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REVIEW ARTICLE

From Concept to Implementation: Establishing Extracorporeal Membrane Oxygenation Services in Resource-limited Settings

Ahsina Jahan Lopa [1], M.B.B.S., F.I.C.M., Payel Bose [2], M.B.B.S., M.D., M.R.C.P., F.N.B., E.D.I.C., I.D.C.C.M., I.F.C.C.M., Ahsan Ahmed [3], M.B.B.S., D.N.B., M.R.C.P., E.D.I.C., I.F.C.C.M., Rajesh Chandra Mishra [4], M.D., F.N.B., E.D.I.C.M., F.C.C.P., F.C.C.M., F.I.C.C.M., F.I.C.P.

[1]Department of ICU and Emergency, Brahmanbaria Medical College Hospital, Bangladesh.
[2]Department of Critical Care Medicine, Manipal Hospital Siliguri and Rangapani, West Bengal, India.
[3]Critical Care Medicine Department, KPC Medical College and Hospital, Kolkata, India.
[4]Shaibya Comprehensive Care Clinic, Ahmedabad, India.

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Corresponding author:
Dr. Payel Bose, M.B.B.S., M.D., M.R.C.P., F.N.B., E.D.I.C., I.D.C.C.M., I.F.C.C.M.
Senior Consultant and Clinical Lead
Department of Critical Care Medicine
Manipal Hospital Siliguri and Rangapani, West Bengal, India
Email: payelnbmc@gmail.com
Phone: +91- 9874110804

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ABSTRACT

Extracorporeal membrane oxygenation (ECMO) can provide temporary respiratory or circulatory support for selected patients with otherwise refractory organ failure. Access, however, remains concentrated in experienced tertiary centres. Distance, limited critical-care infrastructure, workforce shortages and high treatment costs can delay assessment and transfer for patients living outside major urban areas.

This narrative review examines practical and ethical approaches to developing ECMO access in resource-limited and geographically remote settings, with emphasis on regional coordination rather than indiscriminate expansion of stand-alone services. The manuscript synthesises selected clinical trials, professional guidance, registry-based literature and implementation-focused publications relevant to ECMO selection, service organisation, transport, training, safety and affordability. It is a narrative review and should not be interpreted as a systematic review.

A hub-and-spoke pathway can support early recognition and consultation at peripheral hospitals while concentrating complex cannulation, management and rescue capability in experienced centres. Mobile retrieval and tele-ECMO may extend access, but require trained teams, reliable transport systems, clear governance and predefined escalation pathways. Cost estimates and claims of large savings are highly context-dependent and should not be generalised without local economic evaluation. Patient selection, informed consent, transparent resource allocation, adverse-event review and prospective outcome reporting are essential.

ECMO access beyond major cities is most defensible when built around regional networks, timely referral, competent multidisciplinary teams and auditable outcomes. The priority should be to strengthen safe pathways to established expertise; a local ECMO service should be introduced only when minimum clinical, logistical and financial safeguards can be sustained.

Key words: *Critical care transport, extracorporeal membrane oxygenation; regionalization; resource-limited settings; telemedicine.*

INTRODUCTION

Extracorporeal membrane oxygenation (ECMO) provides temporary extracorporeal gas exchange and/or circulatory support when conventional treatment is insufficient and the underlying condition is potentially reversible, or when support is being used as a bridge to a defined next step. In adults with severe acute respiratory distress syndrome (ARDS), randomised trials and subsequent evidence syntheses support consideration of venovenous ECMO in carefully selected patients, while also demonstrating that benefit depends on patient selection, treatment context and the quality of conventional care.[1-3]

ECMO is not a single device-based intervention. It is a complex service requiring trained clinicians and nurses, perfusion or specialist technical expertise, reliable laboratory and transfusion support, imaging, infection prevention, equipment maintenance, rehabilitation and the capacity to manage bleeding, thrombosis, neurological injury and circuit failure. Professional guidance therefore emphasises structured programmes, multidisciplinary competency and ongoing quality assurance.[4,5]

These requirements create an access problem for patients who live far from established centres. In many low- and middle-income settings, tertiary critical-care resources are concentrated in large cities, while peripheral hospitals may lack specialist staff, transport infrastructure or the financial protection needed for prolonged organ support. The practical question is not whether every hospital should own an ECMO system, but how potentially eligible patients can be identified early and connected to an experienced service without unsafe delays. Planning literature highlights the importance of coordinated referral, transport and trained teams, particularly during periods of high demand (Table 1 and Table 2).[6,7]

This review uses the term "hinterland ECMO" to describe a regional approach to ECMO access for patients in rural, semi-urban and otherwise underserved areas. The concept is a service-design framework, not a separate clinical indication. Its central principle is to expand access to expertise and timely referral while avoiding the risks of launching services that cannot reliably meet minimum safety standards.

Review approach and scope

This is a narrative review informed by selected randomised trials, professional guidelines, registry reports and publications addressing ECMO service organisation, transport and implementation. The manuscript did not use a reproducible database search, search dates, screening process or formal eligibility criteria; therefore, this revision does not claim to be a systematic review or to provide an exhaustive evidence synthesis. The literature cited is used to support clinical principles and service-design considerations. Local implementation decisions should be based on current guidance, regional epidemiology, available expertise and a documented assessment of resources.

The evidence base and limits of transferability

The CESAR trial evaluated referral to an ECMO centre for severe respiratory failure, whereas EOLIA examined early venovenous ECMO in very severe ARDS. Their designs and care pathways differ, and neither establishes that an ECMO machine placed in a low-volume peripheral hospital will reproduce the outcomes of a mature referral program.[8] A patient-level meta-analysis of the two trials found lower 90-day mortality in the ECMO groups, but the result should be interpreted alongside crossover, selection and centre-experience considerations.[3]

International guidance recommends considering ECMO for selected patients with severe, potentially reversible respiratory failure after evidence-based conventional management, and emphasises referral to experienced centres.[4,5] Such guidance is not a substitute for local capability assessment. Published outcomes from high-volume programmes may not be directly transferable to hospitals with limited staffing, inconsistent supplies or no reliable retrieval service. Claims about survival advantage, cost savings or the superiority of one delivery model should therefore be stated cautiously unless supported by directly applicable data.[4,5]

Barriers to equitable access

Infrastructure and supply reliability

An ECMO programme depends on more than a console and circuit. It needs continuous power with backup, oxygen and air supply, appropriate ICU isolation and infection-control arrangements, point-of-care and central laboratory testing, blood components, bedside echocardiography, imaging, anticoagulation monitoring, and access to urgent specialist intervention. Supply-chain interruptions involving oxygenators, cannulae, tubing or laboratory reagents can threaten continuity of care. A written inventory, maintenance plan and backup pathway should be in place before the first patient is accepted.

Workforce and competency

Safe delivery requires a multidisciplinary team whose members can recognise deterioration, interpret circuit parameters, respond to emergencies and communicate clearly across shifts. Staffing models must account for continuous observation, leave, illness and staff turnover. Short courses alone are insufficient: competency should be demonstrated through supervised clinical exposure, simulation, structured assessment and periodic reassessment. A hub can support training and consultation, but remote advice cannot replace hands-on expertise when urgent cannulation or circuit intervention is needed.

Financial barriers

Costs include capital equipment, disposable circuits, oxygenators, cannulae, laboratory testing, blood products, staffing, transport, maintenance and prolonged ICU care.

Out-of-pocket payment may expose families to catastrophic expenditure and create pressure to continue or discontinue treatment for non-clinical reasons. The manuscript's earlier estimates of per-run cost and percentage savings should not be presented as universal figures: they require a clearly defined setting, costing method, year, comparator and inclusion of complications and unsuccessful runs. Each programme should undertake local costing and establish financial counselling and funding pathways before treatment begins.

Referral and transport

Delayed recognition and referral can result in prolonged injurious ventilation, shock or additional organ failure before assessment by an ECMO team. Peripheral hospitals should have simple referral criteria, a single point of contact and a process for early discussion while conventional treatment continues. Transport planning must include oxygen and power reserves, compatible monitoring and ventilation, adequate staff, contingency plans and communication with the receiving centre. Cannulation before transfer may be appropriate for selected patients when an experienced retrieval team can provide it; it should not be assumed to be safer or more cost-effective in every geography.

Models for delivering ECMO beyond major centres

Regional hub-and-spoke network

A hub-and-spoke model is a pragmatic starting point. Peripheral hospitals identify potential candidates, initiate evidence-based stabilisation and consult the hub early. The hub provides candidacy assessment, advice on optimisation, acceptance decisions, retrieval coordination and definitive ECMO care. This approach concentrates rare expertise and expensive infrastructure while building local capacity to recognise and refer eligible patients. Service planning guidance supports coordinated pathways and safe movement of patients and staff between non-specialist and specialist sites.[6]

A regional agreement should define referral thresholds, who can accept a patient, expected response times, transport responsibilities, documentation, escalation routes and feedback to referring teams. Referral decisions should be based on clinical suitability and realistic goals of treatment, not solely on geography or ability to pay.

Mobile ECMO retrieval

A mobile team may travel to a referring hospital, assess the patient, initiate ECMO when indicated and transport the patient to the specialist centre. This can avoid transporting a profoundly unstable patient before support is established, but it requires trained staff, a transport-compatible circuit, equipment redundancy and a rehearsed retrieval process. Weather, road conditions, distance, local emergency support and the availability of a return team must be considered. Retrieval should be commissioned as a defined service with explicit activation criteria and audit, not improvised for individual cases.[9]

Local or standalone ECMO units

A local ECMO unit may reduce transfer distance, but only if it can sustain the full clinical and organisational requirements of the therapy. Minimum requirements include experienced medical and nursing leadership, round-the-clock staffing, circuit expertise, transfusion and laboratory support, imaging, emergency surgical or vascular support appropriate to the case mix, rehabilitation, infection prevention and outcome reporting. If these requirements cannot be maintained, formal partnership with a hub is safer than nominally independent operation.[10]

Tele-ECMO and remote consultation

Secure video consultation and shared physiological data can support early triage, ventilator optimisation, review of laboratory results and discussion of complications. A useful tele-ECMO pathway requires named clinicians on both ends, agreed communication channels, documentation, reliable connectivity and clear limits to remote decision-making. Telemedicine should be considered an adjunct to a competent local team, not a replacement for bedside assessment, immediate troubleshooting or specialist retrieval when these are required.

Patient selection and clinical governance

ECMO should be considered only after a structured assessment of reversibility, severity, prior treatment, comorbidity, duration of mechanical ventilation, bleeding risk, neurological status and the patient's goals. Current adult VV-ECMO guidance provides a framework for selection, initiation, management and weaning.[4,5] No single variable should function as an automatic decision rule; the full clinical trajectory and the feasibility of meaningful recovery should be considered by an experienced multidisciplinary team.[4,5]

In resource-constrained settings, scarcity makes transparent governance particularly important. Decisions should use consistent clinical criteria and avoid discriminatory allocation based on social status, disability assumptions, wealth or institutional influence. Before initiation, the team should discuss the indication, major risks, uncertainty, likely duration, alternatives, costs and possible stopping conditions with the patient or surrogate whenever circumstances permit. The plan should be revisited as the clinical course evolves. A time-limited trial can be appropriate when reversibility or trajectory is uncertain, provided that the goals, reassessment interval and criteria for continuation are agreed and documented. Withdrawal or non-initiation decisions require careful communication, symptom control and adherence to applicable law and institutional policy. Ethics consultation may help in disputed cases, but should not delay urgent clinical decisions.

Training and staged programme development

Training should be competency-based and tiered. Staff at referring sites need to recognise potential eligibility, stabilise patients and activate the referral pathway. Staff in the ECMO centre require deeper competence in cannulation, circuit management, anticoagulation, complication recognition, weaning and rehabilitation. Simulation should include emergency scenarios such as pump failure, oxygenator dysfunction, major haemorrhage, accidental decannulation and power interruption. Rotations at an experienced centre, proctored cases and recurring multidisciplinary drills are preferable to a one-off certification course.

Programme development should proceed only after predefined readiness criteria are met. An initial phase can establish referral, teleconsultation, stabilisation and retrieval pathways. A later phase may introduce a limited clinical service under experienced supervision, followed by expansion only when staffing, safety and outcome data demonstrate readiness. ECPR and VA-ECMO require distinct expertise and should not be added automatically to a respiratory ECMO programme.[11]

Anticoagulation, blood conservation and complications

Bleeding, thrombosis, haemolysis, infection, neurological injury and vascular complications are recognised hazards of ECMO. Anticoagulation and transfusion decisions should follow a documented protocol adapted to the patient, circuit and available monitoring, with frequent reassessment. A low-intensity or heparin-sparing approach should not be adopted solely to reduce cost; it requires a clinical rationale, explicit monitoring and readiness to respond to circuit or patient thrombosis.[12]

Blood conservation may include avoiding unnecessary blood sampling, using appropriately sized sampling systems, reviewing transfusion indications and preventing avoidable circuit changes. These measures should be embedded in safety protocols rather than pursued as rigid targets. A shortage of blood products or inability to monitor anticoagulation reliably should trigger reconsideration of programme readiness, not acceptance of an avoidable increase in risk.

Economics, affordability and sustainability

A meaningful economic evaluation should report direct and indirect costs, duration of support, complications, survival to discharge, longer-term functional outcomes and cost per survivor or quality-adjusted life-year where feasible. Comparisons between public and private institutions must use comparable definitions and time periods. Procurement agreements, pooled purchasing, public reimbursement and philanthropic support may reduce financial barriers, but the savings should be measured rather than assumed. The cost of maintaining a safe service—including staff training, standby capacity and transport—must be included, even when those costs are not charged to an individual patient.

Financial counselling should explain what is covered, what may remain payable and what happens if funding is exhausted. A programme should have an institutional policy for financial hardship so that urgent clinical decisions are not made ad hoc at the bedside. Transparent eligibility and funding rules protect both families and clinical teams.

Regionalisation, disaster readiness and special populations

Regionalisation should align ECMO capacity with referral patterns, transport times, workforce availability and existing specialist services. During a pandemic or disaster, demand

Table 1. Core components of a regional ECMO pathway

Component	Minimum operational elements	Key safeguard
Referral and triage	Defined eligibility prompts; 24/7 contact; early hub consultation	Document reasons for acceptance or non-acceptance
Clinical readiness	Trained multidisciplinary team; ICU monitoring; imaging and laboratory support	Competency assessment and emergency drills
Transport	Predefined retrieval activation; equipment and power/oxygen redundancy	Transport checklist and adverse-event review
Governance	Consent, goals of care, escalation and time-limited reassessment	Consistent criteria and documented family discussions
Finance and supplies	Consumable stock plan; funding pathway; transparent cost counselling	No ad hoc bedside financial decisions
Quality assurance	Prospective registry; complications and outcomes review	Regular audit and feedback to spokes

may exceed capacity and supplies may become unreliable. Preparedness plans should identify referral coordination, staffing contingencies, consumable stocks, oxygen resilience, transport options and fair allocation processes. The experience of COVID-19 reinforced the importance of planning and coordination rather than rapid, unsupported expansion of individual units.[13,14]

Paediatric and neonatal ECMO require population-specific cannulation, equipment, staffing and clinical expertise. They should be concentrated in centres capable of providing age-appropriate care and should not be added to adult services without dedicated competency and infrastructure. Similarly, bridge-to-transplant support is only reasonable when a transplant pathway and timely communication with the receiving programme are established. Bridge-to-decision strategies require explicit goals and reassessment.

Digital tools and future research

Decision-support tools and automated monitoring may eventually help identify deterioration or circuit changes, but their safety, generalisability and value in resource-constrained environments need prospective evaluation. Connectivity, data quality, cybersecurity, maintenance and human oversight are practical prerequisites. Artificial intelligence should not be described as a proven means of reducing mortality or staffing requirements until such benefits are demonstrated.

Priority research questions include the comparative effectiveness of hub-and-spoke versus local-service models, the safety and cost of retrieval in different geographies, workforce retention, equity of referral, patient-reported outcomes and the full economic cost of ECMO programmes.[15,16] Multicentre registries with standardised definitions and transparent reporting would help distinguish service feasibility from clinical effectiveness.

Table 2. Suggested staged development and readiness checks

Stage	Focus	Readiness check before progression
1. Network design	Referral criteria, named hub, communication and transport agreements	Successful simulation of referral and transfer pathway
2. Stabilisation and retrieval	Training at referring sites; retrieval protocol; equipment checks	Competency sign-off and documented transport contingency plan
3. Limited supervised service	Restricted indications and case selection; hub oversight	Adequate staffing, supplies, complication response and audit
4. Service review and expansion	Review case mix, outcomes, costs and equity of access	Governance approval based on evidence of sustained capability

Table 3. Suggested minimum outcome dashboard

Domain	Measures	Why it matters
Access	Referral volume; acceptance rate; reason for refusal; referral-to-decision time	Identifies delays and inequity
Process	Time to cannulation; transfer duration; protocol adherence	Measures pathway reliability
Safety	Major bleeding, thrombosis, infection, neurological and transport complications	Supports learning and harm reduction
Clinical outcome	Survival to decannulation and discharge; functional outcome where feasible	Describes patient-centred results
Resource use	ECMO days; ICU length of stay; blood product use; total cost per case and survivor	Supports transparent planning
Equity	Referral and outcomes by geography and relevant demographic groups where lawful and appropriate	Assesses whether access is fair

Outcome measurement and quality assurance

Every programme should maintain a prospective registry and review outcomes at regular intervals. At minimum, reporting should include referrals received and declined, reasons for non-acceptance, time from referral to decision and cannulation, transport events, complications, survival to decannulation and hospital discharge, neurological and functional outcomes where available, length of stay and cost (Table 3). Results should be stratified by indication and severity and interpreted in light of case mix. A low case volume makes estimates unstable; small samples should not be used to make unsupported claims of superiority or safety.[17]

Structured morbidity and mortality meetings should examine both clinical events and system failures, including delayed referral, staffing gaps, stock-outs and communication breakdowns. Feedback should be shared with referring hospitals so that the network improves as a whole. Public reporting should be accurate, contextualised and designed to support accountability rather than marketing.

CONCLUSIONS

Extending ECMO access to underserved regions is best understood as a network-design challenge rather than an equipment-distribution exercise. A hub-and-spoke model, early consultation, safe retrieval, competency-based training and reliable governance can connect patients to specialist care while limiting unsupported proliferation of low-volume services. Telemedicine can strengthen that pathway but cannot replace bedside expertise or essential infrastructure. Economic claims should be grounded in local costing, and treatment decisions must remain transparent, equitable and clinically justified. The success of a hinterland ECMO programme should be judged by timely access, safety, meaningful outcomes and accountability—not by the number of machines installed.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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ORCID iD

Ahsina Jahan Lopa https://orcid.org/0000-0002-5336-4217

Payel Bose https://orcid.org/0009-0007-6549-7635

Ahsan Ahmed https://orcid.org/0000-0003-3970-1536

Rajesh Chandra Mishra https://orcid.org/0000-0001-6305-5998

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