Cureus
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Open Access Original Article

A Treat-on-Berth Model for Maritime Mass Casualty Incidents: A Time-Motion Analysis of System-Level Trauma Care Reconfiguration

Hiroyuki Otsuka [1]

1. Trauma and Acute Care Surgery, International University of Health and Welfare, Chiba, JPN

Corresponding author: Hiroyuki Otsuka, otsuka-hiroyuki-mm@ihwg.jp

Review began 10/14/2026
Review ended 10/28/2026
Published 11/04/2026

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DOI: 10.7759/cureus.119098

Abstract

Background

In maritime mass casualty incidents, prolonged rescue and transport phases create unavoidable delays before definitive trauma care can begin. Additional post-berthing transfer processes may further prolong access to hemorrhage control, representing a potentially modifiable system-level bottleneck.

Objective

To characterize the post-berthing time structure of definitive trauma care and examine the potential of converting unavoidable transfer delay into structured parallel preparation time through on-site deployment of trauma center-equivalent capability (Treat-on-Berth model).

Methods

A time-motion analysis was conducted during a full-scale maritime disaster response exercise in fiscal year 2025. Time to definitive treatment was defined as the interval from completion of berthing to initiation of definitive hemorrhage control or circulatory stabilization. The observed interval from berthing to commencement of CT imaging informed a design-based estimate for the proposed Treat-on-Berth workflow. This estimate was compared with a conventional transport-to-hospital model parameterized using time ranges derived from previously published analyses of prehospital and emergency department workflows.

Results

The exercise demonstrated an approximately 10-minute interval from completion of berthing to commencement of CT imaging. Informed by this observed interval and clinical experience with emergency operations, a 10-20-minute interval to definitive treatment was proposed as a design-based estimate. This interval was not directly measured during the exercise. Comparison with a literature-parameterized conventional workflow suggested a potential time difference of 30-70 minutes; this estimate remains hypothetical and requires prospective validation.

Conclusions

The Treat-on-Berth model proposes a system-level reconfiguration of maritime trauma care by converting unavoidable transport time into parallel preparation for definitive intervention at the point of berthing. The exercise demonstrated the operational feasibility of pre-deploying trauma center-equivalent resources at the pier, while the potential reduction in time to definitive treatment remains to be validated through prospective measurement.

Categories: Trauma, Emergency Medicine
Keywords: damage control surgery, disaster medicine, maritime mass casualty incident, time to definitive treatment, trauma systems

Introduction

Disaster medicine requires the coordinated allocation of limited medical resources to manage mass casualty incidents (MCIs), in which the organization of triage, treatment, and evacuation is critical to response effectiveness [1].

Maritime MCIs present particular challenges because casualties must be rescued from a vessel and transported ashore before accessing land-based medical care. The interval between the incident and berthing may be prolonged by rescue operations and maritime transport constraints, delaying access to definitive treatment [2]. Furthermore, arrival at the shore does not necessarily mean that appropriate treatment can begin immediately, as additional time may be required for disembarkation, patient transfer, and preparation for intervention. The “golden hour” concept emphasizes the importance of timely trauma care, particularly

for patients with hemodynamic instability due to major hemorrhage [3,4]. Similarly, the "platinum 10 minutes" concept highlights the importance of early action following first medical contact [5]. Together, these concepts underscore the importance of time in trauma care, but maritime MCIs also require consideration of how medical preparation can be advanced before casualties reach the shore.

The Treat-on-Berth (ToB) model proposes a shift in how this unavoidable interval is used: rather than treating the time between the incident and berthing solely as a period of delay, it can be used to prepare hospital-level medical capabilities at the pier before casualties arrive. By converting transit time into preparation time, ToB aims to enable appropriate assessment and time-critical interventions to begin promptly upon arrival, while retaining hospital transfer when required.

This study presents the ToB model and examines its operational potential through a scenario-based time-motion analysis of a maritime MCI exercise. The observed operational timeline was compared with a conventional transport-to-hospital workflow estimated using published time parameters. The analysis evaluates the potential operational advantages of this system-level reconfiguration, rather than claiming demonstrated clinical effectiveness or a directly measured reduction in time to definitive treatment (TtoT).

Materials And Methods

Study design

This study analyzed time-motion data obtained during a full-scale maritime disaster response exercise conducted on February 3, 2026, during fiscal year 2025. The exercise simulated a passenger vessel accident involving multiple critically injured patients and was designed to simulate real-world operational constraints. The exercise was conducted in an urban port setting with dense medical infrastructure.

Definition of TtoT

TtoT was defined as the interval from completion of berthing (T = 0) to initiation of definitive hemorrhage control or circulatory stabilization based on DCR and damage control surgery (DCS) principles.

Model overview

Two operational workflows were considered in the time-motion analysis. As shown in Figure *1*, the conventional transport-to-hospital model represented a standard workflow in which patients are transferred from the scene to a receiving hospital before initiation of definitive care. The ToB model was examined as a proposed operational configuration during the exercise. Trauma center-equivalent capabilities, including high-specification medical vehicles and a dedicated trauma surgical team, were pre-deployed to the pier before patient arrival. This configuration was intended to support immediate assessment and, when clinically indicated and operationally feasible, earlier definitive intervention upon berthing. Figures *2*-*3* illustrate the deployed resources and operational setting.

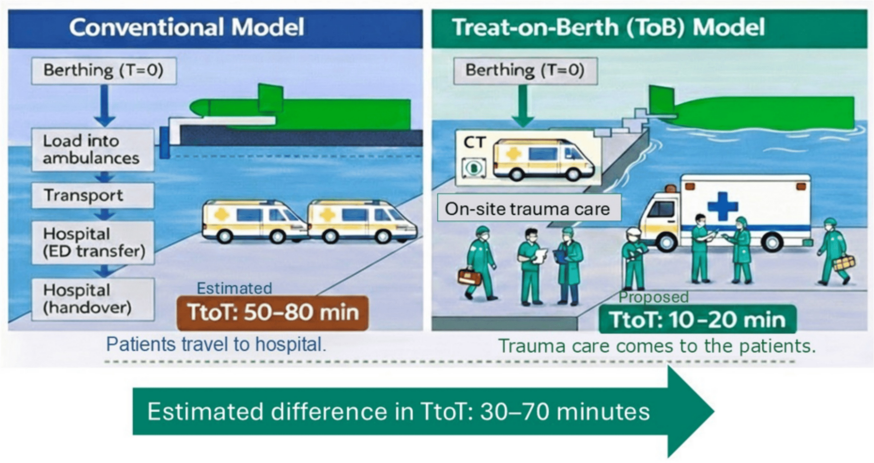


FIGURE 1: Comparison of Time to Definitive Treatment (TtoT) Between the Conventional Transport-to-Hospital Model and the Treat-on-Berth Model

The figure provides a conceptual visualization of a system-level reconfiguration of early trauma care. Clinical details are intentionally simplified to emphasize structural workflow differences rather than procedural complexity. The left panel (Conventional Model) illustrates a sequential, transport-dependent process in which patients are transferred to a receiving hospital following berthing, with definitive treatment estimated to begin 50-80 minutes after berthing. Detailed time assumptions based on previously published workflow parameters are provided in the "Comparison of TtoT between workflows" section. The right panel (Treat-on-Berth Model) depicts an alternative system design in which trauma center-equivalent capability, including specialized medical teams and high-specification medical vehicles, is pre-deployed to the pier. This configuration was designed to support earlier definitive treatment after berthing. A 10-20-minute interval is presented as a design-based operational estimate informed by the observed berthing-to-CT interval and the investigator's clinical experience; treatment initiation within this interval was not directly measured during the exercise. The time ranges illustrate a hypothetical system-level difference of approximately 30-70 minutes and should not be interpreted as a measured treatment effect or clinical outcome benefit. By reversing the direction of care delivery, the Treat-on-Berth model reframes unavoidable maritime delay as structured preparation time.

The image was created by the author. The initial schematic was generated using the Gemini app (Gemini 3 Pro; Google LLC, Mountain View, CA, USA) with the Nano Banana image-generation model and subsequently edited and finalized by the author using Microsoft PowerPoint (Microsoft Corp., Redmond, WA, USA). Generative AI was used in the initial creation of the figure; all subsequent modifications - the final layout, text, labels, and visual composition - were performed by the author.

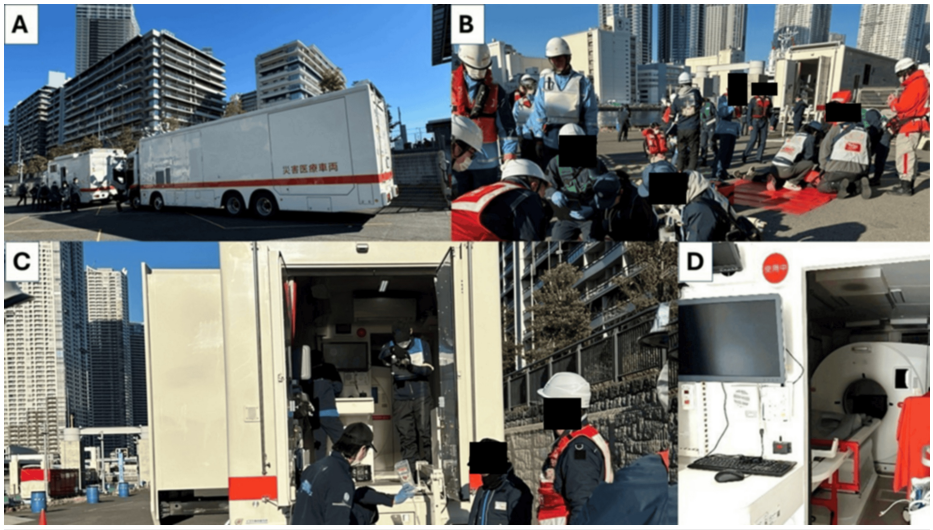


FIGURE 2: CT-Equipped High-Specification Medical Vehicle Deployed at the Pier

Exterior and interior views demonstrating the vehicle's capability for on-site imaging, resuscitation, and potential advanced intervention. (A) Exterior view of the vehicle. (B) Treatment/resuscitation area. (C, D) Interior CT imaging area.

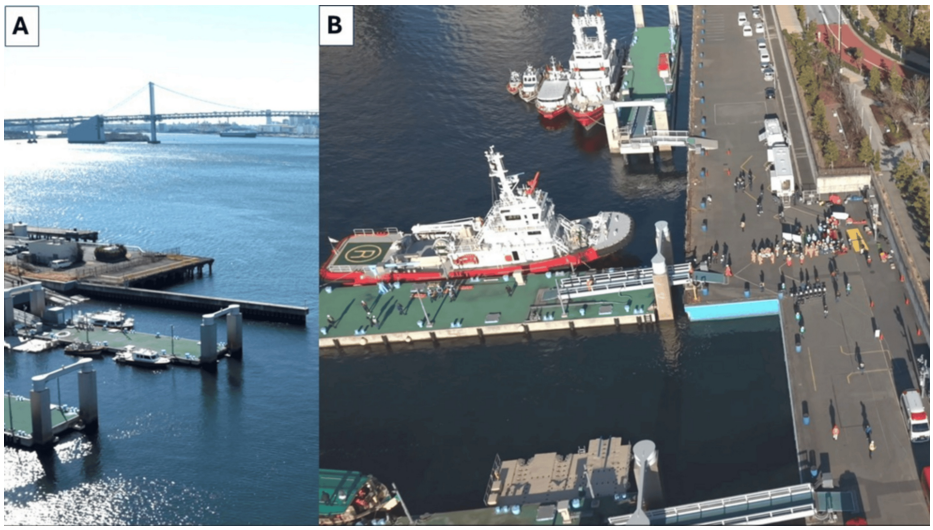


FIGURE 3: Aerial Overview of the Maritime Mass Casualty Incident Scene Obtained by Drone

Representative overhead images illustrating situational awareness, casualty distribution, and the operational layout of the exercise. (A) Overall view of the maritime disaster exercise area. (B) Berthing and casualty distribution area.

The trauma center-equivalent capability deployed at the pier was configured to support immediate definitive and life-saving interventions when clinically indicated, including DCS, DCR, and emergency decompressive procedures. Advanced interventions such as resuscitative endovascular balloon occlusion of the aorta (REBOA) and extracorporeal membrane oxygenation (ECMO) were considered potential options within the broader ToB framework but were not performed during the present exercise and were not assumed to reduce TtoT. The proposed ToB configuration was designed to support immediate DCR, and other indicated interventions upon patient arrival, subject to clinical assessment and resource availability. These interventions were not physically performed during the present exercise.

Time assumptions for the conventional model

To avoid institution-specific bias and excessive methodological detail in the main text, time ranges derived

from previously published analyses of prehospital and emergency department workflows were applied to parameterize the conventional transport-to-hospital model. To ensure a fair and conservative comparison, the conventional model parameters were defined to span a spectrum from optimal (undelayed) to typical conditions. This parameterization was intentionally adopted to allow comparison under the most favorable transport assumptions in the conventional model, without presupposing outcome superiority.

Operational basis of the ToB model

During the full-scale exercise, the intervals from completion of berthing to entry into the pier-side CT room and commencement of imaging were assessed retrospectively through video review. Although these operational intervals were directly observed, invasive procedures, intravenous access, and surgical instrument preparation were not performed as part of the exercise. Accordingly, the time required to initiate definitive treatment was not directly measured.

Ethics approval

The requirement for ethical review was assessed through a simplified determination by the Chair of the Chiba District Ethics Review Committee at the International University of Health and Welfare. The Chair determined that ethical review was not required for this study. No patient-level data or personally identifiable information were collected or analyzed.

Results

Temporal structure of the exercise

The exercise involved 38 simulated casualties: 11 red-tagged, four yellow-tagged, 22 green-tagged, and one black-tagged casualty. As shown in Table *1*, even the first critically injured patient reached the berthing site more than 30 minutes after the incident, and the second patient reached the berthing site at approximately the end of the traditional golden hour. The majority of major critical casualties arrived more than 100 minutes after the incident. These observations illustrate the substantial physiological time that may elapse before critically injured patients reach the point at which definitive trauma care can be initiated.

Phase	Elapsed Time (Min)	Patient Condition/Physiological Threshold
Incident occurrence to first berthing	34	Drowning; respiratory status stable with supplemental oxygen
Incident occurrence to second berthing	58	Hemorrhagic shock with altered consciousness; end of the “golden hour”
Incident occurrence to the last berthing of major critical casualties	119	High-risk period for progression to irreversible shock

TABLE 1: Timeline of Patient Arrivals and Operational Context During the Maritime Disaster Exercise

This table presents the elapsed time from incident occurrence to each berthing event during the 2025 fiscal year exercise. It illustrates the substantial time that had already elapsed before patients reached the pier and provides the operational context for considering immediate on-site intervention within the Treat-on-Berth model.

Comparison of TtoT between workflows

Figure *1* summarizes the TtoT associated with the two operational workflows, using completion of berthing as the reference point (T = 0). The exercise demonstrated an approximately seven-minute and 10-minute interval from completion of berthing to entry into the pier-side CT room and commencement of imaging. This observed interval, together with the investigator's clinical experience with emergency operations, informed a proposed 10-20-minute interval to definitive treatment. The latter was a design-based estimate and was not directly measured during the exercise.

For comparison, the conventional transport-to-hospital workflow was parameterized using time ranges derived from previously published analyses of prehospital and emergency department processes. Under these assumptions, initiation of definitive treatment was estimated to occur 50-80 minutes after berthing. A detailed breakdown of these assumptions is provided in Table *2*. The resulting difference between the proposed ToB workflow and the literature-parameterized conventional model was an estimated 30-70 minutes.

Process Stage	Conventional Model (Min)	Treat-on-Berth Model (Min)	Description/Logic	Supporting Reference
Scene Time (Initial Management)	10-20	10-20	Initial assessment and resuscitation following berthing.	[5,6]
Travel Time	10-20	0	No transport required prior to initiation of definitive treatment.	[6,7]
APOT (Hospital Handover)	20-30	0	Structural and organizational delay eliminated by on-site capability.	[6,7]
Pre-operative Setup	10	0/Simultaneous	Conventional: begins after hospital arrival. Treat-on-Berth: completed in parallel with ongoing resuscitation.	[5,7]
Total TtoT	50-80	10-20	Estimated system-level difference in TtoT: 30-70 minutes.	-

TABLE 2: Comparison of Time Intervals and Assumptions Between the Conventional Model and the Treat-on-Berth Model

This table summarizes the time parameters used to estimate time to definitive treatment (TtoT) in the conventional transport-to-hospital model and compares them with the workflow assumptions of the Treat-on-Berth model. Conventional-model intervals are based on previously published workflow parameters [6,7]. In the ToB model, medical resources and pre-operative arrangements are assumed to be prepared in parallel before berthing. The 10-20-minute interval is a design-based estimate informed by the observed berthing-to-CT workflow and clinical experience, rather than a directly measured TtoT. Zero minutes for hospital handover and pre-operative setup represent model assumptions based on pre-arrival preparation and parallel workflow, not measured durations. The resulting 30-70-minute difference is a hypothetical estimate derived from the modeled intervals, not an observed reduction in treatment time or evidence of clinical effectiveness.

APOT: ambulance patient offload time

This comparison should be interpreted as a time-motion analysis between a proposed exercise workflow and a literature-parameterized conventional workflow rather than as a direct clinical outcome comparison between two prospectively tested treatment strategies.

Discussion

Principal finding and system-level reframing of post-berthing delay

The principal contribution of this analysis is the identification of post-berthing care delivery as a potentially modifiable component of the maritime trauma timeline. The ToB model addresses this interval through a system-level reconfiguration: trauma expertise, equipment, and treatment pathways are prepared in parallel with maritime rescue and transport, rather than being assembled sequentially after berthing. The exercise demonstrated an approximately 10-minute interval from berthing to commencement of CT imaging, providing an operational reference point for this approach. In contrast, the conventional transport-to-hospital workflow, when parameterized using published time ranges, yielded an estimated 50-80-minute interval before initiation of definitive treatment. The comparison with the conventional workflow therefore depends on assumptions that require prospective validation.

These findings should not be interpreted as evidence that the ToB model reduces clinical mortality or that the observed workflow is directly equivalent to a conventional clinical pathway. Rather, the analysis illustrates how pre-deployment and parallel preparation can alter the temporal structure of care after berthing. The estimated 30-70-minute difference represents a system-level time difference derived from comparison of an observed exercise workflow with a literature-based conventional model.

The key concept of the ToB model is therefore not simply the physical relocation of equipment, but the conversion of unavoidable maritime delay into structured preparation time. By pre-deploying trauma capability during the rescue and transport phase, activities that would otherwise occur sequentially after berthing can be prepared in parallel. This changes the role of the pier from a passive transfer point to a potential site of coordinated trauma care.

As shown in Table *1*, critically injured patients in the exercise frequently reached the berthing site only after substantial physiological time had already elapsed, with many arriving more than 100 minutes after the incident. Similar concerns regarding prolonged delays to definitive care have been described in maritime and disaster settings [2,6,7]. Under such circumstances, additional predictable delays after arrival on land may represent a potentially modifiable component of the overall treatment timeline. The present analysis therefore identifies post-berthing processes as a system-level target for further operational evaluation.

Although urban infrastructure facilitates rapid pre-deployment, the underlying principle of the ToB model is

not inherently restricted to metropolitan settings. With appropriate equipment, trained personnel, and coordination with receiving institutions, selected elements of early on-site intervention may also be adaptable to non-urban settings.

Despite originating from a maritime mass casualty exercise, the model addresses a broader trauma-system problem: patients may be physically close to definitive care while remaining functionally delayed by the organization of care delivery.

Generalizability and resource considerations

A potential concern is that the ToB model may appear resource-intensive and therefore difficult to generalize. However, the core concept does not require every advanced technology to be deployed at every incident. Its fundamental principle is the pre-deployment of decision-making authority and trauma expertise, together with parallel preparation of personnel, equipment, blood products, and treatment pathways during unavoidable transport delays.

One possible implementation strategy would be to base high-specification medical vehicles and trauma teams at strategically located hospitals near critical hubs such as ports, airports, or major event venues. Integrating these teams into routine emergency operations at their base hospitals could maintain operational readiness while avoiding the need for permanently dedicated disaster infrastructure. The feasibility and cost-effectiveness of such an approach, however, require evaluation in specific healthcare systems.

In lower-resource settings, a scaled-down ToB configuration may be possible, focusing on early surgical presence, DCR, and selected on-site hemorrhage control without advanced imaging or extracorporeal support. Thus, the physical configuration may differ substantially among systems, while the underlying concept - converting unavoidable delay into active preparation time - may be applicable to trauma systems experiencing access or transport-related delays.

However, deploying a dedicated trauma team, blood products, and specialized equipment for one casualty may reduce the resources available for triage, stabilization, and transport of other casualties. The potential benefit of ToB therefore depends on patient selection, casualty distribution, available resources, and the expected delay to hospital-based definitive care. Resource allocation and the opportunity costs of on-site intervention should be explicitly assessed in future simulations and operational evaluations.

Role of on-site DCR and surgery

From a trauma systems perspective, the ToB model emphasizes that the decision to intervene should be based on the patient's physiological condition and the expected consequences of further delay rather than solely on the physical location of the hospital.

For appropriately selected patients with ongoing life-threatening hemorrhage or physiological deterioration, immediate DCR and, when clinically indicated and operationally feasible, DCS at the pier may provide an alternative to waiting for subsequent hospital transfer. In this context, the concept represents an intentional extension of trauma-center capability to the patient's point of arrival rather than simply an expansion of conventional prehospital care.

The clinical principle underlying this approach is consistent with the broader emphasis in trauma care on minimizing time to hemorrhage control rather than simply minimizing time to hospital arrival [3,4]. The concept of the “golden hour” has evolved toward greater emphasis on early hemorrhage control and timely definitive intervention, while the “platinum 10 minutes” concept further emphasizes the importance of early intervention following initial medical contact [5].

However, the present study did not evaluate clinical outcomes, and the exercise did not establish that any particular advanced intervention improves survival when performed at the pier. The findings therefore support further evaluation of the workflow and operational feasibility rather than a recommendation for routine pierside surgical intervention.

Importantly, the ToB framework does not imply that every critically injured patient should undergo invasive intervention at the pier. Rather, patient selection, physiological status, available expertise, equipment, blood products, environmental conditions, and the expected delay to definitive hospital care would all need to be incorporated into clinical decision-making.

Integration of human resources and equipment

In the present exercise, high-specification medical vehicles, including a vehicle equipped with whole-body CT and point-of-care testing, served as physical anchors for concentrating trauma capabilities at the pier. While the use of mobile CT is well established in other time-critical settings such as stroke care, its role in trauma remains subject to operational and clinical considerations [8]. Mobile CT may provide diagnostic

information that cannot be obtained readily by focused ultrasonography alone; however, the role of advanced imaging in maritime trauma requires selective application and further evaluation.

The principal value of such equipment within the ToB framework is not the technology itself but its integration with a trained multidisciplinary trauma team. Pre-deployment allows personnel to prepare equipment, blood products, treatment spaces, and decision pathways before patients arrive. This parallel preparation may reduce the time required to transition from arrival to intervention.

During the exercise, the first critically injured patient was triaged for direct transport, while the scenario involving profound hemorrhagic shock or neurological deterioration highlighted the potential need for DCS, or rapid imaging and emergency decompressive intervention. These were scenario-based clinical considerations; definitive invasive treatment was not performed during the exercise. These observations illustrate the importance of flexible triage and multidisciplinary decision-making rather than the universal application of any single technology.

Advanced interventions such as REBOA and ECMO were not performed during the present exercise. Within the broader ToB framework, they may represent potential options for selected patients in appropriately equipped systems, but their use would require specific clinical indications, expertise, equipment, blood-product availability, and capacity to manage procedure-related complications [9-11]. The present time-motion analysis does not establish that these interventions shorten TtoT or improve clinical outcomes when performed at the pier.

Potential role of digital transformation

A characteristic feature of maritime MCIs is that surrounding infrastructure may remain functional even when physical access to patients is delayed. In the present exercise, drone-based aerial imaging was used for overall situational assessment. However, real-time information sharing through wearable cameras, tablet-based systems, or continuous telemedical linkage among the scene, pier, and receiving hospitals was not implemented.

Integration of these digital tools could potentially enhance situational awareness, diagnostic interpretation, resource allocation, and preparation of receiving teams while patients remain in transit. Existing literature suggests that wearable devices and telemedicine technologies may improve situational awareness, assessment, and decision-making in disaster medicine and CSCATTT-based operations [12]. Within the ToB framework, digital communication may therefore further support parallelization of physical movement, clinical assessment, and treatment preparation.

These possibilities remain hypotheses for future operational evaluation. Prospective simulation and real-world validation will be necessary to determine whether digital integration improves workflow reliability and whether the resulting time savings translate into clinically meaningful outcomes.

Limitations

This study has several limitations. First, it was based on a single full-scale disaster response exercise rather than an actual maritime MCI. The findings therefore represent an operational proof-of-concept rather than evidence of clinical effectiveness.

Second, the proposed 10-20-minute interval to definitive treatment was not measured during the exercise. It was a design-based estimate informed by the observed interval from completion of berthing to commencement of CT imaging and the investigator's clinical experience with emergency operations. No invasive definitive procedures were physically performed; therefore, patient-level times to definitive treatment could not be determined. The comparison with the conventional workflow consequently relies on assumptions that require prospective validation. Furthermore, the two workflows differed in evidential status: the ToB estimate was informed by an exercise-based operational reference and a proposed workflow, whereas the conventional workflow was parameterized using published literature. The estimated 30-70-minute difference should therefore be interpreted as a scenario-based hypothesis, not a directly measured treatment-time reduction. The planned nature of the exercise may also have limited its ability to reproduce the procedural durations and operational constraints encountered in real-world incidents.

Third, the conventional model incorporated a range extending from optimal or minimally delayed conditions to typical operational conditions. Although this parameterization allows comparison under favorable conventional transport assumptions, actual workflow times may vary substantially among regions, transport systems, hospitals, and incident types. In addition, the transferability of time parameters derived from land-based emergency and hospital systems to maritime mass casualty settings remains uncertain and requires validation in maritime-specific simulations and operational studies.

Fourth, the exercise was conducted in a single urban port environment with dense medical infrastructure, and the number and characteristics of critically injured casualties were limited to a single scenario.

Generalizability to other ports, vessels, geographic settings, and healthcare systems therefore remains uncertain.

Fifth, patient outcomes were not measured. The present analysis cannot determine whether the estimated differences in TtoT translate into differences in survival, neurological outcome, or other clinically relevant endpoints. Finally, although the exercise demonstrated the operational potential of pre-deployment and parallel preparation, further multidisciplinary simulation and prospective operational evaluation are required to assess resource allocation, performance in confined spaces, team coordination, equipment constraints, and reproducibility under more demanding operational conditions.

Conclusions

The ToB model proposes a system-level approach to maritime trauma care in which trauma center-equivalent resources are pre-deployed to the pier and prepared in parallel with rescue and transport. The exercise demonstrated an approximately 10-minute interval from berthing to CT imaging, providing an operational basis for exploring this reconfiguration. Although a 10-20-minute interval to definitive treatment was proposed as a design-based estimate, and comparison with a literature-parameterized conventional workflow suggested a potential difference of 30-70 minutes, neither the proposed treatment interval nor the time difference was directly measured. Prospective studies using directly observed treatment-initiation times are needed to determine operational performance and clinical relevance.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Hiroyuki Otsuka

Acquisition, analysis, or interpretation of data: Hiroyuki Otsuka

Drafting of the manuscript: Hiroyuki Otsuka

Critical review of the manuscript for important intellectual content: Hiroyuki Otsuka

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Acknowledgements

The author sincerely thanks the Japanese Red Cross Society Tokyo Chapter, Tokyo Hikifune Hospital, Tokyo Bay Recreational Fishing Boat Cooperative, the Tokyo Fire Department (Rinko Fire Station), the Tokyo Metropolitan Police Department (Tokyo Bay Area Police Station), the Japan Coast Guard 3rd Regional Headquarters (Haneda Special Rescue Base and Tokyo Coast Guard Office), the Public Health Bureau, Ministry of Health, Labour and Welfare, and Sho-oh College of Medical Technology for their invaluable cooperation during this exercise. The author also gratefully acknowledges the emergency physicians from Odawara Municipal Hospital; nurses and in-hospital emergency medical technicians from Tokai University Hachioji Hospital; and nurses, in-hospital emergency medical technicians, and medical administrative/logistics personnel from International University of Health and Welfare Mita Hospital and Narita Hospital. Their multidisciplinary participation and collaboration, including personnel with experience in disaster medical assistance, contributed substantially to the operational implementation of the Treat-on-Berth model during the exercise.

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