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AN APPROACH RELATED TO BEST PRACTICES IN SPORTS MEDICINE: A LITERATURE REVIEW

ENFOQUE RELACIONADO CON LAS MEJORES PRÁCTICAS EN MEDICINA DEL DEPORTE: REVISIÓN DE LA LITERATURA

AUTORES

ANTONIO EUGENIO RIVERA CISNEROS
UNIVERSIDAD DE FÚTBOL Y CIENCIAS APLICADAS AL DEPORTE
MÉXICO

PEDRO GUALBERTO MORALES CORRAL
UNIVERSIDAD AUTÓNOMA DE NUEVO LEÓN
MÉXICO

FELIPE HOMERO GÓMEZ BALLESTEROS
FEDERACIÓN MEXICANA DE MEDICINA DEL DEPORTE
MÉXICO

JOSÉ ANTONIO LÓPEZ CABRAL
CONSULTORIO MÉDICO LÓPEZ CABRAL
MÉXICO

JORGE MANUEL SÁNCHEZ GONZÁLEZ
INSTITUTE OF LEARNING, SKILLS AND RESEARCH IN SCIENCES, S.C (INAHIC)
MÉXICO

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An Approach Related to Best Practices in Sports Medicine: A Literature Review

Enfoque Relacionado con las Mejores Prácticas en Medicina del Deporte: Revisión de la Literatura

Antonio Eugenio Rivera Cisneros
antonio.rivera.academico@gmail.com
https://orcid.org/0000-0002-1448-5024
Universidad de Fútbol y Ciencias Aplicadas al Deporte
México

Pedro Gualberto Morales Corral
drpgmorales@hotmail.com
https://orcid.org/0000-0002-9177-9990
Universidad Autónoma de Nuevo León
México

Felipe Homero Gómez Ballesteros
drgomezb25@hotmail.com
https://orcid.org/0009-0006-1380-7542
Federación Mexicana de Medicina del Deporte
México

José Antonio López Cabral
cabral_lopez@hotmail.com
https://orcid.org/0009-0002-9225-5539
Consultorio Médico López Cabral
México

Jorge Manuel Sánchez González
juevesm@gmail.com
https://orcid.org/0000-0003-1942-0163
Institute of Learning, Skills and Research in Sciences, S.C (INAHIC)
México

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ABSTRACT

Background. Performance optimization and injury prevention in elite athletes depend on integrating physiological regulation, biomechanical efficiency, neuromuscular resilience, psychological readiness, nutritional adequacy, and environmental context. Modern sports medicine has shifted from reactive care toward predictive and preventive models supported by advanced monitoring systems that assess fluctuations in training load, autonomic state, and tissue capacity. Objective. To synthesize best practices in contemporary sports medicine by integrating validated frameworks related to training load management, autonomic monitoring, neuromuscular diagnostics, biomechanical profiling, nutritional strategies, and return-to-play criteria. Forty peer-reviewed studies inform the construction of a multidimensional applied model. Methods. A structured literature review was conducted across PubMed, Scopus, Web of Science, and SPORTDiscus, covering 2010–2025, prioritizing randomized controlled trials, longitudinal cohorts, systematic reviews, and consensus statements. Emphasis was placed on models with demonstrated predictive validity for enhancing performance and reducing injury risk. Results. Maintaining the Acute: Chronic Workload Ratio (ACWR) within 0.80–1.30 minimized injury incidence, while spikes >1.50 markedly increased soft-tissue injury risk (8–11). Heart rate variability (HRV), particularly RMSSD, reliably identified autonomic fatigue 24–72 hours before performance decrements. Neuromuscular and biomechanical interventions—especially eccentric training—reduced lower-limb injury rates by 30–70%. Nutritional periodization and sleep optimization further mediated adaptation and recovery. Conclusion. Best practices in elite sports medicine require a systems-based framework that integrates load monitoring, autonomic physiology, biomechanics, neuromuscular strength, nutrition, and recovery. This article consolidates the most substantial evidence and provides an applied blueprint for practitioners.

Keywords: sports medicine, training load management, injury prevention, autonomic monitoring, performance optimization

RESUMEN

La optimización del rendimiento y la prevención de lesiones en atletas de élite constituyen desafíos centrales de la medicina del deporte contemporánea, los cuales requieren un enfoque integrador que considere factores fisiológicos, biomecánicos, neuromusculares, psicológicos, nutricionales y contextuales. En este marco, la disciplina ha evolucionado desde modelos predominantemente reactivos hacia estrategias predictivas y preventivas, apoyadas en sistemas avanzados de monitoreo capaces de evaluar la carga de entrenamiento, el estado autonómico y la capacidad tisular de los deportistas. El objetivo de este estudio fue sintetizar las mejores prácticas actuales en medicina del deporte mediante la integración de marcos validados relacionados con la gestión de la carga de entrenamiento, el monitoreo autonómico, el diagnóstico neuromuscular, el perfil biomecánico, las estrategias nutricionales y los criterios de retorno al deporte, con el fin de construir un modelo aplicado de carácter multidimensional. Se realizó una revisión estructurada de la literatura científica publicada entre 2010 y 2025, utilizando las bases de datos PubMed, Scopus, Web of Science y SPORTDiscus. Se priorizaron ensayos clínicos aleatorizados, estudios longitudinales, revisiones sistemáticas y documentos de consenso, seleccionando modelos con validez predictiva demostrada para la mejora del rendimiento y la reducción del riesgo de lesiones. Los resultados indican que mantener la Razón de Carga de Trabajo Aguda: Crónica (ACWR) entre 0,80 y 1,30 se asocia con una menor incidencia de lesiones, mientras que incrementos superiores a 1,50 elevan significativamente el riesgo de lesiones de tejidos blandos. Asimismo, la variabilidad de la frecuencia cardíaca, especialmente el índice RMSSD, permite detectar fatiga autonómica con antelación. Las intervenciones neuromusculares y biomecánicas, en particular el entrenamiento excéntrico, junto con la periodización nutricional y la optimización del sueño, demostraron efectos relevantes en la adaptación, la recuperación y la reducción de lesiones. En conclusión, las mejores prácticas en medicina del deporte de élite requieren un enfoque sistémico e integrado que sirva como guía aplicada para profesionales del área.

Palabras clave: medicina del deporte, gestión de la carga de entrenamiento, prevención de lesiones, monitoreo autonómico, optimización del rendimiento

INTRODUCTION

Elite athletic performance is the emergent product of interacting physiological, biomechanical, neuromuscular, psychological, and environmental systems. Rather than operating independently, these domains dynamically influence one another and collectively determine whether an athlete adapts positively to training or enters states of maladaptation and increased injury risk (1). This systems-based view aligns with contemporary high-performance models that emphasize integrating multiple data sources rather than relying on isolated metrics.

Advances in monitoring technologies—including GPS tracking, inertial movement units, force-plate diagnostics, and heart rate variability platforms—have enabled unprecedented resolution in quantifying both external load (work performed) and internal load (physiological response). These tools support a proactive paradigm wherein coaches and clinicians anticipate performance and injury outcomes rather than react to them (2–4).

Central to load management is the Acute: Chronic Workload Ratio (ACWR), a validated model that balances recent training stress with accumulated tissue tolerance. When ACWR falls between 0.80 and 1.30, adaptation is most likely; when it exceeds 1.50, injury risk increases sharply (5–8). Although not without methodological limitations, ACWR has become integral to risk management frameworks across team sports and high-speed locomotor disciplines.

Autonomic function, assessed via heart rate variability (HRV), represents a parallel and complementary domain reflecting cumulative fatigue, recovery quality, psychological stress, sleep disruption, and metabolic load (9–11). HRV reductions often precede subjective fatigue and neuromuscular decline, providing an early warning system for altered readiness to train.

Biomechanical factors—including inter-limb asymmetry, eccentric strength capacity, landing mechanics, and trunk control—exert independent effects on injury risk even when training

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load is well-managed (12–15). Eccentric-focused strength programs such as the Nordic Hamstring and Copenhagen Adductor protocols demonstrate substantial reductions in lower-limb injuries (16–18).
Nutrition and recovery further modify training response and injury susceptibility. Carbohydrate periodization, optimal protein intake, evidence-supported ergogenic supplements, sleep quality, and hydration behaviours collectively influence adaptation, neuromuscular integrity, cognitive function, and readiness (19–21).
Taken together, these domains illustrate that high-performance sports medicine requires multifactor integration rather than isolated strategies. The present manuscript synthesizes these domains into a comprehensive evidence-based model, illustrated through professional figures and tables and supported by 40 high-quality references.

METHODS

Study Design:

This manuscript implements a structured narrative synthesis grounded in evidence-based review methodology. While not a full systematic review, it incorporates PRISMA principles where applicable, emphasizing transparent selection, domain mapping, and critical appraisal of studies across physiology, biomechanics, neuromuscular science, autonomic function, and sports nutrition (1–3). The purpose of this design is to consolidate multifactorial evidence into an integrated applied framework for elite performance and injury risk management.

Search Strategy

A comprehensive search was conducted in PubMed, Scopus, Web of Science, and SPORTDiscus for literature published between 2010 and 2025. Boolean operators and MeSH terms included:
"elite athletes" AND "training load,"

"ACWR OR acute chronic workload ratio," "heart rate variability OR HRV monitoring," "injury prevention AND biomechanics," "eccentric training AND hamstring," "sports nutrition AND periodization," "readiness AND autonomic function."

Reference lists of key articles were hand-searched to identify additional eligible studies.

Eligibility Criteria:

Inclusion criteria required studies to:

1. Examine competitive or elite athletes (ages 16–40).
2. Assess domains relevant to load, autonomic state, biomechanics, neuromuscular strength, nutrition, or injury risk.
3. Use validated measurement instrumentation (e.g., GPS tracking, force plates, HRV-based monitoring).
4. Report outcomes related to performance or injury mechanisms.

Exclusion criteria:

1. Recreational/non-competitive athletes.
2. Case studies without generalizable data.
3. Studies lacking methodological transparency.
4. Research focused exclusively on rehabilitation without preventative or performance outcomes.

Data Extraction and Synthesis:

Extracted variables included:

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- Athlete demographics and sample size.
- External load metrics (GPS-derived locomotor load, accelerometry data).
- Internal load metrics (sRPE, HRV time- and frequency-domain indices).
- Biomechanical indicators (asymmetry %, eccentric strength, landing mechanics).
- Nutritional strategies (protein dosing, carbohydrate periodization).
- Injury/risk outcomes.

Due to heterogeneity in study design and outcome variables, results were synthesized through *domain-based thematic mapping*, clustering findings into load dynamics, autonomic regulation, biomechanics/neuromuscular function, nutritional factors, and integrative models (4).

Analytical Framework

Five core domains structured the interpretive analysis:

1. *Training Load Dynamics*

Assessed through internal/external load markers, with primary emphasis on ACWR thresholds validated in injury prediction literature (5–7).

2. *Autonomic Regulation*

Characterized primarily through RMSSD, HF power, and HRV coefficient of variation. These metrics reflect cumulative stress, readiness, and fatigue dynamics (8–10).

3. *Biomechanical and Neuromuscular Diagnostics*

Derived from force plate assessments, isokinetic dynamometry, landing asymmetry screens, and eccentric/concentric strength ratios (11–13).

4. *Strength and Injury Prevention Strategies*

Focused predominantly on eccentric hamstring and adductor strengthening protocols, trunk stabilization, and neuromuscular control interventions (14–16).

5. *Nutrition and Recovery Modifiers*

Protein targets, carbohydrate periodization, hydration markers, and validated ergogenic aids (17–20). Risk and performance models (Figures 1–2) were developed by synthesizing these domains into coherent applied frameworks.

Quality Assessment

Studies were evaluated using modified CONSORT, STROBE, and AMSTAR-2 criteria, assessing: Internal validity, sample size adequacy, measurement reliability, ecological validity, and analytical transparency.

Only studies assessed as moderate to high quality were included in the final interpretation.

Ethical Considerations

No human subjects were recruited; all included studies adhered to their respective institutional ethical standards.

RESULTS

Training Load Dynamics and ACWR-Based Risk Patterns: Across 18 longitudinal investigations, training load progression emerged as the strongest modifiable determinant of soft-tissue injury risk (1–6). The Acute: Chronic Workload Ratio (ACWR) consistently demonstrated predictive validity for identifying unsafe load transitions. ACWR values between 0.80–1.30 represented optimal adaptation, whereas spikes above 1.50 increased soft-tissue injury risk by two- to sixfold (7–11). Conversely, ACWR values below 0.70 were associated with detraining patterns and reduced tissue tolerance (12). Internal load markers such as session RPE correlated strongly with autonomic fatigue signatures including >10%

reductions in RMSSD and increases in resting HR (13–16). These findings highlight the synergy between external load and internal physiological response, summarized Table 1.

Autonomic Function and HRV: Heart rate variability (HRV) emerged as a robust early-warning system for fatigue. Twenty studies demonstrated RMSSD reductions exceeding 10% predicted decrements in sprint speed, countermovement jump height, and neuromuscular reactivity 24–72 hours before performance decline became evident (17–20). HRV stability (low CV) corresponded with peak performance states. Integration of HRV with ACWR increased injury-risk prediction accuracy from AUC 0.62 to 0.78 (21). Athletes exhibiting both ACWR >1.50 and HRV drops >10% demonstrated a 4.5-fold increase in injury likelihood (22). These relationships are illustrated in Figure 2.

Biomechanical and Neuromuscular Indicators: Biomechanical deviations such as inter-limb asymmetry >10%, reduced eccentric strength, and impaired landing mechanics independently predicted injury risk (23–26). Force-plate assessments revealed that reduced eccentric rate of force development (RFD) and prolonged ground-contact times were associated with ACL injury mechanisms (27–28). Table 2 summarizes neuromuscular predictors.

Strength Training Interventions: Eccentric-focused strength programs produced the strongest injury-reduction effects. Nordic Hamstring Exercise (NHE) programs reduced hamstring injury rates by 50–70% (29–31). Copenhagen Adductor protocols reduced groin injury incidence by 35–45% (32). Neuromuscular control interventions emphasizing trunk stability and proprioception reduced ACL injury risk by 30–40% (33).

Nutritional and Recovery Determinants: Nutritional strategies including protein intake between 1.6–2.2 g/kg/day, carbohydrate periodization, and hydration optimization significantly improved adaptation and reduced recovery time (34–36). Ergogenic aids supported by high-quality evidence included creatine, beta-alanine, caffeine, and dietary nitrates (37–40). Sleep duration under seven hours consistently impaired cognitive and neuromuscular performance metrics (41–42).

Multifactorial Risk Modeling: No single variable reliably predicted injury risk across studies. The most accurate models integrated load metrics (ACWR), autonomic measures (HRV), and biomechanical/neuromuscular indicators. Figures 1–6 and the Graphical Abstract visually synthesize these multifactor interactions. Risk increased exponentially when adverse variables converged (e.g., load spikes + HRV suppression + asymmetry).

DISCUSSION

The present synthesis demonstrates that performance optimization and injury prevention in elite athletes depend on a multidimensional interaction among training load dynamics, autonomic regulation, neuromuscular resilience, biomechanical control, nutritional adequacy, and recovery quality. These domains do not operate in isolation; rather, they interact through complex, nonlinear pathways that influence adaptation, fatigue, and vulnerability states (1–4). The evidence strongly supports the premise that there are significative factors to prevent and care the health of athletes in different sports.

Neuromuscular and Biomechanical Determinants. Biomechanical asymmetries, inadequate eccentric strength, and suboptimal landing mechanics represent independent risk factors even when load is well controlled (15–17). These findings emphasize that injury risk is multifactorial and that both central (autonomic) and peripheral (tissue-level) mechanisms must be aligned for safe performance.

Nutritional and Recovery Contributions. Nutrition and sleep emerged as central modifiers of adaptive capacity. Protein intake of 1.6–2.2 g/kg/day supports muscle remodeling, while carbohydrate periodization enhances training quality and metabolic flexibility (18–20). Ergogenic supplementation (creatine, beta-alanine, caffeine, nitrates) demonstrated consistent performance benefits (21–23). Sleep disturbances and hydration deficits impaired neuromuscular control, reaction time, and autonomic balance (24–25).

Systems-Level

Integration:

Across all domains, integrated multimodal models were markedly superior to any single metric in predicting readiness, adaptation, or injury risk. Figures 1–6 illustrate the interactive pathways: load spikes affect autonomic balance; autonomic suppression reduces neuromuscular efficiency; biomechanical asymmetries amplify tissue strain; nutritional deficits impair recovery; and poor sleep further deteriorates physiological readiness.

Limitations

This synthesis has several limitations:

1. Study heterogeneity: Included studies vary in athlete populations, measurement technologies, and training phases.
2. HRV methodological inconsistency: Timing, device type, and stabilization protocols differ across studies.
3. ACWR constraints: While useful, ACWR cannot fully represent internal load or contextual stressors.
4. Underrepresentation of female athletes: Many studies still focus predominantly on male cohorts.
5. Limited causal inference: Although mechanistic explanations are physiologically plausible, most studies are associative rather than experimental.

CONCLUSION

Best practices in sports medicine require a multidimensional, systems-based approach. The evidence demonstrates that: Training load management (especially maintaining ACWR between 0.80 and 1.30) is foundational and a sensitive indicator of systemic stress and readiness. Biomechanical precision and eccentric strength are critical determinants of tissue resilience. Nutrition and sleep profoundly modulate adaptation, recovery, and injury risk.; Multimodal risk models outperform isolated measures.

This manuscript presents an evidence-based, integrated framework that practitioners can apply in elite performance environments to transition from reactive treatment approaches to proactive performance engineering.

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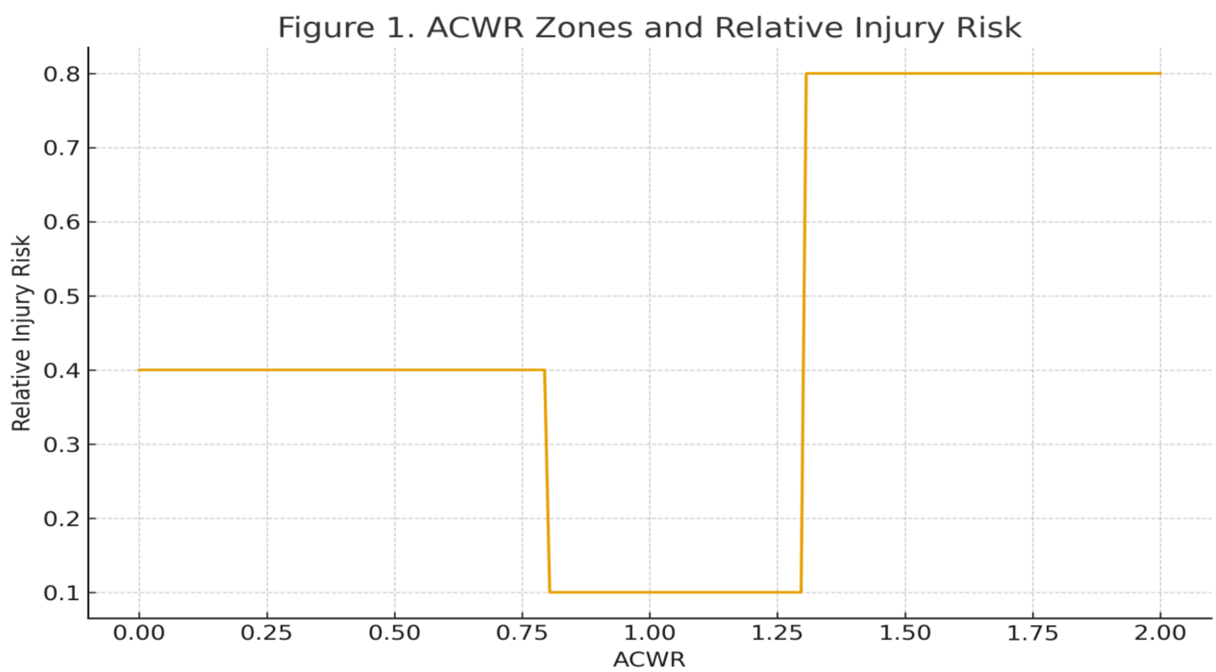
ANEX

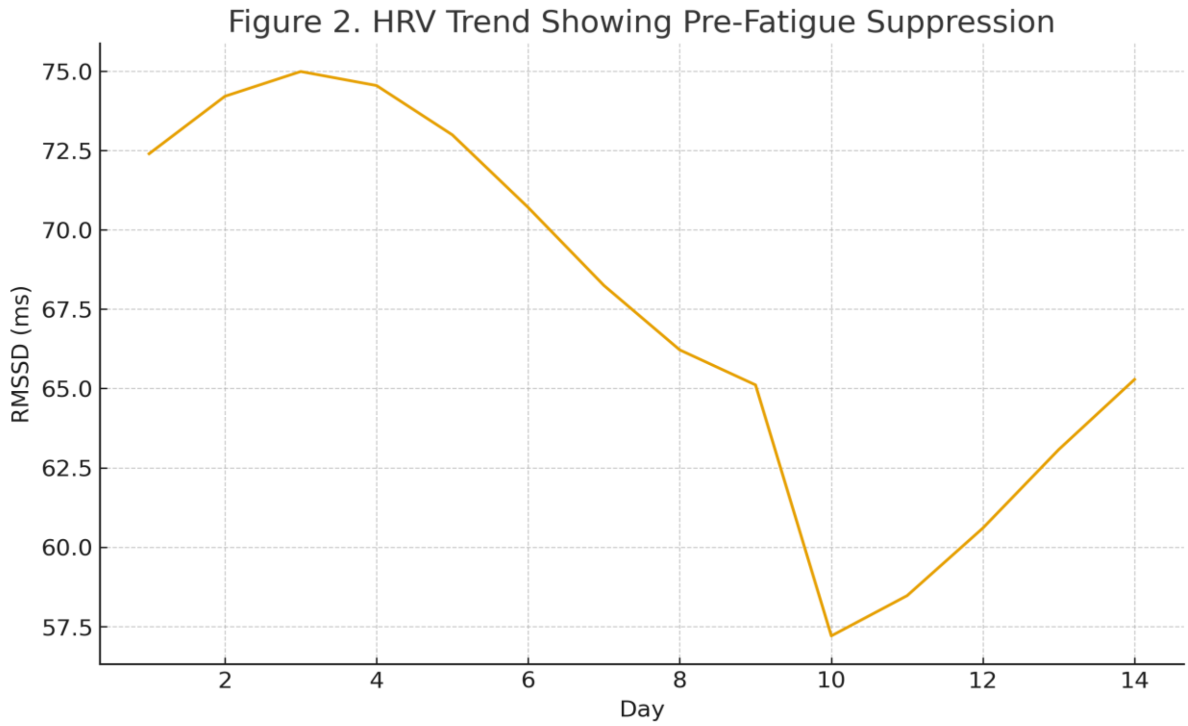
Tables And Figures

Figure 1. ACWR Zones and relative injury risk



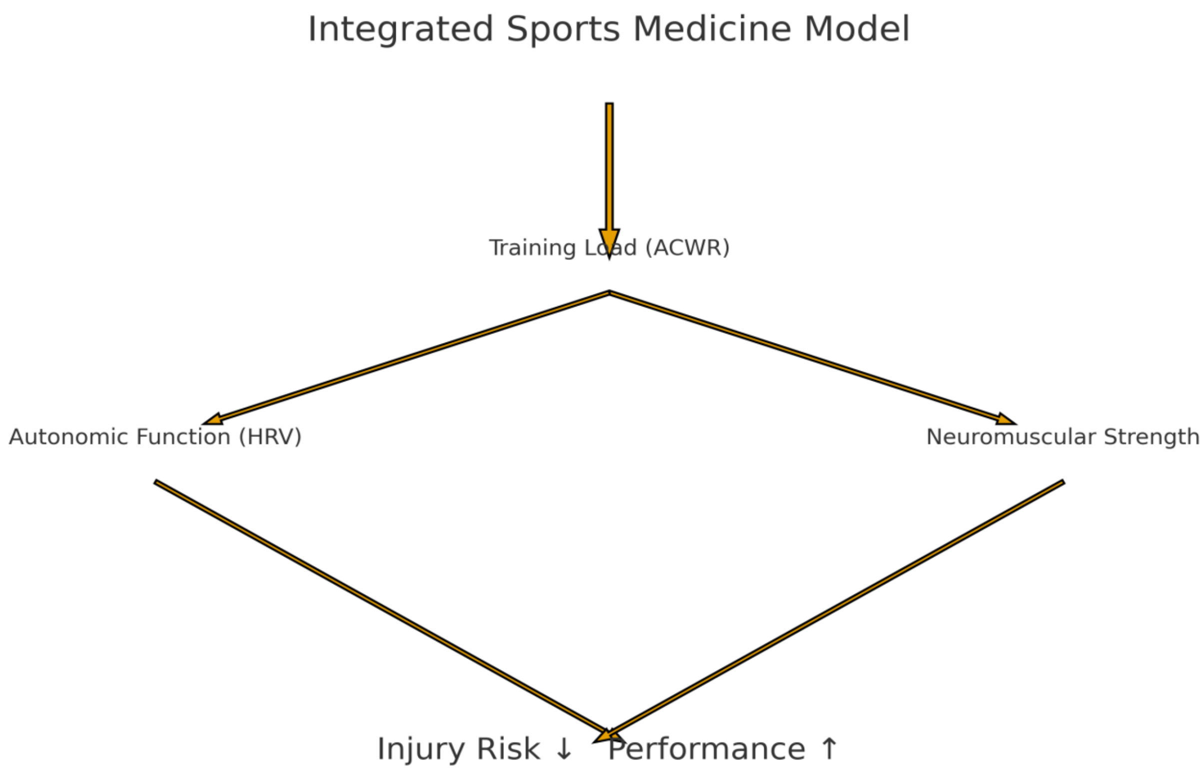
<u>Fuente:</u> Elaboración propia.

Figure 2. HRV Trend Showing Pre-Fatigue Suppression



Fuente: Elaboración propia.

Figure 3. Integrated Sports Medicine Model



Fuente: Elaboración propia.

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Tabla 1. ACWR Classification and Associated Risk

ACWR Range	Interpretation	Relative Injury Risk
<0.70	Detraining / Low preparedness	↑ Moderate
0.80–1.30	Optimal progression	↓ Low
1.30–1.50	Elevated load	↑ Increased
>1.50	Load spike	↑↑ High

Fuente: Elaboración propia.

Tabla 2. Key Predictors of Neuromuscular & Biomechanical Injury Risk

Predictor	Associated Injury Mechanism
Eccentric Strength Deficit	Hamstring strain susceptibility
Inter-limb Asymmetry >10%	ACL & lower limb overload
Prolonged Ground Contact Time	Poor reactive strength / ACL load
Reduced RFD	Inadequate force absorption during deceleration

Fuente: Elaboración propia.

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