REVIEW ARTICLE

Beyond Hemodialysis: Pulse Oximetry as a Predictive Index for Cardiac Health and Holistic Wellness

Motahareh Delshad, MSN
Student Research Committee, Sabzevar University of Medical Sciences, Sabzevar, Iran

Mahtab Khajeh, MD
Assistant Professor of Surgery, School of Medicine, Emdad Trauma Hospital, Sabzevar University of Medical Sciences, Sabzevar, Iran

Mostafa Rad [1&2], PhD
[1] Iranian Research Center of Healthy Aging, Sabzevar University of Medical Sciences, Sabzevar, Iran
[2] Professor of Nursing, School of Nursing and Midwifery, Sabzevar University of Medical Sciences, Sabzevar, Iran

Corresponding author:
Professor Mostafa Rad, School of Nursing and Midwifery, Sabzevar University of Medical Sciences, Sabzevar, Iran

E-mail:
mostafarad633@yahoo.com

https://orcid.org/0000-0002-8590-5348

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Abstract

Background and Objective: Chronic Kidney Disease (CKD) is a major global health concern characterized by the gradual loss of kidney function over time. The objective of this study is to answer the question of whether measuring blood oxygen saturation via pulse oximetry serves as an appropriate indicator for predicting cardiac risks during hemodialysis.
Materials and Methods: In this review study, a search was conducted in the PubMed, ScienceDirect, Scopus, Google Scholar, and SID databases using the keywords "pulse oximetry," "photoplethysmography," "hemodialysis," and "cardiac risks (including hypotension, cardiac arrhythmia, and heart failure)," within the time frame of 2020 to 2025. After reviewing the manuscript, eight relevant studies were finally selected. Letters to the editor were excluded from the study.
Results: The results indicated that monitoring blood oxygen saturation and taking timely action played a role in preventing cardiac risks, alongside other diagnostic methods. This highlights the importance of monitoring this indicator throughout treatment sessions to predict risks in CKD patients, particularly during episodic hypotensive episodes and cardiac complications.
Conclusion: Based on the findings, it is recommended that the assessment of hemoglobin oxygen saturation in dialysis patients be performed as a non-invasive method for the early detection of cardiac problems in hemodialysis patients during dialysis sessions.

Keywords: Chronic kidney disease, oxygen saturation level, pulse oximetry, hypotension.

Introduction

Chronic Kidney Disease (CKD) is a progressive and, in most cases, irreversible condition characterized by a gradual decline in kidney function. It is typically defined as kidney damage lasting for three months or more, with or without a decrease in the Glomerular Filtration Rate (GFR) (1). A GFR of less than 60 mL/min/1.73 m^2 is a critical benchmark for diagnosing CKD (2). Affecting approximately 10% of the current global population, CKD poses significant public health challenges, including the exacerbation of various comorbidities and escalating healthcare costs (3). A substantial portion of this burden is attributable to the complications arising from CKD. Among these complications, cardiovascular risks account for a significant proportion. Given the profound impact of concurrent cardiovascular disease (CVD) and CKD on patient mortality, strategies aimed at controlling, diagnosing, and preventing these complications remain of paramount importance to healthcare providers (4). Furthermore, the presence of comorbidities such as hypertension and diabetes alongside CKD can exacerbate these risks and worsen disease severity (5). Therefore, to address this issue effectively, it is essential to first conduct a comprehensive review of the common cardiac complications that arise during the course of kidney disease, thereby providing a more holistic and profound understanding of the subject.

Patients undergoing hemodialysis frequently experience various cardiac events that significantly impact their health outcomes. One of the underlying causes is that CKD leads to impaired microvascular reactivity, particularly during reperfusion following angiography, which is significantly diminished in advanced stages of CKD. The inability of the microvasculature to respond effectively to stimuli leads to decreased tissue oxygenation, contributing to exercise intolerance and further renal damage in a vicious cycle (6). In other words, not only does kidney disease increase the risk of cardiovascular events, but the presence of CVD also exacerbates renal disease. This process, initiated by renal injury, can culminate in multi-organ failure and, ultimately, patient mortality in its end stages if timely diagnosis and appropriate preventive measures are not implemented. Consequently, the objective of this research is to identify and propose an optimal approach based on the current body of scientific knowledge, aiming to achieve the highest standard of patient care through the most efficient and rapid methods.

The most common intradialytic cardiac events include hypotension, heart failure, and cardiac arrhythmias, which are exacerbated by comorbidities such as hypertension and diabetes. Intradialytic hypotension has been reported in up to 59% of patients, making it the most common complication during hemodialysis (7). Heart failure is recognized as a leading cardiovascular event, frequently associated with fluid overload and underlying comorbidities (8). Cardiac arrhythmias, such as ventricular tachycardia and fibrillation, are major contributors to sudden cardiac death and exhibit a significant prevalence among patients experiencing acute cardiac events (9). As aforementioned, these three categories of conditions are the most likely to occur during hemodialysis sessions and can profoundly impact the patients' hemodynamic status. However, another critical question arises: what methods are available to predict and manage these complications?

One such approach is the continuous monitoring of blood oxygen levels to determine oxygen saturation (SpO2). This is achieved using pulse oximetry to evaluate the efficiency of oxygen exchange in the

systemic circulation. It can provide crucial insights into the health status of these patients and serve as a valuable guide for implementing therapeutic interventions (10). Research indicates that hemodialysis patients frequently experience hypoxemia, which is associated with increased rates of hospitalization and mortality due to cardiovascular complications (11). Previous studies have demonstrated that decreased oxygen saturation is correlated with an increased incidence of cardiovascular events, making the monitoring of this parameter crucial for risk stratification in patients with CKD (12, 13). Cardiovascular diseases can negatively impact the delivery and utilization of oxygen throughout the body. Consequently, monitoring O2 saturation becomes essential, as it assists healthcare providers in assessing the adequacy of tissue-level oxygen delivery and identifying potential cardiovascular complications at their onset. Furthermore, the hemodialysis process itself can affect oxygen levels, particularly during treatment sessions when blood is extracorporeally circulated through the dialysis machine (14). Factors such as the patient's overall health status, the efficiency of the dialysis process, and the presence of comorbidities (or underlying conditions) can significantly influence oxygen saturation levels (15).

By closely monitoring these parameters, healthcare teams can make informed decisions regarding appropriate therapeutic interventions, optimize treatment protocols, and ultimately improve patient recovery outcomes during and after dialysis sessions (16). Regular monitoring also facilitates timely interventions, such as adjusting dialysis parameters to suit the patient's condition or administering supplemental oxygen, which can significantly enhance patient comfort and safety throughout the treatment process (17). Maintaining optimal oxygen saturation levels is essential to ensure adequate tissue perfusion and prevent adverse effects, as oxygen fluctuations can exacerbate disease severity and increase mortality risk in this vulnerable population. It is crucial to maintain optimal oxygen saturation to guarantee that cells receive adequate tissue perfusion, which is vital for their proper function and overall health. Inadequate oxygenation can trigger a cascade of complications, particularly in vulnerable populations such as the elderly, individuals with chronic respiratory diseases, or those in the late stages of recovery from major surgeries (18).

Typically, normal O2 saturation levels range from 95% to 100% (10). In hemodialysis patients, factors that may affect O2 saturation include anemia; many patients with CKD are also anemic, which can lead to decreased O2 saturation levels in the body (19). Furthermore, fluid overload can disrupt this parameter (20). Additionally, pulmonary complications arising from dialysis can affect oxygen uptake (21), as can dialysis-related factors, such as the hemodialysis process itself, which can occasionally induce fluctuations in blood pressure and oxygenation (22).

Given the aforementioned points and the lack of routine, continuous evaluation of oxygen saturation in hemodialysis units, the following question arises: Is the measurement of blood oxygen saturation via pulse oximetry a suitable indicator for predicting cardiovascular risks during hemodialysis? Researchers intend to answer this question through a comprehensive review of existing studies.

Materials and Methods

A comprehensive literature search was conducted across the PubMed, ScienceDirect, Scopus, Google Scholar, Web of Science (WOS), and SID databases for articles

published between 2020 and 2025. The search encompassed both Persian and English literature and utilized the following keywords and their Persian equivalents: pulse oximetry, photoplethysmography device, hemodialysis, and cardiac risks (including hypotension, cardiac arrhythmia, and heart failure). The search process was carried out from April 21, 2025, to July 22, 2025.

The inclusion criteria comprised interventional (experimental and quasi-experimental) and review studies that monitored blood oxygen levels in hemodialysis patients during treatment sessions and discussed the clinical implications of these interventions. One of the exclusion criteria was the omission of "letters to the editor."

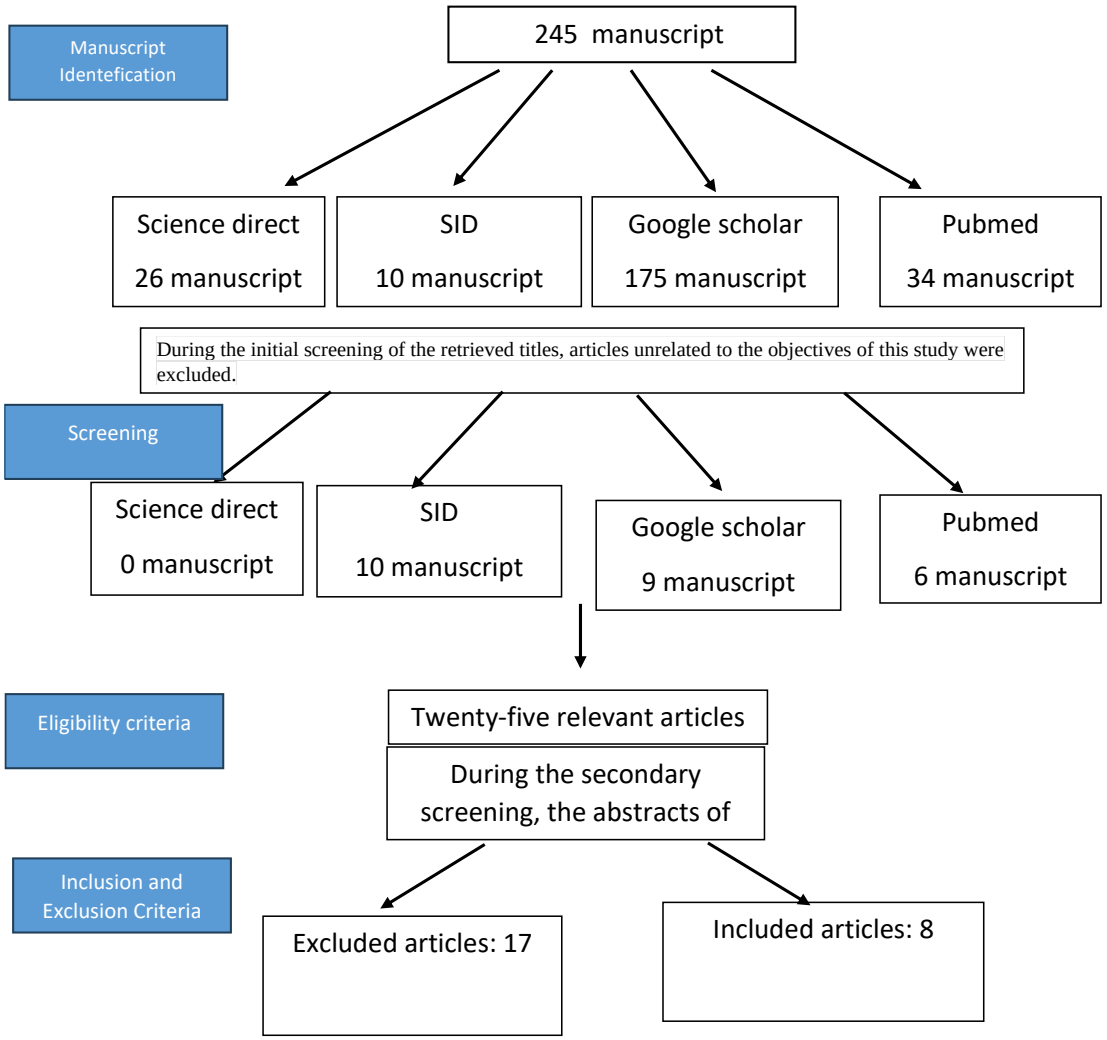

Figure 1. Number of articles reviewed following searches in various databases

An initial comprehensive search yielded 245 articles. Each potentially eligible article was screened by at least one reviewer. First, the titles and abstracts were reviewed to assess

the study objectives and target population. In the first screening phase, 220 articles were excluded due to a lack of thematic relevance to the present study. Subsequently, the full texts of the remaining 25 relevant articles were independently read and assessed. Following further evaluation, 17 articles were excluded for failing to address the research objectives. Ultimately, 8 relevant articles were included in the study and critically appraised (Figure 1).

Results

Ultimately, approximately eight articles deemed most relevant to the research topic by the authors were selected (Table 1). A detailed analysis was then conducted on various aspects of these articles, including their strengths and study gaps. The findings of this review reveal a broad spectrum of evidence regarding pulse oximetry measurements and their associated outcomes in hemodialysis patients. From the authors' perspective, restricting the scope of these findings would obscure the comprehensive understanding obtained. Therefore, it was decided to first provide an overview of the results to offer a broad perspective for healthcare researchers, followed by a more specific discussion of their clinical implications.

Table 1 – Relevant articles

Study	Authors	Method	Results
A pitfall of pulse oximetry of the upper extremity with arteriovenous fistula for hemodialysis: A case of unreasonably low SpO2 readings despite a clear pulsatile pulse wave. (23)	Hayashi et al.	Measuring Pulse Oximetry (SpO2) in Arteriovenous Fistula (AVF) Patients undergoing Hemodialysis	It raised concerns about the accuracy of SpO2 measurements in the upper limb with AVF and highlight the potential for misinterpretation of venous pulses as reliable diagnostic signals, particularly in diabetic patients. In addition, this study highlights the need for further research into how different types of AVF affect SpO2 accuracy.
Intradialytic hypotension related episodes identification based on the most effective features of photoplethysmography signal. Computer methods and programs in biomedicine(24)	Nafisi et al.	The researchers collected PPG signals from patients and processed them to extract key features. For example, by analyzing the shape and spacing of the spirometry waves, they obtained classified data on this topic.	Evaluation of the proposed algorithm showed that the use of PPG signals can significantly aid blood pressure management during hemodialysis and potentially improve patient outcomes and safety. It highlights monitoring of vital signs in hemodialysis patients and how advanced techniques can help predict and prevent complications such as intradialytic hypotension (IDH).
Pre-dialytic spo2 measured with a wearable device as a predictor of mortality in patients with OSA and chronic kidney disease(13)	Lo et al.	The relationship between pre-dialysis oxygen saturation in the blood (SpO2), obstructive sleep apnea (OSA) in hemodialysis patients and the associated risk of mortality was investigated. The study sample included 92 hemodialysis patients with long-term follow-up.	The results showed that SpO2 levels below 95% significantly increased the risk of death, emphasizing the need for regular SpO2 monitoring in this high-risk population. The results also support the development of portable devices for effective SpO2 monitoring.
Correlation of venous oxygen saturations from noninvasive hematocrit monitoring using blood gas measured oximetry in chronic pediatric hemodialysis patients. Blood Purification(25)	Iderou et al.	This study evaluates whether Non-Invasive Hematocrit Monitoring (NIVHM) accurately reflects venous oxygen saturation compared to traditional blood gas measurements in a group of 15 patients under the age of 21 without congenital heart disease at Texas Children's Hospital.	The results show a strong correlation ($r = 0.89$, $p < 0.0001$) between NIVHM O_2 saturation and measured O_2 saturation (MO_2sat) at different times during dialysis (before, during and after)
Exploring Novel Intradialytic Techniques to Identify & Ameliorate	Penny et al.	This study used echocardiography for the detection of hemodialysis (HD) induced	The research model suggests that non-invasive PPG may provide early

of Hemodialysis-induced Myocardial Ischemic Injury: The University of Western Ontario (Canada) (26).		circulatory stress in the form of myocardial ischemia and photoplethysmography (PPG) for the monitoring of peripheral circulation.	detection of cardiac stress during hemodialysis. It may serve as an innovative tool for clinicians to monitor patients throughout the dialysis process.
Non-invasive intradialytic percutaneous perfusion monitoring: a view to the heart through the skin (27).	Penny et al.	Using continuous photoplethysmography (PPG) skin perfusion monitoring and echocardiographic data, researchers studied 12 dialysis patients. Non-invasive PPG monitoring may provide a predictive measure of myocardial perfusion, indicating hemodialysis-induced cardiac injury.	The results suggest that non-invasive methods could serve as an alternative to traditional invasive monitoring techniques that are limited in application and accessibility.
Reliability and benefit of estimated continuous cardiac output measurement using shunt-side SpO2 monitor in hemodialysis (28).	Nakai et al.	This single-center observational study included 43 Japanese patients undergoing dialysis between 27 April 2021 and 28 February 2023. Their vital signs were monitored using the ESCCO device.	Intermittent cardiac output (ESCCO) measurement using pulse oximetry provides accurate hemodynamic monitoring during dialysis and offers a more suitable alternative to conventional methods of monitoring blood pressure during hemodialysis.
The time of onset of intradialytic hypotension during a hemodialysis session associates with clinical parameters and mortality (29).	Keane et al.	This retrospective, observational cohort study analyzed deidentified, routinely collected dialysis treatment data—including demographic, clinical, and Crit-Line monitor parameters—from incident and prevalent patients across 21 Renal Research Institute clinics in the United States between January 2017 and October 2019.	The study briefly mentions a diagnostic approach, noting that there is limited research specifically focused on measuring oxygen saturation (SO_2) during hemodialysis in patients with intradialytic hypotension. The paucity of data makes monitoring of this parameter critical for patient management during dialysis and highlights the need for continued research in this area.

Therefore, based on the data presented in the table, the authors suggest initially adopting a more comprehensive and detailed examination of the cited studies. This approach allows for a well-informed interpretation of the research findings by integrating the authors' perspectives with the empirical evidence reported in the literature. As previously noted, numerous studies have demonstrated that monitoring blood oxygen saturation (SpO2) and photoplethysmography (PPG) signals can serve as valuable tools for assessing cardiovascular risks in hemodialysis patients. Recent research indicates that pulse oximetry not only captures hemodynamic changes during dialysis but also holds potential as a predictive tool for induced complications.

Discussion

The majority of the reviewed studies indicated that monitoring SpO2 and PPG signals can be valuable tools for assessing cardiovascular risks in hemodialysis patients. In this context, a study by Hayashi et al. investigated the accuracy of pulse oximetry in patients with an arteriovenous fistula (AVF). Their findings revealed that in certain patients, particularly those with diabetes, SpO2 readings may be influenced by abnormal blood flow, leading to potential misinterpretation. This underscores the need for broader research into how different types of AVFs affect SpO2 accuracy in specific patient populations and highlights the necessity for meticulous evaluation during clinical monitoring (23).

Furthermore, another study utilized PPG signals to develop an algorithm capable of predicting intradialytic hypotension (IDH) through signal feature processing. This research emphasizes the importance of employing non-invasive methods to monitor patient status during dialysis and

demonstrates that SpO2 monitoring can play a pivotal role in enhancing patient management (24).

Another study in 2021 demonstrated that pre-dialysis decreases in SpO2 levels are associated with an increased risk of mortality in patients with obstructive sleep apnea. This study suggests that pulse oximetry devices can serve as an effective method for continuous oxygen saturation monitoring, thereby mitigating cardiovascular risks in hemodialysis patients. The development of wearable devices for recording and analyzing SpO2 could further improve patient safety and clinical outcomes (13). Additionally, research conducted at Texas Children's Hospital showed a strong correlation between non-invasive hematocrit monitoring (NIVHM) and blood gas analysis (mO2sat). This finding indicates that NIVHM can be employed as an accurate method for monitoring oxygenation status in pediatric patients during hemodialysis, reducing the need for invasive testing (25).

In another study by Penny et al., skin perfusion monitoring was investigated as a non-invasive approach to assess myocardial perfusion in hemodialysis patients. The findings revealed that a decrease in pulse amplitude during dialysis could be associated with myocardial abnormalities, suggesting that PPG techniques could serve as an alternative to traditional invasive methods (27).

Finally, a 2025 study demonstrated that pulse oximetry can be utilized to measure cardiac output in limbs with and without shunts. The results indicated a high reliability coefficient for these measurements, suggesting that this method could be a suitable alternative to conventional blood pressure monitoring techniques in hemodialysis patients (28).

Overall, fluctuations in O2 saturation during hemodialysis can be effective in predicting the patient's hemodynamic stability, including cardiac output and risks, hypotension, and, in later stages, determining morbidity and mortality rates (6). Furthermore, continuous follow-up of this parameter to determine the level of hypoxia in patients can not only detect clinical and silent hypoxia—prior to the onset of clinical symptoms—but also provide early warnings of low oxygen levels. This enables timely therapeutic interventions by healthcare providers, thereby preventing subsequent treatment complications in hemodialysis patients (10).

Conclusion

Based on the findings, it can be concluded that pulse oximetry is not only a practical tool for monitoring oxygenation in hemodialysis patients but also serves as a predictive indicator for cardiovascular complications. The utilization of advanced technologies such as PPG and NIVHM can enhance clinical monitoring and mitigate dialysis-related risks. Therefore, further research is recommended to optimize these methods and expand their clinical applications. Given the importance of continuous oxygen level monitoring during hemodialysis, the analysis of the aforementioned literature leads to the conclusion that continuous O2 saturation monitoring via peripheral vascular assessment—pulse oximetry—can serve as a valuable parameter for predicting clinical events tailored to the patient's clinical condition during hemodialysis. Although the accuracy and precision of this method may vary when used alongside other vital parameters such as electrocardiography, heart rate monitoring, or ultrafiltration volume during hemodialysis, its independent significance, as evidenced by the reviewed literature and the analysis of pulse oximetry

waveforms and patterns, remains substantial. Nevertheless, to gain a broader perspective, this area warrants further attention and continued research.

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Author Contributions

All authors were involved in the preparation of the manuscript and its subsequent follow-ups.

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Conflict of Interest

The authors declare no conflicts of interest regarding this study.

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