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Shoulder asymmetry in tennis players: functional adaptation or misinterpreted indicator of scoliosis?

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ABSTRACT

Shoulder asymmetry is a frequent finding in tennis players and has often been misinterpreted as a clinical sign of scoliosis. This assumption derives from traditional orthopaedic paradigms in which differences in shoulder height were considered secondary indicators of spinal deformity. However, current biomechanical and sport science evidence suggests that, in tennis players, shoulder asymmetry predominantly reflects a functional, sport-specific adaptation rather than a structural spinal pathology. Tennis is a highly asymmetric overhead sport characterized by repetitive, high-velocity movements of the dominant upper limb, particularly during the serve and forehand. These actions promote selective hypertrophy and strength dominance of the shoulder internal rotators, combined with relative weakness of the external rotators and scapular stabilizers. The resulting muscular imbalance and inertial loading contribute to altered scapular positioning and apparent shoulder depression. This article examines the biomechanical basis of shoulder asymmetry in tennis players and discusses practical implications for screening, prevention, and training.

Key words: Tennis, Shoulder asymmetry, Shoulder biomechanics, Functional adaptation, Scoliosis

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INTRODUCTION

Asymmetrical musculoskeletal adaptations are a well-recognized consequence of long-term participation in unilateral and overhead sports. Disciplines such as tennis, baseball, volleyball, and handball require repetitive, high-velocity movements predominantly executed with the same upper limb, leading to sport-specific structural and functional adaptations of the shoulder girdle and trunk (Kibler, 1998; Ellenbecker & Roetert, 2003; Elliott, 2006). In tennis players, these adaptations are particularly evident at the level of the dominant shoulder, where selective hypertrophy, strength imbalances, and changes in scapular positioning are commonly observed across different levels of play.

One of the most visible manifestations of these adaptations is shoulder height asymmetry, often characterized by an apparent lowering of the dominant shoulder. Historically, this clinical sign has generated diagnostic uncertainty and has frequently been interpreted as a possible indicator of spinal pathology, particularly scoliosis. This interpretation originates from traditional orthopedic paradigms in which shoulder asymmetry was considered a secondary sign of structural spinal deformity. However, accumulating evidence from sport science, biomechanics, and clinical sports medicine suggests that, in athletes, shoulder asymmetry more often represents a functional adaptation rather than a manifestation of true scoliosis (Priest, 1988; Kibler, 1995; Negrini et al., 2018).

Recent systematic reviews and narrative syntheses in tennis and overhead athletes have further confirmed that shoulder asymmetries are primarily related to sport-specific loading patterns, strength imbalances, and range-of-motion adaptations rather than structural spinal pathology (Johnson et al., 2018; Moreno-Pérez et al., 2018; Keller et al., 2020). The distinction between structural scoliosis and functional or posture-dependent asymmetries is therefore crucial in the evaluation of athletes. Structural scoliosis is defined as a fixed, three-dimensional deformity of the spine, characterized by vertebral rotation and persistence of the curve irrespective of posture, whereas functional asymmetries are typically flexible, reversible, and strongly influenced by asymmetric loading patterns, muscular imbalances, and neuromuscular adaptations induced by sport-specific training (Nachemson & Lonstein, 1995; Negrini et al., 2018).

Contemporary evidence emphasizes that screening in overhead athletes should focus on modifiable functional factors, including shoulder strength balance, internal-to-external rotator ratios, and range-of-motion adaptations such as glenohumeral internal rotation deficit (GIRD), which have been consistently associated with shoulder injury risk (Johnson et al., 2018; Moreno-Pérez et al., 2018; Keller et al., 2020). Dominant-arm adaptations in tennis players typically include reduced internal rotation range of motion and alterations in total arc, reflecting chronic exposure to asymmetric loading. These features are clinically relevant because deficits in external rotator strength and altered ER/IR ratios have been associated with a history of shoulder pain in elite tennis players (Moreno-Pérez et al., 2018).

Tennis represents a paradigmatic model of asymmetric loading, as match-play analyses have shown that approximately 70–80% of all strokes performed during competitive play consist of the serve and the forehand, both predominantly executed with the dominant arm (Johnson & McHugh, 2006). These strokes are characterized by extremely high angular velocities of shoulder internal rotation, particularly during the acceleration phase of the serve, where peak values exceeding 2,000°/s have been reported in elite players (Elliott et al., 1986; Elliott, 1988). Such biomechanical demands impose substantial mechanical stress on the shoulder girdle musculature, especially on the internal rotators, which play a primary role in power generation.

Isokinetic and electromyographic studies have consistently demonstrated a strength dominance and hypertrophy of the shoulder internal rotators in tennis players, accompanied by relatively lower strength and endurance of the external rotators and scapular stabilizers (Ellenbecker, 1991; Ellenbecker & Roetert, 2003; Kibler et al., 2007). During the serve and forehand, internal rotators act concentrically to accelerate the arm, whereas external rotators are primarily engaged eccentrically during the deceleration and follow-through phases, where they are exposed to high mechanical loads (Ryu et al., 1988; Elliott et al., 2003). This functional imbalance is considered a key factor in both performance enhancement and injury risk.

From a biomechanical perspective, rapid arm rotation generates substantial inertial forces proportional to the moment of inertia of the upper limb and the angular velocity achieved during the stroke (Lisi, 2007). Repeated exposure to these forces promotes adaptive hypertrophy of the muscles primarily involved in acceleration, while the stabilizing and decelerating muscles are subjected to chronic eccentric overload (Bahamonde & Knudson, 2003; Farthing & Chilibeck, 2003). Over time, these neuromuscular adaptations may contribute to altered resting scapular positioning and an apparent depression of the dominant shoulder, without implying any underlying structural spinal abnormality.

Despite early observations reporting the frequent coexistence of shoulder asymmetry and mild spinal deviations in tennis players, no consistent evidence has demonstrated a causal relationship between shoulder height differences and true structural scoliosis (Priest, 1988; Steinbrück & Mauch, 2000). Rather, the available data support the interpretation of shoulder asymmetry as a sport-specific functional adaptation driven by asymmetric muscular development and repetitive biomechanical loading.

The purpose of this article is therefore to analyze the biomechanical and neuromuscular mechanisms underlying shoulder asymmetry in tennis players, to critically re-examine its historical association with scoliosis, and to provide practical implications for screening, prevention, and training. Emphasis is placed on the importance of distinguishing functional adaptations from pathological conditions to avoid misdiagnosis and to guide evidence-based practice in tennis coaching and sports medicine.

The conceptual distinction between functional shoulder asymmetry in tennis players and structural spinal deformity is illustrated in Figure 1.

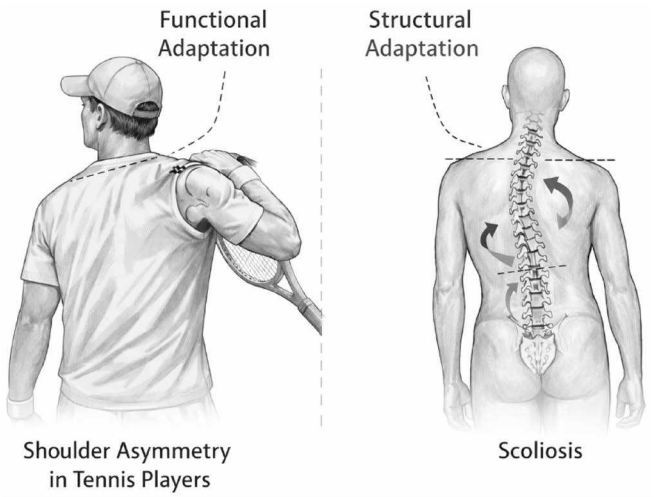

Figure 1. *Comparison between functional shoulder asymmetry in tennis players and structural spinal adaptation. Shoulder asymmetry observed in tennis players represents a sport-specific functional adaptation related to asymmetric loading, whereas scoliosis is characterized by a structural, three-dimensional spinal deformity.*

Shoulder Asymmetry in Tennis Players: Biomechanical Interpretation

The term "tennis player's shoulder" has long been used to describe the characteristic asymmetry observed at the level of the shoulder girdle in tennis players, typically involving an apparent lowering of the dominant shoulder (Rieder et al., 1983; Priest, 1988; Steinbrück & Mauch, 2000). Early observational studies reported a high prevalence of shoulder height asymmetry in competitive players, sometimes associated with mild lateral deviations of the thoracic spine. These findings contributed to the hypothesis that shoulder asymmetry might represent a clinical sign of underlying scoliosis.

However, early critical analyses questioned this interpretation and proposed an alternative explanation based on sport-specific biomechanical adaptations rather than structural spinal pathology (Lisi, 2007). Subsequent investigations failed to demonstrate a statistically significant correlation between shoulder depression and true scoliosis. Although mild thoraco-lumbar deviations were occasionally observed, these deviations were often flexible, posture-dependent, and not consistently oriented toward the dominant arm (Priest, 1988; Steinbrück & Mauch, 2000). Such characteristics are incompatible with the definition of structural scoliosis and instead suggest the presence of functional or apparent spinal adaptations.

Limitations of Early Etiological Hypotheses

Two main mechanisms were originally proposed to explain dominant-side shoulder depression in tennis players (Priest & Nagel, 1976; Priest, 1988). The first attributed the phenomenon to repetitive stretching of the shoulder elevators during the serve, particularly during the acceleration and follow-through phases, leading to progressive elongation and reduced resting tone of these muscles. The second hypothesis suggested that the increased mass of the dominant upper limb, resulting from hypertrophy, would exert a gravitational effect sufficient to lower the shoulder.

A biomechanical critique of these hypotheses highlighted their limitations (Lisi, 2007). During arm elevation, the scapula does not elevate passively but is actively stabilized by coordinated contraction of scapular depressors and rotators, providing a stable base for humeral motion (Boccardi & Lissoni, 1977; 1978; 1984). The modest degree of scapular depression typically observed (approximately 1–2 cm) is unlikely to induce pathological elongation of the elevator muscles, which are subsequently engaged concentrically during arm lowering. This interpretation is further supported by studies on scapular kinematics showing that resting scapular position is maintained primarily by tonic muscular activity rather than by gravitational loading (Ludewig & Cook, 2000). Consequently, the "gravitational mass" hypothesis appears biomechanically implausible.

Role of Inertial Forces and Muscle Imbalance

A more coherent explanation emerges when the dynamic characteristics of tennis strokes are considered (Lisi, 2007). Rapid arm rotation generates inertial forces proportional to the moment of inertia of the upper limb and the angular velocity achieved during the movement. An increase in limb mass or movement speed therefore results in a proportional increase in the mechanical load sustained by the muscles responsible for controlling these motions.

In tennis, both the serve and the forehand rely heavily on high-velocity internal rotation of the shoulder and account for the majority of strokes performed during match play (Johnson & McHugh, 2006). These strokes are characterized by extreme angular velocities, particularly during the acceleration phase of the serve, where peak values exceeding 2,000°/s have been reported in elite players (Elliott et al., 1986; Elliott, 1988). As originally proposed, repeated exposure to such inertial loads promotes selective hypertrophy and strength dominance of the shoulder internal rotators, while placing the external rotators at a relative mechanical disadvantage (Lisi, 2007).

Recent studies and systematic reviews have confirmed that these strength and range-of-motion adaptations persist across different competitive levels and age groups in overhead and racket sports, supporting the concept of long-term functional remodelling rather than pathological alteration (Silva et al., 2025; Madroñal-Sotomayor et al., 2025).

Isokinetic studies have consistently confirmed a functional imbalance between shoulder internal and external rotators in tennis players, demonstrating significantly greater strength of the internal rotators on the dominant side, while external rotator strength often shows minimal side-to-side differences (Ellenbecker, 1991; Ellenbecker & Roetert, 2003; Kibler et al., 2007). The functional imbalance between internal and external rotators in tennis players is schematically illustrated in Figure 2.

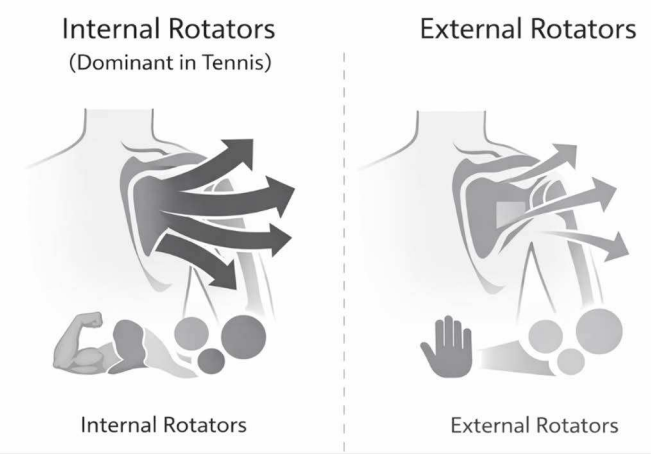

Figure 2. *Conceptual vector model illustrating the functional dominance of shoulder internal rotators compared with external rotators in tennis players. High-velocity strokes generate predominant internal rotation forces, while the external rotators are primarily involved in eccentric control and deceleration.*

This imbalance is further accentuated by biomechanical factors, including thoracic kyphosis and the oblique orientation of the scapula relative to the frontal plane, which reduce the mechanical efficiency of the external rotators during high-velocity movements (Kibler, 1998; Ludewig & Cook, 2000). As a result, the external rotators are required to operate under unfavourable length–tension and moment-arm conditions, particularly during the deceleration phase of the serve. The relationship between angular velocity, inertial forces, and eccentric control demands at the shoulder is central to understanding tennis-related adaptations. High angular velocities generated during the acceleration phase are followed by a rapid deceleration phase, during which substantial eccentric loading is required to dissipate inertial forces and protect the glenohumeral joint (Figure 3) (Bahamonde & Knudson, 2003; Elliott et al., 2003).

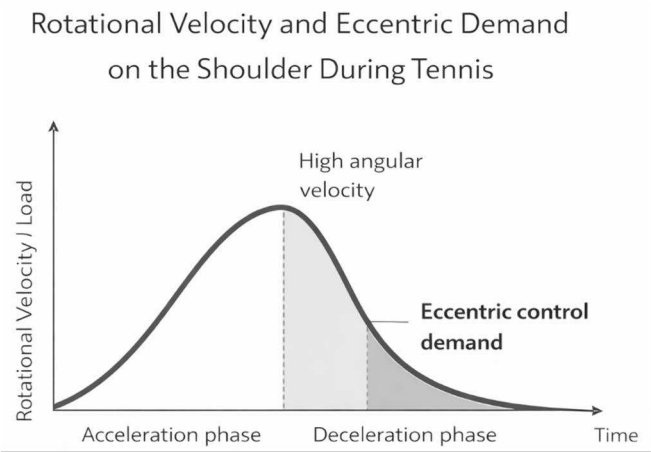

Figure 3. *Conceptual representation of the relationship between rotational velocity and eccentric control demands at the shoulder during tennis strokes. High angular velocities generated during the acceleration phase are followed by a rapid deceleration phase, during which substantial eccentric loading is required to control inertial forces.*

Electromyographic Evidence and Stroke-Specific Loading

Electromyographic analyses of the tennis serve indicate that scapular stabilizers are activated early to position and stabilize the scapula, while rotator cuff activation timing shifts across stroke phases, supporting the need for sequenced scapular–cuff conditioning rather than isolated muscle strengthening (Ryu et al., 1988; Kibler et al., 2007).

Repeated exposure to high-velocity internal rotation during serving and forehand strokes promotes selective hypertrophy and strength dominance of the shoulder internal rotators, including the pectoralis major, latissimus dorsi, teres major, and subscapularis (Ryu et al., 1988; Elliott et al., 2003; Ellenbecker & Roetert, 2003). Over time, this neuromuscular pattern leads to stable, sport-specific adaptations rather than transient functional changes.

These chronic adaptations provide a plausible biomechanical explanation for altered resting scapular positioning and the apparent depression of the dominant shoulder frequently observed in tennis players, without implying any underlying structural spinal abnormality (Kibler, 1998; Lisi, 2007).

Clinical interpretation: functional vs structural asymmetry

Structural scoliosis is defined as a fixed, three-dimensional spinal deformity characterized by vertebral rotation and persistence of curvature irrespective of posture, whereas the asymmetries observed in tennis players are flexible, reversible, and strongly influenced by sport-specific loading patterns (Nachemson & Lonstein, 1995; Negrini et al., 2018). Despite early reports describing the coexistence of shoulder asymmetry and mild spinal deviations in tennis players, no consistent evidence supports a causal relationship between shoulder height differences and true structural scoliosis (Priest, 1988; Steinbrück & Mauch, 2000). Observed spinal deviations are typically mild, posture-dependent, and non-fixed, characteristics incompatible with the definition of structural scoliosis.

DISCUSSION

The present analysis reinforces the interpretation of shoulder asymmetry in tennis players as a functional, sport-specific adaptation rather than a clinical indicator of structural scoliosis. While early observational studies documented a frequent coexistence of shoulder height asymmetry and mild spinal deviations, subsequent biomechanical and clinical investigations have failed to establish a causal relationship between these findings and true scoliosis (Priest, 1988; Steinbrück & Mauch, 2000). Instead, the available evidence consistently supports a model based on asymmetric loading, muscular imbalance, and inertial forces inherent to tennis performance.

A key contribution to this reinterpretation was the biomechanical framework originally proposed by Lisi (2007), which reframed the so-called “tennis player’s shoulder” as an adaptive response to repetitive, high-velocity upper limb actions. To the author’s knowledge, this interpretation was first explicitly proposed in the context of tennis by Lisi (2007), anticipating concepts that have since been supported by electromyographic, isokinetic, and clinical injury-risk studies in overhead athletes.

This biomechanical model anticipated several concepts now widely accepted in sport science, including the central role of internal rotator dominance, the mechanical disadvantage of the external rotators, and the importance of eccentric capacity during high-velocity deceleration. This aligns with evidence showing that external rotator strength deficits and altered ER/IR ratios are associated with shoulder pain history in elite tennis players (Moreno-Pérez et al., 2018), highlighting the clinical relevance of these functional imbalances.

Electromyographic analyses of the tennis serve demonstrate that scapular stabilizers are activated early to appropriately position the scapula, while rotator cuff activation timing shifts across stroke phases, supporting the need for sequenced scapular–cuff conditioning rather than isolated muscle strengthening (Kibler et al., 2007). During acceleration, internal rotators dominate force production, whereas external rotators are primarily engaged eccentrically during deceleration (Ryu et al., 1988).

Dominant-arm adaptations in tennis players typically include reduced internal rotation range of motion and alterations in total rotational arc. These features are clinically relevant because deficits in external rotator strength and altered ER/IR ratios have been associated with shoulder pain history in elite tennis players (Moreno-Pérez et al., 2018), reinforcing the importance of monitoring functional asymmetries rather than static postural signs alone.

The strength of this functional interpretation lies in its consistency with neuromuscular evidence. Studies examining the tennis serve and forehand consistently report high activation levels of the pectoralis major, latissimus dorsi, and subscapularis during acceleration phases, contrasted with intense eccentric loading of the external rotators during deceleration (Ryu et al., 1988; Kibler et al., 2007; Ellenbecker & Roetert, 2003). Over time, this loading pattern promotes selective hypertrophy and strength dominance of the internal rotators, while exposing the external rotators and scapular stabilizers to chronic overload and fatigue.

Such neuromuscular adaptations provide a plausible explanation for altered scapular positioning and apparent shoulder depression at rest. Rather than reflecting structural deformity, these postural features are consistent with long-term functional remodeling driven by asymmetric loading and repetitive inertial demands, as observed across overhead and racket sports (Kibler, 1998; Silva et al., 2025).

Importantly, this functional perspective also explains why shoulder asymmetry in tennis players is often flexible, posture-dependent, and poorly correlated with the direction or magnitude of spinal deviations. These characteristics are incompatible with the definition of structural scoliosis, which requires fixed vertebral rotation and persistence of curvature independent of posture (Nachemson & Lonstein, 1995; Negrini et al., 2018).

Misinterpreting functional adaptations as pathological deformities may lead to unnecessary diagnostic procedures, inappropriate clinical labelling, and misguided interventions. In athletic populations, particularly young players, such misclassification risks diverting attention away from modifiable performance-related factors toward non-indicated medical management (Negrini et al., 2018).

CONCLUSION

Shoulder asymmetry in tennis players should be interpreted primarily as a functional adaptation resulting from the asymmetric biomechanical demands of the sport rather than as a clinical sign of scoliosis. The repetitive, high-velocity actions of the serve and forehand impose substantial inertial loads on the dominant upper limb, promoting selective hypertrophy and strength dominance of the shoulder internal rotators and altering scapular resting position (Elliott, 1988; Bahamonde & Knudson, 2003).

The biomechanical interpretation originally proposed by Lisi (2007) provides a coherent framework for understanding this phenomenon and remains fully consistent with contemporary findings in electromyography, isokinetic, and movement analysis. Distinguishing functional adaptations from structural pathology is essential to avoid misdiagnosis and to guide appropriate training, prevention, and clinical decision-making in tennis players.

Future research should investigate shoulder asymmetry using integrated biomechanical models that consider the entire kinetic chain, individual playing styles, and modern equipment characteristics. Such approaches may further clarify the boundary between adaptive responses and pathological conditions and support evidence-based practice in tennis coaching and sports medicine.

Practical Implications for Coaches and Practitioners

Shoulder asymmetry in tennis players should be interpreted primarily as a sport-specific functional adaptation rather than as an isolated indicator of spinal pathology. In the absence of pain, neurological signs, or progressive deformity, the presence of a lowered dominant shoulder does not justify automatic suspicion of scoliosis. Instead, it should be understood within the context of asymmetric loading and long-term neuromuscular adaptation inherent to tennis performance (Priest, 1988; Lisi, 2007; Negrini et al., 2018).

Static postural assessment alone is insufficient to evaluate shoulder asymmetry in tennis players. Observation of shoulder height at rest does not capture the dynamic demands imposed by high-velocity strokes and may lead to misinterpretation of normal sport-related adaptations. Therefore, assessment should prioritize functional evaluation, including shoulder range of motion, scapular control during dynamic tasks, and strength balance between internal and external rotators (Kibler, 1998; Ellenbecker & Roetert, 2003; Kibler et al., 2007).

Imbalance between shoulder internal and external rotators represents a key modifiable factor in tennis players. Isokinetic and field-based studies consistently show dominant-side internal rotator strength to exceed that of the external rotators, resulting in altered ER/IR strength ratios (Ellenbecker, 1991; Ellenbecker & Roetert, 2003). Importantly, deficits in external rotator strength and altered ER/IR ratios have been associated with a history of shoulder pain in elite tennis players, underscoring their clinical relevance for injury prevention and monitoring (Moreno-Pérez et al., 2018).

Training programs should systematically include targeted strengthening of the external rotators and scapular stabilizers, with particular emphasis on eccentric loading (Figure 4).



Figure 3. *Example of a side-lying eccentric external rotation exercise performed with the shoulder abducted to 90°. This exercise targets the deceleration function of the external rotators and is recommended to counterbalance internal rotator dominance in tennis players.*

During the deceleration and follow-through phases of the serve and forehand, the external rotators are exposed to substantial eccentric demands required to dissipate inertial forces generated during acceleration (Ryu et al., 1988; Elliott et al., 2003). Enhancing eccentric capacity may improve deceleration control, reduce cumulative overload, and support long-term shoulder health (LaStayo et al., 2003; Farthing & Chilibeck, 2003).

Effective management of shoulder asymmetry requires an integrated approach that prioritizes scapular control within the kinetic chain. Early activation of scapular stabilizers is essential to position the glenoid optimally and to allow efficient force transfer from the trunk to the upper limb during high-velocity strokes (Kibler, 1998; Kibler et al., 2007). Off-court strengthening of the serratus anterior, lower trapezius, and rotator cuff should therefore be combined with stroke-specific on-court drills to reinforce appropriate scapulohumeral sequencing.

Dominant-arm adaptations in tennis players typically include reductions in glenohumeral internal rotation and alterations in total rotational arc. While these changes are recognized as common sport-specific adaptations, excessive or asymmetrical range-of-motion deficits warrant attention, particularly when accompanied by strength imbalance or impaired scapular control (Johnson et al., 2018; Keller et al., 2020). Monitoring shoulder range of motion, especially unilateral internal rotation deficits, may facilitate early identification of maladaptive patterns.

From a preventive standpoint, a function-oriented screening framework is recommended. Rather than relying on static postural signs, clinicians and coaches should integrate assessments of strength balance, eccentric external rotator capacity, scapular control, and sport-specific movement patterns. When shoulder asymmetry is identified, it should prompt functional testing and targeted intervention rather than immediate referral for imaging or spinal evaluation.

Education of players, parents, and coaching staff is essential. Clear communication that certain asymmetries represent normal adaptations to tennis practice may reduce unnecessary concern, discourage premature medicalization, and support more appropriate performance-oriented and preventive strategies.

CONFLICTS OF INTEREST

The author declares the absence of conflicts of interest.

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