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NARRATIVE REVIEW

# Muscle imbalances and their role in musculoskeletal injury risk in physically active individuals

*a narrative review*

## HIGHLIGHTS

- Bilateral strength asymmetries exceeding 10–15% are consistently associated with elevated musculoskeletal injury risk in athletic populations.

- Quadriceps asymmetry predicts ACL re-injury; hamstring weakness predicts hamstring strain; adductor deficits predict groin injury in cutting/pivoting sports.
- Isokinetic dynamometry, force plates and countermovement-jump asymmetry are validated assessment tools; thresholds are sport- and muscle-specific.
- Sport-specific demands shape asymmetry profiles — soccer, basketball, overhead and combat sports each require tailored screening protocols.
- Targeted resistance training, eccentric strengthening and neuromuscular interventions effectively reduce asymmetries and lower injury incidence.

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# ABSTRACT

**BACKGROUND:** Musculoskeletal injuries represent a significant burden in athletic and physically active populations, with bilateral strength asymmetries and functional strength ratio deficits increasingly recognised as modifiable intrinsic risk factors. Despite extensive literature, methodological heterogeneity and conflicting evidence on specific thresholds challenge translation into prevention practice.

**AIM:** To synthesise current evidence on the definitions, mechanisms, assessment methods and clinical implications of muscle imbalances with respect to musculoskeletal injury risk, and to identify practical recommendations for screening, prevention and intervention in physically active populations.

**MATERIALS AND METHODS:** A narrative literature review was conducted in PubMed, Scopus and Web of Science, focusing on peer-reviewed publications addressing bilateral asymmetries, functional strength ratios, isokinetic assessment, force-plate testing, and injury outcomes in athletes and physically active adults. Twenty-five studies were selected for detailed analysis, covering lower-extremity, upper-extremity and trunk imbalances across multiple sports.

**RESULTS:** Bilateral strength asymmetries exceeding 10–15% are consistently associated with elevated injury risk, although specific thresholds depend on muscle group and assessment modality. Quadriceps asymmetry is linked to ACL re-injury, hamstring weakness to hamstring strain, and adductor deficits to groin injury. Isokinetic dynamometry and force-plate countermovement-jump assessments are the most widely used quantification methods. Sport-specific demands strongly shape asymmetry profiles. Targeted resistance training, eccentric strengthening (e.g. Nordic hamstring exercise) and neuromuscular training reduce asymmetries and lower injury incidence.

**CONCLUSIONS:** Muscle imbalances are clinically meaningful, modifiable risk factors for musculoskeletal injury when they exceed sport-specific thresholds. Screening programmes should employ validated tools matched to the context, and prevention strategies should combine individualised resistance, eccentric and neuromuscular interventions. Future research must address methodological standardisation, longitudinal cause–effect relationships and population-specific thresholds.


**KEYWORDS** muscle imbalance; bilateral asymmetry; injury risk; strength assessment; athletic injuries; injury prevention; isokinetic dynamometry; neuromuscular training.

# PLAIN LANGUAGE SUMMARY

Many sports injuries are not caused only by accidents — they are also influenced by differences in strength between a person's two sides, or between opposing muscle groups (for example, front versus back of the thigh). When one side is more than 10–15% weaker than the other, the risk of knee, hamstring or groin injury rises. Doctors and coaches can measure these differences using special strength tests and jump-platform tests. The good news is that imbalances can be reduced: training that works each leg separately, eccentric strength exercises like the Nordic hamstring, and full neuromuscular training programmes have all been shown to lower injury risk. This review explains how muscle imbalances arise, how they are measured, why they matter in different sports, and what athletes, coaches and clinicians can do to prevent injuries.

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## GRAPHICAL ABSTRACT

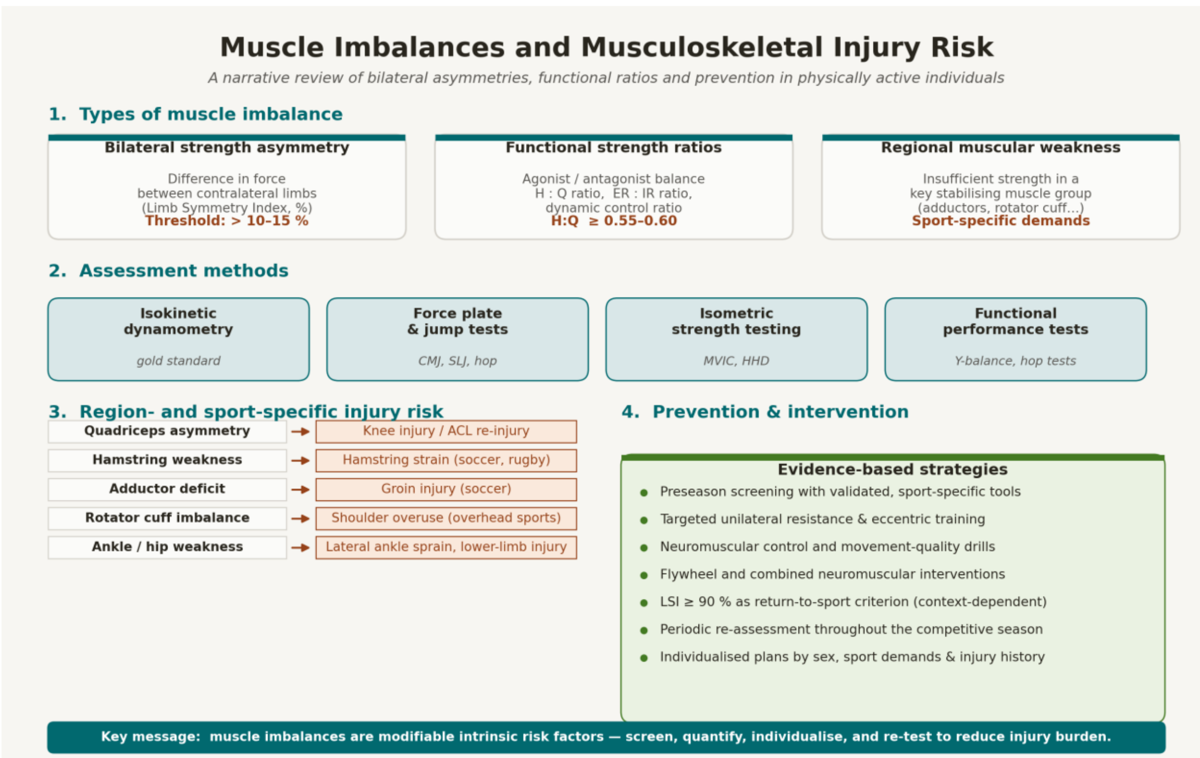


*Figure 1. Graphical abstract — muscle imbalances and musculoskeletal injury risk.*

# 1. INTRODUCTION

Musculoskeletal injuries represent a significant burden in athletic and physically active populations, resulting in substantial time loss from training and competition, increased healthcare costs and long-term consequences for joint health and quality of life [1], [2]. Among the multiple risk factors for these injuries, muscle imbalances — including bilateral strength asymmetries between contralateral limbs and functional strength ratio deficits between agonist and antagonist muscle groups — are recognised as modifiable intrinsic factors warranting systematic investigation [3].

The concept of muscle imbalance encompasses several dimensions of muscular function, including differences in maximal strength, rate of force development, muscular endurance and neuromuscular control between bilateral limbs or opposing muscle groups [3], [4]. While some degree of asymmetry occurs naturally — reflecting limb dominance and sport-specific adaptations — substantial deviations from population norms or established thresholds may compromise biomechanics and elevate injury risk.

Athletic populations are particularly susceptible to muscle-imbalance-related injuries because of high mechanical loads, the repetitive nature of sport-specific movements and the demanding multi-planar tasks characteristic of competitive performance [5]. Knee injuries, especially anterior cruciate ligament (ACL) tears and hamstring strains, are commonly associated with muscle imbalances and remain a major concern across multiple sports [3], [6].

This narrative review aims to synthesise current evidence on the definitions, mechanisms, assessment methods and clinical implications of muscle imbalances with respect to injury risk in athletes and physically active individuals. The review provides an evidence-based framework for clinicians, sports scientists, coaches and athletes to inform screening, intervention and rehabilitation strategies.

## 2. DEFINITION AND CLASSIFICATION OF MUSCLE IMBALANCES

Muscle imbalances can be classified along multiple dimensions, each carrying distinct implications for athletic performance and injury risk. A clear understanding of these classifications is essential for proper assessment, interpretation and clinical application.

### 2.1. Bilateral Strength Asymmetries

Bilateral strength asymmetries refer to differences in muscular performance between contralateral limbs. They are typically quantified using the formula: ((stronger − weaker) / stronger) × 100% [3]. Clinical thresholds of 10–15% are commonly applied, although evidence indicates that injury-relevant thresholds depend on muscle group, assessment modality and population [4]. For example, quadriceps asymmetry ≥10% at return to sport is associated with increased ACL re-injury risk [3], whereas hamstring asymmetries ≥15% may better predict hamstring strain in soccer players [5].

### 2.2. Functional Strength Ratio Imbalances

Functional strength ratios describe the balance of strength between agonist and antagonist muscle groups around a joint, providing insight into joint stability and movement efficiency. The hamstring-to-quadriceps (H:Q) ratio is the most widely studied, with conventional concentric ratios of 0.5–0.6 considered normal [3]. Dynamic control ratios (eccentric hamstring : concentric quadriceps) provide additional functional information [4] and may be more sensitive to hamstring-injury risk in sprinting populations.

### 2.3. Regional Muscular Weakness

Regional muscular weakness refers to inadequate strength in specific muscle groups relative to functional demands or population norms. Examples include adductor weakness in soccer players [9], shoulder muscle weakness in overhead athletes [7], and quadriceps weakness following knee injury [3]. Regional weakness may be either bilateral or unilateral and contributes to injury risk through compromised stabilisation, altered movement mechanics and reduced load-tolerance capacity [9].

# 3. MECHANISMS LINKING MUSCLE IMBALANCES TO INJURY RISK

The relationship between muscle imbalances and injury risk involves multiple interrelated biomechanical and neuromuscular mechanisms that converge to elevate tissue stress and reduce protective capacity during athletic performance.

## 3.1. Altered Force Distribution and Joint Loading

Asymmetric force production between contralateral limbs may result in compensatory movement patterns that redistribute mechanical loads across joints and soft tissues. When asymmetries are present, the stronger limb may be subjected to disproportionate loading during bilateral activities, potentially exceeding tissue tolerance and precipitating overuse injury [9], [10]. Conversely, the weaker limb may be unable to adequately absorb and dissipate forces, increasing risk of acute injury [3].

## 3.2. Compromised Neuromuscular Control

Muscle imbalances are frequently associated with altered neuromuscular activation patterns, including delayed muscle recruitment, reduced coactivation and impaired proprioceptive function [7]. These neuromuscular deficits compromise dynamic joint stability and may predispose to injury during high-velocity, multi-planar movements characteristic of athletic activity [7], [9].

## 3.3. Reduced Functional Capacity and Performance

Beyond direct injury risk, muscle imbalances are associated with reduced functional performance, including diminished jumping, sprinting and change-of-direction capabilities [5]. Reduced performance may indirectly contribute to injury through compensatory movement strategies, decreased ability to avoid hazardous situations and impaired post-injury recovery [3], [5].

## 3.4. Cumulative Loading and Fatigue Interactions

Asymmetric loading patterns may accelerate cumulative tissue stress and contribute to fatigue-related injury [16], [22]. Under fatigued conditions, neuromuscular control deficits typically amplify, and individuals with pre-existing imbalances may demonstrate disproportionate decrements in stability and performance, increasing vulnerability to acute injury [7], [16].

# 4. EVIDENCE FROM RESEARCH ON BILATERAL ASYMMETRIES AND INJURY

## 4.1. Lower Extremity Asymmetries

Most muscle-imbalance research focuses on lower-extremity asymmetries due to their relevance to running, jumping and change-of-direction tasks characteristic of athletic performance. Lower-extremity asymmetries have been extensively studied across multiple sports and populations, with consistent evidence linking specific asymmetry patterns to injury risk [3], [9], [11].

Quadriceps strength asymmetry is among the most-studied predictors of knee injury, particularly following ACL reconstruction. Prospective studies indicate that residual quadriceps asymmetry exceeding 10% at the time of return to sport is associated with increased risk of ACL re-injury, both ipsilaterally and contralaterally [3]. Eagle and colleagues reported that military operators with bilateral quadriceps strength asymmetry were significantly more likely to sustain knee injuries during subsequent service, highlighting the relevance of asymmetry beyond elite sport contexts [3].

Hamstring asymmetries have also received substantial attention, particularly in sports involving high-velocity running and sprinting. Pre-season eccentric hamstring strength asymmetries in young soccer players have been associated with subsequent hamstring strain injury [19]. Bilateral asymmetries appear to be more strongly associated with hamstring injury than concentric H:Q ratios [22], [23].

Adductor strength deficits are particularly relevant in sports involving cutting, pivoting and multi-directional change of movement. Adductor weakness has been associated with groin injury in soccer and similar sports, with deficits affecting both ipsilateral and contralateral injury risk [9], [11]. Force-plate countermovement-jump asymmetries have emerged as additional indicators of lower-extremity injury risk; Mentele and colleagues reported that asymmetries during countermovement jump were associated with injury risk in American football players [1].

### 4.2. Upper Extremity Asymmetries

Upper-extremity asymmetries are most relevant in sports involving overhead movements, such as tennis, throwing sports and swimming. These imbalances often arise from sport-specific adaptations, where repetitive unilateral demands lead to predictable strength patterns. Shoulder muscle imbalances, particularly affecting the rotator cuff and scapular stabilisers, are associated with injury risk in tennis players and other overhead athletes [25]. Cross-sectional comparisons between tennis players and non-tennis controls reveal distinct shoulder activation and recruitment patterns that may contribute to specific injury profiles [25].

## 5. ASSESSMENT METHODS FOR MUSCLE IMBALANCES

Multiple assessment methods are available for quantifying muscle imbalances, each offering distinct advantages, limitations and clinical utility. The choice of assessment method depends on available resources, clinical context, and specific diagnostic or prognostic questions [3], [11], [20].

Isokinetic dynamometry is the gold-standard method for assessing strength asymmetries and functional ratios. It enables controlled-velocity measurement of concentric and eccentric strength across multiple joint angles. The method demonstrates excellent reliability and provides comprehensive information on strength characteristics, though it requires specialised equipment and trained personnel [2], [22].

Functional performance tests, such as single-leg hop tests and Y-balance assessments, are valuable alternatives or complements to laboratory testing. They evaluate integrated movement capacity and may better reflect sport-specific demands than isolated strength measurement [3]. The countermovement jump on bilateral force platforms is increasingly used to quantify between-limb asymmetries during athletic tasks and has been linked to injury risk in football and other sports [1].

Methodological considerations strongly influence interpretation, including testing protocols, calculation formulae, velocity selection and statistical thresholds. Substantial heterogeneity across studies limits direct comparability and complicates clinical decision-making [20].

## 6. SPORT-SPECIFIC CONSIDERATIONS

Different sports impose distinct demands that influence muscle-imbalance profiles, injury patterns and assessment priorities. Understanding these sport-specific characteristics is essential for the development of effective screening and intervention strategies.

In soccer, lower-extremity asymmetries — particularly involving the hamstrings, quadriceps and adductors — are most relevant due to high-velocity sprinting, cutting and kicking demands. Pre-season eccentric hamstring strength imbalances have been associated with subsequent injury [19], [22]. Basketball, with its repetitive jumping and landing demands, places particular emphasis on quadriceps and gluteal strength balance and posterior-chain function. American football generates very high contact and acceleration forces; countermovement-jump asymmetries have been linked to injury risk in this population [1].

Overhead sports such as tennis, swimming and throwing produce sport-specific adaptations of the shoulder girdle, with imbalances in the rotator cuff and scapular muscles linked to overuse pathology [25]. Combat sports, judo and martial arts often involve unilateral loading patterns and high-velocity reactive movements; for example, judo athletes — including those with visual impairment — display interlimb asymmetries that may be relevant to injury reporting [21].

## 7. PREVENTION AND INTERVENTION STRATEGIES

Evidence-based prevention and intervention strategies for muscle imbalances combine targeted resistance training, neuromuscular conditioning, and sport-specific movement education.

Targeted resistance training represents the foundation of muscle-imbalance intervention. Unilateral exercises are particularly effective for addressing bilateral asymmetries, as they require independent force production from each limb and prevent compensation by the stronger side [3]. Progressive resistance training programmes incorporating both concentric and eccentric components have demonstrated effectiveness in reducing bilateral asymmetries and improving functional strength ratios [3].

Eccentric strengthening — particularly using Nordic hamstring exercises and similar interventions — has emerged as a key strategy for hamstring injury prevention [3], [9]. Eccentric training induces specific muscle adaptations including increased fascicle length, improved force production at long muscle lengths and enhanced eccentric strength, all of which may reduce hamstring-strain injury risk [3].

Comprehensive neuromuscular training programmes integrate strength training with balance, proprioception, plyometrics and movement-quality exercises [9]. These programmes address the multifactorial nature of muscle imbalances and demonstrate effectiveness in reducing injury risk across multiple sports and populations [7], [9].

Flywheel resistance training, which provides eccentric overload through inertial loading, represents an emerging modality for addressing muscle imbalances [3]. Initial evidence suggests that flywheel training may be particularly effective for reducing bilateral asymmetries and improving eccentric strength, although high-quality intervention trials are still limited [3].

Beyond traditional strength training, interventions emphasising movement quality, motor control and functional integration may be particularly relevant for addressing the neuromuscular components of muscle imbalances [9]. These approaches integrate strength development with technique refinement and may translate more directly to sport-specific performance and injury reduction [9].

## 8. METHODOLOGICAL LIMITATIONS

Despite substantial progress in understanding muscle imbalances and injury risk, several methodological limitations affect the strength and interpretation of current evidence. Substantial heterogeneity exists in assessment methodologies — testing equipment, protocols, calculation formulae and threshold definitions all vary [3], [20]. Standardisation of assessment protocols represents a critical priority for advancing the field [20]. Threshold determination remains controversial; while 10–15% is widely cited, the optimal cut-off depends on muscle group, sport context and assessment modality.

Many studies are cross-sectional in design, limiting causal inference; longitudinal prospective designs with adequate follow-up are needed to clarify cause-and-effect relationships between asymmetry and injury [3], [4]. Effect-size and confounding considerations — including training history, prior injury and competitive level — must also be more systematically addressed [3], [21].

## 9. FUTURE DIRECTIONS AND RESEARCH NEEDS

Several research priorities have emerged from this synthesis. Standardised assessment protocols accepted across research groups would substantially improve comparability and clinical utility [20]. Large-scale prospective studies with adequate statistical power and follow-up duration are needed to establish robust cause-and-effect relationships, ideally pooled in international registries that account for sport and population.

Population-specific thresholds — by sport, age group, sex and competitive level — represent another priority. Integration of multiple measurement modalities (isokinetic strength, jump asymmetry, functional tests, movement screens) into composite risk profiles may outperform any single metric. Finally, intervention research should evaluate the relative effectiveness of unilateral resistance training, eccentric loading, flywheel training and integrated neuromuscular programmes across populations and competitive levels [3], [9].

## 10. CONCLUSIONS

Muscle imbalances — including bilateral strength asymmetries and functional strength ratio deficits — are clinically meaningful, modifiable risk factors for musculoskeletal injury in physically active populations. Asymmetries exceeding 10–15% are consistently associated with elevated injury risk, although specific thresholds depend on muscle group, assessment modality and sport context. Quadriceps asymmetry, hamstring weakness and adductor deficits show particularly clear links to knee, hamstring and groin injury respectively.

Effective management requires comprehensive assessment using validated tools, individualised intervention combining targeted resistance training, eccentric strengthening and neuromuscular conditioning, and longitudinal monitoring. Sport-specific demands shape both asymmetry profiles and intervention priorities, so screening and prevention programmes should be tailored accordingly. Continued methodological refinement, standardised assessment protocols and longitudinal prospective studies will further refine the evidence base and translation into practice. Until such evidence is available, practitioners should apply current knowledge judiciously, monitor outcomes systematically, and remain responsive to emerging evidence.

## DISCLOSURE

### Author Contributions (CRediT)

*Mapped to the CRediT (Contributor Roles Taxonomy, NISO Z39.104-2022). Author initials: AD = Dobosz Adam; AW = Wojnowski Antoni; JD = Domińczak Jan; OB = Bartkowska Oliwia; JB = Banatkiewicz Joanna; ED = Deka Emilia; SC = Czarnecka Sofia; GŁ = Łuczyńska Gabriela; KB = Babik Karolina; HB = Bojanowska Hanna.*

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The authors declare no conflict of interest.

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## Declaration of the use of generative AI and AI-assisted technologies in the writing process

In preparing this work, the authors used AI tools for the purposes of systematically identifying, organising and analysing relevant scientific literature, and for language editing. After using these tools, the authors reviewed and edited the content as necessary and accept full responsibility for the substantive content of the publication.

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