluating Risk Factor for Internal Derangement of the Knee; Literature Review

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Objective: The objective of this study is to evaluate various research that have examined dynamic knee valgus and to pinpoint a straightforward, clinically practical 2D assessment method for dynamic knee valgus that is user-friendly.

Design: A literature review

Methods: This literature review was conducted in Pubmed, MEDLINE® and Google Scholar with the following key words: Knee valgus angle, Knee valgus evaluation, Knee valgus assessment, Dynamic knee valgus. After removing duplicate studies, 53 articles were initially chosen using this method, with 17 studies ultimately meeting the selection criteria.

Results: Based on the comprehensive review of various studies, the Single Leg Squat (SLS) was identified as the most popular test method, followed by the Single Leg Landing (SLL) as the next most common test method. The Frontal Plane Projection Angle (FPPA) method was the most representative method for measuring dynamic knee valgus (DKV) during these tests. SLS was found in a total of 10 studies, while SLL was found in 7 studies.

Conclusions: The most commonly proposed test for assessing DKV is measuring the SLS using the FPPA method. However, when applied to individuals without knee pathology, the discriminative power of this method may be limited. This suggests the need for further research to explore alternative methods for assessing DKV in this population.

Key Words: Knee Joint, Genu valgum, Motion pictures, Patellofemoral pain syndrome, Anterior cruciate ligament

Introduction

Dynamic knee valgus (DKV) is characterized by a combination of movements including the inward movement of the femur, internal rotation of the femur, outward movement of the knee, and external rotation of the tibia, typically occurring during activities that place significant stress on the knee. [1]. DKV has been extensively discussed in the literature and is one of the significant concerns for clinicians. DKV is particularly associated with anterior cruciate ligament (ACL) injuries. In an eight-year retrospective study of 506 professional female basketball players, 76 (15%) were reported to have suffered ACL injuries [2]. Furthermore, a prospective study of 205 female athletes using dynamic 3D motion analysis found that athletes who sustained ACL injuries exhibited greater knee valgus angles during movement compared to those without ACL injuries [3]. This suggests that the knee valgus angle observed during activities could be a risk factor for non-contact ACL injuries. This observation is also seen in patients with Patellofemoral Pain Syndrome (PFPS). Increased valgus loading during dynamic activities increases the lateral forces

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on the patellofemoral joint, which could promote the development and onset of PFPS as an intrinsic risk factor [4]. This theory was confirmed by a prospective study showing a correlation between increased frontal plane moments and PFPS [5], and other studies have reported that DKV could be a risk factor for internal derangement of the knee, such as ACL injuries or Patellofemoral Pain [6]. A common feature of these studies is the utilization of 3D motion analysis, which is known for its high validity and reliability.

However, the 3D motion analysis used in previous studies requires expensive equipment such as 3D motion analysis cameras, motion capture systems, and data collectors. It also demands complex data processing and programming skills, making it impractical for most sports environments or clinical settings. Therefore, it is meaningful to research simple assessments for measuring DKV that can be used clinically [7].

To replace these high-cost 3D motion analysis systems, many 2D analysis methods have been researched. These methods typically measure DKV in the frontal plane during various physical activities that place significant loads on the knee, such as jumping and squatting. Physical activities conducted for assessment can be broadly categorized into tests using double legs and tests using a single leg. Several studies have already confirmed that single-limb tests are more significant than double-legs tests [8, 9]. However, there is still no consistent consensus on which method is the most significant.

Therefore, the purpose of this study is to review various 2D single-leg tests used to measure DKV and to determine which test is the most popular and efficient. This clinically applicable test will save time and costs for assessing DKV and will greatly aid future research.

Methods

Methods Data sources and study criteria

The collection of theses was carried out by three

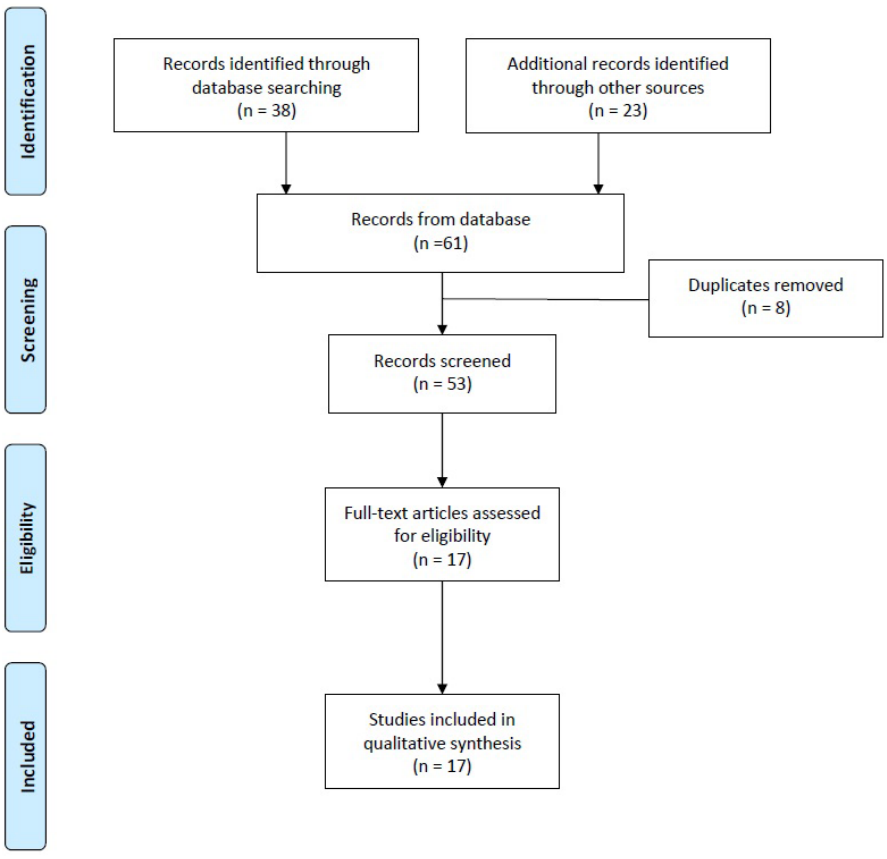

Figure 1. Flow Diagram

physical therapists using selected keywords. The gathered documents were then organized, compared, and analyzed using a bibliographic information program (EndNote 21, Thomson Reuters, USA). These were excluded from the collection process if there was a discrepancy between the abstract and the main text (Figure 1). The study criteria used in the analysis of this study were as follows: (1) studies that measured DKV as an outcome, (2) studies that used a single-leg examination to assess DKV, or (3) studies that utilized a simple 2D assessment method with markers. Furthermore, studies were excluded if they lacked a detailed description of the examination method, even if it was a single-legged 2D assessment, and if they assessed joints other than the knee. In this literature review study, studies from 2010 were searched using the databases of PubMed, MEDLINE® and Google Scholar.

Search terms

The keywords used in the search were as follows and were employed either in combination or independently: 'knee angle', two-dimensional', 'knee valgus', 'dynamic knee valgus', 'knee angle assessment', 'knee valgus assessment', 'dynamic knee valgus assessment', and 'dynamic knee valgus evaluation. As a result, the 17 studies were found with the search tool.

Results

According to our selection criteria, 17 studies were identified and classified using the PICO search strategy (Figure 1<Flow diagram>). Across various studies, SLS and SLL emerged as the most frequently utilized tests for assessing DKV. Specifically, SLS was employed in 10 studies, while SLL appeared in 7 studies. Notably, the terms single leg landing, single legged drop, and hop landing were used interchangeably for SLL. The research methodologies included thirteen cross-sectional studies (Table 1), two experimental studies (Table 2), and two randomized controlled trials (RCT) (Table 3).

Single leg landing (drop)

Numata et al. [7] compared DKV during single leg drop jump in non-contact injured female athletes and a control group with no injury. DKV was assessed by a 2D motion analysis method using the FPPA method to measure maximal knee valgus and the distance from a specific line to the big toe. The results showed that both variables were significantly greater in the non-contact ACL injured group ($p = 0.006$).

Munro et al. [6] measured DKV in 52 female football and basketball players during drop jump (DJ) and SLL tests. Consistent with previous studies, DKV showed greater differences during SLL, which is performed using one leg, compared to DJ, which is performed using both legs ($p < 0.001$). During SLL, basketball players exhibited greater DKV than football players ($p < 0.001$).

Almeida et al. [10] conducted a study involving 22 women with PFPS. They measured the FPPA during a step-down test. The step-down test involves descending a step with one leg, similar to the single leg drop, and thus was included in this analysis. They also measured the Q-angle and compared it with pain intensity, functional capacity, DKV, and hip abductor torque. The results indicated that the Q-angle did not show a significant correlation with any other outcome measures.

Llurda-Almuzara et al. [11] conducted a study on 50 healthy males to measure the FPPA during a single leg drop jump test. They also evaluated hip and knee neuromuscular responses (NMR) as additional outcome measures. The results indicated that there was no significant correlation between DKV and any NMR parameters.

Rostami et al. [12] studied the changes in DKV in 30 basketball players with DKV using the STOP-X program as an intervention. DKV was measured using FPPA during SLL. Comparing pre- and post-intervention results, the experimental group that underwent the STOP-X program showed significantly difference in static balance ($p = 0.001$), total dynamic balance score ($p = 0.001$), and knee valgus angle ($p = 0.001$) compared to the control group.

Table 1. Various 2D Single-legged DKV tests

Author	Subjects	Outcome measures	Result
Numata, H [7]	Injured group: non-contact ACL injuried female athletes (n=27) Control group: uninjured female athletes (n=27)	DKV 1. maximal knee valgus in SLDJ (2D motion analysis by markers: ASIS, medial and lateral femoral condyles) 2. the distance from the tip of the hallux to the point (where the line connecting the center of the patella and ASIS intersected the floor)	DKV was significantly greater in the injured group compared to the control group at hallux-ground contact ($p=0.006$) and at maximal knee valgus ($p=0.007$).
Jamaludin, N. I.[14]	34 physically active females (17 individuals with excessive DKV, 17 individuals without excessive DKV)	SLS with 2D video analysis compared to 3D motion analysis Their lower limb kinematics during SLS at 45° and 60° knee flexion were captured simultaneously by digital cameras (2-D motion capture) and infrared cameras (3-D motion capture)	45° and 60° SLS in normal and excessive DKV groups showed moderate to excellent within-day and between-day reliability In 2D FPPA 45° SLS were valid for non-dominant in both groups, 60° SLS were valid for non-dominant leg in excessive DKV and dominant leg in normal group
de Vasconcelos, D. P. [13]	38 female from runner clubs (17 individuals with patellofemoral pain, 21 asymptomatic individuals)	LSD squat test FPPA : ASIS, the midpoint of tibiofemoral joint, frontal area of talocrural joint	no significant correlation in FPPA values between the LSD test and running in both groups.
Kagaya, Y. [15]	130 female basketball players	1. SLS and SLDL (KID and HOD) 2. DTT and HFT	KID and HOD values for both SLS and drop landings were greater in DTT-positive than negative ($p<0.001$). KID values for both SLS and landings were greater for HFT-positive than negative ($p<0.001$), whereas HOD values did not significantly differ between the groups.
Munro, A. [6]	52 female football and basketball players	1. DJ task 2. SLL task FPPA : center of the ankle, center of the knee, midpoint of the femoral condyles	Both sports exhibited significantly greater FPPA values during SLL than DJ ($p<0.001$). Basketball players demonstrated significantly greater FPPA values during SLL than football players ($p<0.001$).
Karimi, K. [16]	62 students (39 males and 23 females) with and without DKV	SLS (knee flexion angle was nearly 60º during the test) DKV was diagnosed when the midpoint of the patella was moved inward to a point past the big toe in three out of five repetitions	individuals with DKV did not exhibit any significant differences, compared to those without.
Herrington, L. [23]	100 physically active asymptomatic individuals (50 male, 50 female)	1. DJ (Double legs) 2. SL (Single leg) FPPA : ASIS, the midpoint of the femoral condyles, and the midpoint of the malleoli	There were no differences between genders during the SL task and DJ task. Both males and females showed no significant differences between sides for either of the tasks or between the valgus angle generated for either of the tasks

Table 1. Various 2D Single-legged DKV tests (continued)

Author	Subjects	Outcome measures	Result
Wyndow, N. [17]	51 participants with PFOA 23 participants without PFOA	SLS FPPA : ASIS, the midpoint of the femoral condyles, and the midpoint of the malleoli	There was no difference in FPPA values between groups
Almeida, G. P. L. [24]	22 women with Patellofemoral pain synbdrome(PFPS)	SD FPPA : midpoint between the medial and lateral malleoli, the midpoint between the medial and lateral femoral condyles, and following a straight line from this marker to the ASIS	The Q-angle did not present any significant correlation with pain intensity, functional capacity, DKV or hip abductor torque.
Herrington, L. [18]	12 female subjects with unilateral patellofemoral pain(experimental) 30 asymptomatic females(control)	SLS SLL FPPA : ASIS, the middle of the tibiofemoral joint, the middle of ankle	Mean FPPA for SLS and SLL were significantly different between PFP group and control ($p<0.01$)
Llurda-Almuzara, L. [11]	50 healthy males	SLDJ FPPA : the ankle midpoint, the patella midpoint and the projection line between the patella midpoint and the ASIS	The correlation analysis showed no significant correlation between DKV and any NMR parameter ($p>0.05$; $r<0.3$)
Munro, A. [19]	Twenty recreationally active participants (10 women, 10 men)	SLS DJ SLL FPPA : proximal thigh to the knee joint and the line from the knee joint to the ankle	Women demonstrated significantly higher valgus ($p<0.05$) than men for all tests except SLS left ($p=0.057$). Within-session reliability was shown to be good for all tests, with the exception of SLS in women ICCs ranged from .59 to 0.88 for women, the SLS accounting for the fair score of 0.59, and men's ICCs ranged from 0.79 to 0.86
Ugalde, V. [9]	142 middle school and high school athletes	SLL DJ (both legs) FPPA : spheres were placed by a physical therapist onto each subject's left and right greater trochanter, and the center of the left and right patellas	Individuals in the positive SLS group had a significantly lower knee-hip ratio, indicative of greater DKV, than did those in the negative SLS group ($p<0.02$)

DKV: dynamic knee valgus, ASIS: anterior superior iliac spine, SLS: single leg squat, FPPA: frontal plane projection angle, LSD: lateral step down, SLDL: single leg drop landing KID: knee-in distance, HOD: hip-out distance, DTT: dynamic trendelenburg test, HFT: dynamic heel-floor test, DJ: drop jump, SLL: single leg landing, SL: step landing, PFOA: patellofemoral osteoarthritis, SD: step down, SLL: single leg landing, SLDJ: single leg drop jump, NMR: neuromuscular responses

Lateral step down squat

De Vasconcelos et al. [13] conducted a study involving 38 female members of a runner club, comprising 17 individuals with patellofemoral pain and 21 asymptomatic individuals. They observed DKV during LSD squats in both groups. The results showed no significant correlation in FPPA values between the groups during the LSD squat test.

Table 2. 2D Single-legged DKV tests in experimental studies

Author	Subjects	Outcome measures	Result
Di Staulo, A. M.[20]	23 females with patellofemoral pain participants were instructed to keep their hip, knee and ankle in line to avoid DKV and keep their shoulders and pelvis level during all tasks.	DKV by 2D knee FPPA and 3D hip and knee frontal and transverse plane angles at peak knee flexion in SLS (at pre- and post- intervention)	The knee FPPA decreased from a mean of 7.2 degree to a mean of −.9 degrees (SD: 8.9) following the intervention. A large portion of DKV, and change in DKV, was due to hip adduction and knee lateral rotation
Garcí-Luna, M. A.[21]	18 youth male soccer players 1. ACL-IPP Knee-Band squat exercise Side-Steps exercise Bulgarian Split-Squat exercise 2. SSFP	DKV was assessed using the SLS pre- and post-protocols in both legs FPPA (ASIS, the midpoint of tibiofemoral joint, frontal area of talocrural joint)	The ACL-IPP significantly decreased DKV during SLS ($p<0.01$, effect size $=1.39$), while the SSFP significantly increased baseline DKV in the dominant leg during SLS ($p=0.012$; effect size $=1.74$)

DKV: dynamic knee valgus, FPPA: frontal plane projection angle, SLS: single leg squat, ACL-IPP: ACL injury prevention protocol, SSFP: soccer-specific fatigue protocol, ASIS: anterior superior iliac spine

Table 3. 2D single-legged DKV tests in RCTs

Author	Subjects	Outcome measures	Result
Wilczyński, B.[22]	45 young football players (22 Intervention group, 23 Control group) Gluteus medius, Popliteus, Tibialis posterior strengthening exercise	FPPA in SLS test (the depth of the squat which was limited to approximately 60° markers at ASIS, midpoint of patella, midpoint of ankle)	No significant interactions between groups (Control and Exercise) and time (baseline and after 6 week) were noted for dynamic valgus for the left and right knee
Rostami, M.[12]	30 female basketball players with DKV (experimental = 15, control = 15) STOP-X program: running, balance training, a jump-landing pattern, and strength training for 25-40 min for eight weeks (three times per week)	FPPA in SLL (ASIS, midpoint of tibiofemoral joint, midpoint of ankle)	significant difference between the experimental and control groups in variables of the static balance ($p=0.001$), total dynamic balance score ($p=0.001$), and knee valgus angle ($p=0.001$).

RCT: randomized controlled trials, DKV: dynamic knee valgus, SLS: single leg squat, SLL: single leg landing, FPPA: frontal plane projection angle

Single leg squat

Jamaludin et al. [14] used 2D video analysis in a group of 17 healthy excessive DKV subjects and a group of 17 healthy subjects without excessive DKV. The 2D motion analysis was performed by capturing the knee flexion at 45° and 60° during the single leg squat test, and when the collected 2D video analysis was compared to the 3D motion analysis, it showed

moderate to excellent within-day and between-day reliability in both the normal group and the group with DKV at 45° and 60° (ICC ≥ 0.50). The 2D FPPA 45° SLS was valid for non-dominant in both groups, while the 60° SLS was valid for non-dominant in the DKV group and dominant in the normal group.

Kagaya et al. [15] measured DKV in 130 female basketball players during SLS and single leg drop tests. The methods used for measuring DKV included Knee-in distance (KID) and Hip-out distance (HOD). Other outcome measures included the Dynamic Trendelenburg Test (DTT) and the Dynamic Heel Floor Test (HFT). The group that tested positive for DTT showed significantly greater KID and HOD values in both SLS and SLD compared to the group that tested negative ($p < 0.001$). Additionally, in both tests, KID values were higher in the HFT-positive group compared to the HFT-negative group ($p < 0.001$), whereas HOD values did not show a significant difference between the groups.

Karimi et al. [16] measured DKV during SLS in 62 students, comprising 39 males and 23 females, with and without DKV. No significant differences were found between individuals with DKV and those without it.

Wyndow et al. [17] conducted a study involving 51 patients with patellofemoral osteoarthritis (PFOA) and 23 individuals without PFOA. They compared FPPA values during SLS and found no significant differences between the groups.

Herrington et al. [18] conducted a study involving 12 women with unilateral patellofemoral pain (experimental group) and 30 asymptomatic women (control group). The study utilized both the SLS and SLL tests, which are popular methods for assessing DKV. The results showed that in both the SLS and SLL tests, the experimental group exhibited significantly higher FPPA values compared to the control group ($p < 0.01$).

Munro et al. [19] conducted a study measuring FPPA values during SLS, DJ, and SLL tests in 20 healthy subjects (10 males and 10 females). Except for the left SLS, females demonstrated significantly larger valgus angles compared to males in all tests ($p < 0.05$). Except for the SLS in females, within-session reliability was good across all tests. The ICCs for females ranged from 0.59 to 0.88, and for males from 0.70 to 0.86, the SLS accounting for the fair score of 0.59.

Ugalde et al. [9] conducted a study comparing SLS and DJ in 142 middle and high school athletes. FPPA was used to measure DKV during the SLS test, and the knee-hip ratio was used to assess valgus during the DJ test. A smaller knee-hip ratio indicates closer knees and a larger valgus angle. Results showed that the group with positive DKV in SLS (ratio, 0.47) had a smaller knee-hip ratio compared to the negative DKV group (ratio, 0.55). Additionally, female athletes exhibited a significantly lower knee-hip ratio than male athletes (female group average knee-hip ratio = 0.45; male group average knee-hip ratio = 0.63; $p = 0.003$).

Di Staulo et al. [20] conducted an experimental study on 23 women with patellofemoral pain. The experimenters aimed to avoid DKV along the line from the hip to the ankle during various tasks. FPPA during a single-leg squat was used to measure the degree of DKV. As a result, the knee FPPA decreased from a mean of 7.2 degrees to a mean of -8.9 degrees (SD: 8.9) following the intervention.

García-Luna et al. [21] conducted an experimental study involving 18 male soccer players. DKV was measured in both lower limbs during SLS pre- and post- interventions. Participants with moderate or severe DKV before the intervention were assigned to the ACL Injury Prevention Protocol (ACL-IPP), while those with light or no DKV were assigned to the Soccer-Specific Fatigue Protocol (SSFP). The results showed that the ACL-IPP significantly decreased DKV during the SLS ($p < 0.01$, effect size = 1.39), whereas the SSFP significantly increased baseline DKV in the dominant leg during the SLS ($p = 0.012$, effect size = 1.74).

Wilczyński et al. [22] observed the changes in DKV when strengthening the gluteus medius, popliteus, and tibialis posterior muscles in 45 young football players. DKV was measured using FPPA during SLS. The results showed that there were no significant interactions between groups (Control and Exercise) and time (baseline and after 6 week) in either limb.

Discussion

Based on the literature review conducted in this

study, it was found that even when measuring the most popular test method, the SLS, using the FPPA method, various results were observed. Kagaya et al. [15] utilized two of the most common methods, SLS and SLL, in their experiment. They measured DKV using different markers (ASIS, midpoint of the patella, midpoint of the ankle) than usual. In this study, DKV was measured using KID and HOD. The KID values were higher in the HFT positive group compared to the negative group, but the HOD values did not show a significant difference between the groups. This suggests that the KID measurement method can be influenced by both the hip and ankle joints, whereas the HOD method is influenced by the hip joint but less clearly by the ankle joint. Therefore, if we want to consider the influences of both the hip and ankle joints in the future, using the KID method would be better than the HOD method.

Additionally, according to Karimi et al. [16], in a study involving 62 students with and without DKV, measuring SLS using FPPA showed no significant difference between the two groups. This might indicate that SLS is not a sufficiently powerful test to distinguish DKV, but the results might be limited since the study only involved students. Research involving various age groups is needed.

Furthermore, the SLS method revealed gender differences. Various studies that measured DKV through SLS showed significant differences in DKV levels based on gender. Specifically, Ugalde et al. [9] expressed DKV severity using the knee-hip ratio, which considers the distance between both knee joints and both hip joints, providing a more intuitive indicator of alignment between the two joints. However, the method of measuring only the distance between both knee joints and both hip joints is simpler than the methods used in other studies but may be less accurate. More research is needed to validate this simple method.

In a study comparing basketball and football players, it was found that basketball players exhibited higher DKV values during SLS than football players [9]. This suggests that basketball may place more stress on the knee joint compared to football, but it is necessary to measure the direct stress on the knee to confirm this.

Two experimental studies were included in the reviewed literature. Di Staulo et al. [20] provided feedback to reduce DKV during lower limb tasks in patients with Patellofemoral Pain. Comparing their DKV before and after the intervention showed a significant reduction in DKV. This suggests that DKV can be corrected through feedback provided during exercises or tasks. Additionally, García-Luna et al. [21] conducted an experimental study comparing ACL-IPP and SSFP. Depending on the severity of DKV, ACL-IPP was applied for moderate or higher cases, and SSFP was applied for mild cases. The group that underwent ACL-IPP showed improvement in DKV, while the SSFP group showed deterioration. These results indicate that the ACL-IPP, which focuses on neuromuscular and proprioceptive exercises emphasizing hip abductor muscles, is effective in reducing DKV. These two experimental studies will be important cornerstones in intervention research for reducing DKV. Other test methods such as Lateral Step Down did not show significant results. Therefore, the most sensitive test to distinguish DKV is SLS, and the representative measurement method is FPPA. However, for patients with knee instability due to knee disorders, such a high-intensity test may pose a risk. It is essential to modify the test method based on the degree of knee instability. Additionally, if the correlation between the hip and knee joints is to be examined, using the KID method could be a good option.

Conclusion

This study examined various DKV tests and their measurement methods, identifying the SLS as the most popular and sensitive test, with the 2D measurement method of the FPPA as the most effective. However, even in studies measuring SLS using FPPA, the discriminative power may be somewhat limited when applied to individuals without specific knee pathology. Additionally, the KID method, which examines the correlation between the hip and knee joints, can also be a good option. Moreover, interventions that provide feedback to reduce DKV during lower limb tasks or those using the ACL-IPP can be proposed as effective

treatment methods if supported by ongoing research. These approaches could continuously reduce DKV and offer significant therapeutic benefits.

Conflict of interest

The authors of this study declare that there are no potential conflicts of interest with respect to the research, authorship, and publication.

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