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Original Article

The Effect of a 4-Week TRX Suspension Training on Lower Extremity Alignment and Muscle Strength in Male Basketball Players

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ABSTRACT

Background: This study investigated the effectiveness of a 4-week TRX suspension training program on knee and hip alignment as well as hip muscle strength in male basketball players with dynamic knee valgus.
Methods: The present study was Quasi-experimental, and its statistical population consisted of basketball players (18-25 years old) from Mashhad, Iran. Thirty-two athletes diagnosed with dynamic knee valgus were randomly selected as samples and randomly assigned to experimental (n=16) and control (n=16) groups. Data measurement tools included Kinovea software (Kinovea Robotics, Canada, 2006) and an isokinetic dynamometer (JTECH MedicalTM Commander instruments). To measure kinematic angles, athletes performed standardized tasks such as squats and lunges, which were selected to elicit dynamic knee valgus and accurately assess knee and hip alignment. A 4-week TRX suspension training program (3 sessions/week, 30-45 minutes/session) was implemented for the exercise group. Statistical analyses (paired t-tests, ANCOVA) were conducted using SPSS software (P<0.05).
Results: Paired-sample t-tests revealed significant improvements in knee and hip alignment (reduced knee valgus (P=0.003) and hip drop angles (P=0.013)) in the exercise group post-training compared to pre-training. The exercise group's dominant leg also observed significant increases in hip abductor, extensor, and external rotator strength (P=0.0001). Analysis of covariance (ANCOVA) controlling for pre-test scores demonstrated significant between-group differences in all outcome measures, indicating the TRX program's effectiveness in the dynamic knee valgus group compared to the control.
Conclusion: This study suggests that a 4-week TRX suspension training program can effectively improve knee and hip alignment and strengthen hip musculature in male basketball players with dynamic knee valgus.

Introduction

Basketball is a widely played sport, boasting over 300 million participants globally [1]. Originating in the United States in 1891 [2], it is characterized by its fast-paced nature and requires a range of skilled movements [3], including running, jumping, and quick directional changes [4]. These explosive actions place significant stress on the knees, leading to a high incidence of injuries, particularly involving the anterior cruciate ligament (ACL) [5]. Such injuries can result in long-term complications like instability, chronic pain, and an increased risk of

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osteoarthritis [6]. Research indicates that many ACL injuries in basketball players stem from inadequate safety awareness and insufficient physical preparation during play [7]. Consequently, preventive strategies such as neuromuscular and proprioceptive training programs have been recommended to mitigate these risks [7].

The prevalence of knee injuries in men's basketball is particularly concerning [8]. Among lower limb injuries, ankle and knee injuries are the most common [9]. Although recent data suggests a decline in overall injury rates, non-contact ACL injuries remain a significant concern [10], often linked to poor landing mechanics and dynamic knee valgus (DKV) [11]. DKV is recognized as a critical risk factor for various sports-related injuries, including non-contact ACL injuries, patellofemoral pain syndrome, and osteoarthritis [12-15]. Studies have shown that athletes frequently exhibit poor alignment during dynamic movements, which can exacerbate DKV [11]. For instance, research indicates that basketball and volleyball players struggle to maintain proper alignment during dynamic squats, contributing to the development of DKV [16]. This misalignment is particularly alarming given its association with increased ACL injury risk [17].

Strengthening the muscles around the hip joint is vital in reducing DKV and consequently lowering the risk of ACL injuries [18]. The interplay between hip and knee muscle strength is crucial for maintaining proper alignment during athletic activities [18]. Previous studies have demonstrated that targeted hip strengthening exercises can significantly reduce DKV and internal rotation during movement [19]. However, despite these findings, there remains a lack of consensus regarding the relationship between DKV and hip muscle strength among healthy, active males [20].

TRX suspension training has emerged as a versatile exercise modality that utilizes body weight and straps to engage major muscle groups while promoting core strength, improved posture, and enhanced balance [21]. Its practical applications extend across diverse populations, demonstrating effectiveness in performance enhancement and injury risk reduction [22]. TRX training has proven beneficial for rehabilitation following ACL injuries [23] by improving muscle strength [23, 24], joint stability [24], and balance [25].

Knee injuries, particularly DKV, are common issues in athletes, especially in dynamic sports like basketball, where complex movements and improper landings can lead to severe injuries. While previous studies, such as those by Schwameder (2020) and Christensen et al. (2018), have highlighted the general benefits of TRX training for enhancing movement function in athletes [26, 27], limited research has specifically addressed its effects on knee alignment and lower extremity muscle strength in university-level male basketball players. Given the high injury rates in this population and the need for preventative interventions, this study fills a significant gap by examining the effects of a four-week TRX suspension training program on knee alignment and muscle strength in this at-risk group. Additionally, considering the lack of consensus regarding the relationship between DKV and hip muscle strength in active, healthy males [20], our research provides new insights into this connection and contributes valuable knowledge to the literature. This study aims to advance our understanding of the impact of TRX training on reducing DKV and strengthening lower extremity muscles in this targeted demographic, ultimately aiding in the prevention of common musculoskeletal injuries in athletes.

Methods

The study was approved by the Human Ethics Research Committee of the Sport Sciences Research Institute of Iran (IR.SSRI.REC-2404-2728) and the Declaration of Helsinki. This quasi-experimental study involved male basketball players aged 18 to 25 from Mashhad. After a call for participation, 123 individuals expressed interest in joining the study. Following the application of the inclusion criteria, 89 participants were ultimately selected. Using G*Power software with an effect size of 0.5, an alpha error of 0.05, and a power of 0.95, the required sample size for the t-test was calculated to be 32 participants. A total of 32 participants were then randomly selected from a pool of 89 and assigned to either a control group (n=16) or an experimental group (n=16). The randomization process was conducted using a simple randomization method via a computerized random number generator to ensure unbiased group allocation. All participants provided informed consent before participation.

Data collection instruments included Kinovea software (Kinovea Robotics, Canada, 2006) for measuring pelvic drop and knee valgus angles and a JTECH MedicalTM Commander isokinetic dynamometer for measuring isometric strength of the dominant lower extremity's hip abductors, extensors, and external rotators. These instruments were calibrated before data collection, ensuring measurement reliability. Kinovea software was regularly calibrated following the manufacturer's guidelines, and the dynamometer was recalibrated before each session using certified reference standards. This ensured consistent and accurate measurements. Additionally, an accredited exercise specialist supervised all measurements to maintain accuracy.

Inclusion Criteria

Age range 18-25 years; at least five years of regular basketball activity, averaging three sessions per week; normal BMI (20-25); valgus angle greater than 12 degrees during single-leg landing test [28]; no generalized joint laxity by Beighton and Horan criteria [29]; no apparent lower limb abnormalities (anteversion of the femur, genu valgum, genu varum, tibial rotation, and flat feet); no history of surgery in the trunk or lower limbs; no history of permanent injury (such as degenerative changes in the knee joint, unstable ankle, etc.) in the lower limbs; no anterior cruciate ligament (ACL) injury; no history of severe lower limb injury in the past year; no participation in any ACL injury prevention training program.

Exclusion Criteria

Non-cooperation of participants during the study, two consecutive absences, or onset of pain during training.

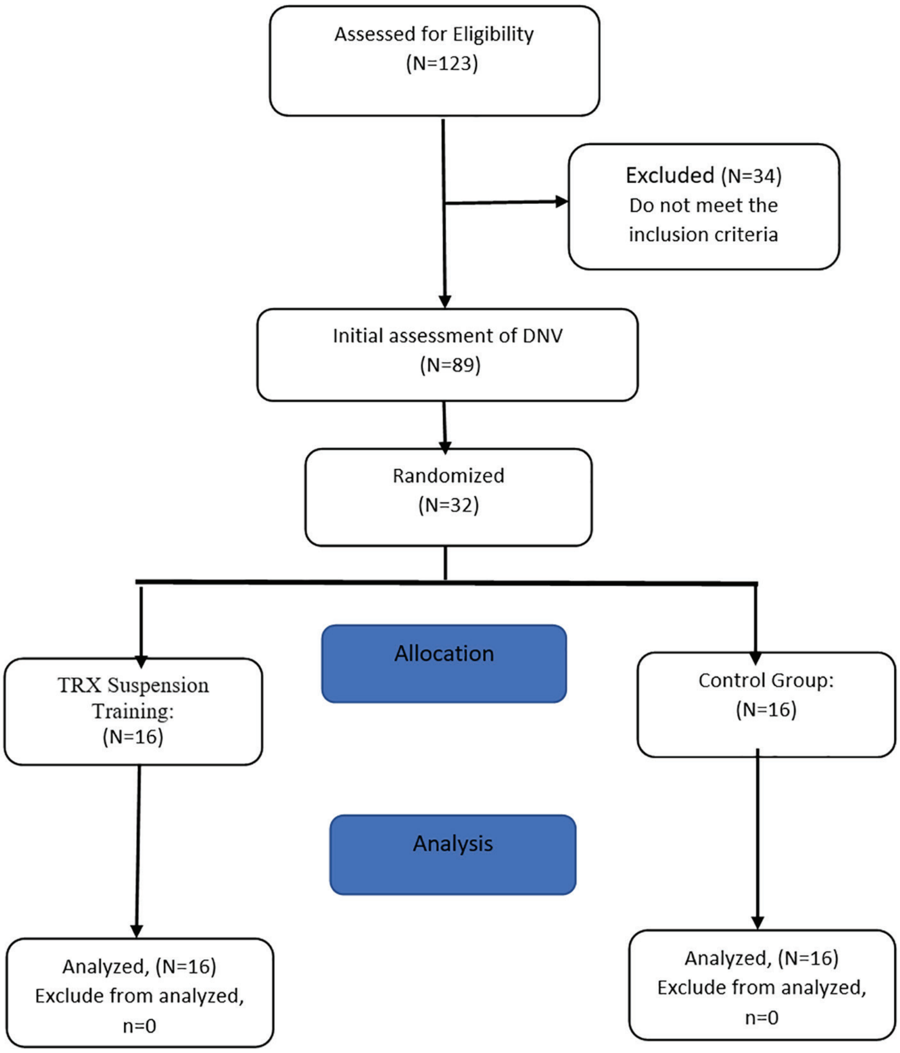

Figure 1: Consort flow chart for enrollment and intervention

Procedure

After a 10-minute warm-up and familiarization with the one-leg jump tests, the control and experimental groups were measured in three successful attempts in the pre-test. A 30-cm box was used for the single-leg landing test. The participant stood in a balanced position near the edge of the box with the dominant foot suspended (heel in contact with the edge of the box). This position limits horizontal body movements by controlling the center of gravity. No instructions were given to the athletes regarding the correct landing technique [30]. A camera was placed on a tripod at a height of 102 cm and a distance of 366 cm from the box in a frontal view so that the entire lower limb of the subject was in the camera frame [31]. The participant practiced the landing movement three times before performing the test. Three successful attempts were recorded for each participant. The average angles of the three attempts were used in the final analysis of knee valgus and pelvic drop angles. A corrective exercise specialist in the gym took measurements. The exercise group performed TRX suspension training at a gym for four weeks, three sessions per week, 30-45 minutes per session, as presented in the Consort flow chart (Figure 1).

Measurement of Knee Valgus and Hip Drop Angle

The knee valgus and hip drop angles were measured by positioning markers at four precise anatomical points: the left and right anterior superior iliac spines (ASIS), the patella's center, and the midpoints of the ankles. The Kinavea software automatically tracks the bilateral ASIS markers, minimizing user error and ensuring consistent measurements.

The angle between two lines was measured to calculate the knee valgus angle: one extending from the dominant leg's ASIS to the patella's center and the other from the patella to the midpoint of the malleolus. This angle was subtracted from 180° to determine the knee alignment angle in the frontal plane. The angle between a line connecting the right and left ASIS and a perpendicular line extending from the landing leg's ASIS was measured for the hip drop angle. The result, subtracted from 90°, was recorded as the hip drop angle (Figure 2).

The Kinovea software has demonstrated high reliability and validity in previous studies. Puig-Diví et al. (2019) reported an ICC above 0.90 and optimal accuracy at 90° for distances up to 5 meters [32]. Kim et al. (2015) observed strong correlations (>0.98) between Kinovea and a standard goniometer, confirming its validity [33]. Furthermore, Grigg et al. (2018) noted a mean error of less than 2°, establishing the software's precision in kinematic analyses [34]. These results confirm Kinovea's reliability for biomechanical measurements.

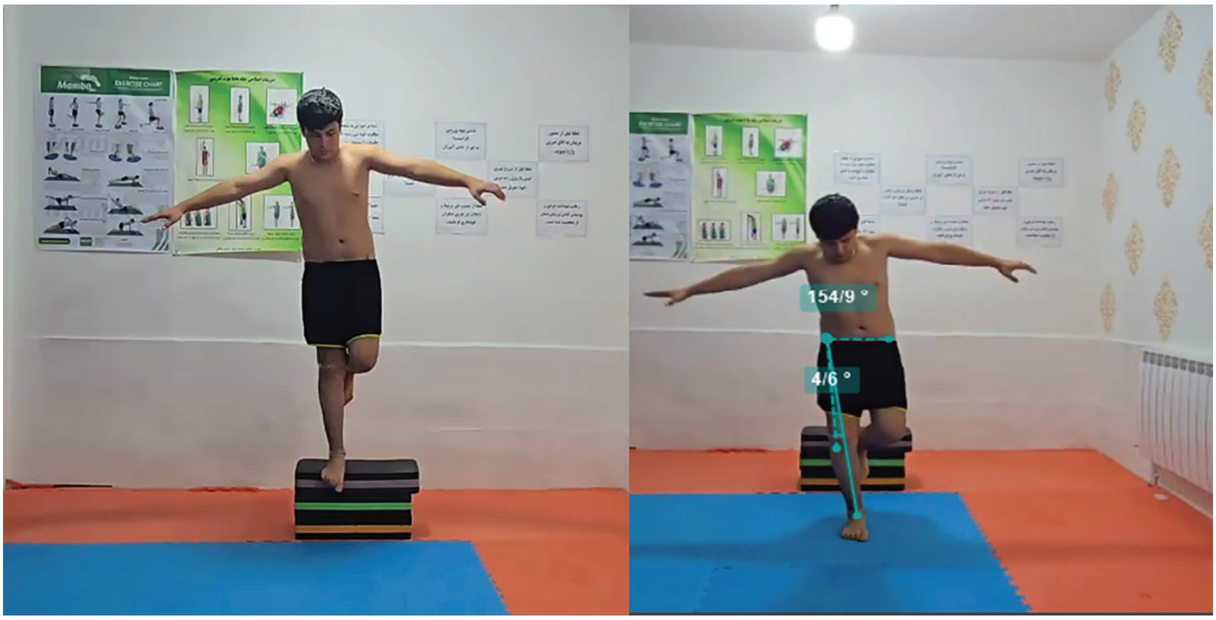

Figure 2: Measurement of the knee valgus angle

Measurement of Hip Muscles Strength

The isokinetic strength of the dominant leg's hip abductors, extensors, and external rotators was measured using the JTECH Medical™ Commander digital dynamometer under standardized procedures. A stabilization strap was used to control the applied force and prevent movement of other body parts. Participants completed a practice set to familiarize themselves with the testing process. During testing, they were encouraged to exert maximum effort against the dynamometer's resistance. Each test was repeated thrice, lasting five seconds per trial, with 15-second rest intervals [35]. The maximum recorded force, normalized to body weight, was used for the final analysis.

To assess hip abductor strength, participants lay on their sides on an examination table with the tested leg elevated. A strap stabilized the pelvis, and another strap above the lateral malleolus secured the dynamometer. A pillow between the thighs maintained the tested limb at 0° abduction. Participants were instructed to point their toes forward, avoid hip flexion or external rotation, and perform maximum-effort abduction [35].

For hip extensor strength, participants lay prone on the examination table with their knees flexed at 90°. A strap stabilized the pelvis, and the dynamometer was positioned at the posterior distal aspect of the thigh. Participants were instructed to extend their hips with maximum effort, generating tension in the dynamometer [35].

To measure external rotator strength, participants sat with their hip and knee flexed at 90°. The dynamometer was placed parallel to the lower leg and secured with a strap 5 cm proximal to the medial malleolus. Participants crossed their arms over their chest to prevent upper body movement and performed external rotation of the tested limb with maximum effort [35].

TRX Suspension Training

Participants in the exercise group engaged in a 4-week TRX suspension training program designed according to established protocols [21, 36]. Training sessions were conducted thrice weekly, lasting 30 to 45 minutes each. The program aimed to strengthen lower-limb muscles, with exercises progressively increasing in difficulty. Intensity was enhanced through gradual adjustments in the complexity of exercises, the number of repetitions, and the duration of activities, following progressive overload and specificity principles. The progression included transitioning from bilateral movements like squats to more demanding unilateral exercises such as single-leg squats, alongside modifications in plank durations to optimize muscle engagement. These changes effectively improved lower-limb strength, balance, and core stability while minimizing the risk of overtraining. All participants adhered to the TRX program, and a corrective exercise specialist and a trainer supervised the exercises. In contrast, the control group did not participate in any specific exercise interventions during this period (Table 1).

Data Analysis

Normality was assessed using the Shapiro-Wilk test, equality of variances was evaluated with Levene's test, and homogeneity of regression slopes was confirmed to satisfy the key assumptions of ANCOVA. Statistical analyses, including paired t-tests and ANCOVA, were performed using SPSS version 22, with a significance level of $P<0.05$.

Results

Table 2 shows the statistical indices of age, height, and weight of the participants in different training groups. Based on the independent t-tests, no significant differences were found between the experimental and control groups regarding age, height, and weight (Table 2).

The normality of the data distribution for the research variables was tested using the Shapiro-Wilk test at the pre-test and post-test stages and between the experimental groups ($P<0.05$). The assumption of equal variances was checked using Levene's test ($P<0.05$), and the homogeneity of variances between the groups was confirmed.

Table 1: TRX suspension training for four weeks

Week	Practice	Set×repetition	Week	Practice	Set×repetition
1	Squat (go to the toe and back)	3×10	3	Single leg squat	3×10
	forward lunge	3×10		Suspended Lunge	3×10
	Side lunge	3×10		Abduction lunge	3×10
	Plank (elbow)	45sec×3		Single leg plank	30sec×3
	Omega	3×10		Single leg omega	3×10
	Plank(supine)	45sec×3		Hamstring curl (hip ground)	3×10
2	squat+hip abduction	2×10	4	single leg squat	3×10
	Cross lunge	2×10		Suspended Lunge	3×10
	Side lunge(steep)	2×10		Abduction lunge	3×10
	Plank(hand)	30sec×3		Single leg plank	45sec×3
	Side omega plank	2×10		Single leg omega	3×10
	Hamstring curl (hip ground)	2×10		Hamstring curl (hip ground)	3×10

Table 2: Statistical indices related to the participant's age, height, and weight

Variable	Group	Number	Mean±SD	t-statistic	P value
Age	Experimental	16	20.50±2.28	-1.49	0.1467
	Control	16	21.62±1.96		
Height	Experimental	16	185.12±6.16	-1.048	0.3028
	Control	16	187.68±7.58		
Weight	Experimental	16	80.00±4.83	-0.6368	0.5291
	Control	16	81.25±6.19		

The results of the homogeneity of regression slope test also showed that the homogeneity of regression slope was observed.

A paired-sample-test was conducted to assess the impact of TRX training on knee valgus angle, hip drop angle, and the strength of hip muscles, including abductors, extensors, and external rotators. The results showed a significant reduction in the mean knee valgus angle (P=0.003) and hip drop angle (P=0.013) from the pre-test to the post-test. Additionally, there was a significant increase in the mean strength of hip abductors, hip extensors, and external hip rotators (P=0.0001) following the training (Table 3).

The ANCOVA results comparing the two groups on hip and knee alignment, as well as hip abductor, extensor, and external rotator muscle strength, revealed significant differences. A notable effect was found for knee valgus angle (P=0.003, ES=0.264) and hip drop angle (P=0.010, ES=0.207). In terms of muscle strength, there were substantial improvements in hip abductors (P=0.0001, ES=0.586), external hip rotators (P=0.0001, ES=0.405), and hip extensors (P=0.0001, ES=0.633) (Table 4).

Discussion

This study investigated the effectiveness of a 4-week TRX suspension training program on knee and hip alignment and muscle strength in male basketball players with DKV. The results of this study demonstrated that a 4-week TRX suspension training program significantly

Table 3: Results of paired-samples t-test for within-group comparison of hip and knee alignment variables

	Variable	Group	Mean±SD		df	T	Sig
			Pre-test	Post-test			
Knee and hip alignment	Knee valgus angle	Experimental	16.18±1.22	13.93±2.01	15	3.57	0.003*
		Control	15.50±1.21	16.25±1.73	15	-1.48	0.158
	Hip drop angle	Experimental	5.06±1.34	3.87±1.36	15	2.82	0.013*
		Control	4.87±1.45	5.37±1.62	15	-0.77	0.451
Muscle strength	Hip abductors	Experimental	29.50±9.57	45.43±4.64	15	-5.07	0.0001*
		Control	31.93±9.64	30.25±8.72	15	0.42	0.675
	External hip rotators	Experimental	24.12±3.86	33.06±4.28	15	-5.99	0.0001*
		Control	25.25±4.75	26.50±3.88	15	-0.85	0.405
	Hip extensors	Experimental	27.93±8.45	44.43±6.59	15	-6.19	0.0001*
		Control	28.87±7.33	26.06±7.86	15	1.12	0.277

DF: Degrees of freedom; Significance level=P<0.05.

Table 4: Results of ANCOVA for comparing the training groups on hip and knee alignment and hip abductor, extensor, and external rotator muscle strength

	Variable	SS	DF	MS	F	Sig	ES
Knee and hip alignment	Knee valgus angle	37.95	1	37.95	10.40	0.003*	0.264
	Hip drop angle	17.29	1	17.29	7.55	0.010*	0.207
Muscle strength	Hip abductors	162.34	1	162.34	41.01	0.0001*	0.586
	External hip rotators	340.48	1	340.48	19.71	0.0001*	0.405
	Hip extensors	271.45	1	271.45	50.08	0.0001*	0.633

DF: Degrees of freedom; SS: Sum of Squares; MS: Mean Square; EF: Effect Size; Significance level=P<0.05.

improved knee valgus angle and hip drop angle while also increasing the strength of the hip abductors, extensors, and external rotators in male basketball players with dynamic knee valgus (DKV).

The observed reduction in knee valgus angle and hip drop angle in the current study (P=0.003, P=0.013) aligns with findings from Schwameder (2020), who reported significant improvements in knee valgus during drop landings after a TRX suspension training program, likely due to improved neuromuscular control [27]. Similarly, Christensen et al. (2018) found that TRX exercises enhanced agility and neuromuscular coordination, further supporting the current study's results on improved joint alignment [26]. Both studies suggest that TRX suspension training effectively addresses common movement dysfunctions associated with DKV, particularly in dynamic sports like basketball.

The significant increase in hip muscle strength in the present study (P=0.0001 for all muscle groups) is comparable to findings by Khorjahani et al. (2021), who observed similar improvements in muscle strength in female athletes with functional ankle instability (FAI) following TRX training [23]. Both studies support the hypothesis that TRX suspension training promotes muscle adaptations, particularly in the hip muscles, which are critical for maintaining proper alignment and reducing injury risks in athletes.

However, differences in the intervention duration and population demographics may explain some discrepancies in the findings. For instance, the present study's shorter four weeks contrasts with Piri et al. (2021), who conducted an 8-week intervention and found a significant reduction in anterior pelvic tilt (APT) using both Pilates and TRX exercises [37]. The longer duration in Piri's study might have allowed for more pronounced changes in pelvic alignment, which may not have been fully captured in this study's shorter intervention period.

Additionally, while the current study focused on male basketball players, Herrington (2010) observed reduced knee valgus angles in female basketball players after a jump-training program, which also targeted knee alignment but differed in exercise modality [31]. These gender and exercise-based variations highlight that the effects of training may differ based on the population studied and the specific exercises employed. Future studies should explore whether the observed improvements in knee and hip alignment translate equally to female athletes or those participating in different sports.

The consistency in findings across studies regarding the effectiveness of TRX training on joint alignment and muscle strength can largely be attributed to the multi-joint nature of TRX exercises. These exercises challenge neuromuscular control and proprioception, resulting in better body alignment and joint stability, as shown in this study and previous research [26, 27, 38]. Incorporating dynamic movements in TRX suspension training closely mimics the biomechanical demands of sports like basketball. This further explains why improvements in movement patterns like knee valgus are seen across multiple studies.

On the other hand, the discrepancies in results, particularly concerning the magnitude of improvements, can be explained by differences in training duration, participant characteristics, and exercise modality. For example, Abtahi et al. (2023) found that just six weeks of TRX training improved both static and dynamic balance in young female athletes [25], while the current study showed significant improvements in four weeks. The shorter duration in this study may have been sufficient for improving alignment and muscle strength. Still, it may not fully capture long-term benefits such as balance or proprioception enhancements requiring extended training. This highlights the comprehensive benefits of TRX training in improving various aspects of physical performance.

Additionally, Yalfani (2021) found that both TRX suspension and core stabilization exercises led to significant improvements in diastasis recti abdominis (DRA) in women, suggesting that TRX exercises are comparable to other core-focused interventions [39]. However, since the present study focused solely on male athletes, it remains unclear whether TRX training would yield similar outcomes in addressing other conditions, such as DRA, in a male population.

The findings have important practical implications for basketball training programs. The study suggests that integrating TRX suspension training into basketball programs could improve knee and hip alignment, strengthen key muscle groups, and reduce the risk of ACL injuries. It may benefit injury prevention and rehabilitation in athletes with movement dysfunctions like DKV. TRX exercises are low-impact and suitable for various populations, including those recovering from injuries or aiming to enhance performance. The study's limitations include a small sample size, a short intervention period, and a focus only on male basketball players. These factors restrict the generalizability of the findings. Further studies are necessary to explore the long-term effects of TRX suspension training, its impact on athletes from different sports, and combining TRX training with other exercises to improve knee and hip alignment and muscle strength.

Conclusion

In conclusion, this study's results demonstrate that a 4-week TRX suspension training program improves lower extremity alignment and muscle strength in male basketball players with DKV. The improvements in knee valgus angle, hip drop angle, and hip muscle strength align with prior research, highlighting the value of TRX training for addressing movement dysfunction and reducing injury risk. However, differences in intervention duration, population demographics, and exercise modality explain the variation in the magnitude of results across studies.

Authors' Contribution

MSA, KK, and AA contributed to the study conception and design, and AA performed clinical examination and data collection. MS and KK participated in the methodological development and design of the statistical analysis. MSA and MAZ wrote the first draft of the manuscript and contributed to the comments and suggestions that significantly improved the manuscript. Finally, all the authors revised it critically for important intellectual content, agreed with the content, contributed to the current study's refinement, and approved the final manuscript.

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