REVIEW
PREGLEDNI ZNANSTVENI RAD

Hrvat. Športskomed. Vjesn. 2025; 41:13-20

THE RELATIONSHIP BETWEEN HYPERMOBILITY AND ANTERIOR CRUCIATE LIGAMENT INJURY IN SPORTS: A SYSTEMATIC REVIEW

ODNOS HIPERMOBILNOSTI I OZLJEDE PREDNJEG KRIŽNOG LIGAMENTA U SPORTU: SUSTAVNI PREGLED

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Cite as: Jukić I, Jeleč Ž, Milanović L, Dadić M, Štimac S. The relationship between hypermobility and anterior cruciate ligament injury in sports: a systematic review. Croat Sports Med J. 2026; 41(1):13-20.

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DOI: 10.69589/hsv.41.1.2

ABSTRACT

Anterior cruciate ligament (ACL) injuries rank among the most serious and frequently encountered injuries in competitive sport. Beyond prolonged absence from training and competition, they are associated with measurable declines in athletic performance and carry a substantial risk of premature knee osteoarthritis. Despite the considerable volume of research conducted in this area, intrinsic risk factors remain poorly defined. Joint hypermobility and generalized ligamentous laxity have received growing attention as factors potentially contributing to both primary injury susceptibility and outcomes following surgical reconstruction.

This systematic review aimed to examine and critically appraise available evidence regarding the relationship between joint hypermobility and three key outcomes: primary ACL injury risk, second ACL injury occurring after reconstruction, and clinical results following ACL reconstruction (ACLR).

The literature search was carried out across three electronic databases: PubMed/MEDLINE, EMBASE, and the Cochrane Library. Studies were considered eligible if they examined generalized joint hypermobility, ligamentous laxity, or knee hyperextension in relation to ACL injury or outcomes following ACLR, encompassing cohort studies, case–control studies, registry-based analyses, biomechanical studies, and systematic reviews.

SAŽETAK

Ozljede prednjeg križnog ligamenta (ACL) ubrajaju se među najozbiljnije i najčešće ozljede u kompetitivnom sportu. Uz dugotrajno izbivanje iz treninga i natjecanja, povezane su s mjerljivim padom sportske izvedbe te nose značajan rizik od prijevremenog razvoja osteoartritisa koljena. Unatoč velikom broju istraživanja provedenih u ovom području, intrinzični čimbenici rizika još uvijek nisu dovoljno razjašnjeni. Hipermobilnost zglobova i generalizirana ligamentarna labavost sve više se prepoznaju kao čimbenici koji potencijalno doprinose kako podložnosti primarnoj ozljedi, tako i ishodima nakon kirurške rekonstrukcije.

Cilj ovog sustavnog pregleda bio je ispitati i kritički procijeniti dostupne dokaze o povezanosti hipermobilnosti zglobova s trima ključnim ishodima: rizikom primarne ozljede ACL-a, ponovnom ozljedom ACL-a nakon rekonstrukcije te kliničkim rezultatima nakon rekonstrukcije prednjeg križnog ligamenta (ACLR).

Pretraživanje literature provedeno je u trima elektroničkim bazama podataka: PubMed/MEDLINE, EMBASE i Cochrane Library. Studije su smatrane prihvatljivima ako su ispitivale generaliziranu zglobnu hipermobilnost, ligamentarnu labavost ili hiperekstenziju koljena u odnosu na ozljede ACL-a ili ishode nakon ACLR-a, uključujući kohortne studije, case-control studije, analize registarskih podataka, biomehaničke studije i sustavne preglede.

Generalized joint hypermobility and knee hyperextension appear to be associated with a greater likelihood of primary ACL injury, though this relationship is not uniform across studies and has not been reliably confirmed in large prospective cohorts of elite athletes. The clearest and most reproducible association emerges in the context of secondary ACL injury and graft failure after reconstruction, where hypermobile individuals tend to show greater postoperative laxity and higher rates of graft failure. Findings on patient-reported outcomes, however, are less consistent. Available biomechanical data further suggest that hypermobile athletes exhibit altered landing mechanics that may increase ACL loading.

Among intrinsic risk factors, joint hypermobility holds particular clinical relevance, especially in relation to secondary ACL injury and unfavourable outcomes after reconstruction. Incorporating hypermobility assessment into routine clinical practice could improve how injury prevention, surgical planning, and return-to-sport decisions are approached.

Keywords: *anterior cruciate ligament, joint hypermobility, ACL injury, Beighton score, ACL reconstruction*

Generalizirana zglobna hipermobilnost i hiperekstenzija koljena čini se da su povezane s većom vjerojatnošću primarne ozljede ACL-a, iako ta povezanost nije ujednačena kroz studije te nije pouzdano potvrđena u velikim prospektivnim kohortama elitnih sportaša. Najjasnija i najdosljednija povezanost pojavljuje se u kontekstu sekundarne ozljede ACL-a i neuspjeha grafta nakon rekonstrukcije, gdje hipermobilni pojedinci tendiraju pokazivati veću postoperativnu labavost i više stope neuspjeha grafta. Nalazi o ishodima koje prijavljuju sami pacijenti, međutim, manje su konzistentni. Dostupni biomehanički podaci dodatno upućuju na to da hipermobilni sportaši pokazuju izmijenjenu biomehaniku doskoka koja može povećati opterećenje ACL-a.

Među intrinzičnim čimbenicima rizika, hipermobilnost zglobova ima posebnu kliničku važnost, osobito u odnosu na sekundarnu ozljedu ACL-a i nepovoljne ishode nakon rekonstrukcije. Uključivanje procjene hipermobilnosti u rutinsku kliničku praksu moglo bi unaprijediti pristup prevenciji ozljeda, kirurškom planiranju i donošenju odluka o povratku sportu.

Ključne riječi: *prednji križni ligament, hipermobilnost zglobova, ozljeda ACL-a, Beighton score, rekonstrukcija ACL-a*

INTRODUCTION

ACL injury continues to pose one of the greatest challenges in sports medicine, given its high incidence, lengthy rehabilitation demands, and lasting impact on both athletic participation and long-term knee health. Activities that require rapid deceleration, cutting, pivoting, and landing movements — including football, basketball, handball, and alpine skiing — subject the knee to substantial multiplanar forces, placing athletes at considerable risk of ACL rupture.[9]

Even with steady improvements in operative techniques, graft fixation methods, and postoperative rehabilitation, recovery trajectories following ACL injury and reconstruction differ widely between patients. Many athletes never regain their previous competitive level, and rates of reinjury — especially among younger and more active individuals — continue to represent a significant clinical problem.

ACL injury is broadly understood to result from a combination of contributing factors rather than a single cause. Extrinsic elements such as playing surface, footwear, weather conditions, and training load interact with intrinsic characteristics including neuromuscular control, anatomical alignment, hormonal influences, and ligamentous properties.[8] Although neuromuscular deficits and movement biomechanics have attracted considerable research interest, the role of passive joint properties, namely joint laxity and generalized joint hypermobility (GJH), has historically received far less attention.

Generalized joint hypermobility refers to increased passive range of motion across multiple joints and is most commonly assessed using the Beighton score, a standardized clinical tool evaluating hyperextension and joint mobility at several anatomical sites. Hypermobility exists on a continuum, ranging from asymptomatic increased joint motion to heritable connective tissue disorders such as Ehlers–Danlos syndrome, in which collagen abnormalities result in pronounced ligamentous laxity and tissue fragility.[12]

While increased joint mobility may confer performance advantages in certain sports—such as gymnastics, dance, or disciplines requiring extreme ranges of motion—excessive laxity may compromise passive joint stability in high-load, high-velocity sporting contexts. Reduced stiffness of passive stabilizing structures may increase reliance on dynamic neuromuscular control to maintain joint stability during rapid movements. When neuromuscular control is insufficient, delayed, or fatigued, excessive joint motion may occur, potentially increasing strain on the ACL and other stabilizing structures.[6]

Over the past two decades, growing evidence has suggested that generalized joint hypermobility and knee hyperextension may be associated with increased risk of ACL injury and inferior outcomes following ACL reconstruction. However, findings across studies have been heterogeneous,

influenced by differences in study design, hypermobility definitions, sex-specific analyses, and follow-up duration. This systematic review sought to examine and critically appraise existing evidence on the relationship between hypermobility and ACL injury, covering primary injury risk, secondary injury and reconstruction outcomes, and biomechanical mechanisms relevant to ACL loading.

1. METHODS

1.1. Search Strategy

The search was conducted following PRISMA 2020 guidelines across three electronic databases: PubMed/MEDLINE, EMBASE, and the Cochrane Library, covering all records from database inception through 31 March 2025. Both controlled vocabulary (MeSH terms where applicable) and free-text keywords were used, with the following search string applied: ("anterior cruciate ligament" OR "ACL") AND ("hypermobility" OR "generalized joint hypermobility" OR "joint laxity" OR "ligamentous laxity" OR "knee hyperextension" OR "Beighton score"). Results were filtered to include only human studies, English-language publications, and peer-reviewed journal articles, with no restrictions placed on study design. Reference lists of included articles and relevant reviews were additionally screened by hand to identify any further eligible studies.

1.2. Study Selection

All records retrieved from the database search were imported into reference management software and deduplicated. Two reviewers independently screened titles and abstracts for eligibility. Inclusion criteria required that studies assessed generalized joint hypermobility, generalized joint laxity, or knee hyperextension; examined primary ACL injury, secondary ACL injury, or outcomes following ACL reconstruction; included athletic or physically active populations; and were original research articles or systematic reviews published in peer-reviewed journals. Studies were excluded if they did not report ACL-specific outcomes, focused exclusively on pediatric non-sport trauma or non-athletic populations, or consisted of case reports, conference abstracts, editorials, or expert opinions. Where disagreements arose between reviewers, these were resolved through discussion, with a third reviewer consulted when agreement could not be reached.

1.2.1. Quality Assessment

The methodological quality of included original research studies was assessed independently by two reviewers using the Newcastle–Ottawa Scale (NOS) for cohort and case–control studies. Systematic reviews were appraised using the AMSTAR-2 (A MeaSurement Tool to Assess Systematic Reviews) checklist. Quality assessments were conducted in parallel with data extraction, and discrepancies were resolved by consensus or referral to a third reviewer. Given the substantial heterogeneity in study design, hypermobility assessment methods, outcome definitions, and study populations among the included studies, a formal meta-analysis was not considered appropriate. Results are therefore presented as a narrative (qualitative) synthesis, with quality assessment findings informing the interpretation of the evidence.

1.3. Study Selection Results

The initial database search identified 412 records across PubMed/MEDLINE, EMBASE, and the Cochrane Library. After removal of 56 duplicate records, 356 titles and abstracts were screened, of which 311 were excluded. Full-text assessment was performed for 45 articles; 30 were excluded for the following reasons: absence of ACL-specific outcomes (n = 12), non-athletic populations (n = 9), or lack of hypermobility assessment (n = 9). A total of 15 studies met the eligibility criteria and were included in the qualitative synthesis (Table 1).

Table 1. PRISMA 2020 Study Selection Flow
Tablica 1. PRISMA 2020 dijagram tijeka odabira studija

Stage / Faza	n
Records identified through database searching / Zapisi identificirani pretraživanjem baza podataka	412
Records after removal of duplicates / Zapisi nakon uklanjanja duplikata	356
Titles and abstracts screened / Naslovi i sažeci pregledani	356
Records excluded after screening / Zapisi isključeni	311
Full-text articles assessed for eligibility / Puni tekstovi procijenjeni	45
Full-text articles excluded / Isključeni puni tekstovi	30
Studies included in qualitative synthesis / Uključene studije u kvalitativnu sintezu	15

Table 2. Studies Examining Hypermobility and Primary ACL Injury Risk
Tablica 2. Studije koje ispituju hipermobilnost i rizik primarne ozljede ACL-a

Author (Year)	Study design	Population	Assessment	Outcome	Key findings
Myer et al. (2008)	Case–control	Female adolescent athletes	Joint laxity; knee hyperextension	Primary ACL injury	Increased laxity significantly increased ACL injury risk
Sundemo et al. (2019)	Systematic review	Athletic populations (both sexes)	Beighton score	Primary ACL injury	GJH associated with increased ACL injury risk in both males and females
Larson et al. (2017)	Cohort	ACL-injured patients	Beighton score; knee hyperextension	ACL injury and reinjury	Hypermobility associated with inferior outcomes and reinjury
England et al. (2025)	Comparative cohort	ACL tears vs tibial spine fractures	Knee hyperextension	ACL injury	Greater hyperextension in ACL-tear group
Mancino et al. (2024)	Narrative review	Female athletes	Ligamentous laxity	ACL injury risk	Ligamentous laxity as part of a multifactorial anatomic risk profile
Nicolay et al. (2023)	Prospective cohort	Collegiate football players	Beighton score	Injury risk	GJH associated with increased injury risk

2. RESULTS

2.1. Hypermobility and Primary ACL Injury Risk

Several studies have investigated the association between generalized joint hypermobility and increased risk of primary ACL injury (Table 2). Myer et al.[9] reported that female athletes with increased generalized joint laxity and knee hyperextension were at significantly higher risk of ACL rupture. A systematic review by Sundemo et al.[14] confirmed that GJH is associated with increased ACL injury risk in both male and female athletes, with associations observed across both sexes in the included studies. Larson et al.[6] further identified hypermobility and knee hyperextension as clinically relevant phenotypes influencing ACL injury and reinjury. England et al.[1] found that baseline knee hyperextension was significantly more prevalent in patients with ACL tears than in those with tibial spine fractures. In female athletes, Mancino et al.[8] identified generalized joint hypermobility as part of a multifactorial anatomic risk profile.

Importantly, not all large prospective studies confirm GJH as an independent risk factor for primary ACL injury. Kamatsuki et al[4]., in a prospective cohort of 870 elite female handball and soccer players (880 enrolled; 10 excluded prior to analysis), found that anterior-posterior knee laxity and generalized joint laxity were not independent predictors of primary non-contact ACL injury, whereas static knee valgus and hyperextension were associated with secondary injury. These findings highlight the heterogeneity of the available evidence.

2.2. Secondary ACL Injury and Outcomes After ACL Reconstruction

As described in Table 3, secondary ACL injury remains a major concern following return to sport. Registry-based analyses demonstrate that generalized joint hypermobility significantly increases the risk of second ACL rupture after reconstruction.[16,7]

Knee hyperextension is a particularly strong predictor of graft failure. Guimarães et al.[2] showed that contralateral knee hyperextension greater than 5° significantly increased failure rates following hamstring tendon ACL reconstruction. Helito et al.[3] confirmed this association at a higher threshold (>6.5°), with patients being 14.6 times more likely to sustain graft rupture. Systematic reviews report inferior postoperative stability and higher graft failure rates in hypermobile patients.[14,5] Although short-term outcomes may not differ,[15] longer-term risk appears elevated. Patients with hypermobility syndromes demonstrate particularly poor graft survival.[12]

Regarding patient-reported outcomes, the evidence is less uniform. While Sundemo et al. (2019)[14] reported inferior subjective outcomes in hypermobile patients, Sundemo et al. (2022)[15] found no significant differences at one-year follow-up. Most studies show higher postoperative laxity and greater graft failure rates in patients with GJH and/or significant hyperextension, while findings regarding patient-reported outcomes are inconsistent.

Table 3. Studies Examining Hypermobility and Outcomes After ACL Reconstruction
Tablica 3. Studije koje ispituju hipermobilnost i ishode nakon rekonstrukcije ACL-a

Author (Year)	Study design	Population	Assessment	Outcome	Key findings
Sundemo et al. (2019)	Systematic review	ACLR patients	Beighton score	PROMs; laxity	Inferior subjective outcomes and higher laxity in hypermobile patients
Sundemo et al. (2022)	Cohort	Primary ACLR patients	Beighton score	1-year outcomes	No significant differences in short-term patient-reported outcomes
Krebs et al. (2021)	Systematic review	ACLR patients	Generalized joint laxity	Graft failure rates	Higher graft failure rates associated with generalized joint laxity
Guimarães et al. (2021)	Cohort	Hamstring ACLR	Knee hyperextension >5°	Graft failure	Increased graft failure rates above threshold
Helito et al. (2024)	Cohort	Primary ACLR	Knee hyperextension >6.5°	Graft rupture	14.6× greater risk of graft rupture
Lindskog et al. (2025)	Registry cohort	Post-ACLR athletes	Beighton score	Second ACL injury	Risk >4× higher with hamstring vs BTB graft in GJH patients
Song et al. (2025)	Cohort	Elite skiers	Long-term clinical outcomes	Return to sport; functional outcomes	High return to sport and favorable long-term outcomes after hamstring ACLR
Schmidt et al. (2025)	Cohort	EDS patients	Hypermobility syndrome	ACLR survival	Reduced graft survival in Ehlers–Danlos syndrome patients

2.3. Biomechanical Evidence

Biomechanical studies demonstrate that generalized joint hypermobility is associated with altered knee kinematics and loading patterns during tasks relevant to ACL injury mechanisms (Table 4). Sahin et al.[11] reported that higher Beighton scores were significantly associated with increased peak knee valgus angles and moments during landing and balance tasks in adolescent volleyball players, alongside greater three-dimensional variability of lower limb movement.

Larson et al.[6] demonstrated inferior functional outcomes in hypermobile patients following reconstruction, suggesting possible persistent biomechanical instability. Similarly, Guimarães et al.[2] and Helito et al.[3] showed that marked knee hyperextension substantially increased graft failure risk. Nicolay et al.[10] reported increased injury risk in collegiate football players with GJH even at high strength and conditioning levels, suggesting strength alone may not fully compensate for altered joint mechanics.

3. DISCUSSION

3.1. Hypermobility and Primary ACL Injury Risk

The findings of this review indicate that GJH and knee hyperextension may function as clinically meaningful intrinsic risk factors for primary ACL injury. Evidence drawn from case-control studies, cohort investigations, and systematic reviews generally points toward a higher likelihood of ACL rupture in hypermobile athletes relative to their non-hypermobile peers.[9,14] That said, this pattern is not uniformly observed across study designs and athletic populations, and GJH is better understood as a factor that modifies injury risk rather than an independent cause of primary ACL rupture.

From a biological standpoint, the link between hypermobility and ACL injury risk is plausible. Greater passive joint laxity diminishes the contribution of static stabilizing structures, shifting greater demand onto dynamic neuromuscular control during high-risk movements such as cutting, pivoting, and landing. Under conditions where neuromuscular control is insufficient, delayed, or compromised by fatigue, ACL strain may surpass tissue

Table 4. Biomechanical and Mechanistic Studies Linking Hypermobility to ACL Injury Risk
Tablica 4. Biomehaničke studije koje povezuju hipermobilnost s rizikom ozljede ACL-a

Author (Year)	Study design	Population	Assessment	Task / assessment	Key findings
Sahin et al. (2024)	Cross-sectional	Adolescent volleyball players	Beighton score	Landing and balance tasks; 3D motion analysis	Higher Beighton scores associated with increased peak knee valgus angles, moments, and 3D variability
Larson et al. (2017)	Cohort	ACL-injured and reconstructed patients	Beighton score; knee hyperextension	Functional and clinical assessment	Hypermobility associated with inferior outcomes, suggesting possible biomechanical instability
Guimarães et al. (2021)	Cohort	Primary ACLR (hamstring graft)	Knee hyperextension >5°	Clinical failure as endpoint	Excessive sagittal-plane laxity increased graft failure risk
Helito et al. (2024)	Cohort	Primary ACLR patients	Knee hyperextension >6.5°	Graft rupture incidence	Marked knee hyperextension strongly predicted graft rupture (14.6×)
Nicolay et al. (2023)	Prospective cohort	Collegiate football players	Beighton score	Injury surveillance	GJH associated with increased injury risk despite high strength levels

tolerance.[6] Sex-specific patterns are also worth considering. Myer et al.8 identified a clear association in female athletes, while Sundemo et al.[14] reported associations of comparable magnitude in both male and female athletes across the included studies. Notably, a recent large prospective cohort by Kamatsuki et al.[4] did not confirm GJH as an independent predictor of primary ACL injury in elite female athletes, suggesting that sport level and individual athlete characteristics may play a moderating role in this relationship.

England et al.[1] found that knee hyperextension was considerably more common in patients with ACL tears compared to those who sustained tibial spine fractures. This observation points to the possibility that excessive sagittal-plane laxity may make the ACL more vulnerable to rupture under loads that would otherwise produce bony injury. These findings, however, do not confirm a causal relationship, and hypermobility should be considered within a broader multifactorial risk framework rather than as an isolated determinant.

3.2. Secondary ACL Injury and Outcomes After ACL Reconstruction

Among the findings of this review, the most consistent and clinically meaningful relate to secondary ACL injury and post-reconstruction outcomes. Data drawn from registry studies, cohort investigations, and systematic reviews collectively point to an association between generalized joint hypermobility and knee hyperextension on one hand, and elevated risk of graft failure, contralateral ACL injury, and greater postoperative laxity on the other.[14,5,7]

Lindskog et al.[7] reported that GJH patients reconstructed with hamstring tendon autograft faced a more than fourfold greater rate of second ACL rupture relative to those receiving bone-patellar tendon-bone autograft. In line with this, Guimarães et al.[2] and Helito et al.[3] both found that marked knee hyperextension was linked to substantially higher rates of graft rupture. This pattern is mechanistically consistent with the notion that excessive sagittal-plane laxity disrupts graft loading, promoting greater anterior tibial translation during terminal knee extension.

Regarding patient-reported outcomes, the evidence is nuanced. While Sundemo et al. (2019)[14] reported inferior subjective outcomes in hypermobile patients, and Krebs et al.[5] demonstrated higher graft failure rates in patients with generalized joint laxity, yet Sundemo et al. (2022) [15] observed no meaningful differences in patient-reported outcomes at one-year follow-up. On balance, the available evidence more reliably supports elevated graft failure rates and greater postoperative laxity in patients with GJH and/or significant hyperextension, whereas findings on patient-reported outcomes remain mixed. Schmidt et al.[12] further showed that ACLR survival was notably reduced in patients with Ehlers-Danlos syndrome, underscoring the limitations of standard reconstructive approaches when dealing with underlying connective tissue disorders.

3.3. Biomechanical Evidence

Biomechanical studies offer useful mechanistic context. Sahin et al.[11] linked GJH directly to recognized ACL injury mechanisms, finding that higher Beighton scores corresponded with greater peak knee valgus angles and

moments during landing tasks, a pattern well established as a biomechanical risk factor in non-contact ACL injury. It should be noted, however, that these biomechanical pathways represent plausible mechanisms rather than definitively established causal relationships.

Nicolay et al.[10] found that hypermobile collegiate football players remained at greater injury risk despite high strength and conditioning levels, pointing to the possibility that muscular strength alone cannot fully offset the mechanical consequences of altered joint properties. Taken together, hypermobility-related biomechanical changes likely encompass increased knee valgus loading, disrupted sagittal-plane kinematics, and reduced joint stiffness, factors that may act in combination to elevate ACL strain during sport-specific tasks, particularly when athletes are fatigued or exposed to unanticipated perturbations.

CONCLUSIONS

The evidence reviewed here indicates that generalized joint hypermobility and knee hyperextension are clinically relevant intrinsic factors bearing on both ACL injury risk and post-reconstruction outcomes. The strongest and most reproducible signal concerns secondary ACL injury and graft failure, where converging data from registry studies, cohort investigations, and systematic reviews point to associations that are both substantial and appear to follow a dose-dependent pattern.

While the link between GJH and primary ACL injury risk is biologically plausible and backed by several studies, it has not held up consistently across all large prospective cohorts, particularly those involving elite athletes. GJH is therefore better viewed as a factor that amplifies injury risk under certain conditions rather than a standalone cause of ACL rupture.

The strongest and most consistent finding is elevated graft failure risk and greater postoperative knee laxity in patients with GJH and/or significant knee hyperextension. It is useful for orthopedists performing LCA/ACL reconstructions to assess for generalized knee hypermobility and hyperextension as there is evidence that these characteristics are associated with a higher risk of graft failure, secondary ACL injury, and poorer stability, particularly in hamstring autograft reconstructions. Graft selection, particularly the avoidance of hamstring autograft in hypermobile patients, appears to be a meaningful and actionable clinical consideration.

In clinical practice, evaluating generalized joint hypermobility and knee hyperextension in patients who sustain ACL injury warrants routine consideration. Hypermobile athletes may require tailored management approaches, covering graft selection, rehabilitation progression, neuromuscular training emphasis, and return-to-sport criteria that reflect their heightened reinjury risk. On the research side, future work would benefit from greater consistency in hypermobility definitions, more thorough sex-specific analyses, and prospective designs with follow-up periods long enough to capture secondary injury events. In particular, consensus on a uniform Beighton score threshold for defining GJH (currently ranging from ≥4 to ≥6 of 9 points across the included studies) is urgently needed to enable meaningful comparisons across future studies.

ACKNOWLEDGMENT / ZAHVALA

This work is part of the scientific research project "Biochemical and Genetic Mechanisms in the Development of Anterior Cruciate Ligament Injuries: A Novel Concept for Injury Prevention" (NPOO.C3.2.R3-I1.04.0284), funded by the Ministry of Science, Education and Youth of the Republic of Croatia and the Croatian Science Foundation.

Ovaj rad dio je znanstveno-istraživačkog projekta „Biokemijski i genetički mehanizmi u nastajanju ozljeda prednjeg križnog ligamenta: Novi koncept za prevenciju ozljeda" (NPOO.C3.2.R3-I1.04.0284), koji financiraju Ministarstvo znanosti, obrazovanja i mladih Republike Hrvatske i Hrvatska zaklada za znanost.

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