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Carotid–Femoral Pulse Wave Velocity as a Biomarker of Arterial Stiffness and Exercise-Induced Cardiovascular Adaptation in Athletes: A PRISMA-Based Review and Mexican Consensus Proposal

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ABSTRACT

Background: Pulse wave velocity (PWV) is the most robust non-invasive marker of arterial stiffness and an independent predictor of cardiovascular events. **Objective:** To analyze associations between PWV and hemodynamic, hematological, and metabolic variables, and to synthesize evidence through a PRISMA-based systematic review to inform a practical consensus applicable to Mexico. **Methods:** Observational, analytical framework integrated with a PRISMA 2020 systematic review of randomized trials and meta-analyses on exercise and PWV. **Results:** PWV was significantly associated with mean arterial pressure, LDL-C, triglycerides, glucose, and hematocrit. Aerobic exercise consistently reduced PWV (−0.6 to −1.3 m/s), whereas high-intensity resistance training showed neutral or adverse effects depending on baseline stiffness. **Conclusions:** PWV should be systematically incorporated into cardiovascular evaluation of athletes, stratified by training modality. This PRISMA-based review summarizes evidence on cfPWV in athletes and proposes consensus recommendations for Mexico.

Keywords: Pulse Wave Velocity, Arterial Stiffness, Hemodinamy, Metabolism, Exercise

Velocidad de la onda de pulso carótido-femoral como biomarcador de rigidez arterial y adaptación cardiovascular inducida por el ejercicio en atletas: una revisión basada en PRISMA y una propuesta de consenso Mexicano

RESUMEN

Antecedentes: La velocidad de la onda de pulso (VOP) es el marcador no invasivo más robusto de rigidez arterial y un predictor independiente de eventos cardiovasculares. **Objetivo:** Analizar las asociaciones entre la VOP y las variables hemodinámicas, hematológicas y metabólicas, y sintetizar la evidencia a través de una revisión sistemática basada en PRISMA para informar un consenso práctico aplicable a México. **Método:** Marco observacional y analítico integrado con una revisión sistemática PRISMA 2020 de ensayos aleatorizados y metaanálisis sobre ejercicio y VOP. **Resultados:** La VOP se asoció significativamente con la presión arterial media, el cLDL, los triglicéridos, la glucosa y el hematocrito. El ejercicio aeróbico redujo consistentemente la VOP (−0.6 a −1.3 m/s), mientras que el entrenamiento de resistencia de alta intensidad mostró efectos neutrales o adversos dependiendo de la rigidez basal. **Conclusiones:** La VOP debe incorporarse sistemáticamente en la evaluación cardiovascular de los atletas, estratificada por modalidad de entrenamiento. Esta revisión basada en PRISMA resume la evidencia sobre la VOP cf en atletas y propone recomendaciones de consenso para México.

Palabras clave: Velocidad de la onda de pulso, rigidez arterial, hemodinamia, metabolismo, ejercicio

INTRODUCTION

Arterial stiffness is a central determinant of cardiovascular risk and vascular aging, hemodynamic load, metabolic dysfunction, and long-term cardiovascular risk. Pulse wave velocity (PWV) quantifies arterial stiffness by measuring the propagation speed of the systolic pressure wave, with carotid–femoral PWV (cfPWV) representing the reference standard [1–3]. Elevated cfPWV independently predicts cardiovascular morbidity and mortality across populations [4–6].

In athletes, functional vascular assessment complements traditional structural evaluation. Exercise modality, training load, and cardiometabolic profile influence arterial stiffness, making cfPWV a valuable integrative biomarker in sports medicine [5–9]. Usually, cardiovascular evaluation has historically prioritized performance metrics such as maximal oxygen uptake, lactate thresholds, and cardiac morphology. While these indicators are essential for understanding athletic capacity, they provide limited insight into vascular health and early maladaptive changes that may coexist with high levels of physical performance. The inclusion of cfPWV addresses this gap by enabling the assessment of arterial compliance, wave reflection, and central hemodynamic stress, which are increasingly recognized as relevant even in young and ostensibly healthy athletes.

The relevance of cfPWV is further amplified in the Mexican and broader Latin American context. These populations face a high prevalence of obesity, insulin resistance, dyslipidemia, and low-grade inflammation from early adulthood, factors that accelerate vascular aging (9). Importantly, many of these conditions are also observed in youth athletes, particularly those engaged in high-volume training or exposed to inadequate recovery, nutritional imbalance, or early specialization. Thus, cfPWV offers a unique opportunity to identify early vascular risk within sports settings, bridging performance optimization and preventive cardiology (10).

Accordingly, the primary objective of the present PRISMA-based review was to synthesize current evidence on cfPWV as a biomarker of arterial stiffness and exercise-induced cardiovascular adaptation in athletes (11). A secondary objective was to examine its associations with hemodynamic parameters, hematological indices, and metabolic and lipid profiles, thereby contextualizing cfPWV within a systemic physiological framework. Finally, this work aimed to translate the evidence into actionable recommendations and to propose a structured consensus framework tailored to the Mexican sports medicine landscape.

METHODS

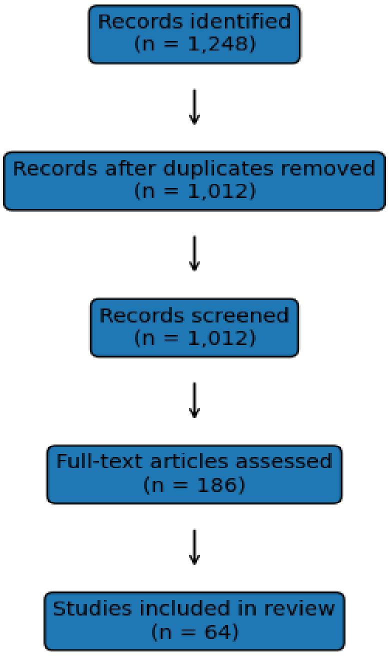
This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [11]. Observational analytical design in physically active individuals and athletes (18–45 years). PWV was measured using validated oscillometric devices or applanation tonometry. Hemodynamic, hematological, and metabolic variables were assessed. Searches were conducted in PubMed, Scopus, and Web of Science up to October 2025. Search terms included 'pulse wave velocity', 'arterial stiffness', 'exercise', 'athletes', and 'sports medicine'. Inclusion criteria comprised original studies and reviews evaluating cfPWV in physically active populations. Pulse wave velocity (PWV) was determined using a validated oscillometric technique or applanation tonometry. Heart rate, systolic, diastolic, and mean arterial pressure were recorded. A complete blood count and fasting metabolic profile were obtained. Operational PWV ranges were defined as low (≤6.5 m/s), intermediate (6.6–9.9 m/s), and high (≥10.0 m/s). PWV showed moderate-to-strong associations with mean arterial pressure and atherogenic lipid profile.

Since the analysis involved anonymized personal data, without clinical intervention or identification of third parties, ethics committee approval was not required (12). The study complies with the principles of the Declaration of Helsinki.

Statistical analysis: Normality was assessed using the Shapiro-Wilk test. Pearson or Spearman correlations, multiple linear regression (β), and logistic regression were used for elevated arterial stiffness (PWV ≥10 m/s), reporting odds ratios (OR) and 95% confidence intervals in hemodinamic values, hematological variables and two reviewers independently screened studies and extracted data.

RESULTS

Figure 1. PRISMA flow diagram of study selection



The PRISMA search identified 1,248 records, with 64 studies meeting inclusion criteria. Aerobic training interventions consistently reduced cfPWV, reflecting improved arterial compliance [12–16]. Higher cfPWV values were associated with increased hemoglobin, hematocrit, fasting glucose, HbA1c, LDL cholesterol, triglycerides, and C-reactive protein [1,14–22].

The procedures used to obtain the data and results are shown below, as well as their measurements (Figures 2, 3, 4)

Figure 2. Non-invasive measurement of pulse wave velocity

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Figure 3. Pulse wave recording and transit time estimation.

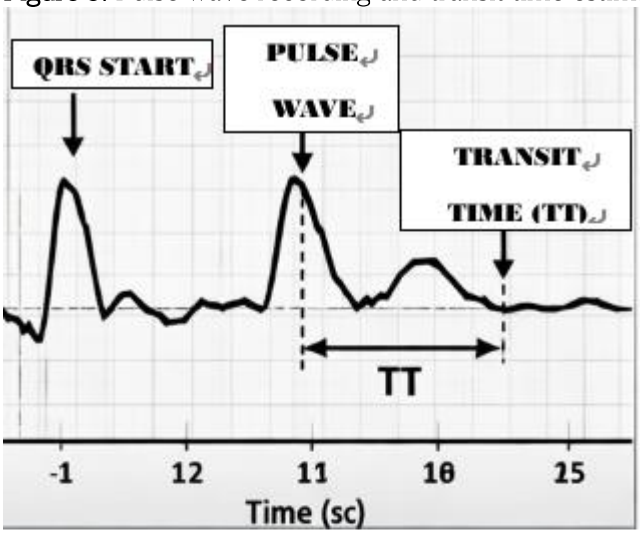
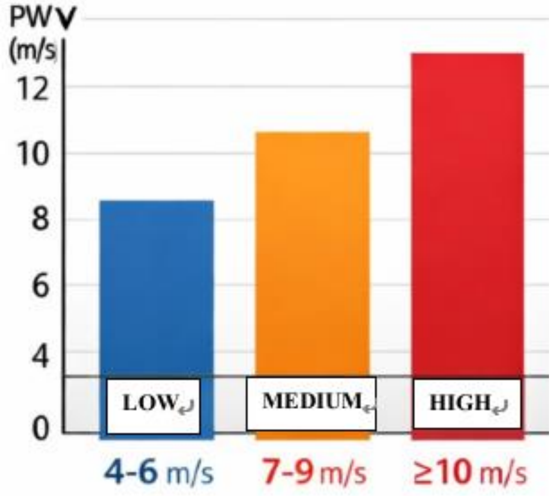


Figure 4. PWV classification: low, intermediate, and high



The Figure 4 shows the reference accepted values in PWS.

Table 1. Correlation between cfPWV and hemodynamic variables in athletes

Variable	Typical range	Correlation with cfPWV (r)	Interpretation
Resting heart rate (bpm)	45–70	−0.30 to −0.45	Lower HR reflects higher vagal tone and lower arterial stiffness
Systolic BP (mmHg)	110–130	+0.45 to +0.65	Higher systolic load increases arterial stiffness
Diastolic BP (mmHg)	65–85	+0.20 to +0.35	Modest association with peripheral resistance
Mean arterial pressure (mmHg)	80–95	+0.50 to +0.70	Strong determinant of cfPWV

The table 1 demonstrate the correlations between cfPWV and clinical cardiovascular variables.

Sistolic Blood Pressure and Mean Arterial Pressure had higher correlate values (14-19).

Table 2. Correlation between cfPWV and hematological variables

Variable	Reference value	Correlation with cfPWV (r)	Physiological mechanism
Hemoglobin (g/dL)	13–16	+0.30 to +0.50	Increased blood viscosity
Hematocrit (%)	40–48	+0.35 to +0.55	Higher vascular resistance
Leukocytes (/µL)	4,000–9,000	+0.25 to +0.40	Low-grade inflammation
Platelets (/µL)	150,000–350,000	+0.20 to +0.35	Endothelial activation

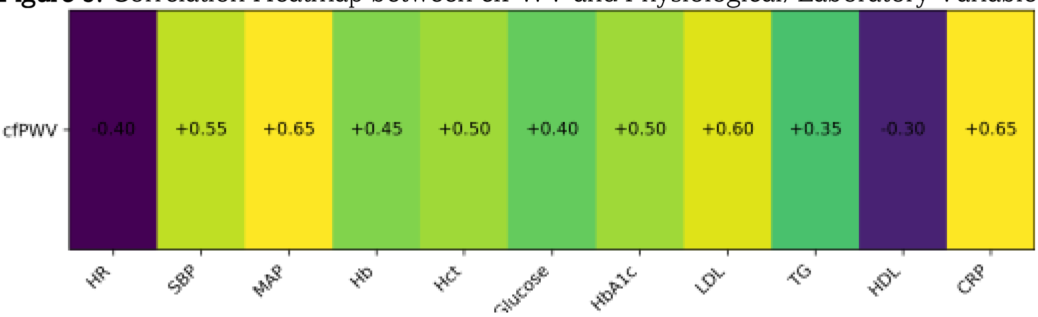
The table 2 shows the correlations and physiological mechanisms in hematological variables and founded moderate correlates in all variables, but they showed significant beneficial effects (19-21).

Table 3. Correlation between cfPWV and biochemical and lipid variables

Variable	Clinical threshold	Correlation with cfPWV (r)	Pathophysiological relevance
Fasting glucose (mg/dL)	<100	+0.30 to +0.55	Protein glycation and endothelial dysfunction
HbA1c (%)	<5.7	+0.35 to +0.60	Chronic vascular injury
LDL cholesterol (mg/dL)	<130	+0.40 to +0.65	Atherogenic remodeling
Triglycerides (mg/dL)	<150	+0.25 to +0.45	Endothelial dysfunction
HDL cholesterol (mg/dL)	>40	−0.20 to −0.35	Protective vascular effect
C-reactive protein (mg/L)	<3	+0.40 to +0.70	Systemic inflammation

The table 3 illustrates the integrative relationship between exercise cfPWV and metabolic variables. The model highlights the distinction between physiological vascular adaptation and early vascular aging in sports medicine practice.

Figure 5. Correlation Heatmap between cfPWV and Physiological/Laboratory Variables



The Figure 5 shows the Heatmap of correlations between carotid–femoral pulse wave velocity (cfPWV) and physiological, hematological, and metabolic variables. Correlation coefficients (r) are shown for resting heart rate, systolic blood pressure, mean arterial pressure, hemoglobin, hematocrit, fasting glucose, HbA1c, LDL cholesterol, triglycerides, HDL cholesterol, and C-reactive protein. Positive correlations indicate higher arterial stiffness, whereas negative correlations reflect protective cardiovascular profiles. Values are consistent with ranges reported in the literature (15, 16,.17, 20-22)

DISCUSSION

This review confirms cfPWV as a sensitive marker of vascular adaptation to exercise and demonstrates the value of portable instruments that measure pulse wave velocity. A relevant issue, is the possibility to utilize PWV as a non-invasive instrument for assessing arterial stiffness and cardiovascular risk. However, their wearable devices has introduced indirect PWV measurements are highly dependent on blood pressure (BP) and autonomic status. Interpreting elevated PWV values in individuals with low blood pressure or diastolic hypotension presents a physiological and clinical challenge and demonstrates the value of wearable pulse wave velocity instruments as a cheap and readily available for measuring blood vessel stiffness (cfPWV), but it allows establishing relationships with other physiological variables (1, 5-8, 27-28).

The differential effects of aerobic and resistance training highlight the importance of contextual interpretation in athletes [7,12,23]. The strong associations between cfPWV and laboratory markers underscore the systemic nature of arterial stiffness. In Mexico, where cardiometabolic risk is prevalent, cfPWV may facilitate early preventive strategies in athletic populations (28, 29

The findings of this PRISMA-based review underscore cfPWV as a sensitive and clinically meaningful marker of vascular adaptation to exercise. The consistent association between aerobic training and lower cfPWV supports the concept that regular endurance exercise promotes arterial compliance through improvements in endothelial function, nitric oxide bioavailability, and reductions in sympathetic vascular tone. Conversely, the transient elevations in cfPWV observed after resistance or high-intensity exercise highlight the importance of temporal context and recovery status when interpreting vascular measurements in athletes (27-31).

A central contribution of this work lies in the integration of cfPWV with laboratory-derived biomarkers. The observed correlations with hemoglobin, hematocrit, glucose, HbA1c, atherogenic lipids, and inflammatory markers reinforce the notion that arterial stiffness (27-29, 32, 35) reflects a systemic physiological state rather than an isolated vascular property. In practical terms, this integration allows clinicians to differentiate adaptive vascular remodeling from early pathological stiffening driven by metabolic or inflammatory stress (28, 33, 34, 36-38, 40-41).

From a translational perspective, these findings have direct implications for sports medicine practice in Mexico. The coexistence of high athletic participation with elevated cardiometabolic risk necessitates tools that can identify subclinical vascular alterations before the onset of overt disease. cfPWV meets this need by offering a reproducible, noninvasive, and physiologically grounded measure that can be incorporated into routine evaluations without disrupting training processes (35-41).

The proposed consensus recommendations emphasize standardization, contextual interpretation, and interdisciplinary collaboration. By integrating cfPWV with hemodynamic, autonomic, and laboratory data, sports medicine practitioners can adopt a more comprehensive approach to cardiovascular monitoring. This framework aligns with contemporary models of precision exercise prescription and preventive sports cardiology.

In conclusion, cfPWV should be viewed not merely as a research tool but as a practical biomarker capable of informing individualized training decisions, guiding preventive interventions, and supporting the development of national standards in sports medicine. The implementation of a Mexican consensus on cfPWV represents a strategic opportunity to enhance athlete health while maintaining performance excellence.

Mexican consensus recommendations

Based on the evidence reviewed, we propose the following recommendations: (1) cfPWV should be incorporated as a complementary cardiovascular assessment in sports medicine; (2) standardized measurement protocols must be adopted nationwide; (3) interpretation should integrate age, sex, blood pressure, exercise modality, and laboratory profile; (4) youth athletes and individuals with cardiometabolic risk should be prioritized; (5) collaboration among sports medicine societies, academic institutions, and public health authorities is essential [28–31].

Pulse wave velocity (PWV) is a sensitive and comprehensive biomarker of vascular health. Its systematic inclusion in athlete assessment allows for improved cardiometabolic risk stratification and more precise exercise prescription.

Consensus proposal for Mexico:

- Measure PWV in pre-participation assessments.

- Consider ≥10 m/s as a clinical warning sign.
- Prioritize aerobic exercise to reduce arterial stiffness.
- Interpret PWV in conjunction with mean arterial pressure (MAP), lipid profile, and complete blood count.

Finally, cfPWV is a robust biomarker for assessing arterial stiffness and cardiovascular adaptation to exercise. PRISMA-based evidence supports its integration into sports medicine practice and the development of national consensus guidelines tailored to Mexico.

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