

RESEARCH ARTICLE

Trends of in-hospital cardiac arrests in a single tertiary hospital with a mature rapid response system

Hohyung Jung¹ , Ryoung-Eun Ko¹ , Myeong Gyun Ko², Kyeongman Jeon^{1,3*} 

1 Department of Critical Care Medicine, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea, **2** Intensive Care Unit Nursing Department, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea, **3** Division of Pulmonary and Critical Care Medicine, Department of Medicine, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea

 These authors contributed equally to this work.

* kjeon@skku.edu


 OPEN ACCESS

Citation: Jung H, Ko R-E, Ko MG, Jeon K (2022) Trends of in-hospital cardiac arrests in a single tertiary hospital with a mature rapid response system. PLoS ONE 17(1): e0262541. <https://doi.org/10.1371/journal.pone.0262541>

Editor: Simone Savastano, Fondazione IRCCS Policlinico San Matteo, ITALY

Received: September 28, 2021

Accepted: December 28, 2021

Published: January 13, 2022

Peer Review History: PLOS recognizes the benefits of transparency in the peer review process; therefore, we enable the publication of all of the content of peer review and author responses alongside final, published articles. The editorial history of this article is available here: <https://doi.org/10.1371/journal.pone.0262541>

Copyright: © 2022 Jung et al. This is an open access article distributed under the terms of the [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Data Availability Statement: The data that support the findings of this study cannot be shared publicly because of legal and ethical restrictions, however, data can be made available to interested researchers upon request. Requests can be

Abstract

Background

Most studies on rapid response system (RRS) have simply focused on its role and effectiveness in reducing in-hospital cardiac arrests (IHCAs) or hospital mortality, regardless of the predictability of IHCA. This study aimed to identify the characteristics of IHCAs including predictability of the IHCAs as our RRS matures for 10 years, to determine the best measure for RRS evaluation.

Methods

Data on all consecutive adult patients who experienced IHCA and received cardiopulmonary resuscitation in general wards between January 2010 and December 2019 were reviewed. IHCAs were classified into three groups: preventable IHCA (P-IHCA), non-preventable IHCA (NP-IHCA), and inevitable IHCA (I-IHCA). The annual changes of three groups of IHCAs were analyzed with Poisson regression models.

Results

Of a total of 800 IHCA patients, 149 (18.6%) had P-IHCA, 465 (58.1%) had NP-IHCA, and 186 (23.2%) had I-IHCA. The number of the RRS activations increased significantly from 1,164 in 2010 to 1,560 in 2019 ($P = 0.009$), and in-hospital mortality rate was significantly decreased from 9.20/1,000 patients in 2010 to 7.23/1000 patients in 2019 ($P = 0.009$). The trend for the overall IHCA rate was stable, from 0.77/1,000 patients in 2010 to 1.06/1,000 patients in 2019 ($P = 0.929$). However, while the incidence of NP-IHCA ($P = 0.927$) and I-IHCA ($P = 0.421$) was relatively unchanged over time, the incidence of P-IHCA decreased from 0.19/1,000 patients in 2010 to 0.12/1,000 patients in 2019 ($P = 0.025$).

directed to the secretariat of the department of critical care medicine (contact via hyerim37.jeong@samsung.com) or the corresponding author. Sharing of individual data is available only when the corresponding author requests to the Research Data Review Committee and obtains approval from the committee.

Funding: This work was supported by a Samsung Medical Center grant (SMO1200901). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing interests: The authors have declared that no competing interests exist.

Conclusions

The incidence of P-IHCA could be a quality metric to measure the clinical outcomes of RRS implementation and maturation than overall IHCAs.

Introduction

Despite the advances in the management of in-hospital cardiac arrest (IHCA) over the past decade, IHCA remains associated with poor outcomes [1,2]. However, while it is frequently preceded by a more gradual, possibly treatable, decline [3–6], many cases of IHCAs are considered preventable based on retrospective reviews [3,5–7]. To reduce the incidence of IHCA, a rapid response system (RRS) was designed to identify early signs of clinical deterioration and activate a specialized team of caregivers [8]. Most recently, the International Society of RRS recommends that hospitals collect data on IHCAs and their potential predictability [9].

A cardiac arrest is treated with cardiopulmonary resuscitation (CPR), which is lifesaving for patients who have a history of acute, potentially reversible illness. However, this is not effective if cardiac arrest occurs in patients in fatal conditions with terminal illness. “Do not attempt CPR” (DNACPR) decisions allow resuscitation to be withheld when the chance of success is little or when the burdens of CPR outweigh the benefits [10]. Nevertheless, physicians are occasionally faced with patients requesting full resuscitation against medical advice. More commonly, neither patients nor their family members make such a request, but physicians simply presume that providing CPR comports with the patient’s wishes [11,12]. Therefore, performing CPR on all IHCAs, regardless of the severity of the underlying illness and end-of-life medical decision, may be inappropriate [13]. In contrast, the implementation of RRS also increases the likelihood of DNACPR [14], which could be partially attributed to the reduced IHCA cases after RRS implementation but with a lesser impact on hospital mortality.

However, most studies on RRS have simply focused on its role and effectiveness in reducing IHCA or hospital mortality, regardless of the type of IHCA [8]. As a result, it has been difficult to determine the overall rate of potentially avoidable IHCA and if this rate is changing with implementation and maturity of RRS. Therefore, this study aimed to identify the rates and characteristics of IHCAs including predictability of the IHCAs as our RRS matures for 10 years, to determine the best measure for RRS evaluation.

Methods

Study design, setting, and participants

This retrospective observational study included all consecutive patients who experienced IHCA and received CPR in general wards at Samsung Medical Center, Seoul, South Korea between January 2010 and December 2019; this university affiliated tertiary referral hospital has a 1,989-bed capacity with a hospital-wide medical emergency team (MET) for the RRS. To address the primary research question of whether characteristics of IHCAs in hospitalized adult patients is associated with maturity of our MET over 10 years, we reviewed the clinical data of all treated IHCAs through the electronic medical records. This study was approved by the institutional review board of the Samsung Medical Center and performed in compliance with Helsinki declaration. The institutional review board waived the requirement for informed consent due to the observational nature of the research. Additionally, the patients’ information was anonymized and de-identified prior to analysis.

Operation of the RRS

The hospital-wide MET at the Samsung Medical Center was introduced at the beginning of March 2009, consisted of either fellows that were training in critical care or senior residents in internal medicine [15–18]. Since March 2013, the MET consists of dedicated intensivist physicians, including critical care fellows and attending intensivists, which provide round-the-clock coverage. All hospital medical personnel were presented with information about the MET and educated to prevent inadequate clinical assessments of patient deterioration that cause delays in the MET activation. Before implementation of the automated system, physicians and nurses directly contacted the MET using a dedicated phone number when a patient met any single criterion (Table 1). Activation was also allowed when the medical staff was concerned about changes in their patient's clinical condition, even in the absence of physiological disorders that meet the criteria. In August 2016, the MET initiated an automated alert and activation system for all ward patients using a modified early warning score (MEWS) [19]. The MEWS was automatically calculated using five physiological parameters (systolic blood pressure, heart rate, respiratory rate, body temperature, and level of consciousness) when nurses records the patient's vital signs on the electronic medical record. Patient vital signs were recorded at the bedside immediately after measurement using a laptop or portable device whenever possible. MEWS was automatically updated with each new vital sign recorded. The frequency of measuring vital signs was made according to the order of the attending physician, but vital signs were usually measured at least four times a day and more often when the patient's clinical condition changed. If the MEWS was 7 or higher, an automated alert was sent to MET as a text message in real-time, 24-hours a day, 7 days a week, and MET was automatically activated. Calls for MET activation were available for all patients regardless of do-not-resuscitate status during the study period.

When activated, the MET is expected to arrive within 10 min, complete patient assessments within 30 min, and order diagnostic tests and therapeutic treatments relevant to the patient's condition. In certain clinical problems requiring specialized expertise, other teams such as acute myocardial infarction team, acute stroke team, and acute care surgery team also can be activated. Following assessment and initial treatment, an individual treatment plan is created for each patient, and a joint decision is made about whether to transfer the patient to the intensive care unit (ICU). The issue of limitation on medical intervention and end-of-life care can also be discussed at this point. After assessment and therapeutic interventions by the MET,

Table 1. Calling criteria for the medical emergency team.

Airway and breathing	<ul style="list-style-type: none"> • Acute respiratory distress: respiratory rate ≥ 30 breaths/min • Acute hypoxia: oxygen saturation derived from pulse oximetry $< 90\%$ for 5 min, despite previous oxygen administration • Acute hypercapnia and acute acidosis: arterial carbon dioxide pressure > 50 mmHg and pH < 7.3 • Upper airway obstruction: stridor or use of respiratory accessory muscle
Circulation	<ul style="list-style-type: none"> • Unexplained hypotension: systolic blood pressure < 90 mmHg • Acute chest pain • Bradycardia or tachycardia: heart rate < 50 beats/min or > 130 beats/min • Arrhythmia with symptom
Neurology	<ul style="list-style-type: none"> • Sudden mental change or unexplained agitation • Seizure
Other	<ul style="list-style-type: none"> • Bedside concern about overall deterioration

<https://doi.org/10.1371/journal.pone.0262541.t001>

patients who are considered to require treatment and monitoring that cannot be provided outside of the ICU are transferred to the ICU, while patients in a stable condition remain on the general ward. For patients who are not fully stabilized and require intensive monitoring but are able to manage with lower levels of care than in the ICU, admission to the unit is decided on a case-by-case basis. The MET determined the patient's disposition and shared information about the advance care plan with the primary care team. Discussion about end-of-life care and ceiling of care were also included in certain patient populations. The decisions about completion of intervention and disposition were left to the judgment of each member of the MET without specific criteria, but the decision making generally followed international guidelines [20].

Details of all MET calls were recorded as soon as possible after the event by a member of the team and were entered into a registry. This recorded patient demographics, reasons for the MET activation based on calling criteria, time of the first documented physiological disorder, modified early warning score, time of the MET activation and deactivation, vital signs at the time of the MET activation and deactivation, interventions delivered by the MET, and the final outcomes including the patient's disposition after the clinical episode [21,22]. These data were supplemented on the next day with a retrospective review of hospital medical records before registration for quality control of registry data.

Definitions

All IHCAs were classified into three groups [23,24]: Preventable IHCA (P-IHCA) was defined as a cardiac arrest with preexisting signs of acute physiologic disturbance that fulfilled the MET activation criteria from 8 hours to 30 minutes before arrest. Non-preventable IHCA (NP-IHCA) was defined as a cardiac arrest that occurred within 8 hours after admission, or without any record of vital signs within 8 hours before arrest, or within 30 minutes after drug administration or procedures, or from unexpected lethal arrhythmia; this includes cardiac arrest that occurred within 30 minutes after MET activation. Inevitable IHCA (I-IHCA) was defined as IHCA in patients who had already requested a DNACPR order or were in terminal health conditions. Cases that were difficult to be classified were resolved by consensus of the MET team.

Statistical analysis

The MET dose was calculated by the number of MET calls per annum divided by the total number of discharged patients per year, represented as cases per 1,000 patients. In addition, each rates of IHCAs according to the classification or in-hospital mortality was calculated by the number of IHCA or in-hospital mortality per annum divided and represented as cases per 1,000 patients. Data were presented as number and percentages. The annual changes of the numbers and rates were analyzed with Spearman correlation analysis and Poisson regression models, respectively. All data were analyzed using SPSS version 22 (IBM Corp., Armonk, NY).

Results

During the 10-years study period, 843,180 patients were admitted to Samsung Medical Center and a total of 824 consecutive IHCAs were recorded for adult patients. After excluding duplicated CPRs for the same IHCAs ($n = 24$), a total of 800 treated IHCAs with CPR on the general ward were retrieved for the primary analysis (0.95/1,000 patients). The baseline characteristics of 800 IHCA patients are given in [Table 1](#). There were 467 (58.4%) male, and the median age was 64.5 (IQR, 53.0–74.0) years. Malignant disease (47.8%) and cardiovascular disease (26.8%) were the most frequent comorbidities. The median hospital admission day before arrest was

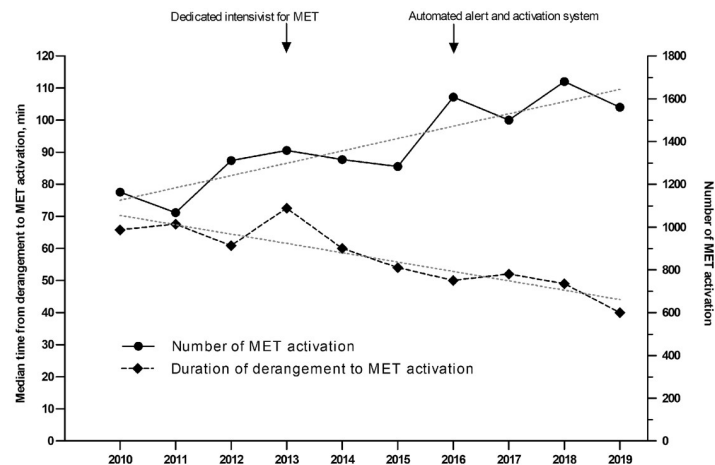


Fig 1. Medical emergency team (MET) maturation per year since 2010. The circles and lines represent of the number of MET activations. The number of MET activations increased from 1,164 in 2010 to 1,560 in 2019 (P for trend = 0.002). The diamonds and dotted lines represent the time from derangement to MET activation. The time from derangement to MET activation decreased from 66 minutes in 2010 to 40 minutes in 2019 (P for trend < 0.001). MET, medical emergency team.

<https://doi.org/10.1371/journal.pone.0262541.g001>

9.7 (IQR 4.0–22.7) days. The most IHCA was occurred during weekdays (68.9%) and half of events occurred at daytime. Common location was general ward (58.3%), followed by monitoring room (36.4%). Cardiovascular (29.5%) was common cause of arrest, and 50.6% initially presented with pulseless electrical activity rhythm. Extracorporeal cardiopulmonary resuscitation was applied to 22 (7.2%) patients.

As MET matured, the number of the MET activations increased significantly from 1,164 in 2010 to 1,560 in 2019 ($P = 0.002$) (Fig 1). In addition, the median time from derangement to MET activation decreased from 66 minutes in 2010 to 40 minutes in 2019 ($P < 0.001$).

Of the 800 IHCA patients, 149 (18.6%) had P-IHCA, 465 (58.1%) had NP-IHCA, and 186 (23.2%) had I-IHCA (Table 2).

Among 252 patients (31.5%) survived at discharge, only 121 (15.1%) patients were managed by our MET within 24 hours before the IHCA. However, the MET dose was relatively unchanged over time ($P = 0.531$), since the number of admitted patients increased from 72,468 in 2010 to 100,788 in 2019 ($P < 0.001$). Finally, in-hospital mortality rate was significantly decreased from 9.20/1,000 patients in 2010 to 7.23/1,000 patients in 2019 ($P = 0.004$) (Table 3).

The trend for the overall IHCA rate was stable from 0.77/1,000 patients in 2010 to 1.06/1,000 patients in 2019 (P for trend = 0.720) (Fig 2). However, the incidence of NP-IHCA (P for trend = 0.382) and I-IHCA (P for trend = 0.054) was relatively unchanged over time, while that of P-IHCA decreased from 0.19/1,000 patients in 2010 to 0.12/1,000 patients in 2019 (P for trend = 0.006) (Fig 2).

Discussion

This study investigated the change of overall and various type of IHCAs following RRS implementation and maturation over 10 years. The major finding is that the RRS call had been increased significantly as the RRS had been matured, and the P-IHCA and in-hospital mortality were decreased significantly. However, the overall rate of IHCAs did not change significantly during the study period.

Table 2. Clinical characteristics of in-hospital cardiac arrests (N = 800).

Variables	No. of patients or median (IQR)
Sex, male	467 (58.4)
Age, year	64.5 (53.0–74.0)
Medical department admission	583 (72.9)
Comorbidities	
Cardiovascular disease	214 (26.8)
Respiratory disease	36 (4.5)
Malignant disease	382 (47.8)
Central nervous system	63 (7.9)
Hepatobiliary disease	37 (4.6)
Chronic kidney disease	42 (5.3)
Documented treatment limitation	103 (12.9)
Hospitalization prior to arrest, day	9.7 (4.0–22.7)
IHCA day and time period	
Weekday	551 (68.9)
Daytime hours (8:00 ~ 18:00)	368 (46.0)
Location of arrest	
General ward	466 (58.3)
Monitoring room	291 (36.4)
Procedure room	18 (2.3)
Others	25 (3.1)
Monitored patients	543 (67.9)
MET activation within 24 hours of IHCA	121 (15.1)
Witnessed arrest	683 (85.4)
Presumed reason for arrest	
Cardiovascular arrest	236 (29.5)
Respiratory arrest	352 (44)
Hypovolemic shock	60 (7.5)
Sepsis	43 (5.4)
Brain injury	10 (1.3)
Anaphylaxis	8 (1.0)
Unknown	91 (11.4)
Initial rhythm	
Shockable	147 (18.4)
Pulseless electrical activity	405 (50.6)
Asystole	216 (27.0)
Not available	32 (4.0)
Extracorporeal cardiopulmonary resuscitation	58 (7.2)
Classification of IHCA	
P-IHCA	149 (18.6)
NP-IHCA	465 (58.1)
I-IHCA	186 (23.2)
Survivor at hospital discharge	252 (31.5)

No., number; IQR, interquartile range; IHCA, in-hospital cardiac arrest; P-IHCA, preventable in-hospital cardiac arrest; NP-IHCA, non-preventable in-hospital cardiac arrest; I-IHCA, inevitable in-hospital cardiac arrest; MET, medical emergency team.

<https://doi.org/10.1371/journal.pone.0262541.t002>

Table 3. Annual trend of the MET activation and in-hospital mortality.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	P for trend
Number of MET activation	1,164	1,068	1,311	1,359	1,316	1,284	1,608	1,500	1,680	1,560	0.002
MET dose, /1000 patients	16.1	14.6	18.0	16.4	14.8	16.9	17.8	16.1	18.3	15.5	0.603
In-hospital mortality, /1000 patients	9.20	10.10	9.64	8.13	8.14	8.37	8.10	8.26	7.97	7.23	0.004
Admitted patients	72,468	73,308	72,960	83,100	89,064	75,852	90,588	93,384	91,668	100,788	<0.001

MET, medical emergency team.

<https://doi.org/10.1371/journal.pone.0262541.t003>

Although there is no standard measure for evaluating the maturity of RRS from the existing literature on RRS maturity, several studies have revealed the correlation of the number of activation with the maturity of RRS [25–27]. In a long-term observational study, Herod R et al. found that progressively increased number of RRS activations concurred with lower hospital mortality [25]. Moriarty JP et al. also found that the reduction in rescue failure rates was associated with a substantial increase in the number of RRS activation [26]. In addition, timeless response to patient deterioration has been recommended as quality metrics of RRS process [9], since delayed activation of RRS is associated with higher in-hospital mortality [28,29]. In the present study, the increased number of the RRS activations and decreased the time from derangement to RRS activation concurred with lowered in-hospital mortality over 10 years, although no causality could be concluded. Therefore, it might be considered that our RRS has matured over the past decade.

Several previous studies have shown reduced incidence of IHCA after the implementation and maturity of RRS [30,31]. However, these studies simply focused on reducing IHCA regardless of the predictability of IHCA, although the overall rate of IHCA might be limited for the evaluation of RRS [8]. Therefore, potentially preventable IHCA, rather than total number of IHCA, is recommended as a quality metric for the evaluation of RRS by the International Society of RRS [9]. In this study, the trend for the overall IHCA rate was stable with maturity of our RRS over 10 years. The lack of change in the overall rate of IHCA might be associated with the number of I-IHCA that were not suitable for resuscitation, which

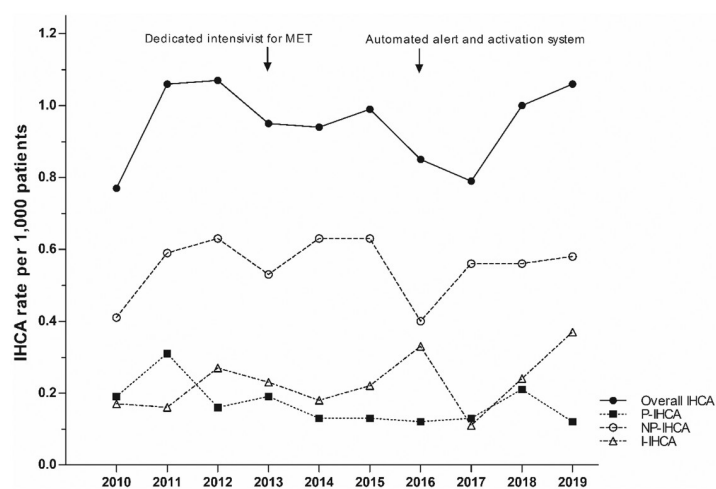


Fig 2. Annual trend of in-hospital cardiac arrests (IHCA) by classification. P-IHCA, preventable in-hospital cardiac arrest; NP-IHCA, non-preventable in-hospital cardiac arrest; I-IHCA, inevitable in-hospital cardiac arrest.

<https://doi.org/10.1371/journal.pone.0262541.g002>

contributed to the overall rate of IHCAs. Therefore, 23.2% of IHCAs might receive inappropriate CPR despite the futile situation reflecting both a low chance of survival and likely poorer quality of life afterward if spontaneous circulation is returned. This highlights a potential problem with using the overall rate of IHCAs as an outcome measure for RRS, which could explain the failure of previous studies to demonstrate consistently the efficacy of RRS in decreasing total hospital mortality [32].

Our results indicate that the most common circumstances of P-IHCAs were sudden critical illness in under-monitored patients and delays in initiating RRS response for monitored patients who met crisis criteria, which are consistent with previous reports [3,5–7]. Therefore, more IHCAs might be preventable by closer monitoring on floors and by preventing delays in addressing deterioration in patient condition. Effective risk management necessitates that preventable IHCA is minimized. Therefore, the effort for reducing preventable IHCA, rather than overall IHCA, could be a more appropriate quality metric to measure the clinical outcomes of RRS implementation and maturation; however, inconsistent definitions have limited its generalizability in a wide range of healthcare settings [9].

Although this study provides additional information on a more appropriate quality metric for RRS implementation and maturation using simple methods that are reproducible within the existing resources of most hospitals, there are several limitations that should be acknowledged. First, the study was limited by its inherent retrospective observational nature. However, data on treated IHCAs were prospectively collected from consecutive patients received CPRs. Therefore, our cohort is more likely to reflect the patients encountered in routine practice and thus can be readily applicable in similar settings. Second, the present study was conducted at a single institution with physician-based MET. Accordingly, our findings may have limited generalizability in other RRS. Finally, an automated alert and activation system was integrated into the original RRS activation process in August 2016. However, this change of activation process could be itself a sign of the maturation of our RRS (S1 Table).

Conclusion

In conclusion, the incidence of P-IHCA could be a more appropriate quality metric to measure the clinical outcomes of RRS implementation and maturation than overall IHCA.

Supporting information

S1 Table. Comparison of MET activation, incidence of IHCAs, and in-hospital mortality before and after implementing the automated alert and activation system in August 2016. (DOCX)

Author Contributions

Conceptualization: Kyeongman Jeon.

Data curation: Hohyung Jung, Ryoung-Eun Ko, Myeong Gyun Ko.

Formal analysis: Hohyung Jung, Ryoung-Eun Ko, Kyeongman Jeon.

Funding acquisition: Kyeongman Jeon.

Investigation: Hohyung Jung, Ryoung-Eun Ko, Myeong Gyun Ko.

Methodology: Hohyung Jung, Ryoung-Eun Ko, Myeong Gyun Ko, Kyeongman Jeon.

Supervision: Kyeongman Jeon.

Visualization: Hohyung Jung, Ryoung-Eun Ko.

Writing – original draft: Hohyung Jung, Ryoung-Eun Ko, Kyeongman Jeon.

Writing – review & editing: Hohyung Jung, Ryoung-Eun Ko, Myeong Gyun Ko, Kyeongman Jeon.

References

1. McGrath RB (1987) In-house cardiopulmonary resuscitation—after a quarter of a century. *Ann Emerg Med* 16: 1365–1368. [https://doi.org/10.1016/s0196-0644\(87\)80420-1](https://doi.org/10.1016/s0196-0644(87)80420-1) PMID: 3318591
2. Fennessy G, Hilton A, Radford S, Bellomo R, Jones D (2016) The epidemiology of in-hospital cardiac arrests in Australia and New Zealand. *Intern Med J* 46: 1172–1181. <https://doi.org/10.1111/imj.13039> PMID: 26865245
3. Schein RM, Hazday N, Pena M, Ruben BH, Sprung CL (1990) Clinical antecedents to in-hospital cardiopulmonary arrest. *Chest* 98: 1388–1392. <https://doi.org/10.1378/chest.98.6.1388> PMID: 2245680
4. Franklin C, Mathew J (1994) Developing strategies to prevent inhospital cardiac arrest: analyzing responses of physicians and nurses in the hours before the event. *Crit Care Med* 22: 244–247. PMID: 8306682
5. Smith AF, Wood J (1998) Can some in-hospital cardio-respiratory arrests be prevented? A prospective survey. *Resuscitation* 37: 133–137. [https://doi.org/10.1016/s0300-9572\(98\)00056-2](https://doi.org/10.1016/s0300-9572(98)00056-2) PMID: 9715771
6. Kause J, Smith G, Prytherch D, Parr M, Flabouris A, Hillman K, et al. (2004) A comparison of antecedents to cardiac arrests, deaths and emergency intensive care admissions in Australia and New Zealand, and the United Kingdom—the ACADEMIA study. *Resuscitation* 62: 275–282. <https://doi.org/10.1016/j.resuscitation.2004.05.016> PMID: 15325446
7. Hodgetts TJ, Kenward G, Vlackonikolis I, Payne S, Castle N, Crouch R, et al. (2002) Incidence, location and reasons for avoidable in-hospital cardiac arrest in a district general hospital. *Resuscitation* 54: 115–123. [https://doi.org/10.1016/s0300-9572\(02\)00098-9](https://doi.org/10.1016/s0300-9572(02)00098-9) PMID: 12161290
8. Lyons PG, Edelson DP, Churpek MM (2018) Rapid response systems. *Resuscitation* 128: 191–197. <https://doi.org/10.1016/j.resuscitation.2018.05.013> PMID: 29777740
9. Subbe CP, Bannard-Smith J, Bunch J, Champunot R, DeVita MA, Durham L, et al. (2019) Quality metrics for the evaluation of Rapid Response Systems: Proceedings from the third international consensus conference on Rapid Response Systems. *Resuscitation* 141: 1–12. <https://doi.org/10.1016/j.resuscitation.2019.05.012> PMID: 31129229
10. Field RA, Fritz Z, Baker A, Grove A, Perkins GD (2014) Systematic review of interventions to improve appropriate use and outcomes associated with do-not-attempt-cardiopulmonary-resuscitation decisions. *Resuscitation* 85: 1418–1431. <https://doi.org/10.1016/j.resuscitation.2014.08.024> PMID: 25195071
11. Georgiou L, Georgiou A (2019) A critical review of the factors leading to cardiopulmonary resuscitation as the default position of hospitalized patients in the USA regardless of severity of illness. *Int J Emerg Med* 12: 9. <https://doi.org/10.1186/s12245-019-0225-z> PMID: 31179942
12. Findlay GP, Shotton H, Kelly K, Mason M (2012) Time to intervene? A review of patients who underwent cardiopulmonary resuscitation as a result of an in-hospital cardiorespiratory arrest. A report by the National Confidential Enquiry into Patient Outcome and Death.
13. Johnson M, Whyte M, Loveridge R, Yorke R, Naleem S (2017) A Unified Electronic Tool for CPR and Emergency Treatment Escalation Plans Improves Communication and Early Collaborative Decision Making for Acute Hospital Admissions. *BMJ Qual Improv Rep* 6. <https://doi.org/10.1136/bmjquality.u213254.w6626> PMID: 28469900
14. Smith RL, Hayashi VN, Lee YI, Navarro-Mariazeta L, Felner K (2014) The medical emergency team call: a sentinel event that triggers goals of care discussion. *Crit Care Med* 42: 322–327. <https://doi.org/10.1097/CCM.0b013e3182a27413> PMID: 23989179
15. Lim SY, Park SY, Park HK, Kim M, Park HY, Lee B, et al. (2011) Early impact of medical emergency team implementation in a country with limited medical resources: a before-and-after study. *J Crit Care* 26: 373–378. <https://doi.org/10.1016/j.jcrc.2010.08.019> PMID: 21036527
16. Song JU, Suh GY, Park HY, Lim SY, Han SG, Kang YR, et al. (2012) Early intervention on the outcomes in critically ill cancer patients admitted to intensive care units. *Intensive Care Med* 38: 1505–1513. <https://doi.org/10.1007/s00134-012-2594-0> PMID: 22592633

17. Lee DS, Suh GY, Ryu JA, Chung CR, Yang JH, Park CM, et al. (2015) Effect of Early Intervention on Long-Term Outcomes of Critically Ill Cancer Patients Admitted to ICUs. *Crit Care Med* 43: 1439–1448. <https://doi.org/10.1097/CCM.0000000000000989> PMID: 25803653
18. Na SJ, Ko RE, Ko MG, Koh A, Chung CR, Suh GY, et al. (2020) Risk Factors for Early Medical Emergency Team Reactivation in Hospitalized Patients. *Crit Care Med* 48: e1029–e1037. <https://doi.org/10.1097/CCM.0000000000004571> PMID: 32941188
19. Subbe CP, Kruger M, Rutherford P, Gemmel L (2001) Validation of a modified Early Warning Score in medical admissions. *QJM* 94: 521–526. <https://doi.org/10.1093/qjmed/94.10.521> PMID: 11588210
20. (1999) Guidelines for intensive care unit admission, discharge, and triage. Task Force of the American College of Critical Care Medicine, Society of Critical Care Medicine. *Crit Care Med* 27: 633–638. PMID: 10199547
21. Devita MA, Bellomo R, Hillman K, Kellum J, Rotondi A, Teres D, et al. (2006) Findings of the first consensus conference on medical emergency teams. *Crit Care Med* 34: 2463–2478. <https://doi.org/10.1097/01.CCM.0000235743.38172.6E> PMID: 16878033
22. Peberdy MA, Cretikos M, Abella BS, DeVita M, Goldhill D, Kloeck W, et al. (2007) Recommended guidelines for monitoring, reporting, and conducting research on medical emergency team, outreach, and rapid response systems: an Utstein-style scientific statement: a scientific statement from the International Liaison Committee on Resuscitation (American Heart Association, Australian Resuscitation Council, European Resuscitation Council, Heart and Stroke Foundation of Canada, InterAmerican Heart Foundation, Resuscitation Council of Southern Africa, and the New Zealand Resuscitation Council); the American Heart Association Emergency Cardiovascular Care Committee; the Council on Cardiopulmonary, Perioperative, and Critical Care; and the Interdisciplinary Working Group on Quality of Care and Outcomes Research. *Circulation* 116: 2481–2500. <https://doi.org/10.1161/CIRCULATIONAHA.107.186227> PMID: 17993478
23. Galhotra S, DeVita MA, Simmons RL, Dew MA, Members of the Medical Emergency Response Improvement Team C (2007) Mature rapid response system and potentially avoidable cardiopulmonary arrests in hospital. *Qual Saf Health Care* 16: 260–265. <https://doi.org/10.1136/qshc.2007.022210> PMID: 17693672
24. Barrett J, Hawdon G, Wade J, Reeves J (2018) Measuring the success of Medical Emergency Teams: potentially preventable deaths versus total cardiac arrest deaths. A single centre observational study. *Intern Med J* 48: 264–269. <https://doi.org/10.1111/imj.13676> PMID: 29131479
25. Herod R, Frost SA, Parr M, Hillman K, Aneman A (2014) Long term trends in medical emergency team activations and outcomes. *Resuscitation* 85: 1083–1087. <https://doi.org/10.1016/j.resuscitation.2014.04.010> PMID: 24769054
26. Moriarty JP, Schiebel NE, Johnson MG, Jensen JB, Caples SM, Morlan BW, et al. (2014) Evaluating implementation of a rapid response team: considering alternative outcome measures. *Int J Qual Health Care* 26: 49–57. <https://doi.org/10.1093/intqhc/mzt091> PMID: 24402406
27. Kurita T, Nakada TA, Kawaguchi R, Fujitani S, Atagi K, Naito T, et al. (2020) Impact of increased calls to rapid response systems on unplanned ICU admission. *Am J Emerg Med* 38: 1327–1331. <https://doi.org/10.1016/j.ajem.2019.10.028> PMID: 31843333
28. Boniatti MM, Azzolini N, Viana MV, Ribeiro BS, Coelho RS, Castilho RK, et al. (2014) Delayed medical emergency team calls and associated outcomes. *Crit Care Med* 42: 26–30. <https://doi.org/10.1097/CCM.0b013e31829e53b9> PMID: 23989173
29. Calzavacca P, Licari E, Tee A, Egi M, Haase M, Haase-Fielitz A, et al. (2008) A prospective study of factors influencing the outcome of patients after a Medical Emergency Team review. *Intensive Care Med* 34: 2112–2116. <https://doi.org/10.1007/s00134-008-1229-y> PMID: 18651130
30. Santamaria J, Tobin A, Holmes J (2010) Changing cardiac arrest and hospital mortality rates through a medical emergency team takes time and constant review. *Crit Care Med* 38: 445–450. <https://doi.org/10.1097/CCM.0b013e3181cb0ff1> PMID: 20029341
31. Jones D, Mercer I, Heland M, Detering K, Radford S, Hart G, et al. (2017) In-hospital cardiac arrest epidemiology in a mature rapid response system. *Br J Hosp Med (Lond)* 78: 137–142.
32. Winters BD, Weaver SJ, Pfoh ER, Yang T, Pham JC, Dy SM (2013) Rapid-response systems as a patient safety strategy: a systematic review. *Ann Intern Med* 158: 417–425. <https://doi.org/10.7326/0003-4819-158-5-201303051-00009> PMID: 23460099