

Endovascular Resuscitation and Trauma Management in the Hybrid Emergency Room System: Ideal Solution for Surgical, Endovascular and Radiological Trinity

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The concept of endovascular resuscitation and trauma management (EVTM) refers to endovascular techniques for resuscitation, hemorrhage control, and definitive trauma management. The use of EVT or computed tomography (CT) imaging is still limited in hemodynamically unstable patients. The hybrid emergency room system (HERS) is a suitable context to facilitate EVT. The HERS consists of an operating table with a C-arm and a sliding CT scanner system in the resuscitation area, allowing emergency diagnostic and therapeutic interventions without relocating the patient. The primary purpose of this study was to present the feasibility and assess the potential for the successful implementation of HERS. The second aim was to reduce concerns on the validity of this context and the third was to lay a foundation for planned intervention studies in EVT and HERS. In the HERS environment, endovascular treatment will be performed in the resuscitation room, which expands the indications of endovascular treatment to include hemodynamically unstable patients. HERS can also reduce the logistic burden and thus provide time to identify injuries with CT. Resuscitative endovascular balloon occlusion of the aorta (REBOA) is a viable adjunct treatment for refractory hemorrhagic shock but its procedure-related complications must be considered. In the HERS environment, REBOA can be performed more safely, rapidly, and accurately with fluoroscopy, followed by immediate definitive hemostasis without relocation. In addition, HERS may safely extend

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Author contributions: YM was responsible for drafting, editing, and submission of the manuscript. JM critically appraised the manuscript. KI, HO, TK, KH, TF, KY, SK, and SF contributed to the critical revision of the manuscript for important intellectual

content and provided intellectual input to the research and manuscript. All authors read and approved the manuscript.

Conflicts of interest: Yosuke Matsumura was a clinical advisory board member of Tokai Medical Products. None of the other authors have any conflicts of interest to declare.

Funding: None.

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the application of REBOA-CT to identify accurate injury sites. HERS may be an ideal EVTm solution for the trinity of surgery, endovascular treatment, and imaging in trauma care. We will continue to explore the most radical and safest EVTm in the HERS environment.

Keywords: *Computed Tomography; Interventional Radiology; Surgery; Resuscitative Endovascular Occlusion of the Aorta; REBOA; Hybrid ER*

Received: 27 December 2018; accepted: 20 January 2019

BACKGROUND

Hemorrhage is a leading cause of potentially preventable trauma death. Historically, open surgery was the only option to isolate and alleviate non-compressible torso hemorrhage [1]. However, endovascular treatment is now widely accepted as another essential hemostasis tool in cases of blunt trauma [2]. The concept of endovascular resuscitation and trauma management (EVTm) refers to the use of endovascular techniques for resuscitation, hemorrhage control, and definitive trauma management [3]. In this regard, the availability and quality of computed tomography (CT) have progressed rapidly thanks to emerging technologies. Furthermore, endovascular treatment has changed standard practices in the treatment of patients with blunt trauma. The popularity of resuscitative endovascular balloon occlusion of the aorta (REBOA) has grown globally. Nonetheless, the use of CT imaging and/or endovascular treatment in patients who are hemodynamically unstable is not standard in the current Advanced Trauma Life Support (ATLS) guidelines [1], and the indication is still limited.

In addition, “circulation” is prioritized over “disability” in the so-called “ABCDE approach,” even in the most recent ATLS guidelines [1]. The scanning and transferring of patients significantly delays hemostasis, resulting in critical circulation collapse. In the resuscitation area, to identify the hemorrhagic source, a focused assessment with sonography in trauma (FAST) examination is carried out, as is plain X-ray of the chest and pelvis. It is usually after this that CT scans of any traumatic brain injury (TBI) are obtained. However, this delay of neurological diagnosis in polytrauma patients with TBI could lead to critical morbidity or death [4].

To overcome the current limitations of endovascular procedures or CT imaging, the hybrid emergency room system (HERS) was introduced in 2011 [5]. It allows all emergency therapeutic interventions without relocating the patient. HERS is a modern trinity, bridging surgery, endovascular treatment, and CT imaging. The current paper proposes solutions to the current limitations of EVTm by using HERS.

Implementation of the HERS and Launch of the Japanese Association for HERS

The accurate CT-based identification of bleeding sites has expanded the indications for endovascular treatment.

Therefore, rapid access to a CT scanner, endovascular procedures, and an operating table are key innovations in trauma care. For this reason, Osaka General Medical Center (Osaka, Japan) installed an operating table with a C-arm and a sliding CT scanner system in the resuscitation area [5]. HERS is located in the resuscitation area of the emergency department, not in the radiology department or operating room (OR). Most open surgery, except for cardiovascular surgery or thoracic endovascular aortic repair, can be performed in the HERS. In addition, the HERS Institute installed a high-quality air flow the same as in the OR. Emergency procedures are prioritized 24/7, thus each procedure time should be limited, usually within 60 mins.

In the dual room HERS system, the sliding gantry CT scanner emerges from the neighboring room to the patient in the angio-resuscitation room (Figure 1a, Supplement 1). After scanning, the CT scan may work independently for other patients during the surgery or angiography (Figure 1b, Supplement 1). An elective or non-emergent CT scan or fluoroscopic procedures may be planned in the dual room HERS system to increase the occupancy rate in a moderate volume center. HERS absolutely has the risk of overlap with new emergent trauma cases, especially in a high volume center. Trauma leaders need to coordinate and deny full treatment in HERS, and to force the trauma team to move to the OR or angiography suite when receiving multiple patients.

Within our “HERS” terminology, the term “hybrid” refers to the combination of examinations and treatments in the same space. This differs from other uses of the term, such as in “Hybrid OR,” which is the combination of “surgery” and “angiography.” Because HERS is widely used in Japan, we launched the Japanese Association for HERS (JA-HERS) on June 21, 2018, in Kyoto, Japan. JA-HERS has been exploring the ideal utilization of HERS.

Innovative Use of Time-Rigorous Interventional Radiology in Trauma

Endovascular embolization, the most frequently employed endovascular treatment procedure in patients with trauma, is widely used to control hemorrhage in torso trauma, such as pelvic or solid organ injuries. In all patients with severe trauma, time to hemostasis is a critical factor. This is known as the “golden hour.” Meanwhile, the time from a patient’s arrival until their angiography

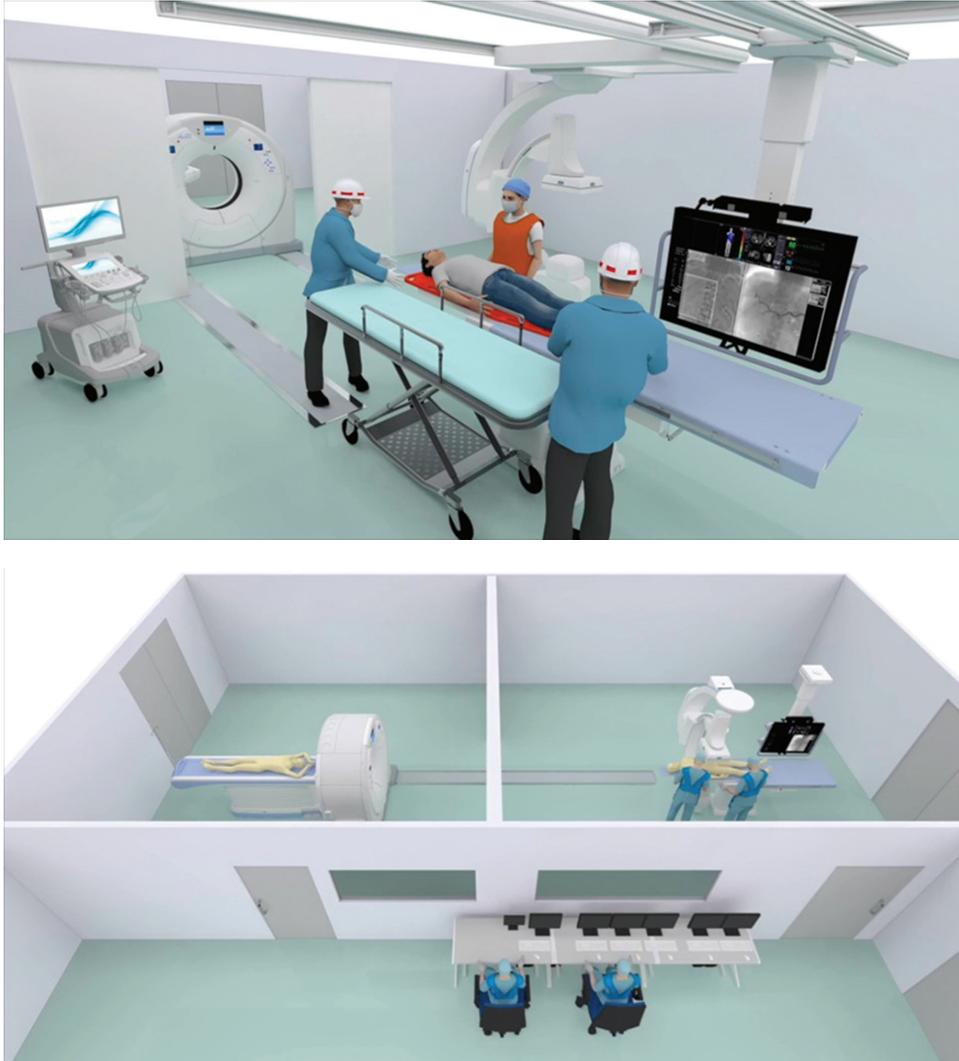


Figure 1 The dual room type hybrid emergency room system. **(a)** The patient is transferred to the angio-resuscitation room. The sliding gantry CT scanner comes from neighboring room to achieve immediate and safe scan even in a hemodynamically unstable patient. Surgery or embolization can be performed without moving elsewhere. **(b)** CT scan works independently in the neighboring room for other patients during the surgery or angiography.

examination can be several hours, even in Level 1 trauma centers in the United States [6]. One of the reasons why embolization might not be the current treatment of choice in unstable patients is because it, in general, is time-consuming and in most centers results in a patient transfer. Since endovascular embolization delays are related to an increased risk of in-hospital mortality [7], to employ rapid embolization will benefit hemodynamically unstable patients in a forthcoming trauma care system [8,9].

To maximize the potential benefits of endovascular treatment, the concept of “Prompt and Rapid Endovascular strategies in Trauma Occasions” (PRESTO) has been proposed [9]. PRESTO is characterized by a time-rigorous workflow that can deliver prompt and effective diagnosis and treatment to patients with severe

exsanguinating injuries. This concept has recently received much attention in EVTm. In the PRESTO protocol, the endovascular team should be activated before the patient’s arrival. The early activation of the endovascular team, quick focused evaluation of the CT images, and immediate rapid surgery or endovascular treatment reduce the time to hemostasis, potentially saving the patient’s life. With PRESTO, endovascular treatment can be used in hemodynamically unstable trauma patients, even in conventional trauma settings. However, such proactive endovascular treatment use in unstable patients does risk sudden collapse during the procedure. It also carries an inherent uncertainty due to variations in vessel anatomy and atherosclerosis, especially in elderly patients. Thus, it is not recommended in the current guidelines [1].

In the HERS environment, hemodynamically unstable patients can be scanned safely in the resuscitation area. Whole-body CT promptly provides precise information regarding the patient's injury, playing a pivotal role in decisions regarding endovascular-based treatment for trauma. Moreover, patients can undergo endovascular treatment without the need for transfer from the resuscitation area. Thus, PRESTO advances the use of endovascular treatment in patients with severe trauma, and the combination of HERS and PRESTO may expand the indications of endovascular treatment to include patients with hemodynamically unstable trauma.

Maximizing the Potential Benefits of Computed Tomography

Although CT findings confer accurate anatomical information, the technique was ridiculed as the “tunnel of death” in early days. However, a survival benefit of whole-body CT scan has been reported in several recent reports [10], although the results have been inconsistent [11], perhaps because the duration of the examination and quality of image reading can vary.

Japan has the longest life expectancy in the world (84.2 years; 2016), although life expectancy has increased in many other developed countries as well. For this reason, elderly patients who have suffered blunt injury and who are often taking antithrombotic agents present unexpected bleeding due to coagulopathy. In patients who have suffered polytrauma, physicians need to isolate and prioritize the main source of the bleeding. FAST examination and X-ray of the chest and pelvis evaluate only cavitory hemorrhages and pelvic fractures. However, retroperitoneal hemorrhage, which cannot be detected using FAST or X-ray, can lead to hemorrhagic death [12]. To control cavitory hemorrhage, open surgery is preferable, while endovascular treatment is preferred in the treatment of non-cavitory hemorrhage, including extra-pelvic retroperitoneal hemorrhage, paravertebral hematoma, and lumbar artery injury, which present a “triple negative” (FAST, chest, and pelvis X-ray) situation in the resuscitation room. Whole-body CT can identify whether patients should undergo endovascular treatment rather than open surgery [13]. Although the ATLS guidelines do not recommend scanning hemodynamically unstable patients, trained teams and regular drilling could shorten the duration of whole-body CT to approximately 7 minutes [14]. Although scanning patients may delay the start of surgery, it may also expedite the completion of the surgery by revealing the location of injuries and allowing surgeons to choose the appropriate hemostasis modality [15].

Because HERS can reduce scanning time, it increases the likelihood that unstable patients will be scanned safely and that unexpected injuries will be identified. According to the ABCDE approach in the ATLS, TBI evaluation, which prevents secondary brain injury, is to be carried out after hemostasis. However, earlier brain CT

may provide a red flag for possible neurological deterioration, leading to prompt neurosurgical intervention that can be performed simultaneously with hemorrhage control in HERS [16,17].

Rapid and Safe Resuscitative Endovascular Balloon Occlusion of the Aorta

REBOA is a viable adjunct treatment for refractory hemorrhagic shock [18]. It works as a bridge toward definitive hemostasis and can be used as a proximal control for subdiaphragmatic hemorrhage. Although REBOA constitutes minimally invasive aortic occlusion, particularly when compared to resuscitative thoracotomy, it is not a magic tool. Japanese observational study implied that REBOA delays definitive hemostasis [19]. Thus, subsequent immediate hemostasis using surgery and/or endovascular treatment must follow temporary stabilization with REBOA. The HERS confers safe and rapid hemostasis without the need for patient relocation.

Even though REBOA is minimally invasive, its procedure-related complications must be considered [20]. REBOA can be carried out under ultrasound guidance or portable X-rays outside the angiography suite. However, fluoroscopy also helps ensure that REBOA is performed more safely, rapidly, and accurately. Fluoroscopy accurately visualizes the occlusion zone of the aorta without any external measurement. It also immediately notifies the operator when they have misinserted the guidewire or catheter into the vena cava. Thus, it is of great help, especially in the elderly patients with a tortuous aorta, as are often seen in developed countries with aging societies. In summary, HERS is an ideal environment to employ REBOA in life-threatening situations.

Current Limitations and Future Directions of HERS

HERS may change trauma care drastically. However, it has several limitations. Firstly, no standard workflow has yet been established, unlike current ATLS initial assessment and resuscitation. FAST and X-ray can be omitted during HERS, but obstructive shock evaluation, intubation timing, CT scan duration, and scan protocol during HERS have not been well examined. Secondly, HERS requires a trained trauma team consisting of multidisciplinary professions—previous reports have shown that estimated mortality rose temporarily during the first year of HERS implementation and then decreased to lower than baseline [16]. Despite these limitations, HERS may be an ideal EVTm solution for the trinity of surgery, endovascular treatment, and imaging in civilian trauma care. We at the JA-HERS will continue to explore the most radical and safest EVTm in the HERS environment.

SUPPLEMENTARY DIGITAL CONTENT

Supplementary material related to this article can be found, in the online version.

ACKNOWLEDGMENTS

We thank all the founding members of the Japanese Association for Hybrid Emergency Room System: Kazuma Yamakawa, Satoshi Fujimi, Atsushi Watanabe (Osaka General Medical Center, Osaka), Kazuhiro Sugiyama (Tokyo Metropolitan Bokutoh Hospital, Tokyo), Michiaki Hata (Yonemori Hospital, Kagoshima), Takashi Moriya (Saitama Medical Center Jichi Medical University, Saitama), Shigenari Matsuyama (Hyogo Emergency Medical Center, Hyogo), Takashi Fujita (Teikyo University School of Medicine, Tokyo), Yasushi Nakamori (Kansai Medical University General Medical Center, Osaka), Hiroaki Watanabe (Shimane University Faculty of Medicine, Shimane), Tomohiro Funabiki (Saiseikai Yokohamashi Tobu Hospital, Kanagawa), Shigeki Kushimoto (Tohoku University Graduate School of Medicine, Miyagi), Junichi Matsumoto (St. Marianna University School of Medicine, Kanagawa), Isao Ukai (Hyogo Prefectural Nishinomiya Hospital, Hyogo), Takahiro Kinoshita (Osaka University Graduate School of Medicine, Osaka).

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