



LOWER-LIMB STRENGTH AND BALANCE ASYMMETRIES IN ADOLESCENT FEMALE BASKETBALL PLAYERS

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ABSTRACT

Purpose: Adolescent female basketball players experience increased risk of lower-limb injury, particularly during periods of rapid growth and maturation. Lower-limb strength and balance asymmetries are recognized contributors to injury risk and are commonly assessed after injury, yet they are less frequently evaluated as part of preventive screening in healthy athletes.

Methods: Twenty-two female U18 basketball players (mean age, 16.2 ± 1.2 years) underwent preventive assessment of lower-limb symmetry. Isokinetic knee flexor and extensor strength were measured at angular velocities of 60°/s, 180°/s, and 240°/s, with peak torque and hamstring-to-quadriceps (H:Q) ratios analysed. Dynamic balance was assessed using the Y-Balance Test (YBT), with reach distances normalized to limb length. Limb Symmetry Index (LSI) was calculated for all measures. Clinically relevant asymmetry was defined as LSI >10% or an anterior YBT reach difference >4 cm.

Results: At the group level, lower-limb symmetry appeared generally acceptable, with mean LSI values below 10% for isokinetic strength, H:Q ratios, and YBT performance. However, in most of the tested parameters, 25% of athletes demonstrated strength asymmetries exceeding 10%. On the YBT, 32% of participants exhibited LSI >10% in at least one reach direction, and 36% of athletes demonstrated anterior reach asymmetry greater than 4 cm, indicating potential functional imbalance.

Conclusion: Although group-level findings suggest good symmetry, a substantial proportion of healthy adolescent female basketball players display clinically meaningful individual asymmetries in strength and dynamic balance. These asymmetries may represent neuromuscular profiles relevant to lower-limb injury risk and support the

use of preventive screening to identify athletes who may benefit from targeted injury-prevention strategies.

Keywords: lower-limb symmetry, basketball, isokinetic strength testing, functional performance testing, Y balance test

ASIMETRIJA MIŠIČNE ZMOGLJIVOSTI IN RAVNOTEŽJA SPODNJIH UDOV PRI MLADIH KOŠARKARICAH

IZVLEČEK

Namen: Pri mladih košarkaricah je povečano tveganje za poškodbe spodnjih okončin, zlasti v obdobjih hitre rasti in pubertete. Asimetrije mišične zmogljivosti in ravnotežja spodnjih udov so pomemben dejavnik tveganja za poškodbe in se pogosto ocenjujejo po poškodbi, redkeje pa v okviru preventivnega presejanja pri zdravih športnicah.

Metode: V raziskavo je bilo vključenih 22 košarkaric kategorije U18 (povprečna starost $16,2 \pm 1,2$ leta), pri katerih je bila izvedena preventivna ocena simetrije spodnjih udov. Izokinetična jakost fleksorjev in ekstenzorjev kolena je bila izmerjena pri kotnih hitrostih 60°/s, 180°/s in 240°/s, pri čemer sta bila analizirana največji navor in razmerje med zadnjimi stegenskimi mišicami in kvadricepsom ($H : Q$). Dinamično ravnotežje je bilo ocenjeno z Y- testom ravnotežja (YBT), pri čemer so bile razdalje dosega normalizirane glede na dolžino uda. Za vse meritve je bil izračunan indeks simetrije udov (LSI). Klinično pomembna asimetrija je bila opredeljena kot $LSI > 10\%$ ali razlika v anteriornem dosegu pri YBT > 4 cm.

Rezultati: Povprečne vrednosti LSI-ja pri meritvah izokinetične jakosti, razmerju $H : Q$ in rezultatih YBT-ja so bile nižje od 10 %. Kljub temu je pri večini testiranih parametrov vsaj 25% športnic doseglo $LSI > 10\%$. Pri YBT-ju je 32 % udeleženk doseglo $LSI > 10\%$ v vsaj eni smeri dosega, pri 36 % športnic pa je bila ugotovljena anteriorna asimetrija dosega, večja od 4 cm, kar kaže na mogoče funkcionalno neravnovesje.

Zaključki: Čeprav rezultati vzorca kažejo dobro simetrijo, ima pomemben delež zdravih mladih košarkaric klinično pomembne individualne asimetrije v mišični jakosti in dinamičnem ravnotežju. Te asimetrije so lahko živčno-mišični profili, pomembni za tveganje za poškodbe spodnjih okončin, in podpirajo uporabo preventivnega presejanja za prepoznavanje športnic, ki bi jim lahko koristili ciljno usmerjeni preventivni programi.

Ključne besede: simetrija spodnjih udov, košarka, izokinetično testiranje, testiranje v funkciji, Y-test ravnotežja

INTRODUCTION

High school sports participation in developed countries is on the rise. In the United States alone, participation increased by more than 200,000 in the previous season, continuing an upward trend and reaching an all-time high. The largest gains were observed in girls' sports, with basketball remaining among the top four most widely participated sports (National Federation of State High School Associations, n.d.).

Despite its numerous health benefits, participation in a physically demanding sport such as basketball is associated with an increased risk of injury (Andreoli et al., 2018). Girls are injured more frequently than boys, with injury rates of 2.08 and 1.83 injuries per 1,000 hours of basketball participation, respectively (Borowski, Yard, Fields & Comstock, 2008), furthermore, females typically require longer rehabilitation periods and therefore remain out of competition for longer (Zuckerman et al., 2018; Leppänen et al., 2017). They are more likely to sustain knee injuries, with ligament sprains being the most common type of injury, and they are also more likely to require surgical intervention (Borowski et al., 2008).

Differences in injury rates can be attributed to physiological factors and anatomical differences in joint and bone structure (Borowski et al., 2008), variations in flexibility and strength, and hormonal influences (Adachi, Nawata, Maeta & Kurozawa, 2008; Myer, Ford, Khoury, Succop & Hewett, 2011). In addition, girls often train under less favourable conditions, with more limited access to high-quality equipment, training facilities, and competitive environments, reflecting lower levels of financial investment in female sport (Clifton et al., 2018).

Adolescents are at the highest risk of injury because ongoing growth and physical development affect muscle capacity and neuromuscular control (Parry et al., 2024). Research comparing pre- and post-pubertal athletes reports that hormonal changes associated with puberty alter muscle strength and balance, causing strength imbalances between knee flexors and extensors, which are considered risk factors for knee injuries in adolescents (Amado et al., 2023). As a result, adolescent athletes may not have the same level of physical fitness as professional athletes (Agresta, Church, Henley, Duer & O'Brien, 2017), despite often being exposed to similar or even greater training volumes. Sudden or excessive increases in training load may lead to compensatory adaptations, resulting in muscular imbalances that can cause pain and injury (Moseid et al., 2019).

Developmental trajectories reveal critical periods for the emergence of sex-specific risk factors. Prepubescent male and female athletes show no significant

differences in anterior cruciate ligament (ACL) injury risk factors, with the disparity emerging post-puberty. Rapid increases in bone length and body mass during puberty occur without corresponding increases in strength and neuromuscular control, contributing to increased knee abduction moments (Myer et al., 2011).

Lower limb symmetry is a key criterion for normalizing function and ensuring a safe return to sport (Wilk, Romaniello, Soscia, Arrigo & Andrews, 1994). Asymmetry between the lower limbs, even in otherwise healthy and uninjured individuals, can result from muscular imbalances that may negatively affect an athlete's physical performance and be associated with an increased risk of injury (Leister et al., 2018). Asymmetry most commonly occurs in sports involving rapid changes of direction and jumping (Mehl et al., 2018; Bishop, Turner & Read, 2018).

Lower limb symmetry testing is commonly used as a criterion for a safe return to training after injuries such as anterior cruciate ligament reconstruction but is rarely used as a preventive measure in healthy athletes. Functional asymmetry of the lower limbs is often researched because the results provide valuable insight into the effects of training and may help identify opportunities to modify training programmes and incorporate preventive exercises aimed at reducing the risk of lower limb injuries (Fousekis, Tsepsis & Vagenas, 2010). If the symmetry index was not measured before the injury occurred, its use as a return-to-sport criterion becomes unreliable. This may lead to a premature return to training, thereby increasing the risk of re-injury, or excessive asymmetry may be misinterpreted, delaying a return to competitive sport (Lambert et al., 2020).

Taken together, the existing evidence highlights adolescence as a particularly vulnerable period for the development of lower-limb strength and balance asymmetries, especially in female basketball players exposed to high training demands. Despite the recognized importance of limb symmetry for performance, injury prevention, and safe return to sport, the preventive assessment of lower-limb asymmetries in healthy adolescent athletes using combined strength and functional measures remains limited. Therefore, the aim of this study was to quantify the lower-limb symmetry index in young female basketball players using isokinetic strength testing, the Y-Balance Test (YBT) to better characterize asymmetry profiles and inform injury-prevention strategies.

METHODS

Participants

Twenty-two female athletes from a U18 basketball team participated in the study. The team competed in the top national U18 division during the 2023–2024 season. All athletes were registered with the Slovenian National Basketball Federation. The participants trained five times per week and competed regularly in official league matches. Inclusion criteria were an age of 13–18 years, membership of the cadet or junior category, the absence of a professional contract, and full participation in training during the preceding six months. Participants with a history of lower-limb injury resulting in an absence of more than six months were excluded. Participant characteristics, including age, height, body mass, limb dominance, previous sports participation, basketball training duration, and injury history, were collected using a questionnaire. Body mass and height were measured with participants wearing light clothing and no footwear, and lower-limb length was measured in the supine position from the anterior superior iliac spine to the medial malleolus. All participants, or their parents or legal guardians for minors, provided written informed consent. The study was approved by the National Medical Ethics Committee (No. 0120-16/2024-2711/3).

Testing protocol

Testing was conducted as a single session between March and April 2024 at the Faculty of Health Sciences, University of Ljubljana. The order of limb testing was randomized. Participants first completed the YBT, followed by isokinetic assessment of knee flexor and extensor strength.

Isokinetic Strength Assessment

Knee strength was measured using a HUMAC NORM dynamometer (CSMi Medical Solutions, USA). Participants were seated with hips at 85° flexion, the knee axis aligned with the dynamometer, and the tested limb secured 2 cm above the ankle. The trunk, pelvis, and thigh were stabilized. The knee range of motion was restricted from full extension to 100° of flexion. Concentric

contractions of the quadriceps femoris and hamstring were performed at 60°/s, 180°/s, and 240°/s. At 60°/s and 180°/s, participants performed four submaximal warm-up repetitions followed by five maximal repetitions; at 240°/s, the protocol consisted of four submaximal warm-up repetitions followed by 15 maximal repetitions. Peak torque (Nm) and hamstring-to-quadriceps ratio (H:Q) were analysed for each velocity.

Y-Balance Test

YBT is a standardized, instrumented functional assessment used to evaluate dynamic balance, neuromuscular control, and lower-limb symmetry. Dynamic balance was assessed using the standardized Plisky protocol (Plisky et al., 2009).

During the testing procedure, participants wore basketball shoes and performed reaches in the anterior, posteromedial, and posterolateral directions while keeping their hands on their hips and maintaining constant contact between the stance foot and the floor. Three practice trials were performed in each direction for both legs. Trials were deemed invalid if balance was lost, the reaching leg bore weight, the hands left the hips, or the stance heel lifted. For each reach direction, the reach distance was calculated as the mean of three trials and normalized to limb length.

RESULTS

Participant Characteristics

Twenty-two players, aged 16.2 ± 1.2 years, completed all testing procedures. The participants were 172.9 ± 6.8 cm tall and weighed 64.9 ± 9.1 kg on average. The players had an average 7.7 ± 2.0 years of basketball experience and trained an average of five times per week. All participants belonged to a single U18 team competing in the top national U18 division in Slovenia and were registered with the Slovenian National Basketball Federation during the 2023-2024 season. Before taking up basketball, 86% of participants had participated in other sports, with 68% practising more than one sport. The most frequently practised sports were dance, gymnastics, football, athletics, and

handball. Detailed individual athlete profiles are available in the accompanying repository (Urbančič & Tomc Žargi, 2026).

Injury History

The most common lower-limb injury was ankle sprain, affecting 33% of participants, and some participants experienced multiple sprains or bilateral involvement. The average absence due to ankle sprains was 1.4 ± 1 weeks. Other reported lower-limb injuries included partial hamstring ruptures, ligament injuries, tendon injuries, meniscus injuries, and fractures. Seven participants reported no previous lower-limb injuries.

Upper-limb or trunk injuries were reported by 18% of participants, most commonly wrist or clavicle fractures and partial shoulder tendon injuries. The timing of injuries varied, with all injuries occurring at least six months before participation in the study, in accordance with the inclusion criteria. Details of previous injuries are presented in Table 1.

Isokinetic Strength Assessment

Overall, the findings indicate minimal lower-limb strength asymmetry at the group level in isokinetic knee peak torque and hamstring-to-quadriceps (H:Q) ratios, with slightly higher mean values observed in the right leg. Although the average limb symmetry index (LSI) values suggest good bilateral symmetry, several participants showed LSI values exceeding 10% at one or more testing velocities, indicating potential individual strength imbalances. Table 2 presents the mean ($\pm$ SD) isokinetic knee peak torque values and H:Q ratios for female athletes at angular velocities of 60°/s, 180°/s, and 240°/s.

Table 1. Previous injuries in U18 female basketball players (N = 22)

Injury region	Injury type	n (%)
Lower limb	Ankle sprain	8 (33)
	Partial hamstring rupture	2 (9)
	Ligament injuries (Anterior Talofibular Ligament/Calcaneofibular Ligament)	2 (9)
	Quadriceps (vastus lateralis) rupture	1 (5)
	Meniscus injury	1 (5)
	Tendinopathy (patellar/Achilles)	2 (9)
	Fractures (femur, metatarsal, lateral malleolus)	3 (14)
	No lower limb injury	7 (32)
Upper limb / trunk	Wrist fracture	2 (9)
	Clavicle fracture	1 (5)
	Shoulder tendon (supraspinatus) injury	1 (5)

Note: Participants could report more than one injury; percentages reflect the number of participants reporting for each type.

Table 2. Isokinetic knee peak torque and H:Q ratio in female athletes (Mean ± SD)

Velocity	Measure	Left Leg (Mean ± SD, Nm)	Right Leg (Mean ± SD, Nm)	LSI (Mean ± SD, %)	Participants with Clinically Meaningful Asymmetry (%)
60°/s	Extensors	133.0 ± 27.6	133.3 ± 28.6	8.13 ± 4.49	32
	Flexors	90.0 ± 24.3	91.8 ± 26.9	7.26 ± 5.92	27
	H:Q	67.7 ± 11.5	68.6 ± 12.3	8.46 ± 5.77	32
180°/s	Extensors	82.3 ± 18.8	86.2 ± 17.4	7.60 ± 5.60	32
	Flexors	65.6 ± 20.9	65.6 ± 19.1	8.28 ± 5.42	36
	H:Q	78.7 ± 10.8	75.7 ± 12.8	8.21 ± 5.44	32
240°/s	Extensors	67.5 ± 16.2	69.9 ± 15.8	8.24 ± 5.34	27
	Flexors	59.3 ± 16.2	60.5 ± 15.9	5.66 ± 6.10	27
	H:Q	87.5 ± 16.2	86.7 ± 11.5	6.89 ± 3.28	23

Note: H:Q – Hamstring-to-quadriceps ratio

Table 3. Y-Balance Test reach distances, limb differences, and LSI in female athletes (Mean ± SD)

Measure	Left Leg (% limb length)	Right Leg (% limb length)	Difference L–R (%)	Participants with Clinically Meaningful Difference (%)	LSI (%)	Participants with Clinically Meaningful Asymmetry (%)
Anterior Reach	65.3 ± 5.5	67.8 ± 5.0	2.9 ± 3.1	36	4.9 ± 3.3	9
Composite Reach	89.2 ± 5.8	91.0 ± 5.0	2.9 ± 3.1	29	3.1 ± 3.0	0

Note: LSI – Limb symmetry index

Y-Balance Test

Overall, the Y-Balance Test findings indicated small mean differences between limbs at the group level, suggesting generally good dynamic balance symmetry. However, a substantial proportion of participants showed clinically relevant asymmetries, with 32% exhibiting an LSI greater than 10% in at least one reach direction and eight participants demonstrating anterior reach differences exceeding 4 cm, suggesting potential functional imbalance. Table 3 presents the mean reach distances, inter-limb differences, and LSI values for the Y-Balance Test in female athletes.

DISCUSSION

This study examined lower-limb strength and dynamic balance symmetry in adolescent female basketball players using isokinetic knee testing and the Y-Balance Test. At the group level, bilateral symmetry appeared generally good, with mean LSI values for isokinetic peak torque and H:Q ratios were typically below the commonly used 10% asymmetry threshold. However, a clinically meaningful proportion of individuals exceeded this threshold on one or more isokinetic velocities, indicating that group means may mask relevant inter-limb strength deficits in individual athletes. Similarly, YBT group means showed only small side-to-side differences, yet 32% of participants demonstrated LSI >10% in at least one direction, and eight athletes presented anterior reach asymmetry > 4 cm. Such asymmetry has previously been associated with elevated lower-limb injury risk in adolescent basketball populations when assessed using related reach-based balance screening (Plisky, Rauh, Kaminski & Underwood, 2006). The authors of the test (Plisky et al., 2006) reported that female athletes who achieved less than 94% of their lower limb length on the test had a 6.5-fold increased risk of lower-limb injury. In the present study, five female athletes scored below this critical threshold, none of whom had clinically significant inter-limb asymmetry. This finding is consistent with the broader literature, which indicates that inter-limb asymmetry is common in adolescent female basketball players, with magnitudes varying substantially depending on the task and assessment method (Arboix-Alió, Buscà Peralta-Geis, Montalvo & Fort-Vanmeerhaeghe, 2025).

The clinical relevance of these findings lies in the possibility that the observed asymmetries reflect neuromuscular profiles potentially associated with

increased lower-limb injury risk. Strength asymmetries may indicate unilateral deficits in force production or force absorption capacity, and similar asymmetries have been linked to altered landing mechanics in female basketball players (Acar, Umutlu, Gencer, Güven, & Taşman, 2025). Dynamic balance asymmetries may reflect reduced postural control during single-leg tasks, with previous basketball-specific evidence showing that reach-based balance measures can help identify players at increased risk of lower-limb injury (Plisky et al., 2006). More broadly, inter-limb asymmetries may contribute to unequal loading, unequal force absorption, or reduced frontal-plane stability during sport-specific movements, although systematic evidence on their predictive value for sport injury remains inconsistent (Guan et al., 2022). Therefore, although the cross-sectional design of the present study does not allow causal conclusions or direct prediction of future injuries, athletes exceeding commonly used clinical thresholds may warrant closer monitoring and targeted preventive intervention.

The pattern observed in Table 2, namely higher absolute peak torques at slower speeds and progressively higher H:Q ratios at faster angular velocities, is consistent with established isokinetic principles and with contemporary basketball profiling work that reports velocity-dependent changes in knee extensor/flexor torque and strength ratios in elite basketball cohorts (Coto Martín et al., 2025). Importantly, while average between-limb differences were small, the presence of >10% LSI in several participants suggests potentially meaningful unilateral deficits that may be relevant in a sport characterized by frequent single-leg landing, deceleration, and cutting actions. Such individual asymmetries are consistent with previous isokinetic findings in youth and professional female basketball players and have been linked to altered landing mechanics and force absorption strategies during high-demand tasks (Acar et al., 2025). These findings suggest that individual strength imbalances may carry greater clinical relevance than group-level symmetry when considering injury prevention.

From an injury-mechanism perspective, H:Q is not merely a descriptive measure; it is frequently interpreted as one proxy for the capacity of the hamstrings to counter anterior tibial shear and modulate knee loading during dynamic tasks. Experimental work has linked lower H:Q profiles to altered knee forces and potentially greater ACL-related loading during landing in females, supporting the rationale for monitoring knee strength balance alongside absolute torque (Heinert, Collins, Tehan, Ragan & Kernozek, 2021).

Despite small mean between-limb differences on the YBT, approximately one-third of participants demonstrated LSI values exceeding 10%, and multiple athletes showed anterior reach asymmetry greater than 4 cm. These findings are clinically relevant, as dynamic balance asymmetries have been associated

with altered neuromuscular control and reduced change-of-direction performance in adolescent female basketball players (Arboix-Alió et al., 2025; Fort-Vanmeerhaeghe et al., 2022). Importantly, the evidence highlights that balance and strength asymmetries do not consistently co-occur, reinforcing the need for multidimensional screening rather than reliance on a single metric (Arboix-Alió et al., 2025).

A key clinical implication of studying U18 athletes is that adolescence represents a developmental period during which neuromuscular risk factors can emerge or intensify as growth outpaces strength and motor-control development. Longitudinal biomechanical research shows that sex differences in knee abduction mechanics and loading can diverge across maturation, with females demonstrating increases in knee abduction motion/moments during/after the adolescent growth period, whereas males do not show comparable changes (Ford, Shapiro, Myer, Van Den Bogert & Hewett, 2010). This provides a plausible developmental context for why some athletes in the current sample demonstrated strength or balance asymmetries despite being healthy and fully engaged in training. The current results should therefore be interpreted within the broader developmental framework of adolescence, during which rapid increases in bone length and body mass may outpace neuromuscular adaptation (DiCesare et al., 2019). Evidence from studies of normalized strength indicates that female athletes demonstrate earlier plateaus in hamstring strength development (Barber-Westin, Noyes & Galloway, 2006), lower hamstrings-to-quadriceps ratios (Nagai et al., 2021), and reduced proximal strength relative to body mass compared with males (Schultz et al., 2022).

In addition, cross-sectional evidence in female youth populations indicates that hamstring–quadriceps ratio characteristics can vary with age across adolescence, reinforcing the notion that knee strength balance is not static during maturation (Andrade et al., 2021). Although sport and testing protocol differences limit direct numerical comparisons, the overall implication is that preventative screening and training should be periodized across adolescence rather than performed as a one-off assessment.

From a prevention standpoint, early identification of asymmetries during adolescence offers a critical opportunity to intervene before high-risk movement patterns become established. Although neuromuscular training has been shown to improve strength and reduce biomechanical risk factors, evidence specific to basketball suggests that standard warm-up–based programmes may be insufficient in volume or intensity to meaningfully modify high-risk mechanics in this population. Preventive programmes should therefore prioritize unilateral strength development—particularly of the hamstrings and hip

musculature—alongside dynamic balance and landing technique training tailored to the specific demands of basketball.

Regarding generalizability, several limitations should be acknowledged. First, the sample size was relatively small, and all participants were recruited from a single U18 basketball team competing in the top national U18 division in Slovenia. Therefore, the results may primarily reflect this specific training and competition environment. Team-specific factors, including coaching style, weekly training frequency, strength and conditioning exposure, injury-prevention routines, and match demands, may have influenced the observed strength and balance profiles. Consequently, the findings should not be directly generalized to recreational players, athletes from lower competitive levels, senior elite players, or professional basketball players without further confirmation in larger and more diverse samples.

Second, this study was cross-sectional and did not include prospective injury surveillance. Therefore, it quantified lower-limb strength and dynamic balance asymmetry profiles but cannot determine whether the observed asymmetries predict subsequent lower-limb injuries.

Third, isokinetic testing was performed using concentric contractions only, whereas many basketball-related high-risk movements involve substantial eccentric demands, particularly during landing, deceleration, and cutting. Consequently, concentric peak torque and conventional H:Q ratios do not fully reflect eccentric hamstring function or functional knee-joint control during sport-specific movements. Future studies should include eccentric knee flexor assessment, functional H:Q ratios, single-leg hop or jump testing, task-specific landing assessments, and prospective injury surveillance.

Fourth, although the players belonged to the selected U18 team, they may still have differed in growth and biological maturation status. This is relevant because some adolescent athletes may still be undergoing rapid growth and neuromuscular development, whereas others may be closer to or have already reached physical maturity. Biological maturation, pubertal status, age at menarche, menstrual-cycle phase, timing of testing within the menstrual cycle, and hormonal contraceptive use were not assessed. Consequently, the potential influence of maturation status, menstrual-cycle phase, or contraceptive use on the observed strength and balance asymmetry profiles cannot be ruled out. Future studies should include indicators of biological maturation and menstrual-cycle status, particularly when assessing adolescent female athletes across different stages of development.

CONCLUSION

From a clinical perspective, the present findings underscore that apparently normal group-level symmetry may conceal clinically relevant individual asymmetries in adolescent female basketball players. A notable proportion of athletes demonstrated meaningful inter-limb asymmetry in isokinetic knee strength and dynamic balance, despite being healthy and fully engaged in training. From an injury-prevention perspective, these individual asymmetries may be clinically relevant because they could indicate deficits in neuromuscular control, unilateral force capacity, or dynamic balance that are important during basketball-specific high-risk movements. Given the well-documented emergence of sex-specific knee injury risk factors during and after puberty, these findings support the potential value of preventive lower-limb symmetry screening in this population. Integrating isokinetic strength assessment with functional measures such as the Y-Balance Test may help identify athletes who could benefit from targeted neuromuscular and unilateral strength training before injury occurs. Early identification and correction of asymmetries may be particularly important during adolescence, when rapid growth and high training loads coexist, and may inform more individualized injury-prevention strategies for female basketball players.

Study limitations

This study has several limitations, including a small, single-team U18 cohort and a cross-sectional design without prospective injury surveillance. Additionally, the reliance on concentric-only isokinetic testing and the lack of biological maturation or hormonal assessments constrain the generalizability of these asymmetry profiles. Future research should utilize prospective designs, multi-club sampling, dynamic functional testing, and maturity tracking across diverse athlete populations.

DATA AVAILABILITY

The dataset generated and analysed during the current study is publicly available in the Zenodo repository (Urbančič & Tomc Žargi, 2026).

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