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Evaluating the Impact of a Hypothetical Termination of Resuscitation Protocol on Out-of-Hospital Cardiac Arrest Outcomes and Health System Utilization: A Markov Model Approach

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Abstract

Many out-of-hospital cardiac arrests have virtually no chance of meaningful survival, yet current practice often involves transporting these patients to hospital, where death is subsequently pronounced. This process generates potentially avoidable resource utilization and costs. Termination of Resuscitation (TOR) protocols empower paramedics to discontinue resuscitation efforts at the scene in cases deemed medically futile. This study quantifies the differences in resource-intensive events and outcomes between routine transport (current practice) and the application of a validated TOR protocol. Data were drawn from the Singapore cohort of the Pan-Asian Resuscitation Outcomes Study (PAROS) registry between 1 January 2014 and 31 December 2017. A Markov decision model was constructed to simulate clinical pathways and resource use under two strategies: (1) existing practice (universal transport) and (2) implementation of a TOR protocol. The model was run on a hypothetical cohort of 10,000 OHCA patients over a 30-day post-arrest cycle. Probabilistic sensitivity analysis was performed to address parameter uncertainty, with key outcomes being the number of emergency transports and emergency department interventions, inpatient bed days, total deaths, and associated costs. Compared with TOR protocol use, current practice was projected to generate an additional 1,118 (95% uncertainty interval: 1,117–1,119) emergency transports and subsequent emergency treatments per 10,000 OHCA cases. It also resulted in 93 (95% UI: 66–120) excess inpatient bed days. However, universal transport was associated with 3 fewer deaths (95% UI: 2–4) per 10,000 patients, suggesting a small number of potentially avoidable prehospital deaths under the TOR protocol. Implementation of a Termination of Resuscitation protocol in Singapore could substantially reduce emergency transports, emergency interventions, hospital bed utilization, and overall healthcare expenditure for out-of-hospital cardiac arrest. Although the protocol may carry a small risk of premature termination in rare salvageable cases, the evidence supports its adoption as a means to improve resource allocation and minimize non-beneficial interventions.

Keywords: Out-of-hospital cardiac arrest, Termination of Resuscitation, prehospital emergency care, emergency medical services, Markov modeling, health economics

Introduction

In conventional prehospital practice, all patients experiencing out-of-hospital cardiac arrest (OHCA) are actively resuscitated and transported to hospital irrespective of apparent medical futility, with termination of resuscitation and pronouncement of death permitted only by an emergency physician in the hospital setting. Sudden cardiac arrests carry a dismal prognosis, with survival-to-discharge rates reported at approximately 10% in North America and Europe [1, 2], 0.5–8.5% across Asia-Pacific countries [3], and around 3% in Singapore [4].

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The recognition of frequent medical futility in OHCA has driven the development of formal Termination of Resuscitation (TOR) protocols for emergency medical services (EMS). The American Heart Association has endorsed both basic and advanced life support TOR rules [5]. The basic life support rule mandates transport if return of spontaneous circulation occurs at any point, if an automated external defibrillator delivers a shock, or if the arrest is witnessed by EMS personnel. The advanced life support rule incorporates additional criteria recommending transport if the arrest is witnessed by bystanders or EMS personnel and/or if bystander cardiopulmonary resuscitation was initiated [6].

Implementation of TOR protocols for OHCA is supported by several clinical and operational rationales. Multiple validation studies—conducted prospectively and retrospectively in Canada, Japan, Singapore, and the United States—have demonstrated 100% specificity and positive predictive value of validated TOR criteria for predicting death or severe neurological disability [7–10]. Amid rising demand on EMS resources [11], appropriate application of TOR protocols has been shown to substantially decrease unnecessary emergency transports without compromising overall survival to hospital discharge [8]. In Singapore, the Civil Defence Force recorded a 7.4% year-on-year increase in emergency calls in 2016, with 75.3% of cases involving chest pain, shortness of breath, altered consciousness, or cardiac arrest [12]. Without a TOR protocol, virtually all OHCA patients—including those with no realistic prospect of survival—are transported and treated in hospital, generating potentially avoidable expenditure. In the United States, the annual nationwide cost of transporting futile OHCA cases has been estimated at approximately US$500 million [13], while total resource utilisation (ambulance, physician, and hospital reimbursement) for unsuccessful resuscitations has been projected at US$58 million per year [14].

Although previous research has examined overall healthcare costs associated with OHCA [15,16] and the economic impact of non-adherence to TOR rules [17], there remains limited evidence quantifying the potential cost savings achievable through systematic TOR implementation. The present study therefore aims to estimate the reduction in resource-intensive events and associated costs resulting from the adoption of an advanced life support TOR protocol compared with current universal transport practice in Singapore. A Markov modelling approach was employed to simulate time-dependent stochastic processes in OHCA management [18], enabling simultaneous projection of costs, clinical outcomes, and the influence of parameter uncertainty.

Materials and Methods

Setting and population

Singapore is a highly urbanized city-state with a resident population exceeding 5 million within a land area of approximately 710 km² [19]. Emergency medical services (EMS) are provided exclusively by the Singapore Civil Defence Force (SCDF) through a centralized, nationally integrated dispatch system. All out-of-hospital cardiac arrest (OHCA) cases are conveyed to one of six major public acute hospitals [20]. Prior to the nationwide implementation of an advanced life support Termination of Resuscitation (TOR) protocol in July 2019, universal transport of all OHCA patients to hospital for ongoing resuscitation was mandatory.

Study data

Data were obtained from the Singapore cohort of the Pan-Asian Resuscitation Outcomes Study (PAROS) registry [21], a multinational collaborative research network established in 2010 to enhance prehospital and emergency care outcomes across the Asia-Pacific region. The registry includes standardized clinical and operational variables for OHCA cases. For the present analysis, all OHCA episodes occurring between 1 January 2014 and 31 December 2017 were extracted.

Termination of resuscitation protocol

The advanced life support TOR protocol formally adopted in Singapore in July 2019 was used as the intervention strategy in this modelling study. An emergency physician independently reviewed all retrieved OHCA cases and applied the locally adapted TOR criteria to classify each case retrospectively. Cases were excluded from the TOR-eligible cohort if any of the following were present: age ≤16 years; presumed non-cardiac etiology (including trauma); obvious signs of irreversible death on scene (rigor mortis, dependent lividity, decomposition, or decapitation); presentation of a valid do-not-attempt-resuscitation order; or post-hoc determination that the event did not constitute a true cardiac arrest [22].

All remaining cases were then categorized according to the Singapore advanced life support TOR rule **(Figure 1)** into one of two outcomes:

- "Transport recommended" (resuscitation continuation and conveyance to hospital indicated), or
- "Termination of Resuscitation recommended" (on-scene cessation of efforts deemed appropriate).

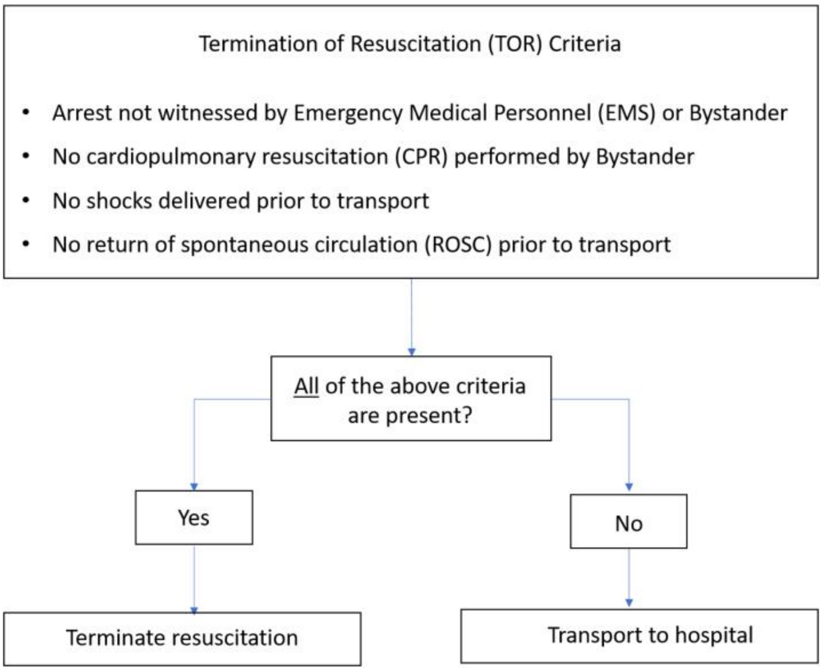

Figure 1. Criteria for Termination of Resuscitation

Patient-Level data

Data extracted for each out-of-hospital cardiac arrest (OHCA) case included survival to hospital admission, in-hospital mortality, and exact timestamps for critical events (hospital arrival, hospital discharge, and date of death when applicable). These variables were used to derive transition probabilities and to calculate inpatient length of stay.

Markov model

A Markov cohort model was developed, as depicted in **Figure 2**, consisting of six mutually exclusive and exhaustive health states:

1. Out-of-hospital cardiac arrest (starting state for all patients)
2. Urgent transport to hospital
3. Emergency department (ED) resuscitation/treatment
4. Inpatient admission
5. Discharged alive
6. Death (absorbing state)

Transitions between states are represented by directional arrows; self-loops allow patients to remain in transient states (e.g., inpatient admission) across multiple cycles, whereas the death state is permanent.

All simulated patients begin in the "cardiac arrest" state. Under current universal-transport practice, every patient moves to "urgent transport" and subsequently to "ED resuscitation." Under the advanced life support TOR protocol, patients meeting termination criteria transition directly from "cardiac arrest" to "death" on scene, bypassing transport and hospital care.

Patients reaching the ED may either die in the department or survive to "inpatient admission." Those admitted may remain hospitalised across cycles, transition to "discharged alive," or move to "death."

The model employed a daily cycle length and was evaluated over a maximum of 30 days from the index arrest (or from admission for transported cases) to accurately quantify inpatient bed-day consumption. Simulations were performed for a hypothetical cohort of 10,000 OHCA patients, with all transition probabilities estimated directly from the 2014–2017 Singapore PAROS dataset stratified by TOR eligibility.

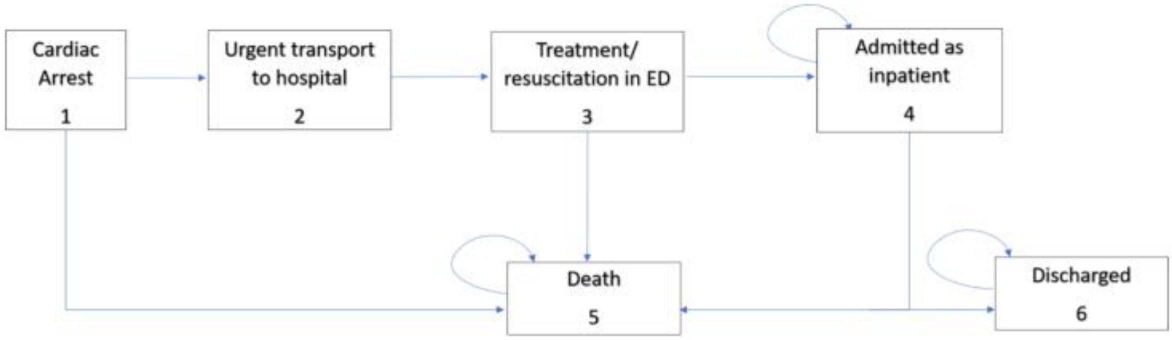

Figure 2. Markov model structure for out-of-hospital cardiac arrest (OHCA) management. All patients begin in the "Cardiac arrest" state. Directional arrows represent permissible transitions between states; self-looping arrows indicate that patients may remain in the same state across consecutive daily cycles

Model scenarios and comparators

The baseline comparator, "Existing Practice," reflects real-world events observed in the PAROS registry (2014–2017), during which 100% of OHCA patients were urgently transported to hospital. The intervention scenario, "TOR Protocol," simulates the counterfactual pathway in which patients meeting Singapore's advanced life support TOR criteria are declared dead on scene and do not enter subsequent states (transport, ED treatment, or admission). Differences in outcomes between the two strategies were quantified for a hypothetical cohort of 10,000 OHCA patients.

Transition probabilities

Daily transition probabilities between health states were estimated separately for "Existing Practice" and "TOR Protocol" scenarios. Both time-homogeneous and time-dependent probabilities were derived by dividing the observed number of patients who transitioned from one state to another by the number of patients at risk of transition at the start of each cycle. To incorporate parameter uncertainty, Dirichlet distributions were assigned as prior distributions to all transition probabilities [23].

Model evaluation and uncertainty analysis

The primary outcomes evaluated were: number of urgent ambulance transports and subsequent ED resuscitations, total inpatient bed days, total number of deaths (prehospital and in-hospital)

The model was simulated for 10,000 hypothetical patients. Probabilistic sensitivity analysis was conducted using 5,000 Monte Carlo iterations, drawing transition probabilities simultaneously from their fitted Dirichlet distributions. This approach ensured stable and robust estimates of differences in outcomes and costs between the TOR protocol and existing universal-transport practice. All model parameters were directly informed by the Singapore PAROS registry data.

Results and Discussion

From the Singapore PAROS registry (2014–2017), a total of 9,753 out-of-hospital cardiac arrest (OHCA) episodes were identified. After applying exclusion criteria (age ≤16 years, obvious irreversible death on scene, valid do-not-attempt-resuscitation order, non-cardiac aetiology, or event subsequently classified as non-arrest), 4,357 cases were removed. The final analytic cohort comprised 5,396 confirmed cardiac-arrest patients who were actively resuscitated and transported to hospital.

Among the included patients, mean age was 67.5 years (SD 15.6), and 67% were male.

Transition probabilities for the Markov model were derived directly from these 5,396 cases and scaled to a hypothetical cohort of 10,000 patients. **Table 1** presents the time-homogeneous transition probabilities for both the "Existing Practice" (universal transport) and "TOR Protocol" scenarios.

Table 1. Transition probabilities for 'Existing Practice' and 'TOR' for each state

From	To	Existing Practice (Universal Transport)	TOR Protocol
		Mean value (%) [95% UI]	Distribution (E, NE)
Cardiac Arrest	Death (on scene)	0%	Fixed (0, 5396)
	Urgent Transport to ED	100%	Fixed (5396, 0)
Urgent Transport	Treatment/resuscitation in ED	100%	Fixed (5396, 0)
Treatment/resuscitation in ED	Inpatient Admission	16.3%	Dirichlet (880, 4516)

	Death (in ED)	83.7%	Dirichlet (4516, 880)
Inpatient Admission	Remain Inpatient	Time-dependent	Dirichlet (see Appendix A1)
	Discharged Alive	Time-dependent	Dirichlet (267, 613)
	Death (in-hospital)	Time-dependent	Dirichlet (573, 307)

ED, Emergency Department; Distr. = Distribution type; E = count of Events, NE count of non-events.

Implementation of the advanced life support Termination of Resuscitation (TOR) protocol resulted in 11.2% of out-of-hospital cardiac arrest cases being declared dead on scene by paramedics, thereby eliminating the need for urgent transport to hospital. Among patients who still reached the emergency department, 83.7% died under Existing Practice compared with 82.4% under the TOR protocol, yielding inpatient admission rates of 16.3% and 17.6%, respectively.

For patients admitted to an inpatient ward, in-hospital mortality was 65.1% under Existing Practice (with 30.3% discharged alive and a mean length of stay of 9.2 days) versus 63.8% under the TOR protocol (with 31.6% discharged alive and a mean length of stay of 9.4 days).

When applied to a hypothetical cohort of 10,000 patients, Existing Practice resulted in emergency transport and ED treatment for all 10,000 cases, whereas the TOR protocol reduced this figure to 8,883 cases. The remaining 1,117 patients under the TOR scenario were declared dead on scene and did not undergo transport. **Figure 3** demonstrates that these 1,117 additional deaths occurred either in the pre-transport "Cardiac Arrest" state or during ED resuscitation—states in which no deaths were recorded under Existing Practice because of mandatory conveyance of every patient.

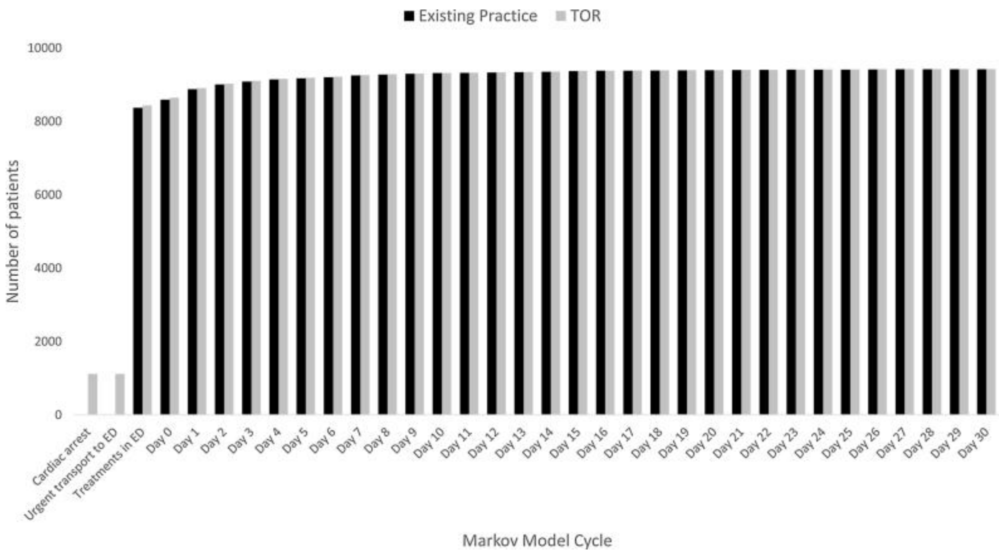

Figure 3. Cumulative number of deaths in Markov Model cycle for Existing Practice and TOR models

Figure 4 shows the number of patients admitted as inpatients following ED treatment. A slight difference is observed between Existing Practice and the TOR protocol in the early phase, with 1,631 versus 1,562 inpatients, respectively, which converges to nearly the same level from Day 10 onward.

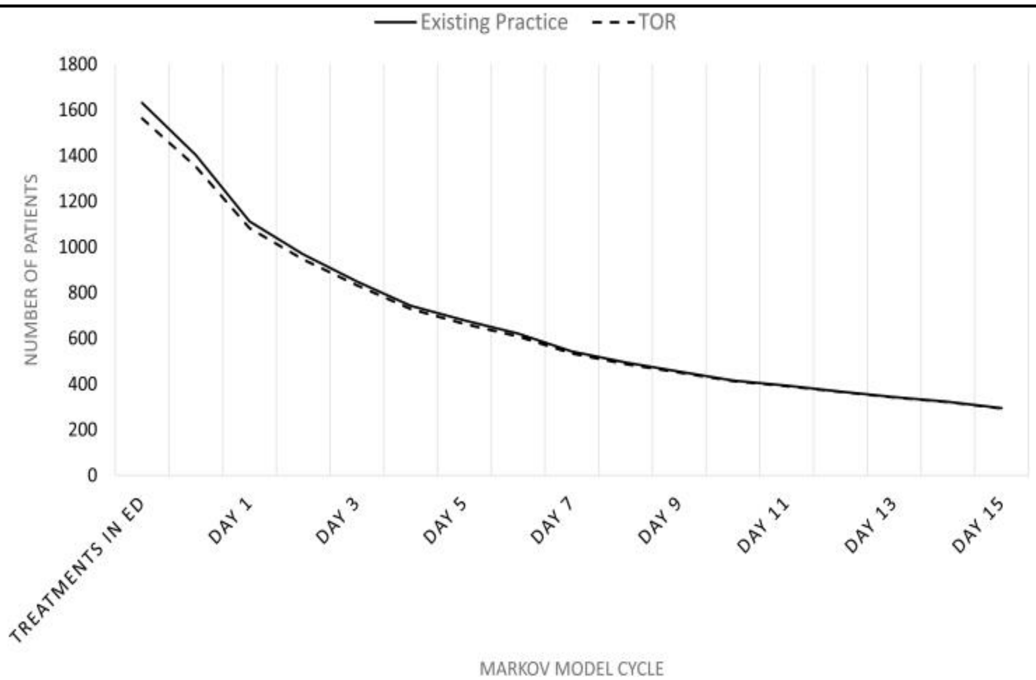

Figure 4. Number of inpatients after ED treatments for Existing Practice and TOR models

Table 2 presents summary statistics comparing key outcomes between the 'Existing Practice' and 'TOR' models based on the simulation. On average, Existing Practice resulted in 1,118 more patients being urgently transported for ED treatment compared to TOR. Additionally, Existing Practice required 93 more inpatient bed days and was associated with three fewer deaths relative to the TOR protocol.

Table 2. Difference in key outcomes between Existing Practice and TOR models

Outcome	Mean difference (Existing Practice minus TOR)	Standard deviation	95% uncertainty interval
Urgent transports and ED treatments	+1,118	43	1,117 – 1,119
Inpatient bed days	+93	978	66 – 120
Total deaths	–3	45	–4 – –2

The present analysis demonstrates that implementation of an advanced life support Termination of Resuscitation (TOR) protocol would substantially decrease resource-intensive events, most notably urgent ambulance transports with subsequent emergency department resuscitation and inpatient bed-day utilisation. However, it would also be accompanied by a small increase in total mortality compared with universal transport practice. Although precise monetary cost savings were not calculated in this study, such estimates would be essential for weighing the economic benefits against the modest number of additional lives lost. In traditional cost-effectiveness frameworks, deliberate withdrawal of interventions that confer even marginal survival benefit is rarely entertained [24]. Nevertheless, the economic case for TOR is inherently tied to the trade-off between cost savings and potential life-years forgone, and extending the current model to quantify this ratio would provide critical evidence to guide policy decisions.

Adoption of the TOR protocol reduced the projected transport rate from 100% to 88.8%, a finding broadly consistent with international evidence. A systematic review of advanced life support TOR rule performance across seven countries reported mean transport rates of approximately 76% (range 66–94%) after protocol application [6]. These data confirm that TOR can achieve meaningful reductions in unnecessary conveyances, with the exact magnitude varying according to population characteristics and local resuscitation outcomes.

Substantial healthcare expenditure associated with out-of-hospital cardiac arrest has been documented elsewhere, driven primarily by prolonged hospitalisation of patients with extremely poor prognosis. For example, a large Japanese cohort study of over 21,000 OHCA patients reported mean inpatient stays of 23–32 days and costs ranging from US$28,097 to US$31,161 [16]. Similarly, German data highlighted the high resource demands of intensive care for cardiac arrest survivors [25], while a North American analysis described hospital charges exceeding US$3.8 million for six traumatic arrest patients who survived in persistent vegetative states [17]. Cost-effectiveness evaluations of OHCA interventions have likewise revealed high incremental costs for marginal survival gains [15, 26].

Prehospital emergency medical services and emergency departments represent high-fixed-cost environments that must maintain immediate availability, rapid multi-casualty response capacity, advanced equipment, and highly trained personnel [27]. Strict adherence to a validated TOR protocol would liberate ambulance crews, emergency physicians, resuscitation bays, and inpatient beds for patients with time-critical conditions and far greater prospects of meaningful recovery. This reallocation of scarce resources is especially relevant in Singapore, where emergency call volume has risen steadily in recent years [12, 28] and where high-rise architecture and traffic congestion frequently delay access to patients [29]. By enabling on-scene termination in futile cases, a TOR protocol would allow faster redirection of assets toward conditions with higher salvageability, such as acute stroke, ST-elevation myocardial infarction, and major trauma.

The observation of three additional deaths per 10,000 OHCA cases under the TOR protocol merits close attention. This small excess mortality originates from two patients in the PAROS registry who, despite fulfilling TOR criteria for on-scene termination (i.e., they would not have been transported), were conveyed to hospital under existing practice, survived beyond 30 days, and achieved acceptable neurological recovery (Cerebral Performance Category score of 2). The retrospective design precludes identification of the specific factors that enabled their unexpected survival. A recent systematic review of TOR diagnostic performance noted that, although overall positive predictive value remains high, specificity and predictive accuracy tend to be slightly lower in Asian compared with Western settings [6]. This underscores the critical importance of local validation of any TOR rule before widespread adoption. Reassuringly, a 2012 Singapore-based validation study reported 100% specificity and positive predictive value for both basic and advanced life support TOR criteria in predicting death or severe neurological disability [7].

Several limitations should be acknowledged. First, detailed data on intensive care unit (ICU) length of stay were unavailable; because ICU beds are considerably more expensive than general ward beds, the true cost differential between strategies is likely underestimated, as patients transported under existing practice who were subsequently admitted probably required disproportionate ICU resources. Second, real-world adherence to a TOR protocol may be imperfect, with occasional deviations that could attenuate the projected reductions in transport and resource use. Third, survival rates for OHCA may have improved since the 2014–2017 data collection period, potentially altering the contemporary trade-off between lives saved and resources conserved. Fourth, the model did not incorporate additional workload imposed on paramedics by TOR implementation, including time required for family communication, grief support, completion of extended documentation, and awaiting police corroboration of death. Fifth, transporting apparently futile cases to hospital may confer non-clinical benefits to bereaved families (e.g., witnessing continued resuscitation efforts), a psychosocial value that is lost with on-scene termination. Finally, the current analysis was restricted to cardiac-aetiology arrests eligible for the Singapore TOR protocol; extending similar termination rules to non-cardiac medical collapses—which carry even higher mortality—could yield additional resource savings not captured here.

Many of these limitations can be addressed through prospective evaluation after nationwide rollout. Accordingly, a follow-up study using post-implementation real-world data is planned to refine estimates of clinical, economic, and operational impact of the TOR protocol in Singapore.

Conclusion

This study provides supportive evidence for the adoption of a Termination of Resuscitation (TOR) protocol in the management of out-of-hospital cardiac arrest in Singapore. Compared with universal transport practice, implementation of the advanced life support TOR rule markedly reduced the number of emergency ambulance conveyances, emergency department resuscitations, and total inpatient bed-day utilisation. Although the protocol was associated with a small increase in mortality (approximately three additional deaths per 10,000 cases), the magnitude of this difference emphasises the importance of conducting a full health economic evaluation that explicitly quantifies the trade-off between resource savings and potential lives forgone.

Prolonged resuscitation and transport of medically futile OHCA cases consume scarce pre-hospital and hospital resources that could otherwise be redirected toward time-critical emergencies with substantially higher prospects of meaningful recovery. A well-validated and consistently applied TOR protocol therefore represents an effective strategy for optimising resource allocation, ensuring that advanced resuscitation efforts are focused primarily on patients most likely to benefit. While additional real-world evidence following nationwide implementation will further refine these estimates, the current findings suggest that adherence to TOR guidelines has the potential to yield considerable reductions in non-beneficial transports, emergency interventions, and hospital admissions, thereby improving overall system efficiency and equity.

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Ethics statement: The Centralised Institutional Review Board (2013/604/C) and Domain Specific Review Board (2013/00929) granted approval for this study with a waiver of patient informed consent. This project was deemed exempt from Duke Institutional Review Board (Pro00103613).

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