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Yapay Zekâ Tabanlı Yaklaşımlarla VA-ECMO Uygulanan Hastalarda Weaning Sürecinin Değerlendirilmesi

Evaluation of the Weaning Process in Patients Undergoing VA-ECMO Using Artificial Intelligence Based Approaches

Gülşah Çelik Korhan[1*]

*1. Harran Üniversitesi: Perfüzyon Teknolojisi, Şanlıurfa/TÜRKİYE
gulsahcelik4861@gmail.com, ORCID: 0009-0001-2949-6287

ÖZET

Veno-arteriyel ekstrakorporeal membran oksijenasyonu (VA-ECMO) ciddi kardiyak disfonksiyon yaşayan hastalarda geçici bir yaşam desteği sunarak organ perfüzyonunu sürdürebilmek amacıyla yaygın olarak kullanılmaktadır. Ancak bu desteğin sonlandırılması yani weaning süreci, hasta sonuçları üzerinde doğrudan belirleyici bir rol oynamakta, zamanlama ve başarı tahmini ise klinik karar verme açısından karmaşık bir alan olarak öne çıkmaktadır. Konvansiyonel yöntemlerin sınırlı öngörü gücü, klinisyenleri daha ileri analiz tekniklerine yöneltmiştir. Bu noktada yapay zekâ (YZ) algoritmaları; çok değişkenli klinik verileri analiz etme kapasiteleri, öğrenme yetenekleri ve tahmin performansları sayesinde yeni bir perspektif sunmaktadır. Özellikle makine öğrenmesi tabanlı modellerin, hasta takibinde yüksek doğrulukla erken uyarı sistemleri geliştirmeye olanak tanıdığı görülmektedir. Son yıllarda yapılan çalışmalar, YZ'nin VA-ECMO hastalarında weaning sürecine dair objektif veriye dayalı çıkarımlar yapılmasını kolaylaştırdığını göstermektedir.

Bu derlemenin amacı; VA-ECMO desteği alan hastalarda weaning (destekten ayrılma) başarısının öngörülmesine yönelik geliştirilen güncel yapay zekâ tabanlı yaklaşımları irdelemek, klinik karar destek sistemlerindeki uygulanabilirliğini değerlendirmek ve bu alandaki literatüre bütüncül bir bakış sunmaktır.

Anahtar Kelimeler: Veno-arteriyel-ECMO, Kardiyojenik şok, Yapay zekâ, Mortalite riski tahmini, Weaning.

ABSTRACT

Veno-arterial extracorporeal membrane oxygenation (VA-ECMO) is widely used as a temporary life support strategy to maintain organ perfusion in patients experiencing severe cardiac dysfunction. However, the discontinuation of this support known as the weaning process plays a critical role in patient outcomes, with its timing and success prediction representing a complex challenge in clinical decision-making. The limited predictive power of conventional methods has led clinicians to seek more advanced analytical techniques. At this point, artificial intelligence (AI) algorithms offer a novel perspective due to their ability to analyze multivariate clinical data, their learning capabilities, and high predictive performance. In particular, machine learning-based models have shown promise in enabling the development of early warning systems with high accuracy in patient monitoring. Recent studies suggest that AI facilitates data driven and objective insights into the weaning process in VA-ECMO patients.

The aim of this review is to examine current AI-based approaches developed to predict weaning success in patients receiving VA-ECMO support, to evaluate their applicability in clinical decision support systems, and to provide a comprehensive overview of the literature in this field.

Keywords: Veno-arterial ECMO, Cardiogenic shock, Artificial intelligence, Mortality risk prediction, Weaning.

Sorumlu Yazar/Corresponding Author: Gülşah ÇELİK KORHAN Harran Üniversitesi: Perfüzyon Teknolojisi, Şanlıurfa/TÜRKİYE gulsahcelik4861@gmail.com, ORCID: 0009-0001-2949-6287

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INTRODUCTION

Venoarterial extracorporeal membrane oxygenation (VA-ECMO) is a life-saving technology that provides temporary cardiac and circulatory support to patients experiencing cardiogenic shock. The primary indications for VA-ECMO include medical cardiogenic shock such as that associated with acute myocardial infarction, fulminant myocarditis, acute exacerbation of severe chronic heart failure, drug intoxication, hypothermia, and acute circulatory failure due to refractory arrhythmias. VA-ECMO ensures continuous organ perfusion, allowing for patient stabilization and providing time for cardiac recovery, while also supporting clinical decision-making processes (1). It can also be employed in patients with post cardiotomy cardiac failure, following heart or lung transplantation, or in cases of cardiac arrest requiring cardiopulmonary resuscitation. Additionally, in selected cases VA-ECMO may be utilized in patients with pulmonary embolism, sepsis-associated cardiomyopathy, and pulmonary hypertension (2). Despite the increasing use of VA-ECMO, its costs and complication rates remain high. A significant proportion of patients do not survive, while others experience long-term sequelae that severely impair quality of life. Inappropriate use of VA-ECMO can lead to excessive resource consumption and increased hospital costs and is also associated with high mortality rates. Therefore, early identification and prediction of mortality risk factors is essential. However, to date, only a limited number of studies have investigated the factors influencing mortality and long-term prognosis in patients with severe cardiogenic shock treated with VA-ECMO. Accordingly, the development of reliable models capable of accurately predicting mortality risk in this patient population is of great importance (3, 4). Impaired cardiac function affects all organs, including the liver. Systemic congestion and hypoperfusion resulting from cardiogenic shock can lead to liver dysfunction and increased levels of hepatic fibrosis markers. Studies have demonstrated that reduced arterial perfusion and systemic congestion may contribute to liver dysfunction and fibrosis. Liver dysfunction observed in patients with cardiogenic shock is referred to as cardiohepatic syndrome, a condition that significantly influences clinical outcomes and mortality risk (5).

In this review, a comprehensive literature search was conducted between November 2023 and May 2024 using PubMed and Google Scholar databases. Searches were performed using the keywords “VA-ECMO”, “weaning”, “artificial intelligence”, “machine learning”, “mortality prediction”, and “cardiogenic shock”. Studies published in English over the last 10 years, involving human subjects, and with full-text availability were considered. Case reports, editorials, conference abstracts, and studies lacking sufficient scientific data were excluded. As a result of the screening, 32 studies were initially reviewed, and after evaluation for methodological and content relevance, 24 studies were included in this review.

Short-Term Outcomes in Patients Receiving VA-ECMO Support

The Extracorporeal Life Support Organization (ELSO) registry reports an overall hospital discharge survival rate of 41% among adult patients receiving VA-ECMO support. The data within this registry are derived from observational studies and show significant variability depending on the primary indication. Outcomes appear most favorable in patients requiring VA-ECMO support due to acute severe myocarditis, pulmonary embolism accompanied by right ventricular failure, or primary graft failure following heart transplantation, with hospital discharge survival rates reported to be as high as 80% (6).

In cardiogenic shock complicating acute myocardial infarction, hospital discharge survival rates of up to 70% have been reported in patients treated with VA-ECMO and percutaneous coronary intervention (PCI). Additionally, VA-ECMO is increasingly utilized in extracorporeal cardiopulmonary resuscitation (eCPR) to provide circulatory support in patients who fail to achieve sustained return of spontaneous circulation. Survival rates to hospital discharge following eCPR in out-of-hospital cardiac arrest patients remain low, ranging between 8% and 29%. However, higher survival rates have been reported in selected subgroups. Overall, the outcomes of VA-ECMO support remain unsatisfactory, with in-hospital mortality rates reaching up to 60% (7). To more accurately assess the necessity of VA -ECMO support and improve clinical decision-making, risk scoring systems such as the Survival After Veno-Arterial ECMO (SAVE) score and the Prediction of Cardiogenic Shock Outcome for AMI Patients Salvaged by VA-ECMO (ENCOURAGE) score have been developed for patients with cardiogenic shock secondary to acute myocardial infarction undergoing VA-ECMO. These scoring systems are based on pre-ECMO risk factors independently associated with adverse clinical outcomes. Relevant studies have identified advanced age, female sex, and high body mass index, along with markers reflecting disease severity such as elevated serum lactate levels, renal, hepatic, or central nervous system dysfunction, prolonged mechanical ventilation duration, and decreased prothrombin activity, as independent predictors of poor clinical outcomes (8).

Factors Predicting Mortality After Weaning from VA-ECMO Support

Successful weaning from VA-ECMO support does not always guarantee patient survival. Numerous studies have evaluated factors predicting mortality following ECMO weaning, particularly in cases of post-cardiotomy shock and out-of-hospital cardiac arrest. Notably, markers associated with post-weaning mortality include diabetes, obesity, duration until VA-

ECMO initiation, duration of cardiopulmonary resuscitation, impaired renal and hepatic function, elevated lactate levels, and high Sequential Organ Failure Assessment (SOFA) scores (9).

Factors Assisting Prediction of Successful Weaning from VA ECMO

VA ECMO support is utilized to provide temporary cardiac and pulmonary assistance in critically ill patients experiencing life-threatening cardiogenic shock. However, even if the weaning process from the device is successful, it does not necessarily indicate complete patient recovery. Clinical observations and literature reports demonstrate that some patients may succumb despite successful separation from ECMO. Therefore, accurately predicting which patients are at risk during this critical period is of great importance. Identifying factors associated with post-weaning mortality enables the development of more effective patient management strategies and allows for the optimal allocation of healthcare resources.

Clinical Predictors

Pulse Pressure

Among clinical parameters, age, sex, comorbidities, and severity of illness at the time of VA-ECMO initiation have not been identified as predictors of successful weaning. Pulse pressure is the only clinical parameter associated with successful weaning. Studies have observed that among patients whose ECMO flow was reduced, those who were successfully weaned had higher mean pulse pressures. For example, in some investigations, the mean pulse pressure was reported as 52±12 mmHg in patients with successful weaning, compared to 39±15 mmHg in those with unsuccessful weaning. Similarly, another study reported a mean pulse pressure of 59 (53–69) mmHg in patients who were successfully weaned. However, no clinically definitive predictive threshold value has been established for this parameter (10).

Biomarkers

Cardiovascular biomarkers have been associated with clinical outcomes in patients with heart failure. Since these biomarkers reflect pathological processes occurring in the heart they are considered useful for predicting cardiac recovery and identifying patients with recovery potential among those receiving VA-ECMO therapy. However, some studies have shown that levels and temporal changes of biomarkers measured during the first week of ECMO treatment such as N terminal pro B type natriuretic peptide troponin Ic pro atrial natriuretic peptide proadrenomedullin and copeptin did not differ significantly between patients who were successfully weaned from ECMO and those who were not. This finding suggests that the predictive efficacy of these biomarkers for cardiac recovery may be limited (11).

Echocardiographic Parameters

Given that comprehensive and dynamic echocardiographic assessments are essential in the management of patients with cardiogenic shock receiving ECMO support, evaluating the predictive ability of echocardiographic parameters for successful weaning appears reasonable. In this context, the predictive capability of echocardiographic variables for successful weaning was investigated in 51 patients undergoing VA-ECMO. High values of parameters assessing left ventricular systolic function, such as aortic velocity-time integral, left ventricular ejection fraction (LVEF), and lateral mitral annulus peak systolic velocity, were found to be associated with successful weaning. Doppler parameters reflecting left ventricular filling pressures including mitral E and tissue Doppler imaging (TDI) Ea velocities and the E/Ea ratio did not show significant differences at ECMO flow levels and were not effective in predicting weaning outcomes; this indicates that preload conditions were similar between the two groups (12).

Hemodynamic Assessment During Weaning Trial

Hemodynamic evaluation during a weaning trial may be beneficial for clinical teams involved in the management of critically ill patients. Pulmonary artery catheter measurements provide valuable information regarding right ventricular (RV) and left ventricular (LV) filling pressures. In patients considered for weaning from VA-ECMO, the following hemodynamic parameters are expected while the pump is turned off: cardiac index>2.4 L/min/m², mean arterial pressure >60 mmHg, pulmonary capillary wedge pressure <18 mmHg, and central venous pressure <18 mmHg (13).

Necessary Conditions for Weaning from VA-ECMO

According to the ELSO guidelines normalization of liver function is required before attempting weaning from VA-ECMO, regardless of the extent of cardiac recovery. However, complete renal function recovery is not considered a prerequisite for the weaning process. Typically, weaning is not initiated within the first 72 hours following VA-ECMO implementation, as this period is crucial for the recovery of organ function. In certain clinical scenarios such as drug intoxication, the duration of ECMO support may be shorter, allowing for earlier weaning attempts. In the literature, the average duration of ECMO support has been reported as 3.3 ± 2.9 days, although some cases have shown support times extending up to 8.0 ± 6.0 days. This timeframe is also essential for myocardial recovery from transient functional loss, such as stunned myocardium, and verifying this recovery is critical before discontinuation of support. Additionally, the underlying cause of cardiac failure must be compatible with myocardial recovery potential, as seen in acute myocarditis, acute myocardial infarction, post-cardiotomy syndromes, drug intoxication, septic cardiomyopathy, or arrhythmia-induced cardiomyopathy (14).

A successful weaning process from VA-ECMO requires a comprehensive, multidimensional evaluation of the patient. Key parameters include cardiac performance, systemic perfusion, left ventricular loading conditions, pulmonary function, and metabolic stability. Laboratory assessments such as liver enzymes (ALT, AST), renal function markers (creatinine, BUN) and platelet count play a critical role in evaluating end-organ function. Elevated serum lactate levels, a hallmark of systemic hypoperfusion, are frequently associated with unsuccessful weaning attempts. Additionally, markers of systemic inflammation, including C-reactive protein, procalcitonin, and the neutrophil-to-lymphocyte ratio, may reflect the degree of physiological stress and influence weaning outcomes. Furthermore, clinical variables such as vasopressor requirement, inotropic score, duration of ECMO support, length of mechanical ventilation, depth of sedation, and the patient's ability to initiate spontaneous breathing have a direct impact on prognosis. Patients who are hemodynamically stable, able to maintain sufficient perfusion on minimal inotropic support, and demonstrate improvement in metabolic markers generally show a higher likelihood of successful weaning.

Nevertheless, the temporal variability of these parameters and interpatient clinical heterogeneity complicate the decision-making process and highlight the limitations of relying on single clinical indicators. These challenges underscore the need for a more holistic, integrative, and dynamic approach to patient monitoring and assessment. At this point, data-driven analysis methods particularly those based on artificial intelligence have begun to play a pivotal role in supporting multidisciplinary decision-making processes by enabling more accurate interpretation of complex and evolving clinical data (15).

Practical Clinical Considerations

The weaning process from VA-ECMO requires an integrated evaluation of hemodynamic, laboratory, and imaging parameters. In clinical practice, key hemodynamic indicators include mean arterial pressure (>60 mmHg), pulse pressure (>40 mmHg), and cardiac index (>2.4 L/min/m²). Pulmonary capillary wedge pressure (<18 mmHg) and central venous pressure (<18 mmHg) provide important insights into ventricular filling status. Among laboratory markers, serum lactate levels, liver enzymes (ALT, AST) and renal function tests (creatinine, BUN) should be closely monitored. Elevated lactate is a recognized indicator of systemic hypoperfusion and is associated with unsuccessful weaning attempts. In echocardiographic evaluation, parameters such as left ventricular ejection fraction (LVEF), aortic velocity-time integral, and lateral mitral annulus peak systolic velocity play a critical role in assessing cardiac performance.

AI-based decision support systems offer the ability to analyze large, complex, and dynamic datasets, facilitating earlier and more accurate clinical predictions. However, the outputs of these models must be interpreted within a clinical context by a multidisciplinary team. User-friendly interfaces and algorithm transparency are crucial for enhancing clinical confidence and promoting effective integration into routine care. A multidisciplinary approach is essential in VA-ECMO management. Perfusionists oversee device operation, while intensivists, cardiac surgeons, and nursing staff collaboratively manage patient care. Regular clinical assessments and effective team communication are vital for the early detection and management of complications. Weaning protocols should be initiated only after achieving hemodynamic stability, metabolic improvement, and organ function recovery. During gradual pump flow reduction, continuous monitoring of hemodynamic, laboratory, and imaging parameters is mandatory. If abnormal findings such as increasing lactate levels, hypotension, or organ dysfunction are observed, the process should be halted and supportive therapy should be prioritized. AI-assisted systems have the potential to enhance the objectivity and timing of clinical decisions in this critical period. Nonetheless, challenges such as difficulties in data acquisition, limited user experience, and a lack of trust in algorithms may hinder effective implementation. Therefore, comprehensive training programs and structured user support systems are essential for the successful adoption of AI technologies in clinical settings (16).

Artificial İntelligence (AI)

AI is a system that employs technologies such as machine learning and its subfield deep learning to perform tasks that require human intelligence. In medicine, AI has enabled revolutionary advances particularly in diagnostic processes and has improved success rates in various applications including treatment planning, risk prediction, clinical management, and drug development. These systems process and interpret data through semantic analysis, contextual learning, and various cognitive computing algorithms, thereby mimicking human-like decision-making abilities. Artificial intelligence operates through three primary learning approaches: supervised learning, unsupervised learning, and reinforcement learning. These learning methods enable the system to improve itself by interacting with data from the external environment. One of the core components of artificial intelligence, machine learning, guides the model's decision-making processes using training data and specific algorithms. Among the most frequently used models in classification problems are binary classification, multiclass classification, multilabel classification, and imbalanced classification. Particularly in multiclass classification, where tasks must be divided into more than two categories, methods such as decision trees, support vector machines (SVM), random forests, and gradient boosting algorithms are commonly employed (17).

Predicting the Weaning Process Using Artificial Intelligence Supported Methods

The high variability, susceptibility to subjective interpretation, and dynamic nature over time of clinical, laboratory, and imaging data used during the weaning process complicate reliable prediction. Accurately analyzing these complex and multidimensional datasets with traditional methods is often not feasible. At this point, artificial intelligence (AI)-based algorithms come into play by simultaneously analyzing large amounts of data, enabling earlier and more accurate prediction of the weaning process.

As shown in Figure 1, AI plays an active role in guiding appropriate interventions by analyzing clinical data during the decision-making process of weaning from VA-ECMO. The flowchart illustrates the AI-supported analysis of clinical data obtained from ECMO patients and the decision-making mechanism based on the clinical outputs derived from these analyses (18).

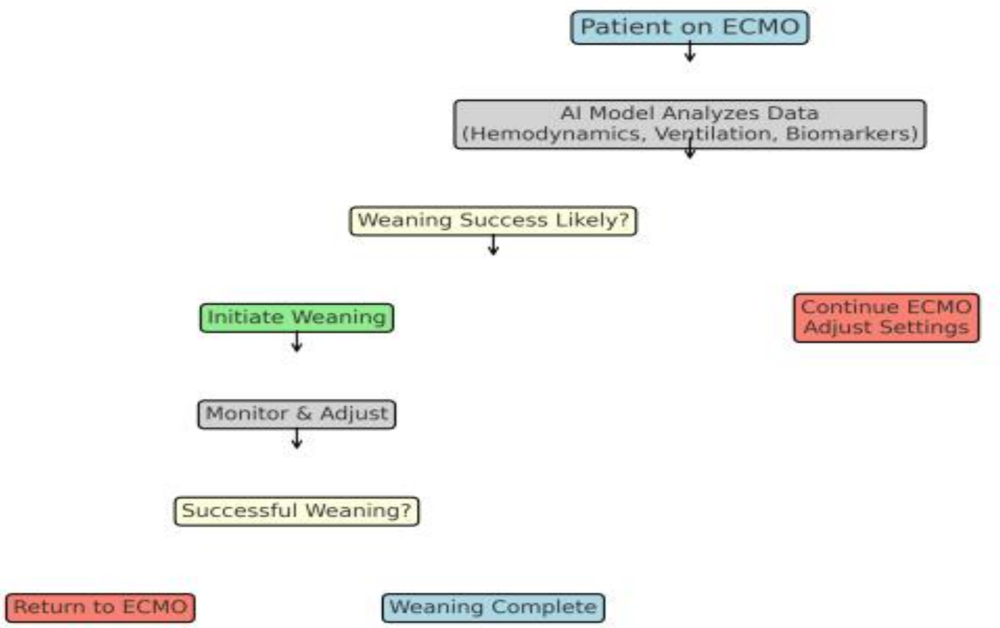

Figure 1. Flowchart of artificial intelligence-supported clinical data analysis during the weaning process from VA-ECMO (18).

Integration of AI Models into Real-Time Patient Monitoring Systems

The clinical effectiveness of AI-based models in VA-ECMO depends on their seamless integration with real-time patient monitoring systems. This integration allows continuous collection and rapid analysis of patient data, supporting timely and accurate clinical decisions. AI algorithms connected to electronic health records (EHR) can monitor vital parameters such as hemodynamics, laboratory values, and imaging findings to detect early signs of hemodynamic instability, organ dysfunction or weaning failure.

Automated extraction and analysis of key indicators including mean arterial pressure, serum lactate, pulse pressure, and echocardiographic data directly from EHR, ECMO machines, ventilators, and hemodynamic monitors reduce manual workload and improve data reliability. This not only accelerates clinical decision-making but also enhances patient safety. Such integrated systems decrease the burden on clinical teams and provide user-friendly, interpretable interfaces, which are especially valuable in intensive care units. Overall, this synergy between AI and clinical practice enhances multidisciplinary team management and supports personalized care (19).

Investigation of Weaning Success in VA-ECMO Patients Using Artificial Intelligence-Based Models

In recent years, there has been a growing interest in the use of artificial intelligence and machine learning algorithms to predict weaning success in VA-ECMO patients more accurately and at earlier stages. These methods possess the capacity to simultaneously analyze a wide range of clinical, laboratory, and imaging data, capturing subtle changes in the patient's condition and complex interactions between variables. In this context, a machine learning based model was developed and published in 2025 to enhance the prediction of clinical outcomes in patients receiving VA-ECMO support. In the study, data from a total of 225 patients collected from multiple centers were utilized. The primary objective of the developed model was to predict the 28-day mortality risk of patients with high accuracy. A total of 25 clinically accessible parameters were evaluated in model development, including key indicators of general health status and organ function such as body mass index (BMI), Acute Physiology and Chronic Health Evaluation II (APACHE II) score, Fibrosis-5 (FIB-5) index, serum phosphate level, and brain natriuretic peptide (BNP). To effectively capture complex data interactions and improve predictive performance, the Random Forest algorithm was employed. The model's performance was tested both in the development dataset and across different validation cohorts, with AUROC values ranging from 93% to 100%, indicating remarkably high predictive accuracy. This demonstrates that the model is reliable not only within its own dataset but also across different patient populations. Moreover, to enhance the interpretability of the model's decision-making process and increase its credibility in clinical practice, SHapley Additive exPlanations (SHAP) analysis was performed. This approach identified the most influential variables in the model's predictions and helped address concerns regarding the transparency of artificial intelligence applications. Therefore, the Extracorporeal

Membrane Oxygenation and Machine Learning (ECMO-ML) model not only predicts 28-day mortality but also has the potential to indirectly estimate the likelihood of successful weaning from VA-ECMO support. When integrated into clinical decision support systems, this model could enable earlier and more accurate interventions, ultimately contributing to improved patient outcomes (20).

The ELSO registry is a large-scale database that compiles comprehensive data on patients receiving ECMO therapy worldwide. Through contributions from various centers, the registry encompasses not only clinical and demographic information but also treatment outcomes. This extensive data pool plays a vital role in evaluating patient outcomes in VA-ECMO applications and in developing more accurate predictive models. In recent years, the use of the ELSO registry in multicenter studies has highlighted the growing importance of artificial intelligence and machine learning techniques in this field. These methods can process a large number of parameters from thousands of patients simultaneously and reveal complex connections and subtle changes within the data. Thus, model performance in predicting mortality and weaning success is significantly improved. These studies include numerous variables such as patient age, ECMO duration, laboratory test results, and clinical condition in machine learning algorithms. Powerful methods like Random Forest, Gradient Boosting, and Deep Learning enable capturing hidden patterns within the data, allowing for highly accurate prediction of patient prognosis. Thus, by not being limited to data from a single center, more generalizable and reliable results are obtained. ELSO-based models serve as guides for clinicians in decision-making processes and enable the early identification of patients at risk. Consequently, patients who are likely to fail the weaning process can be identified in advance, allowing timely planning of necessary interventions. This leads to a significant improvement in the quality of patient care. Therefore, artificial intelligence based models developed using the ELSO database provide effective and reliable tools for predicting both mortality and weaning success in VA-ECMO treatment, which can be applied in clinical practice. This facilitates more informed management of treatment processes and increases patients' chances of survival (21).

Prediction of VA-ECMO Weaning Process Using Support Vector Machines (SVM): A Theoretical Clinical Evaluation

Support Vector Machines (SVM), a long-standing algorithm in the field of machine learning for classification problems, is notable for its ability to analyze complex data structures and achieve high accuracy rates. It is especially known to perform well in settings with limited patient numbers and multidimensional, variable clinical parameters. In this context, the potential application of SVM algorithms to predict the success of the weaning process in patients undergoing VA-ECMO is increasingly being discussed. A large number of clinically significant variables such as lactate level, age, inotropic support score, ECMO duration, presence of spontaneous breathing, and comorbidities are suitable for the learning capability of the SVM algorithm. Models developed using such data can determine optimal classification boundaries to separate patients into successful or unsuccessful weaning groups. Additionally, thanks to kernel functions, non-linear data structures can also be integrated into the model, allowing for a more accurate representation of the complex relationships among clinical variables. Although direct large-scale clinical studies based on SVM in this field are still limited, the literature theoretically supports the applicability of SVM in ECMO patient groups. It has been reported that SVM performs well particularly in small sample datasets, is resistant to noisy data, and can operate stably in environments without data redundancy. With these features, the SVM algorithm stands out as a potential tool for personalized risk prediction and clinical decision support processes in patients receiving ECMO support (22, 23).

Table 1 presents a comparative evaluation of AI models used to predict weaning success in VA-ECMO patients. The ECMO-ML model, developed with a multicenter dataset using the Random Forest algorithm, demonstrated a high predictive performance with AUROC values ranging from 93% to 100%. In contrast, Support Vector Machines (SVM) have been theoretically applied to small sample datasets and are reported to show adequate performance. Both models offer significant potential for predicting mortality and weaning outcomes in VA-ECMO patients (20-23).

Table 1. Comparative performance of AI models in predicting weaning success in VA-ECMO patients

Model	**AUROC (%)**	**Sensitivity (%)**	**Specificity (%)**	**Dataset Description**	**Algorithm**
ECMO-ML	93–100	Not reported	Not reported	Multicenter, n=225 (clinical data)	Random Forest
SVM	~85–92*	Not reported	Not reported	Theoretical/small sample-based data	Support Vector Machines

*AUROC values for SVM are approximate and based on theoretical or limited sample data.

Future Perspective and Clinical Recommendations

The integration of AI technologies into the clinical management of patients undergoing VA-ECMO is expected to play an increasingly pivotal role in contemporary medical practice. This is particularly relevant in complex decision making processes such as the weaning phase, which demands the concurrent assessment of multiple dynamic parameters. The computational capabilities of AI facilitate more rapid and precise clinical judgments, thereby supporting improved patient outcomes. However, to ensure the safe and widespread clinical implementation of such systems, several key steps must be taken. Foremost among these is the necessity of validating developed models not only on limited sample sizes but also on large and diverse patient populations from multiple centers.

Most current studies are single centered, which limits the generalizability of their findings. Therefore, to enhance the reliability of algorithms and facilitate their clinical adoption, prospective multi-center validation studies are essential. Furthermore, the transparency of the algorithms' decision-making processes will improve healthcare professionals' trust in these systems. However, artificial intelligence systems intended for clinical use must be designed to interact with users, feature simple and intuitive interfaces, and allow for patient-specific interpretations. It is also crucial that model outputs are not limited to numerical values, as enriched interpretability contributes meaningfully to the clinical decision making process. On the other hand, the development and implementation of artificial intelligence technologies should not overlook ethical responsibilities.

A transparent and accountable approach must be adopted, particularly regarding patient data privacy, algorithm reliability, and the accountability of decisions. The objective should not be to delegate clinical decisions entirely to machines but to build support systems that assist healthcare professionals in the decision-making process. In the long term, it is anticipated that automated decision support systems will be developed, capable of working in coordination with VA-ECMO devices, collecting real-time data from monitors for analysis, and alerting the clinical team when necessary. Such systems will not only improve patient outcomes but also facilitate time management in intensive care units, thereby reducing the workload of healthcare professionals. Considering all these advancements, AI-based approaches have the potential to serve as powerful tools in making the weaning process after VA-ECMO safer, more predictable, and more personalized (24).

CONCLUSION

VA-ECMO is a powerful treatment option used to support life in cases of severe heart failure. However, this treatment is not merely a technical intervention; it also involves a dynamic and challenging clinical management process that requires the simultaneous evaluation of numerous variables in patient monitoring. Particularly, the weaning process from VA-ECMO, that is, the discontinuation of treatment, plays a decisive role in the patient's overall recovery. Making accurate decisions regarding the timing and success of this process is critical both for survival and for the efficient use of healthcare resources.

Current clinical parameters are often insufficient to accurately predict the success of extubation. The diversity of data and variability in patient conditions further complicate decision-making processes. In this context, recently developed artificial intelligence-based models have emerged as important alternatives to overcome this complexity and provide more accurate predictions. Specifically, some machine learning-based approaches, such as ECMO-ML, can process large volumes of patient data simultaneously to generate highly accurate mortality predictions, thereby enabling early detection of potential risks associated with the weaning process. Overall, AI-based clinical decision support technologies are considered promising tools for the management of VA-ECMO patients. These technologies not only facilitate a more successful weaning process but also contribute to improved patient outcomes and a safer care environment. In the coming years, the integration of these systems into intensive care practices is expected to accelerate decision-making, increase objectivity, and enhance the effectiveness of patient care.

Scientific Responsibility Statement

The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.

Ethics Approval and Consent

Ethical approval was not required since it was a review article.

Conflict of Interest

No conflict of interest was declared by the authors.

Author Contributions

Gülşah Celik Korhan: Article hypothesis, Literature review, Writing.

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