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Clinical patterns of ocular motor and vestibular impairments in professional athletes after sport-related concussion (SRC) and diagnostic challenges: a narrative review

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Abstract

Background. Sport-related concussions (SRC) are complex injuries often involving ocular motor and vestibular impairments. While standardized acute tools, such as the SCAT6, are essential for initial evaluation, they lack clinical sensitivity after the first 72 hours. Furthermore, subacute subjective clinical screening is heavily limited by elite athletes frequently minimizing or concealing symptoms.

Aim. The aim of this narrative review is to summarize the existing literature on the clinical patterns of ocular motor and vestibular impairments in professional athletes following SRC, and to highlight the critical need for an objective, multimodal diagnostic approach.

Material and methods. A comprehensive literature review was conducted using PubMed and ScienceDirect, incorporating recent clinical studies, international consensus statements, and literature reviews published between 2014 and 2025. The analysis focused on the limitations of traditional subjective symptom reporting and evaluated the clinical utility of objective technological instruments in assessing ocular motor and vestibular impairments in SRC management.

Results. The problem with standard concussion tests is that they rely on athletes telling the truth about their symptoms - which they often don't. Technologies like the vHIT and iVOMS get around this issue completely by providing raw, computer-recorded metrics. Because a player has absolutely no conscious control over these automatic physical responses, these tests are a much more reliable way to detect deficits.

Conclusions. The management of SRC in professional athletes requires a transition from subjective evaluations to targeted, objective diagnostics. Adding objective technologies to standard clinical screening provides an accurate, data-driven way to track brain recovery. This solves the issue of subjective symptom reporting and ensures proper recovery.

Key words: sport-related concussion, ocular motor impairment, vestibular impairment, objective diagnostics, diagnostic tools.

1. Introduction

Sport-related concussions (SRCs) are mild brain injuries that continue to challenge the professional sports world. The clinical fallout of every injury is different, but ocular motor and vestibular impairments routinely stand out as some of the most common and disabling issues [1,2,3]. These deficits heavily disrupt an athlete's dynamic balance, steady vision, and cognitive processing [3,4]. While sideline tests like the SCAT6 are effective for flagging immediate red flags, they simply are not sensitive enough to pick up on ongoing ocular motor and vestibular dysfunctions after the first 72 hours [5,6]. Ultimately, accurately diagnosing athletes later in their recovery process requires much more targeted clinical tests, such as the VOMS [7].
The reality of professional sports is that athletes often downplay or hide their symptoms just to stay in the game [8,9]. Because we cannot always trust what players report, there is a major push to use objective, technology-based tools like the iVOMS and vHIT instead [9,10,11,12]. With that in mind, this narrative review aims to map out what we currently know about how ocular motor and vestibular impairments show up in pro athletes after an SRC.

We also look at why shifting away from old-school subjective tests toward a data-driven, multimodal approach is the only real way to accurately track brain healing and get around the problem of hidden symptoms [1,6,13].

2. Research materials and methods

In order to conduct this narrative review, a comprehensive literature search was performed using primary scientific databases, including PubMed and ScienceDirect. The search targeted peer-reviewed articles published predominantly between 2014 and 2025 to ensure the inclusion of the most recent clinical data. The selected literature primarily encompassed clinical studies, literature reviews, and international consensus statements. Keywords utilized in the search strategy included: “sport-related concussion”, “ocular motor impairment”, “vestibular impairment”, “objective diagnostics”, and “diagnostic tools”. Articles not published in English, as well as single case reports lacking a broader population context, were excluded from the synthesis.

3. Definition and Biomechanics of Sport-Related Concussion

A sport-related concussion (SRC) happens when an impulsive force damages the brain. Most of the time, this comes from a direct strike to the head, neck, or another part of the body during sports and exercise-related activities [14]. SRC typically results in a reversible clinical syndrome manifested by a diverse range of signs and symptoms affecting the physical, cognitive, emotional, and sleep domains, reflecting a predominantly functional rather than structural injury [15].

Linear vs. Rotational Acceleration

When researchers study the physics of a head impact, they generally focus on two main measurements: linear acceleration, recorded in gravitational force units (g), and rotational or angular acceleration, measured in radians per second squared (rad/s^2). Interestingly, these two forces damage the brain in completely different ways. Direct linear hits cause sudden, sharp spikes in pressure inside the skull, which most experts believe is the main reason for localized, focal brain damage [16]. On the other hand, recent biomechanical studies strongly point to angular twisting motion as the primary factor that drives the risk of getting a concussion. This specific vulnerability comes down to the brain's unique physical makeup and exactly how it sits inside the skull [17]. Because brain tissue cannot be easily compressed but stretches and tears quite easily under twisting stress, rotational forces cause the brain to shift violently and rub against the inner walls of the skull [16]. That intense shearing motion is exactly what triggers the widespread brain injuries and functional network failures that we so often see in a sport-related concussion (SRC) [15,17].

Even though they work through different mechanisms, sports biomechanics experts agree that real-world head impacts are never purely linear or purely rotational. Instead, every single hit on the field involves a complex mix of both types of forces working together [16]. Because of this, if we want to accurately evaluate concussion risk and how the injury develops, we must look at how linear and rotational forces combine to physically deform the brain, rather than just looking for one single, isolated impact threshold [1,16].

4. Neuroanatomy, Physiology, and Biomechanical Vulnerability of the Ocular Motor and Vestibular Systems

To see exactly how the previously outlined biomechanical forces - especially rotational acceleration and the severe shear strain it creates - translate into functional clinical deficits, we must examine the vestibular and ocular motor systems. Researchers know these systems possess completely distinct neuroanatomical structures. But they absolutely do not operate in a vacuum. Rather, they are fundamentally braided together, creating a massive, integrated sensorimotor network. Maintaining visual stability, spatial orientation, and postural control during dynamic head movements depends entirely on this exact network [3,18]. The vestibulo-ocular reflex (VOR) acts as the primary functional bridge connecting the two systems. Its purpose is constant. It ensures the eyes remain securely fixed on a target while the rest of the head or body is in motion [3,19]. Because their extensive neural pathways overlap so heavily and constantly exchange signals across the brainstem, cerebellum, and cortex - a concussive blow almost never isolates just one system [3,12]. Once rotational acceleration triggers those diffuse shear strains, the biomechanical trauma overloads both pathways at the exact same time. The result is a severe functional overload. It completely disrupts how the brain centrally integrates visual and vestibular data, creating a breakdown that perfectly defines a classic sport-related concussion [3,18].

The Ocular Motor System

Structure and Neuroanatomy: The ocular motor system is highly complex. It simply does not rely on a single, localized brain region. What it utilizes, instead, is an extensively distributed neural circuitry. If we map this highly ramified network, we see it spans multiple subcortical and midbrain structures (this heavily involves the basal ganglia, the pons, and the cerebellum). Simultaneously, the circuitry extends outward to various cortical areas. To be exact, it engages the frontal eye fields and the supplementary eye fields, alongside the intraparietal sulcus and the dorsolateral prefrontal cortex [3,12].

Physiological Function: Functionally speaking, we rely on this complex system to maintain visual stability. It also actively coordinates dynamic eye movements and scans the surrounding space for visual information. To achieve all of this, the brain utilizes a highly specific combination of mechanics. You have your versional movements - specifically smooth pursuits and saccades. Then you add vergence movements (such as convergence as well as divergence) into the mix. Ultimately, it anchors all this using visual-fixation mechanisms, which heavily involve gaze holding and optokinetic responses [3,7].

Mechanism of Biomechanical Injury: The vulnerability of these functional neural pathways lies in their sheer length. They must cover significant physical distances across the brain simply to properly integrate sensory and motor inputs. Because of this extensive reach, they become exquisitely susceptible to the diffuse shear strains generated by rotational acceleration during a head impact [12,16]. Once the resulting angular motion hits, the tissue suffers. It triggers massive diffuse axonal stretching as well as microstructural white matter damage. Severe mechanical tissue deformation follows immediately. This deformation physically disrupts the rapid communication happening within these widespread networks. It leaves the athlete with a complete functional breakdown in ocular motor control (a deficit that, notably, occurs entirely without causing a gross structural lesion) [12].

The Vestibular System

Structure and Neuroanatomy: Vestibular system anatomy essentially boils down to two main components: peripheral sensory organs and central integrative pathways. They never work alone; the interconnection is remarkably deep. Start with the peripheral apparatus located inside the inner ear. It relies on a highly specific set of structures. The utricle and saccule (meaning the otolithic organs) sit right alongside three orthogonally arranged semicircular canals [10]. All these peripheral organs do is constantly gather sensory input. They send it straight into a massive, extensive central network. Look at the sheer size of it. The network actively engages the vestibular nuclei, alongside the reticular formation. At the exact same time, it manages to stretch deep into the brainstem and the thalamus. Finally, it completely links the cerebellum to the cerebral cortex [3,7].

Physiological Function: Functionally speaking, the primary purpose of this system is straightforward. It must detect the continuous motion of the head in time and space. This constant detection is what actively relays a subjective sense of self-motion [3]. It operates through two very distinct functional units. Look at the vestibulospinal component. This specific part exists to help regulate postural stability as well as general balance. The other part is the vestibulo-ocular component. It directly integrates vision and head movement to actively stabilize gaze. That specific integration is what allows the eyes to remain firmly fixed on a target while the head or body moves [3,7].

Mechanism of Biomechanical Injury: Physiologically, the delicate inner ear structures are explicitly designed to register linear and angular head movements [10]. Consequently, the extreme kinematic forces transmitted to the head during a sport-related concussion can directly overload and mechanically disrupt these peripheral sensory receptors. Simultaneously, the diffuse shear forces generated by rotational acceleration stretch and damage the widespread central sensorimotor connections. This combination of direct peripheral mechanical overload and shear-induced disruption of central networks creates a profound vulnerability to functional vestibular impairment [7,18].

To systematically summarize how impact biomechanics disrupt these specific neuroanatomical pathways, the vulnerabilities of both systems are outlined in **Table 1**.

Table 1. Anatomical and Biomechanical Vulnerabilities of the Vestibular and Ocular Motor Systems in SRC

System	Anatomical Structures	Biomechanical Mechanism of Injury
Ocular Motor System	Widespread cortical and subcortical networks (spanning the midbrain, pons, basal ganglia, cerebellum, and specific cortical areas such as the frontal eye fields and dorsolateral prefrontal cortex).	Diffuse shear strains from rotational acceleration cause widespread axonal stretching and microstructural white matter damage, disrupting long-range rapid neural communication.
Vestibular System	Peripheral sensory organs (semicircular canals, otolithic organs) and extensive central sensorimotor pathways (vestibular nuclei, brainstem, thalamus, cerebellum).	Extreme linear and angular forces directly overload delicate peripheral sensory receptors, while rotational shear strains stretch and disrupt widespread central integrative networks.

Source: Own elaboration based on current literature.

5. Clinical Phenotypes of SRC

A sport-related concussion is not a simple condition; it is a highly heterogeneous injury. Practically speaking, this means no two athletes will ever present with the exact same clinical picture. The physiological disruption of brain networks simply does not create a uniform set of deficits. Rather, it manifests in completely diverse symptom clusters. If you look at the current literature, these are increasingly recognized as distinct "clinical profiles" - or what some refer to as "phenotypes". The value here is practical. Categorizing SRC into these specific profiles allows clinicians to completely move away from a traditional, uniform management approach (such as just assigning strict cognitive and physical rest) and shift towards truly individualized clinical care [1]. These clinical profiles often overlap, mainly due to the deeply integrated nature of the sensorimotor networks. Even so, the ocular motor and vestibular systems still present with their own unique symptom constellations and highly specific functional impairments [1,2].

5.1. The Ocular Motor Profile

The ocular motor phenotype is highly specific. It manifests directly through dysfunction within the widespread neural networks controlling both dynamic eye movements and binocular vision [3]. Patients fitting this exact profile share a common reality. They typically experience blurred or double vision (diplopia), constant difficulty reading, eye strain, and frontal headaches [2,7]. Visual tasks specifically trigger or exacerbate every single one of these symptoms. These include prolonged visual focus, standard reading, tracking moving targets, as well as extended screen time [2,3]. Move to the clinical examination; it often reveals clear functional deficits in versional movements and vergence. The most common presentation is convergence insufficiency - meaning a near point of convergence (NPC) distance exceeding 5 cm [7,20]. Objective measurement of these deficits requires technology. Recent studies utilizing instrumented eye-tracking (iVOMS) provided the proof. They demonstrated that patients dealing with mild traumatic brain injury exhibit significantly higher maximum saccadic velocities and far more frequent saccadic intrusions during smooth pursuits than healthy controls [9]. Advanced neuroimaging goes a step further by confirming the microstructural basis of these exact clinical signs. Take specific ocular motor deficits, such as longer antisaccade latencies, they strongly correlate with reduced fractional anisotropy right inside the prefrontal cortex [12]. Ocular motor control does not exist in isolation. It remains tightly intertwined with these higher-order cortical networks. Consequently, this specific profile frequently overlaps with cognitive fatigue alongside severe difficulties in visuospatial attention. Ultimately, this combination significantly impairs an athlete's academic and athletic performance [3,20].

5.2. The Vestibular Profile

We define the vestibular phenotype by looking at where the damage occurs. Specifically, it involves disruptions within the central and peripheral pathways that govern an athlete's spatial orientation and postural stability [1,3]. When athletes exhibit this exact profile, they tend to report a specific cluster of somatic symptoms. Nausea, dizziness, and vertigo are consistently the most frequent complaints. We also see visual motion sensitivity and impaired balance heavily present in these cases [2,7]. These subjective symptoms are typically provoked or exacerbated by rapid head movements or by navigating highly stimulating, busy visual environments, such as crowded school hallways or supermarkets [3]. On a purely clinical level, every one of those subjective complaints maps directly onto objective findings. The most prominent finding by far is an abnormal vestibulo-ocular reflex (VOR) gain. Deficits directly affecting tandem gait and overall dynamic postural stability are routinely measured as well [2,7,18]. The impact of these vestibular deficits extends beyond mere physical discomfort to significantly interfere with cognitive function. Computerized neurocognitive tests show that athletes dealing with vestibular abnormalities often score more poorly. The affected domains primarily include processing speed, memory, and reaction time [18]. Vestibular symptoms very rarely emerge in isolation. Symptom cluster research points to a clear pattern: athletes reporting severe post-injury fatigue concomitantly display the lowest vestibulo-ocular reflex (VOR) gain. This specific relationship demonstrates a significant functional overlap between objective vestibular impairment and subjective exhaustion [2]. As a result, clinicians widely consider the vestibular profile a risk factor for a far more complicated clinical trajectory. Athletes presenting with these specific deficits at the initial examination take significantly longer to recover, pushing back their return to school [7,18].

Table 2. Clinical and Diagnostic Comparison of the Ocular Motor and Vestibular Profiles in SRC

Clinical Feature	**The Ocular Motor Profile**	**The Vestibular Profile**
Primary Symptoms	Blurred or double vision (diplopia), reading difficulty, eye strain, and localized frontal headaches	Dizziness, vertigo, nausea, impaired balance, and visual motion sensitivity
Common Triggers	Prolonged visual focus, reading, tracking moving targets, and extended screen time	Rapid head movements, changes in body position, navigating busy or highly stimulating visual environments
Objective Clinical Findings	Convergence insufficiency (NPC > 5 cm), prolonged antisaccade latencies, and frequent saccadic intrusions	Abnormal vestibulo-ocular reflex (VOR) gain, deficits in tandem gait and dynamic postural stability

Source: Own elaboration based on current literature.

6. Diagnostic Tools: Beyond the SCAT6

6.1. The Limitations of Standard Sideline Assessments

The globally recognized standard for the acute, sideline evaluation of sport-related concussions is the Sport Concussion Assessment Tool. It is currently in its sixth iteration (SCAT6). During the first 72 hours post-injury, it proves highly effective. Clinicians use it for identifying immediate red flags and assessing gross cognitive function. It is also heavily used for evaluating basic postural stability via the modified Balance Error Scoring System (mBESS) [5,6]. That is the acute phase. Contemporary research, however, indicates a shift; its clinical utility significantly diminishes right after that acute phase ends [6]. More importantly, the tool has a major diagnostic blind spot. The SCAT6 lacks the specific sensitivity required to detect subtle, targeted microstructural impairments buried within the extensively distributed vestibular and ocular motor networks [7]. Standard protocols still rely heavily on the mBESS to evaluate the vestibular system. Yet, this test is fundamentally limited. It solely examines the vestibulospinal reflex (which is just static balance). It completely fails to assess the vestibulo-ocular reflex (VOR) [21]. Because of this massive gap, relying exclusively on standard sideline assessments is risky. It can directly lead to the premature clearance of athletes who still harbour underlying sensorimotor deficits [7,21].

6.2. Targeted Clinical Screening: The Role of VOMS

To address the diagnostic gaps of acute sideline assessments, clinicians must transition to targeted, multidomain evaluations in the subacute office setting [1,6]. The Vestibular/Ocular Motor Screening (VOMS), which is now integrated into the subacute Sport Concussion Office Assessment Tool (SCOAT6) framework, is a clinical tool explicitly developed to evaluate the interconnected neural pathways that standard protocols frequently overlook [6,7]. Unlike static balance tests, the VOMS actively stresses the sensorimotor network by evaluating specific domains: smooth pursuits, horizontal and vertical saccades, near point of convergence (NPC) distance, horizontal and vertical vestibulo-ocular reflex (VOR), and visual motion sensitivity (VMS) [4,7]. During the administration of these dynamic tasks, the clinician systematically records the provocation of specific symptoms - namely headache, dizziness, nausea, and fogginess - allowing for the identification of pathological thresholds, such as an increase of 2 points in symptom severity or an NPC distance of 5 cm [7,20]. This active symptom provocation acts as a critical clinical bridge, enabling medical professionals to move beyond a generalized concussion diagnosis and precisely identify distinct clinical trajectories, such as the vestibular or ocular motor phenotypes. Ultimately, utilizing the VOMS facilitates the implementation of targeted, active rehabilitation strategies tailored to the individual athlete's specific neurophysiological deficits, which represents the contemporary standard in concussion management [1,3].

6.3. The Shift Towards Objective Technologies: Ocular Motor Assessment

Diagnostic precision improves with targeted tools like the VOMS. The core design, however, is flawed. It inherently depends on the athlete's subjective reporting of symptom provocation [9]. Elite sports face a critical challenge here. Concussion disclosure attitudes are notoriously poor. Athletes actively minimize their symptoms. The singular goal? To expedite a return to play [8]. Subjective assessments have absolute limits.

Modern diagnostics alter the methodology completely. Mobile eye-tracking devices now fully instrument the VOMS. This creates the iVOMS. The result is a purely objective evaluation. It directly reflects actual task performance [9]. High-resolution video-oculography quantifies precise kinematic variables. Conscious manipulation by the athlete is impossible, for metrics such as reduced saccadic velocity and prolonged reaction times [11]. Furthermore, eye-tracking technology can detect subtle physiological anomalies, including frequent saccadic intrusions during smooth pursuit tasks [9]. Advanced ocular motor paradigms, such as antisaccade and prosaccade switch tasks, further reveal prolonged latencies and increased error rates, which indicate underlying deficits in cognitive flexibility and inhibitory control. By relying on these objective neurophysiological metrics, clinicians can mitigate the risks of symptom underreporting and make safer, data-driven return-to-play decisions [12,22].

6.4. Objective Quantification of Vestibular Deficits

Objective quantification of vestibular deficits is the new critical advancement in the clinical management of SRC. This runs right parallel to ocular motor assessments. Take the video Head Impulse Test (vHIT). It is a sophisticated technological instrument. Its specific design objectively evaluates the vestibulo-ocular reflex (VOR) straight across all six semicircular canals [10]. The hardware relies entirely on high-speed cameras. Through these, the vHIT precisely measures the VOR gain. That is exactly the ratio of eye velocity to head velocity, recorded strictly during rapid, unpredictable head movements [10,13]. This technology actively detects pathological corrective saccades. You classify these as either covert (meaning they occur during the head movement) or overt (occurring immediately after the movement). Both types serve directly as objective biomarkers of true vestibular impairment [10,23]. Interestingly, contemporary research demonstrates that high-frequency peripheral VOR gain measured by vHIT often remains entirely within normal limits following an SRC. It strongly suggests that persistent post-concussion vestibular symptoms are primarily centrally derived, rather than peripherally [13]. Still, clinicians must integrate vHIT into the diagnostic paradigm. It remains crucial. The tool provides quantifiable, machine-derived data. Clinicians need this specific data to effectively differentiate between actual structural inner-ear damage and central network dysfunction. Ultimately, this supports safe, data-driven return-to-play decisions; it completely bypasses relying on the athlete's subjective symptom reporting [13,23]. Integrating these objective measures ensures the complete resolution of symptoms at rest and post-exertion, effectively mitigating the risks of premature return and subsequent injuries [6,13].

6.5. Summary of Diagnostics

In conclusion, the clinical management of professional athletes following a sport-related concussion necessitates a shift from generalized assessments to targeted, multimodal diagnostics [1,3]. In the acute sideline setting (0 - 72 hours), tools such as the SCAT6 and mBESS evaluate immediate red flags, gross cognitive dysfunction, and static balance; however, they fail to assess the vestibulo-ocular reflex (VOR) and detect subtle deficits once the acute window has passed [5,6,7]. Targeted clinical screening using the VOMS (within the broader SCOAT6 framework) actively provokes symptoms to identify specific clinical phenotypes [3,6,7]. Because elite athletes frequently minimize symptoms to expedite clearance, this subjective screening must be supplemented [8,9]. Consequently, objective technological quantification using tools like iVOMS and vHIT provides empirical, machine-derived metrics - such as VOR gain and saccadic intrusions - that cannot be consciously manipulated [9,10,11,12]. Ultimately, clinicians must integrate this multidisciplinary data to verify neurophysiological recovery. By ensuring the complete resolution of symptoms at rest and post-exertion, this comprehensive approach ensures a safe, data-driven medical clearance, mitigating the risks of premature return and subsequent injuries [1,6,13].

7. Discussion

Vestibular and ocular motor impairments manifest in highly diverse clinical patterns. SRC management protocols must move away from basic, static tests toward more comprehensive, dynamic assessments [1,2,3].

Standard sideline tools like the SCAT6 perform well initially. They identify immediate red flags. Past the 72-hour mark, clinical sensitivity drops [5,6]. Subtle vestibulo-ocular deficits remain undetected [7]. Therefore, clinicians must use targeted screening, such as the VOMS (part of the SCOAT6), to actively provoke symptoms and identify specific clinical profiles [6,7]. However, a major flaw of these clinical tests is their reliance on the athlete's honesty. In professional sports, elite athletes often hide their symptoms to return to play faster [8,9]. To solve the problem of subjective reporting, modern diagnostics must include objective technology. Tools like mobile eye-tracking (iVOMS) and the video Head Impulse Test (vHIT) provide machine-derived data - such as VOR gain and saccadic intrusions [9,10,11,12]. Conscious manipulation of these exact physiological metrics by athletes is impossible [11,12]. This multimodal diagnostic approach changes the protocol entirely. Return-to-play decisions stem directly from hard data, not subjective symptoms. This effectively mitigates the severe risks of premature clearance and subsequent injuries [1,6,13]. Despite these benefits, the widespread use of these technologies is limited by high equipment costs, occasional calibration issues, and the need for specialized training [9]. Furthermore, more large-scale studies are needed to establish definitive cutoff scores for these devices. Ultimately, the continued refinement of this multimodal approach will be essential to optimize return-to-play protocols and ensure the comprehensive neurophysiological recovery of elite athletes [1,13].

8. Conclusions

Sport-related concussions in professional athletes present a specific challenge. Complex ocular motor and vestibular impairments manifest frequently. This reality demands targeted, multidomain assessments [1,3]. While acute sideline tools like the SCAT6 are essential for identifying immediate red flags, their limited sensitivity after the initial 72 hours necessitates transitioning to subacute clinical screening, such as the VOMS, to actively identify specific clinical profiles [5,6,7]. Elite athletes introduce a massive confounder. To avoid being sidelined, they frequently minimize or conceal symptoms, so subjective screens fail here. They must be supplemented with objective technologies [8,9]. Integrating tools such as iVOMS and vHIT provides empirical, machine-derived metrics - such as saccadic intrusions and VOR gain - that cannot be consciously manipulated [9,10,11,12]. Ultimately, transitioning toward a comprehensive, multimodal diagnostic approach is essential to overcome the limitations of subjective symptom reporting, ensuring an accurate, data-driven evaluation of neurophysiological recovery and mitigating the risk of subsequent injuries [1,6,13].

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Declaration of use of artificial intelligent

During the preparation of this work, the authors utilized artificial intelligence (AI) as a supportive tool to enhance the readability, linguistic flow, and overall formatting of the manuscript, including citation structuring. The use of this artificial intelligence was strictly limited to technical and stylistic refinement. All scientific content, including literature selection, critical analysis, interpretation of findings, and final conclusions, was developed independently by the authors. After using this tool, the authors have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication.

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