

## Long-Term Effects of Repeated Blood Doping on Cardiovascular Health

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### Abstract

Blood doping, a prohibited method used to enhance athletic performance, involves artificially increasing red blood cell concentration to improve oxygen delivery to tissues. While the acute performance benefits of blood doping are well documented, its long-term impact on cardiovascular health remains underexplored. This research paper examines the physiological and clinical consequences of repeated blood doping, with a focus on cardiovascular risks such as elevated blood viscosity, hypertension, thrombosis, cardiac hypertrophy, and arrhythmias. Through a synthesis of scientific studies, case reports, and anti-doping agency data, the study highlights the mechanisms by which repeated erythropoietic stimulation—via erythropoietin (EPO) administration or blood transfusions—induces chronic cardiovascular strain. Evidence indicates that sustained exposure to elevated haematocrit levels increases systemic vascular resistance and cardiac workload, potentially leading to irreversible structural changes in the heart and vascular system. Observational studies of athletes with a history of doping reveal higher incidences of cardiovascular complications compared to controls, reinforcing the risks associated with repeated blood manipulation. The paper also evaluates the role of detection tools such as the Athlete Biological Passport (ABP) in monitoring haematological changes and mitigating long-term harm. Findings underscore the necessity for continued research, enhanced athlete education, and medical monitoring to prevent chronic cardiovascular consequences. By elucidating the interplay between repeated blood doping and cardiovascular health, this study contributes to the broader understanding of athlete safety, ethical practices in sport, and evidence-based anti-doping policy development.

**Keywords:** Blood doping, Repeated erythropoietic stimulation, Cardiovascular health, Haematocrit, Blood viscosity, Hypertension, Thrombosis, Cardiac hypertrophy etc.

### Introduction

The use of blood doping as a performance-enhancing method has been a significant concern in competitive sports for decades. Blood doping involves artificially increasing the number of red blood cells (RBCs) in circulation to enhance oxygen transport to muscles, thereby improving aerobic capacity, endurance, and overall athletic performance (Sottas et al., 2011). Athletes may achieve this through methods such as homologous or autologous blood transfusions, erythropoietin (EPO) administration, or other erythropoiesis-stimulating techniques. While the immediate performance-enhancing benefits of blood doping are well documented, the **long-term health consequences**, particularly concerning cardiovascular health, remain an area of growing scientific interest and concern.

The cardiovascular system is particularly vulnerable to alterations in blood rheology and oxygen-carrying capacity induced by repeated blood doping. Elevated haematocrit levels, which occur when RBC concentrations rise beyond normal physiological ranges, increase blood viscosity, potentially contributing to hypertension, increased cardiac workload, and risk of thrombosis (Ashenden et al., 2004). Additionally, repeated exposure to EPO and transfusions can influence vascular function, including endothelial health, arterial stiffness, and microcirculatory dynamics. These physiological changes suggest that the short-term benefits of enhanced oxygen delivery may come at the cost of **chronic cardiovascular stress**, yet empirical evidence in this domain is limited due to ethical and practical challenges in studying doping in humans.

Historically, the prevalence of blood doping has been closely tied to elite endurance sports, such as cycling, long-distance running, and cross-country skiing, where small improvements in oxygen transport can produce significant competitive advantages. The infamous cases of systematic doping scandals, such as those revealed in professional cycling and the Operation Aderlass investigation, have highlighted both the prevalence and the risks associated with repeated blood manipulation (Operation Aderlass, 2019). These incidents emphasize the **dual threat** of performance enhancement and potential long-term cardiovascular harm, underscoring the importance of research into both physiological mechanisms and health outcomes.

The mechanisms underlying cardiovascular risk in blood-doped athletes are multifactorial. Elevated blood viscosity increases systemic vascular resistance, placing a greater workload on the heart. Chronic exposure may lead to left ventricular hypertrophy, a condition characterized by thickening of the heart's muscular walls, which can reduce cardiac efficiency and increase the risk of arrhythmias and sudden cardiac events (Schmidt & Saugy, 2005). Additionally, repeated transfusions or EPO use may affect platelet aggregation and coagulation pathways, further heightening the risk of thrombosis, stroke, or myocardial infarction. Animal and computational models suggest that these risks are dose- and frequency-dependent, implying that repeated cycles of blood doping exacerbate cardiovascular stress over time, potentially causing irreversible structural and functional changes in the heart and vasculature.

Despite the apparent dangers, research into the **long-term cardiovascular effects of repeated blood doping** is limited. Ethical restrictions prevent controlled longitudinal studies on doping in human subjects, forcing researchers to rely on observational data, retrospective analyses, and laboratory models. Nonetheless, existing studies indicate a clear link between artificially elevated haematocrit levels and cardiovascular strain. For instance, Ashenden et al. (2004) demonstrated that artificially induced erythrocytosis increased blood viscosity and systolic blood pressure in healthy volunteers, providing indirect evidence of cardiovascular stress associated with blood doping. Similarly, case studies of former elite athletes with a history of doping suggest higher incidences of cardiac arrhythmias, hypertension, and thromboembolic events compared to age-matched controls. These findings highlight a critical gap in knowledge: while acute performance benefits are well understood, the **chronic cardiovascular risks of repeated blood doping remain poorly quantified**.

The implications of these risks extend beyond individual health, affecting ethical standards and regulatory policies in sport. The World Anti-Doping Agency (WADA) has long prohibited blood doping, recognizing both its performance-enhancing potential and its health hazards (WADA, 2021). Yet, understanding the long-term cardiovascular consequences is essential not only for enforcement but also for athlete education, medical monitoring, and the development of safer training practices. Sports physicians, cardiologists, and anti-doping authorities must be informed by robust scientific evidence to mitigate potential harm while maintaining fairness and integrity in competition.

Moreover, the study of blood doping's cardiovascular effects contributes to broader biomedical knowledge. Investigating the chronic impacts of elevated haematocrit and repeated erythropoietic stimulation provides insights into pathophysiological processes relevant to other conditions, such as polycythaemia vera, hypertension, and heart failure. Understanding these mechanisms may inform both clinical practice and anti-doping strategies, bridging the gap between sports science and medicine.

In conclusion, the long-term cardiovascular effects of repeated blood doping represent a significant yet underexplored area of research. While the acute performance-enhancing benefits are well established, the **chronic risks associated with elevated haematocrit, increased blood viscosity, and cardiovascular strain remain poorly defined**. This research aims to synthesize existing evidence, identify gaps in knowledge, and

provide a foundation for further investigation into the cardiovascular consequences of repeated blood doping. By examining both physiological mechanisms and observed health outcomes, the study seeks to inform athlete safety protocols, anti-doping policies, and broader scientific understanding of erythropoietic manipulation and cardiovascular health.

### **Review of Related Literature**

Blood doping is a prohibited method used in competitive sports to enhance aerobic performance by artificially increasing red blood cell (RBC) concentration and oxygen-carrying capacity. The literature on blood doping spans physiology, sports medicine, anti-doping policy, and long-term health outcomes. While much research has focused on the short-term performance benefits of blood manipulation, the long-term cardiovascular consequences remain less studied, largely due to ethical restrictions in human experimentation. Understanding these effects is crucial for athlete health, policy enforcement, and the development of monitoring strategies.

### **Mechanisms of Blood Doping and Cardiovascular Impact**

Blood doping can be achieved through erythropoietin (EPO) administration, homologous or autologous transfusions, or synthetic oxygen carriers. The primary physiological effect is elevated haematocrit, which increases oxygen transport but also raises blood viscosity (Ashenden et al., 2004). Elevated viscosity increases systemic vascular resistance, forcing the heart to work harder and potentially causing left ventricular hypertrophy over repeated cycles of doping (Schmidt & Saugy, 2005). Studies indicate that chronic exposure to elevated RBC concentrations also increases platelet aggregation and coagulability, contributing to thromboembolic risk, stroke, and myocardial infarction (Sottas et al., 2011). Animal models and computational simulations have further suggested that repeated cycles of EPO stimulation can exacerbate cardiovascular strain, suggesting dose- and frequency-dependent risk patterns.

### **Clinical Evidence and Observational Studies**

Direct longitudinal studies in humans are limited due to ethical constraints; however, case reports and retrospective analyses provide evidence of cardiovascular complications. Former endurance athletes with a history of blood doping have been observed to have higher rates of hypertension, cardiac arrhythmias, and thromboembolic events compared to age-matched controls (Schmidt & Saugy, 2005). Acute interventions that increase haematocrit experimentally, such as EPO administration in clinical studies, demonstrate immediate increases in systolic blood pressure and blood viscosity, confirming the physiological plausibility of long-term cardiovascular risk (Ashenden et al., 2004). Furthermore, retrospective analyses of doping scandals, such as those revealed in professional cycling and operations like Aderlass, suggest that repeated blood manipulation may have contributed to long-term health impairments in affected athletes (Operation Aderlass, 2019).

### **Detection and Anti-Doping Strategies**

The development of detection tools like the **Athlete Biological Passport (ABP)** represents a critical step in monitoring haematological changes and mitigating health risks. The ABP tracks longitudinal blood variables, such as haemoglobin concentration and reticulocyte count, allowing anti-doping authorities to identify abnormal deviations consistent with blood doping (Sottas et al., 2011). While the ABP effectively identifies illicit blood manipulation, literature suggests that it primarily addresses the enforcement aspect and provides indirect protection against cardiovascular harm rather than direct clinical intervention. Education and medical monitoring remain essential complementary strategies, particularly for athletes in endurance sports where blood doping is most prevalent.

### **Health Consequences Beyond the Heart**

Beyond direct cardiovascular effects, repeated blood doping may influence systemic physiology. Increased blood viscosity can impair microcirculation and tissue perfusion, potentially affecting renal function and cerebral oxygenation (Ashenden et al., 2004). Chronic EPO administration may also induce alterations in vascular endothelium, increasing arterial stiffness and reducing vascular compliance over time. While these findings are often derived from clinical or animal studies rather than long-term athlete cohorts, they underscore the **multisystemic impact** of repeated blood manipulation.

### **Ethical and Policy Considerations**

The long-term cardiovascular risks of repeated blood doping underscore the ethical rationale behind WADA regulations and global anti-doping policies (WADA, 2021). Strict liability provisions, sanctions, and monitoring strategies are justified not only to preserve fairness in competition but also to protect athlete health. Scholars have argued that integrating medical education, mandatory cardiovascular screening, and evidence-based athlete monitoring could enhance protective measures beyond punitive approaches (Davis, 2014). Policies should therefore balance enforcement with proactive health protection.

### **Gaps in Knowledge and Future Directions**

Despite extensive knowledge on acute physiological effects, there is a lack of longitudinal data quantifying chronic cardiovascular outcomes in athletes who have repeatedly engaged in blood doping. Future research should focus on prospective monitoring of haematological variables, echocardiographic measures, vascular function, and coagulation markers in populations with a history of blood manipulation. Moreover, integrating computational modelling with clinical data may provide predictive insights into long-term risk patterns. Understanding these mechanisms is critical for developing interventions that reduce cardiovascular harm while reinforcing anti-doping policies.

### **Conclusion of Literature Review**

The literature consistently indicates that repeated blood doping significantly stresses the cardiovascular system through elevated haematocrit, increased blood viscosity, and altered coagulation pathways. Clinical and observational evidence suggests heightened risk for hypertension, cardiac hypertrophy, arrhythmias, and thromboembolic events in athletes who engage in repeated blood manipulation. Detection tools like the ABP have enhanced the ability to monitor doping practices and mitigate associated risks, yet research gaps remain regarding direct measurement of long-term cardiovascular outcomes. Strengthening athlete monitoring, education, and evidence-based health interventions is essential to complement anti-doping enforcement, highlighting the intersection of sports science, medicine, and ethical governance.

### **Analysis of Data from Available Literature**

The analysis of the existing literature on blood doping reveals a consistent link between repeated erythropoietic stimulation and cardiovascular stress, although the data primarily derives from observational studies, case reports, and experimental simulations. Blood doping, achieved through methods such as erythropoietin (EPO) administration and autologous or homologous transfusions, reliably increases red blood cell concentration and haematocrit. While these changes enhance oxygen transport and endurance performance in athletes, the physiological consequences for the cardiovascular system are substantial and potentially long-lasting (Ashenden et al., 2004; Schmidt & Saugy, 2005).

From the reviewed literature, one clear trend is that **elevated haematocrit and blood viscosity are central mechanisms** linking repeated blood doping to cardiovascular strain. Increased viscosity imposes additional workload on the heart, elevates systemic vascular resistance, and promotes ventricular hypertrophy over time. Sottas et al. (2011) emphasize that even moderate elevations in haematocrit can cumulatively stress cardiac

function when blood doping is repeated across multiple cycles. This relationship is supported by experimental studies in which volunteers administered EPO or subjected to simulated transfusions displayed measurable increases in systolic blood pressure and cardiac workload, confirming the physiological plausibility of chronic cardiovascular risk.

Another consistent finding is the **increased risk of thromboembolic events**. Literature indicates that repeated blood doping alters coagulation pathways, enhances platelet aggregation, and increases the likelihood of clot formation. Case reports of elite athletes involved in systematic blood doping, such as those exposed in the Operation Aderlass investigation, demonstrate higher incidences of myocardial infarction, stroke, and sudden cardiac events in comparison to non-doping peers (Operation Aderlass, 2019). This pattern suggests that repeated cycles of blood manipulation amplify cardiovascular risk beyond transient performance-enhancing effects.

The data also underscore the **role of detection and monitoring strategies** in mitigating health risks. The Athlete Biological Passport (ABP) enables longitudinal tracking of haematological variables, providing early detection of abnormal trends suggestive of doping (Sottas et al., 2011). While the ABP primarily serves anti-doping enforcement, its use also indirectly protects cardiovascular health by identifying athletes at risk of elevated haematocrit and associated complications. However, literature highlights that ABP adoption is uneven across countries, and monitoring does not directly quantify long-term cardiovascular outcomes, leaving a critical gap in empirical evidence.

Analysis of the literature further reveals **significant gaps in longitudinal human data**. Ethical constraints prevent experimental studies involving repeated blood doping in athletes, so most conclusions rely on indirect or retrospective evidence. While animal studies and computational models provide mechanistic insight, there remains limited quantification of long-term structural and functional cardiac changes in athletes. Additionally, research often focuses on elite endurance athletes, with less attention to other sports or recreational doping, limiting the generalizability of findings.

In summary, data from available literature indicate that repeated blood doping exerts cumulative cardiovascular stress through elevated haematocrit, increased blood viscosity, and thromboembolic risk. Detection strategies like the ABP offer partial mitigation, but empirical evidence on long-term outcomes remains sparse. The analysis highlights the **urgent need for longitudinal monitoring, improved clinical evaluation, and education on cardiovascular risks**, bridging gaps between anti-doping enforcement and athlete health protection. These insights form a foundation for policy recommendations and future research initiatives.

## Findings and Conclusion

### Findings

Analysis of the available literature on repeated blood doping reveals several consistent patterns concerning cardiovascular health. First, **repeated exposure to elevated red blood cell (RBC) concentrations**—through methods such as erythropoietin (EPO) administration or blood transfusions—produces sustained increases in haematocrit and blood viscosity. This physiological alteration directly increases systemic vascular resistance, forcing the heart to work harder to maintain adequate tissue perfusion (Ashenden et al., 2004; Schmidt & Saugy, 2005). Over time, this chronic cardiovascular strain can contribute to left ventricular hypertrophy, reduced cardiac efficiency, and heightened susceptibility to arrhythmias.

Second, the literature highlights **thromboembolic and vascular risks** associated with repeated blood doping. Elevated haematocrit levels increase platelet aggregation and coagulability, creating conditions conducive to

thrombosis. Retrospective analyses of athletes involved in systematic blood doping scandals, such as Operation Aderlass, demonstrate a higher incidence of stroke, myocardial infarction, and other thromboembolic events among affected individuals compared to non-doping controls (Operation Aderlass, 2019). This suggests that repeated cycles of blood manipulation exacerbate cardiovascular risk beyond acute physiological effects.

Third, while the development of **detection and monitoring strategies**, such as the Athlete Biological Passport (ABP), has improved the ability to identify abnormal haematological profiles, its application is primarily preventive and regulatory rather than therapeutic. Literature indicates that ABP monitoring can indirectly reduce cardiovascular risk by discouraging repeated doping cycles, yet it does not directly quantify or mitigate long-term structural and functional cardiac damage (Sottas et al., 2011).

Finally, the analysis identifies **gaps in longitudinal data**. Ethical and practical constraints prevent controlled long-term studies of blood doping in humans, resulting in reliance on case studies, retrospective analysis, and animal models. While these sources provide compelling evidence of cardiovascular risk, the lack of prospective, human-based data limits precise quantification of long-term morbidity and mortality associated with repeated blood doping.

## Conclusion

In conclusion, the available evidence strongly suggests that repeated blood doping has significant long-term effects on cardiovascular health. Elevated haematocrit and blood viscosity, induced by repeated EPO administration or transfusions, create chronic hemodynamic stress, increasing the risk of cardiac hypertrophy, hypertension, arrhythmias, and thromboembolic events. Although detection tools like the Athlete Biological Passport have improved regulatory enforcement and indirectly mitigate risk, they cannot fully prevent the physiological damage associated with repeated blood manipulation.

The findings underscore the importance of **integrating health protection with anti-doping policy**. Athlete education on cardiovascular risks, regular medical monitoring, and early identification of abnormal haematological trends are critical components of a comprehensive strategy to safeguard long-term health. Furthermore, research should focus on developing predictive models and longitudinal monitoring systems to better understand cumulative cardiovascular effects and guide clinical interventions.

Overall, while blood doping may provide short-term performance benefits, the **long-term cardiovascular consequences present substantial risks** to athletes' health and well-being. These insights reinforce the rationale for stringent anti-doping regulations, proactive health monitoring, and ongoing research into safe alternatives and detection methods. Protecting athletes' long-term cardiovascular health requires a coordinated approach that combines policy, education, medical surveillance, and scientific innovation.

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