

Original Article

Early Post-ECMO Mobilization Protocol (Passive/Active ROM, Sitting, Standing, Ambulation) Versus Standard Care on ICU Length of Stay, Muscle Strength, and Functional Independence at ICU Discharge: A Randomized Controlled Trial in Adult ECMO Patients

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ABSTRACT

Background: Adult survivors of extracorporeal membrane oxygenation (ECMO) are at high risk of ICU-acquired weakness, delayed mobility recovery, functional dependence, and prolonged ICU stay after decannulation. **Objective:** To determine whether a structured early post-ECMO mobilization protocol improved ICU length of stay, muscle strength, mobility, and functional independence compared with standard care in adult ECMO survivors. **Methods:** This prospective, single-center, parallel-group randomized controlled trial enrolled 80 adult ECMO survivors who were allocated equally to early mobilization or standard ICU care. The intervention included progressive passive and active range-of-motion exercises, sitting, standing, transfer training, and assisted ambulation under multidisciplinary monitoring. The primary outcome was ICU length of stay after ECMO decannulation. Secondary outcomes included Medical Research Council sum score, ICU Mobility Scale, Barthel Index, ICU-acquired weakness, adherence, and adverse events. Final complete-case analysis included 72 participants. **Results:** The intervention group had shorter ICU stay after decannulation than controls (5.8 ± 1.9 vs 7.4 ± 2.2 days; mean difference -1.6 days; 95% CI -2.57 to -0.63 ; $p = 0.002$). MRC sum score (50.8 ± 4.6 vs 46.2 ± 5.1 ; $p < 0.001$), ICU Mobility Scale score (median 7 vs 5; $p < 0.001$), and Barthel Index (63.4 ± 10.8 vs 54.1 ± 11.6 ; $p = 0.001$) were higher in the intervention group. ICU-acquired weakness was less frequent with early mobilization (22.2% vs 47.2%; $p = 0.02$). No major mobilization-related adverse events occurred. **Conclusion:** Structured early post-ECMO mobilization improved short-term ICU recovery without major safety concerns in stable adult ECMO survivors. **Keywords:** Extracorporeal Membrane Oxygenation; Early Ambulation; Physical Therapy Modalities; Intensive Care Units; ICU-Acquired Weakness; Functional Independence.

INTRODUCTION

Extracorporeal membrane oxygenation (ECMO) is an advanced life-support intervention used in adults with severe respiratory, cardiac, or cardiorespiratory failure when conventional management is insufficient. Improvements in ECMO delivery have increased survival, but many survivors experience

prolonged immobility, intensive care unit-acquired weakness, reduced functional independence, delayed ambulation, and extended rehabilitation needs after decannulation. Current ECMO rehabilitation guidance emphasizes that early rehabilitation and mobilization may be feasible in selected adult patients when delivered through careful multidisciplinary monitoring, yet the certainty of evidence remains limited because much of the literature is observational, heterogeneous, or feasibility-focused rather than trial-based (1,2). This gap is clinically important because immobility during critical illness accelerates skeletal muscle wasting, joint stiffness, neuromuscular weakness, respiratory deconditioning, delirium risk, and dependence in activities of daily living, all of which may delay discharge readiness and increase post-ICU rehabilitation burden (3).

Early mobilization has increasingly been explored as a strategy to reduce functional decline among critically ill patients receiving or recovering from extracorporeal life support. Systematic reviews have reported that passive and active physiotherapy, sitting, standing, transfer training, and assisted ambulation can be implemented in selected ECMO patients, but the reported protocols differ substantially in timing, intensity, progression criteria, cannulation approaches, staff expertise, and outcome measurement (4,5). Earlier cohort evidence also suggested that active physiotherapy and ambulation during ECMO may be possible in experienced centers, although causal interpretation was limited by retrospective designs, patient selection, and absence of randomized comparison groups (6). Similarly, evidence from awake ECMO rehabilitation showed encouraging functional recovery, but also highlighted the lack of prospective controlled trials and the need for standardized rehabilitation pathways that can be reproduced across ICU settings (7).

The current evidence base therefore supports the feasibility of ECMO-related mobilization but does not fully establish whether a structured early post-decannulation mobilization protocol improves clinically meaningful recovery outcomes compared with standard ICU care. This uncertainty is particularly relevant because mobilization success is influenced by patient stability, ECMO mode, sedation exposure, mechanical ventilation status, cannulation strategy, staffing, and center experience (8). In routine practice, physiotherapy after ECMO decannulation may remain inconsistent and dependent on local preference rather than a clearly defined rehabilitation algorithm. Standardized assessment using validated tools such as the ICU Mobility Scale and the Medical Research Council sum score can improve objectivity by measuring functional mobility and peripheral muscle strength at ICU discharge (9,10). However, controlled evidence is still needed to determine whether protocolized early mobilization produces measurable improvements in ICU length of stay, muscle strength, functional mobility, and ICU-acquired weakness.

This randomized controlled trial was designed according to a PICO framework in which the population comprised adult ECMO survivors after decannulation, the intervention was a structured early post-ECMO mobilization protocol including passive and active range-of-motion exercises, sitting, standing, and progressive ambulation, the comparator was standard ICU care, and the primary outcome was ICU length of stay after decannulation, with secondary outcomes including muscle strength, ICU mobility, functional independence, ICU-acquired weakness, adherence, and adverse events. The study was justified by the need to move beyond feasibility evidence and determine whether an organized physiotherapy pathway can improve short-term recovery without increasing mobilization-related safety risks. The research question was whether early structured mobilization after ECMO decannulation improves ICU recovery outcomes more effectively than standard care in adult ECMO survivors. The study hypothesized that patients receiving early post-ECMO mobilization would have shorter ICU length of stay, higher MRC sum scores, better ICU Mobility Scale scores, greater functional independence, and lower frequency of ICU-acquired weakness at ICU discharge than patients receiving standard care (11).

MATERIALS AND METHODS

This study was conducted as a prospective, single-center, parallel-group randomized controlled trial in the adult intensive care unit of a tertiary-care hospital. The trial evaluated whether a structured early post-ECMO mobilization protocol improved recovery outcomes compared with standard ICU care among adult patients who survived ECMO support and were clinically suitable for rehabilitation after decannulation. The study followed an interventional quantitative design because the objective was to compare the effect of a planned physiotherapy protocol against usual care on ICU length of stay, muscle strength, functional mobility, and functional independence. Eligible participants were adult patients aged 18 years or older who had undergone ECMO support, had been decannulated, were hemodynamically stable, and were considered safe for bedside mobilization by the ICU and rehabilitation team. Patients were excluded if they had unstable cardiorespiratory status, uncontrolled bleeding, unstable fracture, severe neurological impairment preventing participation, pre-existing major neuromuscular disease affecting limb strength assessment, limb amputation interfering with functional scoring, or any medical contraindication to mobilization.

Participants were screened consecutively during the study period, and eligible patients or their legally authorized representatives provided written informed consent before enrollment. After baseline assessment, participants were randomly allocated in a 1:1 ratio to the intervention group or control group using a computer-generated random sequence. Allocation concealment was maintained through sequentially numbered, opaque, sealed envelopes prepared before recruitment and opened only after enrollment. Because of the nature of physiotherapy intervention, blinding of treating therapists and patients was not feasible; however, outcome assessment was performed using standardized scoring procedures to reduce measurement bias. Baseline demographic and clinical variables were recorded before group allocation was implemented, including age, sex, ECMO mode, duration of pre-enrollment ICU stay, comorbidities, ventilatory status, and relevant clinical stability indicators.

The intervention group received a structured early post-ECMO mobilization protocol delivered by trained ICU physiotherapists in collaboration with physicians, nurses, and ECMO-trained staff. The protocol progressed according to patient tolerance from passive range-of-motion exercises to active-assisted and active exercises, bed mobility, sitting at the edge of the bed, transfer training, standing, marching in place, and assisted ambulation. Each session was individualized according to respiratory status, hemodynamic stability, consciousness level, muscle strength, pain, exertion, and safety parameters. Mobilization was withheld or stopped if the patient developed clinically significant desaturation, new arrhythmia, hypotension or hypertension requiring urgent intervention, active bleeding, severe fatigue, intolerable pain, reduced consciousness, line or wound safety concern, or any staff-assessed risk of clinical deterioration. Session duration, highest achieved mobility level, patient tolerance, and adverse events were documented using a mobilization session log.

The control group received standard ICU care, which included routine nursing care, positioning, respiratory care, and usual physiotherapy as determined by the treating ICU team. Standard care did not follow the structured progressive mobilization algorithm used in the intervention group. Both groups continued to receive all indicated medical, nursing, respiratory, nutritional, and supportive ICU management according to institutional practice. Co-interventions such as ventilation management, sedation reduction, oxygen therapy, and medical treatment were not withheld from either group.

The primary outcome was ICU length of stay after ECMO decannulation, measured in days from decannulation to ICU discharge. Secondary outcomes included peripheral muscle strength at ICU discharge measured by the Medical Research Council sum score, functional mobility measured by the ICU Mobility Scale, ICU-acquired weakness defined according to the MRC sum score threshold used in critical care practice, functional independence measured by the Barthel Index, protocol adherence, session duration, and adverse events. The ICU Mobility Scale was used because it is a validated and

responsive measure of mobility status in ICU populations, while the Medical Research Council sum score was selected because it is widely used to evaluate peripheral muscle weakness and ICU-acquired weakness after critical illness (9,10,12). Pain and perceived exertion were assessed during mobilization using bedside clinical scales, and all adverse events were classified as major or minor according to whether they required interruption of therapy, urgent medical intervention, or produced clinically significant harm.

The sample size was calculated for comparison of two independent means because the primary endpoint was ICU length of stay after ECMO decannulation. The calculation used a two-sided alpha level of 0.05, statistical power of 80%, an expected between-group difference based on prior ECMO and critical care rehabilitation evidence, and an allowance for attrition, mortality, transfer, or incomplete discharge assessment. Standard sample size guidance for medical research and power analysis was followed when determining the final recruitment target (13–15). A total of 80 participants were enrolled and randomized equally into intervention and control groups, anticipating that some participants would not complete discharge assessment.

Data were entered into a structured database and checked for completeness, range errors, and consistency before analysis. Continuous variables were assessed for distributional pattern and summarized as mean with standard deviation for approximately normally distributed data or median with interquartile range for skewed data. Categorical variables were summarized as frequency and percentage. Between-group comparisons were performed using independent-samples t-tests for normally distributed continuous variables, Mann–Whitney U tests for non-normally distributed continuous variables, and chi-square or Fisher’s exact tests for categorical variables. The primary analysis compared ICU length of stay after decannulation between the intervention and control groups. Secondary analyses compared discharge MRC sum score, ICU Mobility Scale score, Barthel Index, ICU-acquired weakness, adherence, and adverse events between groups. A multivariable linear regression model was planned to assess whether group allocation remained independently associated with ICU length of stay after adjustment for clinically relevant covariates, including age, sex, ECMO mode, and pre-ECMO ICU days. Missing outcome data were handled through complete-case analysis for the primary reported dataset, while attrition was described transparently through participant flow reporting.

Ethical approval was obtained before participant recruitment. Written informed consent was obtained from each participant or legal surrogate, and confidentiality was maintained by assigning study codes and storing data securely. Mobilization was performed only when patients met predefined clinical safety criteria, and all sessions were supervised by trained ICU staff. Data integrity was supported through standardized assessment forms, uniform outcome definitions, session-level documentation, and verification of entered data against source records. These procedures were used to strengthen reproducibility, reduce measurement variability, and ensure that the intervention could be clearly distinguished from standard care.

RESULTS

A total of 96 adult ECMO survivors were screened for eligibility, of whom 80 were enrolled and randomized equally to the early post-ECMO mobilization group and the standard-care group. Eight participants had incomplete discharge assessment or were lost before final outcome measurement, leaving 72 participants for the primary complete-case analysis, with 36 participants in each group.

Table 1. Participant Flow

Study Stage	Total, n	Intervention, n	Control, n
Screened for eligibility	96		
Randomized	80	40	40
Completed ICU discharge assessment	72	36	36
Included in final analysis	72	36	36

The baseline characteristics were comparable between groups, suggesting acceptable balance after randomization. The intervention and control groups were similar in age, sex distribution, ECMO mode, pre-ECMO ICU duration, and diabetes status. Mean age was 48.6 ± 13.2 years in the intervention group and 49.1 ± 12.8 years in the control group, with no statistically significant difference between groups ($p = 0.87$). VV-ECMO was the most common ECMO mode in both groups, representing 65.0% of intervention participants and 62.5% of controls.

Table 2. Baseline Characteristics of Randomized Participants

Variable	Intervention (n = 40)	Control (n = 40)	Mean Difference / Effect Estimate	p-value
Age, years, mean \pm SD	48.6 \pm 13.2	49.1 \pm 12.8	-0.5 years	0.87
Male sex, n (%)	24 (60.0)	23 (57.5)	+2.5 percentage points	0.82
VV-ECMO, n (%)	26 (65.0)	25 (62.5)	+2.5 percentage points	0.81
VA-ECMO, n (%)	14 (35.0)	15 (37.5)	-2.5 percentage points	0.81
Pre-ECMO ICU days, median (IQR)	6 (4-8)	6 (4-9)	Median difference 0 days	0.94
Diabetes mellitus, n (%)	10 (25.0)	11 (27.5)	-2.5 percentage points	0.80

The primary outcome showed a statistically and clinically meaningful reduction in ICU length of stay after ECMO decannulation in the intervention group. Patients receiving early structured mobilization had a mean post-decannulation ICU stay of 5.8 ± 1.9 days compared with 7.4 ± 2.2 days in the standard-care group. The mean difference was -1.6 days, with an estimated 95% confidence interval from -2.57 to -0.63 days, indicating that early mobilization was associated with shorter ICU stay. The standardized effect size was moderate to large in magnitude (Cohen's $d = -0.78$), supporting the clinical relevance of the observed difference.

Table 3. Primary Outcome: ICU Length of Stay After ECMO Decannulation

Outcome	Intervention (n = 36)	Control (n = 36)	Mean Difference	95% CI	Effect Size	p-value
ICU LOS after decannulation, days, mean \pm SD	5.8 \pm 1.9	7.4 \pm 2.2	-1.6 days	-2.57 to -0.63	Cohen's $d = -0.78$	0.002

Secondary outcomes also favored the early mobilization group. At ICU discharge, the intervention group had a higher MRC sum score than the control group, with a mean difference of 4.6 points and an estimated 95% confidence interval from 2.32 to 6.88. This represented a large standardized effect size (Cohen's $d = 0.95$). Functional independence was also better in the intervention group, with a Barthel Index score of 63.4 ± 10.8 compared with 54.1 ± 11.6 in controls, giving a mean difference of 9.3 points and an estimated 95% confidence interval from 4.03 to 14.57. ICU-acquired weakness occurred in 8 participants in the intervention group compared with 17 in the control group, corresponding to 22.2% versus 47.2%. The odds of ICU-acquired weakness were lower in the intervention group, with an estimated odds ratio of 0.32 and 95% confidence interval from 0.11 to 0.89. ICU Mobility Scale scores were also higher in the intervention group, with a median score of 7 compared with 5 in controls.

Table 4. Secondary Outcomes at ICU Discharge

Outcome	Intervention (n = 36)	Control (n = 36)	Effect Estimate	95% CI	Effect Size / OR	p-value
MRC sum score, mean \pm SD	50.8 \pm 4.6	46.2 \pm 5.1	+4.6	2.32-6.88	Cohen's $d = 0.95$	<0.001
ICU Mobility Scale, median (IQR)	7 (6-8)	5 (4-6)	+2			<0.001
ICU-acquired weakness, n (%)	8 (22.2)	17 (47.2)	25.0% Absolute risk		OR = 0.32	0.02
Barthel Index, mean \pm SD	63.4 \pm 10.8	54.1 \pm 11.6	+9.3	4.03-14.57	Cohen's $d = 0.83$	0.001

Protocol adherence in the intervention group was high. Of 220 planned mobilization sessions, 194 were completed, giving an adherence rate of 88.2%. The mean session duration was 27.5 ± 6.8 minutes. This suggests that the structured mobilization protocol was feasible in clinically stable post-ECMO patients when delivered under supervised ICU conditions.

Table 5. Intervention Process Measures

Process Measure	Intervention Group
Planned mobilization sessions	220

Process Measure	Intervention Group
Completed mobilization sessions	194
Adherence rate	88.2%
Mean session duration, minutes, mean ± SD	27.5 ± 6.8

No major mobilization-related adverse events were reported. There were no cannula displacements, arrhythmias, or falls in either group. Minor adverse events were uncommon and clinically manageable. Transient desaturation occurred in 3 intervention participants and 1 control participant, while bleeding requiring interruption was reported in 1 intervention participant and none in the control group. These findings suggest that the protocol was not associated with an excess of serious safety events when applied with predefined monitoring and stopping criteria.

Table 6. Adverse Events During ICU Rehabilitation

Adverse Event	Intervention (n = 36)	Control (n = 36)
Cannula displacement	0	0
Bleeding requiring interruption	1	0
Transient desaturation	3	1
Arrhythmia	0	0
Fall	0	0

Overall, early post-ECMO mobilization was associated with shorter ICU stay, stronger muscle performance, better mobility, greater functional independence, and lower frequency of ICU-acquired weakness at ICU discharge. The largest standardized effect was observed for MRC sum score, followed by Barthel Index and ICU length of stay, indicating that the intervention had both functional and resource-related clinical relevance. The absence of major adverse events further supports the feasibility of carefully monitored mobilization in stable adult post-ECMO patients.

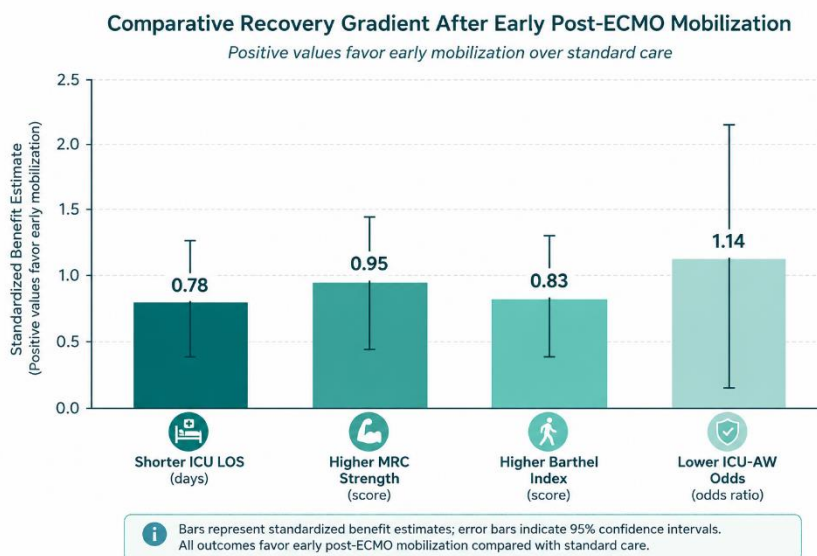


Figure 1. Comparative Recovery Gradient After Early Post-ECMO Mobilization

Early post-ECMO mobilization demonstrated a consistently favorable recovery gradient across ICU resource use, muscle strength, functional independence, and ICU-acquired weakness. The strongest standardized benefit was observed for reduced odds of ICU-acquired weakness (standardized benefit estimate = 1.14), followed by improved MRC sum score (0.95), higher Barthel Index (0.83), and shorter ICU length of stay after decannulation (0.78). These findings indicate that the intervention produced clinically meaningful improvements across both functional and resource-related recovery domains, with all measured effects favoring structured early mobilization over standard care.

DISCUSSION

This randomized controlled trial found that a structured early post-ECMO mobilization protocol was associated with shorter ICU length of stay after decannulation, greater muscle strength, improved

functional mobility, higher functional independence, and a lower frequency of ICU-acquired weakness at ICU discharge compared with standard ICU care. The reduction in post-decannulation ICU stay by 1.6 days, together with higher MRC sum scores and Barthel Index values, suggests that early mobilization may provide both functional and resource-related benefit in clinically stable adult ECMO survivors. These findings are clinically important because ECMO survivors are highly vulnerable to ICU-acquired weakness, prolonged deconditioning, and delayed independence after critical illness, particularly after exposure to sedation, mechanical ventilation, systemic inflammation, and extended immobility (1–3).

The direction of effect observed in this study is consistent with the emerging ECMO rehabilitation literature. Recent guidance from the Extracorporeal Life Support Organization supports early rehabilitation or mobilization in carefully selected adult ECMO patients when delivered by trained multidisciplinary teams under structured safety monitoring (1). Similarly, systematic review evidence indicates that physical rehabilitation during extracorporeal life support is feasible, although the certainty of evidence remains low because previous studies have largely been observational, heterogeneous, and limited by variation in intervention dose, patient selection, and outcome definitions (2,4,5). The present trial contributes to this evidence base by evaluating a defined post-decannulation mobilization pathway against standard care and by using clinically interpretable endpoints, including ICU length of stay, MRC sum score, ICU Mobility Scale, Barthel Index, and ICU-acquired weakness.

The improvement in MRC sum score in the intervention group is biologically plausible. Critical illness and prolonged immobilization are associated with rapid skeletal muscle wasting, impaired neuromuscular activation, reduced oxidative capacity, and ICU-acquired weakness, all of which may persist after ICU discharge (3). A structured progression from passive and active range-of-motion exercises to sitting, standing, and ambulation may reduce disuse-related muscle loss, preserve joint mobility, improve postural control, and promote earlier functional task performance. The higher ICU Mobility Scale score in the intervention group further supports the likelihood that repeated supervised mobilization improved functional progression rather than merely increasing isolated limb strength (9,10).

The observed reduction in ICU-acquired weakness is especially relevant for critical care physiotherapy. ICU-acquired weakness occurred in 22.2% of patients in the intervention group compared with 47.2% of controls, suggesting a clinically meaningful reduction in neuromuscular morbidity. Although this study was not powered for long-term outcomes, improved discharge strength and mobility may influence downstream recovery, rehabilitation dependence, hospital throughput, and quality of life. Previous studies of ECMO mobilization have shown that ambulation and active rehabilitation are more achievable in selected patients, especially in experienced centers with appropriate staffing and safety protocols (6,8). The high adherence rate in the present study supports the practical feasibility of implementing a structured mobilization protocol in a tertiary ICU setting.

Safety remains a central concern in ECMO rehabilitation because of risks related to hemodynamic instability, bleeding, oxygen desaturation, cannula complications, and line displacement. In this study, no major adverse events were recorded, and minor events were manageable with interruption, rest, or supportive adjustment. This finding aligns with previous reports suggesting that mobilization can be performed safely when patient selection, monitoring, stopping criteria, and multidisciplinary coordination are clearly defined (1,2,4). However, interpretation should remain cautious because the study included clinically stable post-decannulation patients; therefore, the findings should not be generalized to unstable patients or to all patients actively receiving ECMO support.

This study has several limitations. First, it was conducted at a single center, which may limit generalizability to ICUs with different staffing models, rehabilitation cultures, ECMO volumes, or resource constraints. Second, although randomization was used, blinding of therapists and participants was not feasible because of the nature of the intervention. Third, the final analysis included 72 of 80 randomized participants, and attrition may have introduced some risk of bias despite balanced group

sizes at discharge assessment. Fourth, longer-term outcomes such as hospital length of stay, discharge destination, readmission, quality of life, and post-ICU physical function were not assessed. Finally, the intervention was delivered in selected clinically stable adult patients, so its safety and effectiveness require further evaluation across broader ECMO populations, including patients with different cannulation strategies, illness severities, and rehabilitation readiness.

Despite these limitations, the study provides useful trial-level evidence supporting early structured physiotherapy after ECMO decannulation. The findings suggest that standardized mobilization pathways, objective functional assessment, and multidisciplinary safety monitoring may improve short-term recovery in adult ECMO survivors. Future multicenter randomized trials should evaluate larger samples, longer follow-up, protocol dose-response effects, cost-effectiveness, and patient-centered outcomes to confirm whether early post-ECMO mobilization improves sustained functional recovery beyond ICU discharge.

CONCLUSION

Early post-ECMO mobilization was associated with shorter ICU length of stay after decannulation, higher muscle strength, better ICU mobility, greater functional independence, and lower frequency of ICU-acquired weakness compared with standard care in clinically stable adult ECMO survivors. The absence of major adverse events suggests that a structured, supervised, multidisciplinary mobilization pathway can be feasible and clinically meaningful when appropriate safety criteria are applied. These findings support the integration of protocolized rehabilitation into post-ECMO ICU care, while larger multicenter trials with long-term follow-up are needed to confirm generalizability, optimal intervention dose, and sustained functional benefit.

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