

## REVIEW ARTICLE

# Hybrid emergency room: Installation, establishment, and innovation in the emergency department

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**Abstract**

A novel trauma workflow system called the hybrid emergency room (Hybrid ER) that combines a sliding computed tomography (CT) scanning system with interventional radiology features was first installed in Osaka General Medical Center in 2011. The Hybrid ER enables CT diagnosis and emergency therapeutic interventions without transferring the patient to another examination room. In this article, the history of CT in trauma care, the world's first installation of the Hybrid ER, clinical experiences, and evidence for the Hybrid ER in trauma workflow and nontrauma fields are summarized, and the future and innovation of the Hybrid ER are reviewed.

**KEYWORDS**

hybrid emergency room, hybrid ER

## INSTALLATION OF A HYBRID ER

### Whole-body computed tomography for trauma

Whole-body computed tomography (WBCT) has become increasingly important in the early diagnostic phase of trauma care. Huber-Wagner et al.<sup>1</sup> and Yeguiayan et al.<sup>2</sup> have both reported the benefits of WBCT for patient survival. In a multicenter randomized study by Sierink et al., although the diagnosis of patients with the aid of an immediate WBCT scan did not reduce in-hospital mortality compared with a standard radiological work-up, future study of means to improve the selection of patients who can benefit from immediate WBCT was suggested.<sup>3</sup> Wada et al. reported that performing computed tomography (CT) before control of emergency bleeding is obtained might be associated with improved survival, especially when the Trauma and Injury Severity Score probability of survival in severe trauma patients is less than 50%.<sup>4</sup> Huber-Wagner et al. also found that survival of hemodynamically unstable patients with major trauma was significantly increased when WBCT was performed during trauma resuscitation.<sup>5</sup>

### Computed tomography scanner installation in the emergency room

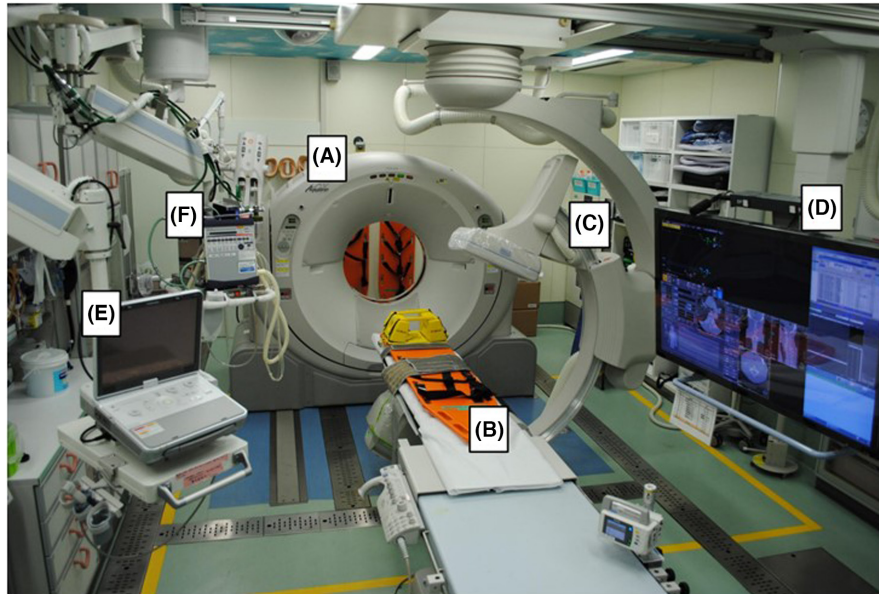
The importance of the installation of a CT scanner in the emergency room (ER) was also reported for early diagnosis in trauma care. As several studies have shown, installation of a CT gantry enhances ER management by providing time and patient benefits.<sup>6-8</sup> Although such an installation substantially reduces delays in transferring patients to the CT scanner, their transfer to other specialized departments for definitive therapy is a continuing rate-limiting step when trying to maximize the speed of the therapeutic workup.

### Introduction of hybrid ER into the ER

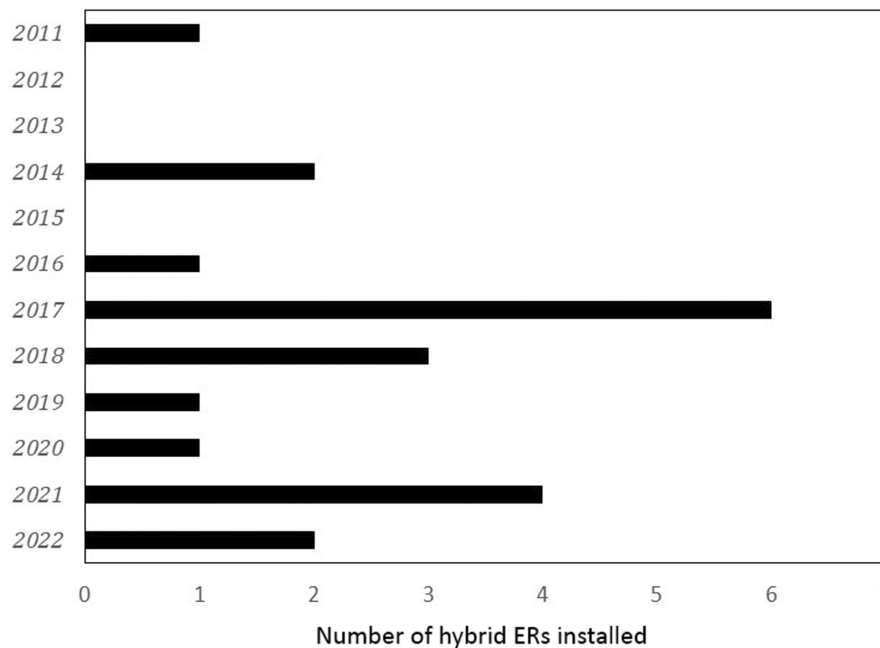
In 2011, a new trauma workflow concept that incorporated a sliding CT scanning system with interventional radiology (IR) features that was named the "hybrid ER" was installed into the ER of Osaka General Medical Center (Figure 1).<sup>9</sup> The study by Wada et al.<sup>9</sup> found significant reductions in time from arrival to CT, to damage control surgery, and to transcatheter arterial

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**FIGURE 1** Photograph showing our interventional radiology–computed tomography (CT) system in the emergency room. All life-saving procedures including airway management, emergency surgery, and transarterial embolization can be carried out on the table without relocating the patient. (A) Sliding CT scanner. (B) CT examination and intervention table. (C) Moveable C-arm. (D) 56-Inch monitor screen. (E) Ultrasonography equipment. (F) Mechanical ventilator.



**FIGURE 2** Graph showing the number of hospitals that installed a hybrid emergency room (ER) in Japan and the year of installation.

embolization in patients treated in the hybrid ER versus those treated conventionally (10 vs. 29 min,  $p < 0.001$ ; 45 vs. 108 min,  $p = 0.004$ ; and 54 vs. 75 min,  $p = 0.007$ , respectively).

With the hybrid ER, multiple emergency procedures such as damage control surgery and endovascular intervention could be carried out after early CT diagnosis without moving the patient. This novel trauma workflow allowing for immediate CT diagnosis and rapid control of bleeding without patient transfer was suggested to improve mortality in patients with severe trauma.<sup>10</sup>

## ESTABLISHMENT OF A HYBRID ER

### Current installations

Since the installation of the first hybrid ER, 21 trauma centers in Japan have now added a hybrid ER (Figure 2). We installed hybrid ER into the emergency department of Kansai Medical University General Medical Center in 2016. Each of these trauma centers reconsidered the feasibility of installing a hybrid ER and the efficiency it would offer and adopted

new concepts. One such concept was reported by Watanabe et al., in which a new table-rotated-type hybrid ER was devised to provide a wide working space and enhance immediate surgical functions during trauma resuscitation.<sup>11</sup>

## Evaluation of the hybrid ER outside Japan

In the traditional trauma care systems in the United States (US), Tatum et al. noted that in the typical early hospital course of a severely hemorrhaging patient, valuable minutes are wasted as the patient is transferred from the trauma resuscitation bay to the operating room or angiography suite, with a potential delay also incurred for additional radiological imaging, and this extended journey can be fatal for the patient.<sup>12</sup> They stated that the most novel recent advancement in attempts to reduce potentially preventable mortality from hemorrhage is the hybrid ER system devised in Japan and that it represents a significant step in reducing preventable deaths to zero. They realized, however, that even if the hybrid ER is proven to yield superior outcomes, significant obstacles to its adoption were present in the US. Such obstacles included the high cost of building and implementing the system, return on investment, and significant differences between Japan and the US in regard to physician training, trauma center operation, and reimbursement schemes, which might render installation of the hybrid ER unachievable in most current US trauma centers.

## Return on investment of the hybrid ER

The cost effectiveness of the hybrid ER in patients with severe trauma but without severe traumatic brain injury (TBI) was investigated by Kinoshita et al.<sup>13</sup> They reported that the hybrid ER was associated with a gain of 1.03 quality-adjusted life years (QALYs) and an increment of \$33,591 lifetime costs compared to the conventional ER system, resulting in an incremental cost-effectiveness ratio (ICER) of \$32,522 per QALY gained. The ICER was lower than the willingness-to-pay threshold if the odds ratio of 28-day mortality was <0.66. Probabilistic sensitivity analysis indicated that the hybrid ER was cost-effective with a 79.3% probability. Their cost-utility analysis compared the hybrid ER to the conventional ER system from the viewpoint of a third-party healthcare payer and found the hybrid ER to likely be a cost-effective strategy for treating these patients.

## High cost of building a hybrid ER and introduction of a dual-room hybrid ER

As a single-room solution, the hybrid ER can potentially affect the efficacy of other in/outpatient diagnostic workflow as only one room is required to treat a severely injured patient by providing both emergency trauma care and CT scanning. This resulted in an economic problem in that the efficacy of in/outpatient diagnostic workflow was reduced when the

hybrid ER was occupied. Recently, Frellesen et al. reported that a sliding-gantry CT as part of a dual-room solution without IR features saved significant time in the diagnostic workup of polytrauma patients, thus resulting in quicker resumption of the regular in/outpatient CT schedule.<sup>14</sup> Therefore, in July 2017, to increase patient throughput, we implemented a new trauma workflow concept that included a dual-room IR-CT in the emergency department of Kansai Medical University General Medical Center (Figure 3).<sup>15</sup> These two rooms are separated by moveable door, and the sliding CT scanner moves between these two rooms depending on need. When we perform emergency surgery or IR procedures for a severely injured or ill patient in the hybrid ER, the sliding CT scanner is moved to the new CT suite, and we can perform CT scanning of another in/outpatient. Likewise, to provide treatment of two multiple trauma patients simultaneously, Kippnich et al. introduced a new, large-scale trauma resuscitation area with a dual-room sliding-gantry CT scanner.<sup>16</sup> They measured the time from patient arrival in the resuscitation room to the start of CT and of emergency surgery to evaluate the time process of trauma care achieved by use of a dual-room WBCT. The time to operation was reduced when compared to a historical control group treated in a single room with one WBCT scanner. They partly attributed their findings to the higher computing capacity and faster reconstruction capability of the CT scanner system and concluded that twin-CT technology was a fascinating tool with which to provide two multiple trauma patients high-quality trauma care simultaneously.

## Evidence for the benefits of the hybrid ER in various fields of emergency medicine and use with extracorporeal membrane oxygenation

The hybrid ER offers potential benefits for severely injured or ill patients requiring percutaneous coronary intervention supported by either veno-arterial extracorporeal membrane oxygenation (VA ECMO) or veno-venous ECMO (VV ECMO). The cannulae can be immediately and safely positioned with use of moveable C-arm fluoroscopy and ultrasonography equipment soon after early CT examination. As some researchers have reported,<sup>17-20</sup> initiation of VA or VV ECMO in the hybrid ER could be a safe and highly effective treatment to rescue severely injured or ill patients.

In regard to severe injury, Wada et al. reported on a pediatric patient with tracheobronchial injury who received VV ECMO in the hybrid ER as a bridge to definitive surgical intervention and was successfully treated surgically under ECMO support.<sup>17</sup> In the case of a hemodynamically unstable patient with a cardiac injury caused by impalement, Hara et al. reported that the injury was diagnosed by CT and managed by VA ECMO in the hybrid ER and by surgery in the operating room.<sup>18</sup>

Among patients with severe illness, Matsumura et al. reported a rare case of negative pressure pulmonary edema, which is a potentially life-threatening complication of general anesthesia with tracheal intubation. Because the patient could not





**FIGURE 3** Photographs showing the dual-room sliding computed tomography (CT) scanner system with interventional radiology features. The new CT suite has another radiolucent table. When we perform emergency surgery or interventional radiology for a severely injured or ill patient in the regular emergency room, the sliding CT scanner is moved to the new adjacent CT suite with the radiolucent table, where we can perform CT scanning of another in/outpatient.

be optimally managed with mechanical ventilation, VV ECMO could be started within 18 min of the patient's arrival in the hybrid ER without complications, and cardiopulmonary arrest was prevented.<sup>19</sup> In patients with massive pulmonary embolism (PE) requiring extracorporeal cardiopulmonary resuscitation (ECPR), safe and prompt initiation of VA ECMO is essential. Miyazaki et al. reported on treatment in the hybrid ER of nine patients with PE requiring ECPR by VA ECMO, eight of whom survived.<sup>20</sup> Their experience showed that safer and more rapid cannulation and initiation of ECMO could be achieved in the hybrid ER and was likely effective for PE requiring ECPR.

### Workflow for resuscitation from cardiopulmonary arrest in the hybrid ER

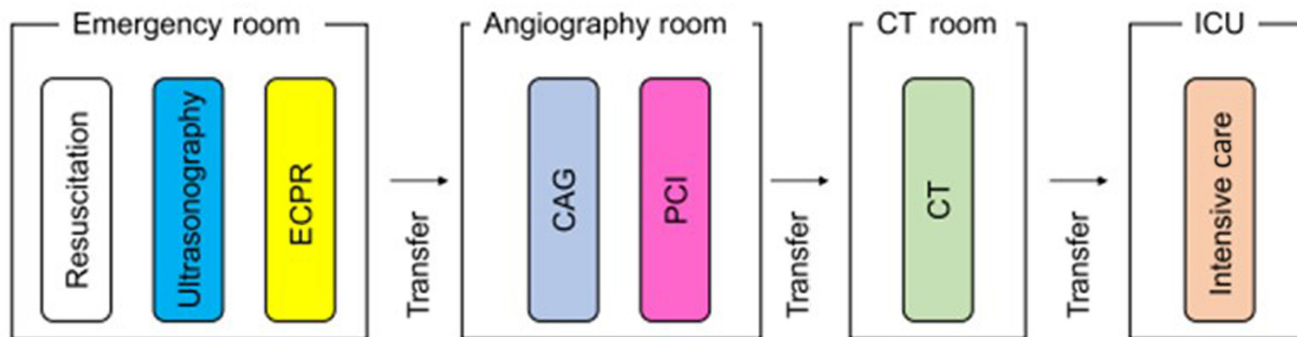
In selected patients with out-of-hospital cardiac arrest (OHCA), ECPR could increase survival and provide neurologic benefits. One retrospective study found that a hybrid ER could significantly reduce the incidence of complications

stemming from cannulation for ECMO.<sup>21</sup> Because of the potential of the hybrid ER to drastically shorten implementation time of ECPR and to more quickly facilitate definitive interventions than with conventional advanced cardiovascular life support workflow, the ECPR strategy in the hybrid ER was investigated in patients suffering OHCA. Hayashida et al. described the schematic concept of a hybrid ER system (HERS) that integrated workflow including ECPR (Figure 4). They reported that advanced cardiovascular life support with a HERS could be seamlessly followed by the induction ECPR and other post-ECPR procedures, including CT, coronary angiography, and percutaneous coronary intervention, all without transferring the patient.<sup>22</sup>

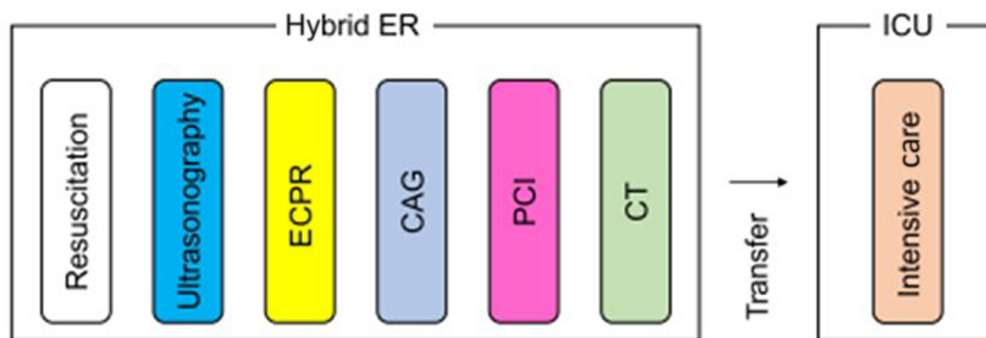
### Clinical experience with cerebral infarction in the hybrid ER

Early successful recanalization after the onset of symptoms following an acute ischemic stroke (AIS) is an important

## Conventional ECPR workflow



## Novel ECPR workflow using the hybrid ER



**FIGURE 4** Schematic of the integrated concept of workflow in the hybrid emergency room (ER) system. CAG, coronary angiography; CT, computed tomography; ECPR, extracorporeal cardiopulmonary resuscitation; ICU, intensive care unit; PCI, percutaneous coronary intervention.

factor affecting a favorable outcome. Kashiura et al. reported on a patient with AIS who underwent the entire process, from diagnosis to endovascular treatment, in the hybrid ER.<sup>23</sup> Patient door-to-puncture and door-to-reperfusion times were 85 and 159 min, respectively, shorter than those in patients treated conventionally for stroke in their institution. They found the hybrid ER facilitated evaluation and definitive interventions in patients with AIS more quickly and safely and in one place, with no need to transfer the patient to a CT scanner or angiography suite.

### Benefits and use of resuscitative endovascular balloon occlusion of the aorta in the hybrid ER

Morbidity and mortality rates are high in patients with a ruptured abdominal aortic aneurysm (rAAA). Leading to these risks are the highly time-consuming multiple transfers from the ER to the CT scanning room and then to the operating room for treatment. In contrast, both rapid, accurate diagnosis and definitive treatment of a rAAA can be achieved in the single hybrid ER room. In the successfully treated case of a patient with an rAAA, Murai et al. reported the rapid diagnosis and treatment of the condition in a hybrid ER, for which the door-to-intervention time was 35 min.<sup>24</sup> Their report indicated the potential

of the hybrid ER to enhance diagnostic speed and quality and definitive treatment of rAAA, which can lead to optimal outcomes. In contrast, in a recent national clinical registry study in the United States, among patients who had undergone emergency endovascular aneurysm repair for a rAAA, only 53.5% of the patients had a door-to-intervention time of  $\leq 90$  min.<sup>25</sup>

### Clinical experience with severe trauma in the hybrid ER

Preventable trauma death is defined as that in which significant delays occur before the control of exsanguinating hemorrhage can be achieved.<sup>26</sup> A multidisciplinary team needs to carry out the diagnostic evaluation and required therapeutic procedures concomitantly.<sup>27</sup> Time is crucial to the success of early management of multiple trauma patients,<sup>28</sup> and the hybrid ER can potentially resolve the time delay to CT scanning and definitive therapy. Since the installation of the first hybrid ER in 2011, trauma centers that have installed a hybrid ER have reported retrospective single-center cohort studies and case reports on their clinical experiences with, and the effectiveness of, the hybrid ER.

Kinoshita et al. was the first to report on the effectiveness of the installation of a hybrid ER in the trauma resuscitation

room on clinical outcomes and prognosis achieved with the innovative trauma workflow.<sup>10</sup> In their historical controlled study, time to initiation of CT (Conventional group 26 [21–32] vs. hybrid ER 11 [8–16] min;  $p < 0.0001$ ) and an emergency procedure (68 [51–85] vs. 47 [37–57] min;  $p < 0.0001$ ) were both shorter in the hybrid ER group. A significant association was found between the hybrid ER and decreased mortality (adjusted odds ratio [aOR], 0.50; 95% confidence interval [CI], 0.29–0.85;  $p = 0.011$ ) and reduced deaths from exsanguination (aOR, 0.17; 95% CI, 0.06–0.47;  $p = 0.001$ ). The times to initiation of CT and emergency bleeding control procedures were also both shorter in the hybrid ER group versus the Conventional group (11 [8–16] vs. 26 [21–32] min,  $p < 0.0001$ ; and 47 [37–57] vs. 68 [51–85] min,  $p < 0.0001$ , respectively).

The first retrospective observational study on blood transfusion amounts during resuscitation in the hybrid ER was reported by Watanabe et al. The amount of blood transfused was significantly lower in the hybrid ER versus non-hybrid ER group (whole blood: 8 vs. 14 units,  $p = 0.004$ ; red blood cells: 2 vs. 6 units,  $p = 0.012$ ; fresh frozen plasma: 6 vs. 9 units,  $p = 0.021$ ).<sup>29</sup> This difference remained after propensity score matching (whole blood: 6 [4–16.5] vs. 28 [10–54] units,  $p = 0.015$ ; red blood cells: 2 [0–8.5] vs. 8 [2.75–26.5] units,  $p = 0.020$ ; fresh frozen plasma: 6 [3.5–7.5] vs. 18 [5.5–27] units,  $p = 0.057$ ).

In patients with severe TBI and impending herniation, Kinoshita et al. reported that these patients can also benefit from the hybrid ER due to the ability to rapidly perform intracranial surgery and immediately deliver neurocritical care.<sup>30</sup> Likewise, in their historical, controlled study, Ito et al. reported that the hybrid ER improved the timeliness of angioembolization in patients with pelvic fracture, and the more severely injured patients could survive in the hybrid ER.<sup>31</sup>

In the hybrid ER, multiple emergency bleeding control can be applied in more than one body region of a patient. In patients with severe torso trauma that includes severe TBI, exsanguinating hemorrhage in the torso must be controlled and an optimal cerebral perfusion pressure must be maintained for neuroprotective therapy. Kinoshita et al. reported a good outcome in 10 patients who underwent concurrent bleeding control and intracranial pressure monitoring in the hybrid ER.<sup>32</sup> Wada et al. reported a case of severe multiple blunt trauma treated in the hybrid ER by combined total pneumonectomy, thoracic endovascular aneurysm repair, and trepanation for subdural hematoma along with intracranial pressure monitoring.<sup>33</sup>

Further studies involving a cluster randomized trial in multiple institutions with and without a hybrid ER is warranted to better assess the benefits of the hybrid ER. Important insights can be gained into the benefits of managing patients with time-critical injuries in a single-room solution by undertaking future collaborative studies that compare outcomes obtained with revolutionary systems to those obtained with conventional systems.

## Clinical experience with COVID-19 in the hybrid ER

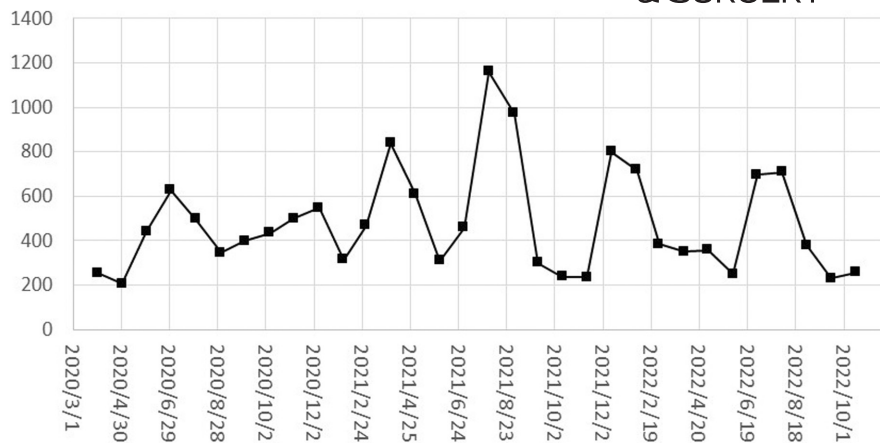
The coronavirus disease 2019 (COVID-19) pandemic has caused significant morbidity and mortality worldwide, including in Japan. Despite some hospitals with a hybrid ER having to accept many COVID-19 patients, avoidance of nosocomial infection was still very important. Ito et al. reported that they performed screening chest CT scans in their hybrid ER during the initial patient assessment, because plain chest CT was found to be beneficial in the screening for COVID-19 infection when the screening polymerase chain reaction or antigen test for COVID-19 was not sufficient.<sup>34</sup> This hybrid ER was a resuscitation room equipped with a CT scanner and an air conditioning system equivalent to that used in regular operating rooms. However, because they could not simultaneously accept other patients with no risk of COVID-19 while also taking steps to prevent nosocomial infections, their capacity to accept patients from ambulances was reduced. With a dual-room hybrid ER, however, this problem can be resolved. The two rooms are separated by a moveable door, and the sliding CT scanner can be moved between rooms as needed. If a severely injured patient is being treated in the hybrid ER and another COVID-19 patient is admitted, the patient can be examined in the adjacent CT suite. During the COVID-19 pandemic in Osaka prefecture, in the dual-room hybrid ER at Kansai Medical University General Medical Center, CT was safely performed on many admitted inpatients and outpatients with COVID-19 by utilizing the adjacent CT suite for COVID-19 patients while still maintaining throughput of severely injured patients in the hybrid ER. Over a 32-month period, approximately 15,000 patients with COVID-19 underwent CT scanning (Figure 5).

## INNOVATION OF THE HYBRID ER

### Training for best utilization of the HERS

To achieve optimal utilization of the hybrid ER in trauma care, a specialized team must be formed that is focused on effectively working within the hybrid ER. Ito et al. indicated that trauma management in the hybrid ER requires implementation of functions of the operating room and the angiography suite in the emergency department.<sup>35</sup> In addition to traditional trauma resuscitation team members (involving professionals from surgery, emergency medicine, and anesthesiology) and secondary subspecialties (orthopedics and neurosurgery), the hybrid ER requires personnel who can perform emergency transarterial embolization, including nurses and radiology technicians. Multidisciplinary conferences are usually held in each hospital to assess performance and promote teamwork. The Japanese Association for Hybrid Emergency Room System (HERS) was established in 2018, with its primary objectives being the standardization of trauma





**FIGURE 5** Number of COVID-19 patients undergoing computed tomography (CT) at Kansai Medical University General Medical Center from March 2020 to 2022. Squares indicate the number of COVID-19 patients undergoing CT performed in the dual-room hybrid emergency room (ER) at Kansai Medical University General Medical Center.

management protocols specialized for HERS, education and improvement of the sophistication of trauma teams, reduction of preventable trauma deaths to zero, and the increase in unexpected survivors. Although periodic meetings of the Association have been held on a limited basis during the COVID-19 pandemic, it is important that serious discussion of actual workflows in many interesting cases is undertaken and clinical protocols or guidelines for HERS will be discussed and established. As of March 2023, four meetings have been held, and the first edition of guidelines on ECPR and initial trauma care in the hybrid ER were established in 2021. Although the greatest advantage of the hybrid ER is the ability to obtain CT scanning quickly without patient transport, the importance of the assessment and intervention of impending problems regarding airway, breathing, and circulation before safely performing CT is described in this initial trauma care in the hybrid ER. In severe trauma patients at risk of imminent cardiopulmonary arrest, resuscitative thoracotomy (RT) or resuscitative endovascular balloon occlusion of the aorta (REBOA) should be preferred before CT scan. There is currently insufficient evidence about criteria for RT or REBOA in HERS. Although there is no report discussed about the criteria of tolerable circulatory dynamics to perform CT scans in the hybrid ER, each emergency physician should carefully judge the criteria for its implementation.

### Challenge of artificial intelligence in the hybrid ER

In the hybrid ER, patient diagnosis and treatment can be performed without transferring the patient, thus considerably reducing medical practice times. However, we have experienced cases in which the physicians determining the diagnosis and treatment could not keep up with the speed of care afforded by HERS. We thus feel that HERS needs a

function to assist the medical staff in their medical treatment of the patient. We envision a HERS that could collect medical information on vital signs, blood gas analysis, laboratory data, and CT scans of patients so that the entire process from diagnosis to treatment can be performed in one room. We made an integrated viewer, which assembles and displays the timeline information (vital signs, blood gas analysis, and laboratory data), alerts when there are dangerous changes in vital signs, and reads out the resulting information immediately. In the future, CT imaging information including the reading function of artificial intelligence should also be integrated into the platform. Efforts being made to aggregate this medical information with the use of artificial intelligence to assess the patient's condition and advise on the course of treatment might be the next evolution of care provided by HERS in the future.

### Potential disadvantages of the hybrid ER

#### Radiation exposure

Although there are no reports about assessment of radiation exposure in the hybrid ER, Watanabe et al. suggested that radiation exposure should be reduced for medical examination and an accurate dose of radiation should be assessed in the future.<sup>29</sup>

#### Infection

Ito et al. pointed out that, as the hybrid ER is located in the ER, there could be an increased risk of infectious complications with damage control surgery.<sup>35</sup> They discussed that further investigation is needed into the risks of infectious complications in patients undergoing surgeries in the ER.

## Education

The surgical team must facilitate themselves to perform damage control surgery and to collaborate with the IR team in the hybrid ER.<sup>35</sup> Therefore, hybrid ER institutions must implement a program to train general surgeons to perform emergency IR, which will lead sufficient available staff to undertake IR procedures to cover the 24 h/7 days on-call system. However, trauma patient care simulation is more important, because a multidisciplinary team involves treatment in the hybrid ER. Ito et al. developed a new trauma patient care simulation system by applying Extended reality technology to review the treatment workflow of patients who were treated in the hybrid ER. They reported that a more realistic simulation was accomplished by converting the CT image of an actual patient into a hologram and then projecting this hologram into a simulated real space observable by a multidisciplinary team.<sup>36</sup>

## CONFLICT OF INTEREST STATEMENT

Authors have no conflict of interest for this article.

## DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

## ETHICS STATEMENT

Approval of the research protocol: N/A.

Informed consent: N/A.

Registry and registration no. of the study/trial: N/A.

Animal studies: N/A.

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