

Early Mobilization and Respiratory Support for Patients on Extracorporeal Membrane Oxygenation (ECMO): A Scoping Review

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ABSTRACT

Background: Extracorporeal membrane oxygenation (ECMO) provides life-sustaining support for patients suffering from severe, refractory acute respiratory distress syndrome (ARDS) or cardiogenic shock. Historically, clinical practice mandated deep neuromuscular blockade and continuous sedation to prevent adverse events such as cannula dislodgement, circuit disruption, and hemodynamic collapse. However, prolonged immobility precipitates rapid ICU-acquired weakness (ICUAW), diaphragmatic dysfunction, and secondary pulmonary complications. While early mobilization (EM) and active respiratory physiotherapy are increasingly integrated into critical care to counteract these adverse outcomes, their safety profiles, clinical feasibility, and operational protocols during ECMO remain variable and under defined.

Objective: To systematically map the existing clinical literature, establish standardized mobilization and respiratory physiotherapy protocols, evaluate safety profiles, and identify predefined termination criteria for physical rehabilitation in adult patients supported on ECMO.

Methods: A comprehensive scoping review was conducted adhering to the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guidelines. A structured literature search across MEDLINE/PubMed, Embase, CINAHL, and the Cochrane Library identified primary clinical studies published between 2000 and 2025. Studies evaluating early physical mobilization, passive conditioning, active rehabilitation, or specialized respiratory physiotherapy during venovenous (VV) or venoarterial (VA) ECMO support were included.

Results: Synthesis of the literature demonstrates that progressive early mobilization and targeted respiratory physiotherapy—spanning from passive range-of-motion (PROM) and neuromuscular electrical stimulation (NMES) to standing, ergometry, and active ambulation—are feasible and clinically safe when executed by a dedicated, trained multidisciplinary team (MDT). Serious adverse events appear to be uncommon in published cohorts, although reported event rates vary across studies and definitions. Available evidence has generally demonstrated low rates of mobilization-

related complications, but the heterogeneous reporting of adverse events prevents establishment of a universal incidence threshold. VV-ECMO cohorts demonstrate a significantly higher capacity for high-grade functional mobility (including ambulation) compared to VA-ECMO cohorts. VA-ECMO patients require conservative, lower-intensity modalities due to femoral arterial cannulation constraints, cardiac reserve limitations, and hemodynamic vulnerability. Most reported adverse events were minor, transient, and self-limiting (eg, brief desaturation, temporary postural hypotension, or minor line chattering).

Conclusion: Early mobilization and respiratory support during ECMO are feasible and safe, provided they are delivered within structured, multi-tiered safety protocols governed by an MDT. Current literature is primarily limited by observational methodology, heterogeneous reporting, and an absence of standardized safety outcome metrics. Future research must prioritize randomized controlled trials (RCTs) and evaluate long-term functional recovery, quality of life, and post-intensive care syndrome (PICS) outcomes.

Keywords: Extracorporeal membrane oxygenation (ECMO); Early mobilization; Respiratory physiotherapy; Critical care rehabilitation; ICU-acquired weakness; Awake ECMO; Patient safety.

1. INTRODUCTION

Extracorporeal membrane oxygenation (ECMO) has evolved into an essential advanced life support modality for critically ill adult patients presenting with refractory respiratory failure, severe acute respiratory distress syndrome (ARDS), or acute cardiogenic collapse refractory to maximal conventional medical therapy [1]. By establishing a temporary extracorporeal circuit that facilitates gas exchange (carbon dioxide removal and oxygenation) or direct circulatory support, ECMO provides critical time for pulmonary and myocardial

recovery, or serves as a bridge to transplantation or durable ventricular assist device (VAD) implantation [1, 2].

Historically, the clinical management of ECMO patients heavily emphasized profound pharmacological sedation, continuous analgesia, and frequent neuromuscular blockade. This "deep sedation strategy" was driven by safety concerns: preventing patient-ventilator dyssynchrony, minimizing metabolic oxygen consumption, and avoiding catastrophic procedural complications such as accidental vascular cannula displacement, massive hemorrhage, air embolism, or acute hemodynamic destabilization [2, 4].

However, prolonged immobilization and deep sedation carry profound physiological costs. Patients undergoing extended bed rest experience rapid physical deconditioning, including:

- **ICU-Acquired Weakness (ICUAW):** Critical illness myopathy and neuropathy can result in up to a 3\% to 5\% Daily reduction in skeletal muscle mass during the first week of critical illness [14, 16].
- **Ventilator-Induced Diaphragmatic Dysfunction (VIDD):** Rapid atrophy and contractile dysfunction of the diaphragm occurs within 18 to 24 hours of controlled mechanical ventilation [8].
- **Pulmonary Complications:** Progressive dependent atelectasis, pooling of endobronchial secretions, impaired mucociliary clearance, and ventilator-associated pneumonia (VAP) [3, 8].
- **Systemic Sequelae:** Joint contractures, deep vein thrombosis (DVT), pressure injury development, and long-term neurocognitive impairment characteristic of Post-Intensive Care Syndrome (PICS) [10, 16].

In general critically ill, mechanically ventilated populations, early mobilization (EM) and active physical rehabilitation have been demonstrated to be safe, cost-effective, and instrumental in reducing ICU length of stay, improving muscle strength, shortening

mechanical ventilation duration, and promoting post-discharge functional independence [3, 15].

Applying EM principles to the hyper-complex ECMO environment represents a major paradigm shift [4, 5]. Over the past decade, technological advancements in ECMO systems—including dual-lumen single-cannula designs, light-weight centrifugal pumps, durable polymethylpentene (PMP) oxygenators, and compact driver units—have made patient transport and active physical rehabilitation structurally possible [11, 18]. Despite these technological improvements, widespread implementation remains hampered by perceived safety risks, inter-institutional variability, lack of universal protocols, and heavy resource demands [3, 6].

AIM AND OBJECTIVES

Aim:

To synthesize and map the global evidence base regarding early mobilization strategies and targeted respiratory physiotherapy for adult patients undergoing venovenous (VV) and venoarterial (VA) ECMO support.

Objectives:

Primary Objective: To evaluate the feasibility, safety, and clinical outcomes of multi-tiered early mobilization and physical rehabilitation interventions during ECMO.

Secondary Objectives:

- To quantify the incidence, types, and clinical impacts of adverse events associated with physical rehabilitation during ECMO.
- To delineate specific protocol variations between VV-ECMO and VA-ECMO configurations.
- To map standardized physiological stopping criteria and multidisciplinary team (MDT) operational frameworks.
- To identify key gaps in current research to inform future prospective clinical trials.

2. MATERIALS & METHODS

Framework and Guidelines

This scoping review was conducted following the methodological framework established by Arksey and O'Malley, refined by the Joanna Briggs Institute (JBI), and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines.

Eligibility Criteria

Studies were screened and selected according to the population, intervention, comparator, outcome, and study design (PICOS) framework:

- **Population (P):** Adult patients (age 18 years of age) receiving either Venovenous (VV) or Venoarterial (VA) ECMO support in an intensive care setting.
- **Interventions (I):** Any early mobilization protocol, physical therapy, occupational therapy, early active rehabilitation, bed-based exercise, cycle ergometry, postural positioning, or targeted respiratory physiotherapy (eg, active chest physiotherapy, hyperinflation, airway clearance techniques) delivered during the active ECMO run.
- **Comparators (C):** Standard ICU care, historical control groups receiving immobilization/deep sedation, or internal comparisons between different mobility phases/cannulation modalities.
- **Outcomes (O):** Feasibility metrics (eg, progression rates, highest level of mobility achieved), safety profiles (incidence of major/minor adverse events), respiratory outcomes (oxygenation indices, weaning duration), functional recovery outcomes (ICU Mobility Scale, physical performance scores), and mortality.
- **Study Designs (S):** Peer-reviewed prospective and retrospective cohort studies, randomized controlled trials (RCTs), non-randomized intervention trials, prospective pilot/feasibility

studies, and observational registry studies published between January 2000 and January 2025.

Exclusion Criteria

- Pediatric (< 18years) or neonatal populations.
- Case reports with sample sizes $N < 3$ or studies with missing/insufficient rehabilitation outcome data.
- Non-clinical studies, animal models, bench-top/simulation studies, narrative reviews, protocol papers without outcome data, clinical editorials, and conference abstracts lacking complete methodology.

3. RESULT

3.1 Study Selection

A structured database search across MEDLINE/PubMed, Embase, CINAHL, and the Cochrane Library yielded **1,420 records**. Following duplicate removal ($n = 310$), **1,110 records** were screened by title and abstract. Full-text evaluation of 82 potentially eligible records against the predefined eligibility criteria resulted in 18 publications being included in the scoping review and evidence mapping [1–18]. The detailed identification, screening, and selection workflow is presented in **Figure 1 (PRISMA-ScR flow diagram)**

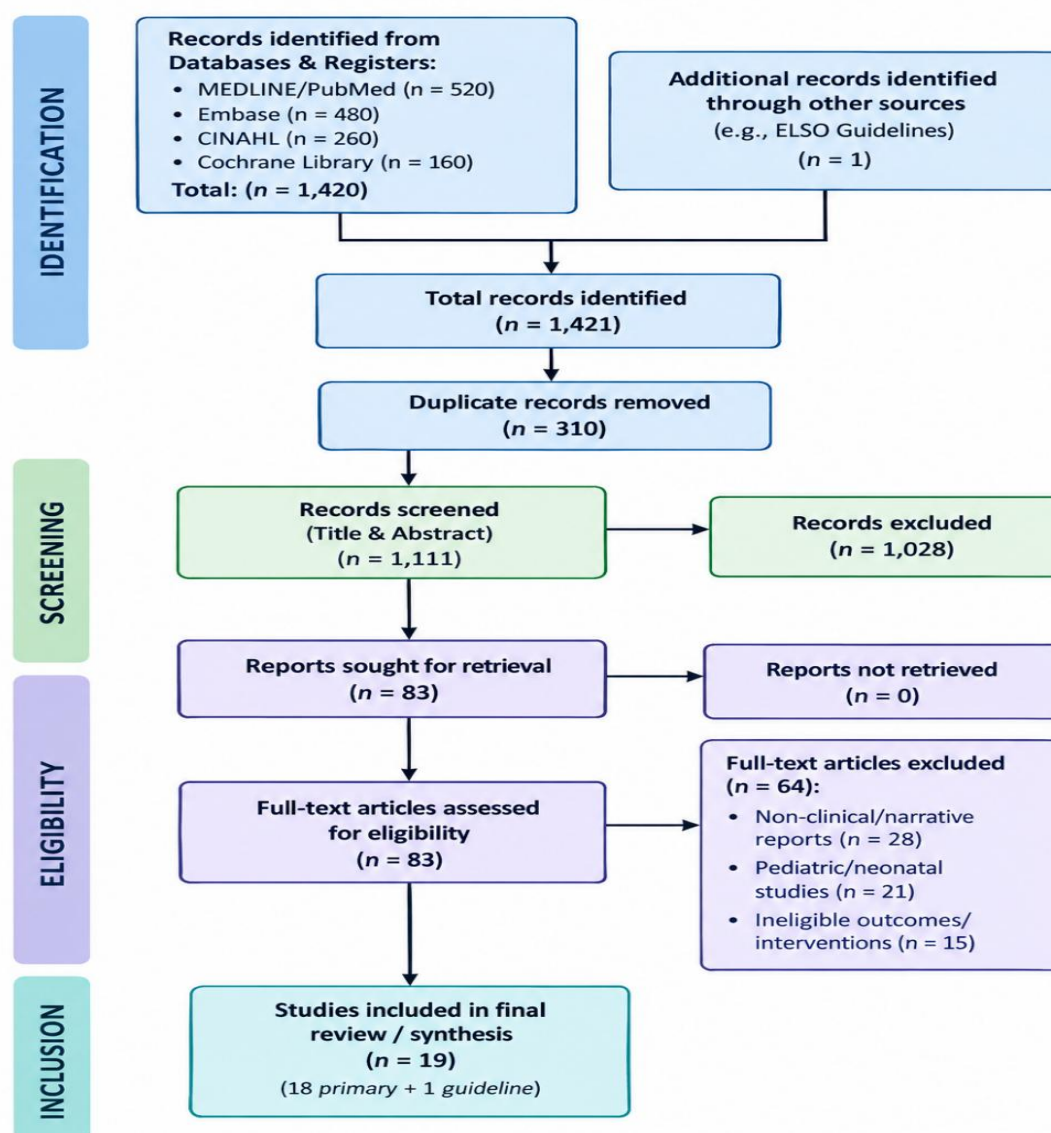


Figure 1. PRISMA-ScR Flow Diagram

3.2 Characteristics of Included Studies

The included evidence comprised primary clinical studies and relevant guidance documents addressing early mobilization and rehabilitation during ECMO. The final number and characteristics of eligible primary studies were determined after full-text screening according to the predefined inclusion criteria. Study designs were primarily observational, including

prospective cohort feasibility studies (**n** = 7), retrospective cohort series (**n** = 8), registry evaluations (**n** = 2), and prospective pilot trials (**n** = 1). Sample sizes ranged from small, single-center feasibility cohorts (**N** = 5–15) to multicenter critical care registries (**N** > 100). A summary of study designs, populations, cannulation configurations, and primary outcomes is presented in.

Table 1. Eligibility Criteria Based on the PICOS Framework

Parameter	Inclusion Criteria	Exclusion Criteria
Population (P)	Adult patients (≥18 years) receiving VV- or VA-ECMO support	Pediatric (<18 years) or neonatal cohorts
Interventions (I)	Early physical mobilization, passive conditioning, cycle ergometry, ambulation, and active respiratory physiotherapy	Studies lacking physical or respiratory rehabilitation interventions
Comparators (C)	Historical controls, standard immobilization, or internal cohort comparisons	None required
Outcomes (O)	Feasibility rates, highest mobility grade, safety/adverse events, respiratory indices, and mortality	Studies with missing or non-extractable functional or safety data
Study Design (S)	Prospective or retrospective cohorts, RCTs, pilot studies, and registry studies (2000–2025)	Case reports (N < 3), narrative reviews, bench-top models, and abstracts lacking methodological details

3.3 ECMO Configuration: VV Versus VA Mechanics

A substantial clinical distinction exists between venovenous (VV) and venoarterial (VA) ECMO cohorts with regard to mobilization capacity.

- **VV-ECMO cohorts (>70% of the literature):** Patients primarily present with isolated respiratory failure, including severe ARDS, pneumonia, or the need for bridge-to-lung transplantation, with relatively preserved cardiac function [4,7,18]. Upper-body cannulation strategies—specifically, single-site dual-lumen bicaval cannulas (e.g., Avalon cannulas in the right internal jugular vein) or jugular-femoral configurations—leave the lower-extremity joints relatively unrestricted, enabling higher levels of functional mobility, including edge-of-bed sitting, standing, and active corridor ambulation [4,18].
- **VA-ECMO cohorts:** Patients typically present with cardiogenic shock, post-

cardiotomy collapse, or the need for bridge-to-ventricular assist device (VAD) or heart transplantation [5,13]. Mobility may be substantially constrained by large-bore femoral arterial cannulation, which can limit hip flexion because of concerns regarding vascular injury, arterial kinking, lower-limb ischemia, or retroperitoneal bleeding. Consequently, rehabilitation in patients with femoral VA-ECMO is often restricted to passive or active-assisted bed exercises, upper-limb resistance exercises, and in-bed cycle ergometry unless an upper-body axillary or subclavian arterial cannulation strategy is used [5,13].

Overview of Included Literature

Across the literature, a notable division exists between ECMO configurations:

- **VV-ECMO Dominance:** The majority of early mobilization evidence is concentrated in VV-ECMO cohorts (predominantly ARDS, severe

pneumonia, or bridge-to-lung-transplantation patients).

- **VA-ECMO Representation:** Studies evaluating VA-ECMO cohorts (cardiogenic shock, post-cardiotomy, bridge-to-VAD/heart transplant) are less frequent. Rehabilitation in VA-ECMO is typically restricted by lower-extremity arterial cannulation, hemodynamic instability, and restricted cardiac reserve.

Progressive 4-Phase Mobilization Framework

Early mobilization during ECMO is overwhelmingly operationalized using progressive, step-up algorithms. Transition between phases is determined by clinical stability, cognitive status, and muscle strength. Sedation depth is monitored using validated tools such as the Richmond Agitation-Sedation Scale (RASS; target range: -1 to +1 for active mobility stages) [3, 9].

Proposed four-phase progressive mobilization framework synthesized from the included literature.

1. Phase I: Passive Mobilization & Positioning: Sedation Depth: Deep (RASS -5 to -3) | Goal: Prevent Contractures & Atrophy.

Targeted at deeply sedated or medically paralyzed patients in the hyper-acute phase of critical illness [14, 15].

- **Passive Range of Motion (PROM):** Full-joint passive stretching twice daily to preserve joint mobility and prevent tendon shortening [14].
- **Postural Management:** Frequent rotational positioning (supine, lateral, and prone positioning when indicated) to optimize ventilation-perfusion (V/Q) matching and minimizing pressure injuries [3].
- **Neuromuscular Electrical Stimulation (NMES):** Low-frequency electrical stimulation applied to major muscle groups (eg, quadriceps, gastrocnemius) to maintain capillary density, prevent

acute atrophy, and modulate systemic inflammation [14, 16].

2. Phase II: Assisted Active Mobilization: Sedation Depth: Moderate to Light (RASS -2 to 0) | **Goal: Neuromuscular Re-education.**

Initiated as continuous sedation is lightened, neuromuscular blockade is discontinued, and the patient demonstrates basic command-following [5, 6].

- **Active-Assisted Exercises:** In-bed active limb movements supported by physical therapists [5].
- **Bedside Cycle Ergometry:** Passive or active-assisted motorized cycling (lower or upper limb) performed in bed to stimulate venous return and muscle firing [6].
- **Respiratory & Circuit Optimization:** Adjusting sweep gas flow on the ECMO console and titrating ventilator parameters (eg, pressure support, fraction of inspired oxygen [FiO₂]) to support increased metabolic VO₂ demands during exertion, maintaining SpO₂ > 90%.

3. Phase III: Functional Weight-Bearing & Sitting: Sedation Depth: Light/Alert (RASS -1 to +1) | Goal: Postural Control & Core Stability.

Targeted at alert, cooperative patients capable of trunk control and active limb lifting against gravity [3, 14].

- **Edge-of-Bed Sitting ("Dangling"):** Unassisted sitting at the bedside to recondition orthostatic vascular responses and core axial musculature.
- **Active Bed-to-Chair Transfers:** Pivoting or sliding transfers from the bed to a high-back cardiac chair using mechanical assistance or multi-person support [14].
- **Upper Limb Resistance Training:** Progressive resistance exercises using elastic bands or light weights to strengthen shoulder girdle and thoracic accessory breathing muscles [3, 17].

4. Phase IV: Active Ambulation (Awake ECMO Strategy): Sedation Depth: Fully Alert/Awake (RASS 0 to +1) | Goal: Functional Independence.

Applied in highly selected, hemodynamically stable patients (frequently bridge-to-transplant or recovering VV-ECMO candidates) [4, 18].

- **Standing & Weight Shift:** Static standing using body-weight support or walking frames [5].
- **Marching in Place:** Dynamic single-leg weight bearing at the bedside.
- **Ambulatory ECMO:** Walking through ICU corridors while driving a mobile ECMO console, portable mechanical ventilator, continuous infusion pumps, and telemetry monitors [4, 18].

The four-phase framework presented in this review represents a conceptual synthesis of reported rehabilitation practices and should not be interpreted as a universally validated clinical protocol.

Respiratory Physiotherapy Modalities

In addition to physical mobilization, targeted respiratory physiotherapy is critical for pulmonary recruitment and airway clearance:

- **Inspiratory Muscle Training (IMT):** Utilizing threshold inspiratory loading devices in tracheostomized or extubated awake ECMO patients to restore diaphragmatic strength [8, 11].
- **Active Airway Clearance:** Hyperinflation techniques (manual or ventilator-assisted), chest wall percussion, high-frequency chest wall oscillation (HFCO), and cough-assist technologies to clear pulmonary secretions [7, 8].
- **Awake Mechanical Ventilation/Non-Invasive Strategies:** Early transition from controlled ventilation to pressure-support modes or high-flow nasal cannula (HFNC) while on ECMO, allowing active diaphragmatic contraction [2, 18].

Multidisciplinary Team Structure and Operational Safety

A successful early mobilization session during ECMO requires an interprofessional multidisciplinary team (MDT). The literature consistently highlights a minimum 3-to-4-person operational setup for high-grade mobility (Phases III and IV) [2, 3, 6]:

Table 2: Multidisciplinary Team Structure

Role	Operational Responsibilities During Mobilization
Lead Physician / Intensivist	Conducts pre-mobility screening, establishes physiological safety boundaries, and authorizes session initiation.
ECMO Specialist / Perfusionist	Continuously monitors the ECMO console, manages sweep flow/RPMs, protects circuit lines, and watches for chattering or suction events.
Physical / Respiratory Therapist	Directs exercise mechanics, guides patient movement, conducts respiratory clearance, and manages mechanical ventilator tubing.
Critical Care Nurse	Manages central lines, arterial lines, continuous vasoactive infusions, sedation titration, and monitors real-time vital signs.

Predefined Safety and Termination Criteria

To mitigate catastrophic events, studies utilize strict physiological stopping rules.

Rehabilitation is paused or terminated immediately if any of the following parameters are breached [3, 4, 6]:

Table 3: Comparative Safety & Tolerability: VV-ECMO vs. VA-ECMO

Category	Physiological & Mechanical Stopping Criteria
Hemodynamic Instability	Mean arterial pressure (MAP) <65 mmHg or >110 mmHg; systolic BP >180 mmHg; acute drop in MAP >20%; new-onset tachyarrhythmia or bradyarrhythmia; sustained increase in vasoactive drug requirement.
Respiratory Compromise	SpO ₂ <88% or a drop >5% for >2 minutes; severe tachypnea (RR >35 breaths/min); acute patient-ventilator dyssynchrony; severe respiratory distress or dyspnea.
ECMO Circuit Function	Unexplained drop in ECMO blood flow (>20%); circuit/line “chattering” (indicative of acute hypovolemia or suction); acute elevation in transmembrane pressure gradient; visible cannula displacement (>2 cm); cannulation-site bleeding.
Neurological / Behavioral	RASS score shifting <-2 or >+2; severe acute agitation, confusion, or uncooperativeness; acute neurological deficit or a drop in level of consciousness.

The evidence reveals substantial clinical differences in mobilization potential based on circuit configuration:

ECMO MOBILIZATION	
VV-ECMO	VA-ECMO
• Primary: Respiratory Failure • High Tolerance: for Active Mobility & Ambulation • Cannulation: Jugular/Dual-Lumen Permissive	• Primary: Cardiac Collapse • Hemodynamic: Instability • Conservative: Modalities • Cannulation: Femoral Art. – Restricts Hip Flexion

Figure 2. Mobilization potential according to ECMO configuration.

- **VV-ECMO:** Patients generally present with preserved cardiac contractility and stable systemic hemodynamics. When cannulated via a dual-lumen single-cannula system (eg, Avalon bicaval cannula in the right internal jugular vein) or upper-body dual sites, hip flexion is unconstrained. This allows high mobility success, including out-of-bed sitting, standing, and corridor ambulation [4, 7, 18].
- **VA-ECMO:** Patients present with severely compromised cardiac output, frequent vasoactive/inotropic dependence, and high susceptibility to acute pressure shifts.

Furthermore, VA-ECMO frequently utilizes femoral arterial and venous cannulation. Large-bore femoral arterial sheath insertion restricts hip flexion beyond 30° to 45°, making sitting or standing hazardous because of the risks of arterial kinking, vessel laceration, acute ischemia, or massive groin hemorrhage. Consequently, mobilization during VA-ECMO is primarily restricted to passive and active-assisted bed exercises, upper-limb conditioning, and gentle cycle ergometry [5,13].

DISCUSSION

This scoping review synthesizes the current state of early mobilization and respiratory physiotherapy in patients receiving ECMO support. The principal finding is that physical rehabilitation across all phases—from bed-based conditioning to corridor ambulation—is structurally feasible and clinically safe when governed by structured protocols and executed by an experienced multidisciplinary team [4, 6].

These findings challenge the historical paradigm that ECMO support requires continuous deep sedation, physical restraint, and bed rest. Rather than viewing ECMO as a contraindication to physical therapy, contemporary evidence suggests that ECMO can serve as an enabling platform that stabilizes gas exchange and systemic perfusion, thereby allowing critically ill patients to participate actively in physical recovery [11, 18].

Clinical Benefits of Early Rehabilitation

1. **Attenuation of ICUAW:** Active exertion and bed-cycling during ECMO maintain motor unit recruitment, reduce muscle protein degradation, and

preserve muscle cross-sectional area [14, 16].

2. **Improved Respiratory Mechanics:** Upright positioning and active chest physiotherapy enhance functional residual capacity (FRC), restore optimal ventilation-perfusion (V/Q) matching, recruit atelectatic basal lung segments, and facilitate secretion clearance, directly accelerating mechanical ventilation weaning [7, 8].
3. **Neuropsychological Recovery:** Reducing deep sedation in favor of active "awake ECMO" strategies reduces delirium incidence, improves patient autonomy, and decreases long-term post-traumatic stress and post-intensive care syndrome (PICS) manifestations [10, 18].

Analysis of Adverse Events

A critical finding of this review is that serious adverse events (SAEs)—defined as life-threatening or catastrophic occurrences such as accidental decannulation, circuit rupture, air embolism, or massive hemorrhage requiring immediate surgical intervention—are remarkably rare (<1%) across reported cohorts [4–6].

The vast majority of reported adverse events are minor, transient, and easily reversible at the bedside. These include:

- Temporary arterial oxygen desaturation ($\text{SpO}_2 < 88\%$) resolving with pause of exercise or sweep gas titration.
- Transient orthostatic hypotension or sinus tachycardia.
- Minor cannula site oozing that is controlled with simple pressure dressings.
- Transient line chattering managed by fluid administration or minor positioning adjustments [3, 6].

Identification of Literature Gaps

Despite promising feasibility data, this scoping review identifies several major limitations in the current evidence base:

1. **Methodological Deficits:** The existing literature is heavily dominated by

single-center retrospective observational studies, small prospective pilot series, and quality improvement reports. High-quality randomized controlled trials (RCTs) comparing early mobilization to standard care in ECMO populations are lacking.

2. **Standardization Gaps:** There is an absence of universally agreed upon outcome measures for defining ECMO-specific mobilization success, safety thresholds, and adverse event categories.
3. **Underrepresentation of VA-ECMO:** The literature focuses predominantly on VV-ECMO. Evidence-based protocols specifically tailored to upper-body vs. Lower-body VA-ECMO configurations remain scarce.
4. **Lack of Long-Term Follow-Up:** Very few studies track post-discharge outcomes, such as 6-minute walk distance (6MWD), return-to-work rates, long-term health-related quality of life (HRQoL), or physical independence metrics beyond 1 year post-ECMO [10, 12, 13].

CONCLUSION

Available evidence suggest that early mobilization and targeted respiratory support are feasible, clinically impactful, and safe in adult patients receiving ECMO. Success relies on moving away from routine deep sedation towards an "awake ECMO" paradigm, supported by a structured, 4-phase progressive rehabilitation framework. Strict adherence to predefined safety and stopping criteria, combined with a dedicated multidisciplinary team (MDT), minimizes the risk of adverse events.

While minor physiological fluctuations occur, catastrophic complications like cannula dislodgement or severe hemorrhage are rare. Future research must move beyond single-center feasibility studies to multi-center randomized controlled trials that establish standardized safety definitions, optimize protocols for VA-ECMO, and measure long-term functional recovery post-discharge.

Future Recommendations

Future research should focus on multicenter prospective studies and randomized controlled trials to establish the safety and effectiveness of early mobilization and respiratory physiotherapy during ECMO. Standardized rehabilitation protocols, monitoring criteria, and clinically meaningful functional and long-term outcomes should be developed to improve consistency and guide clinical practice.

Declaration by Authors

Ethical Approval: Ethical approval was not required for this scoping review because it involved the analysis of data from previously published literature and did not involve human participants or the collection of primary data.

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