Reduction of hospital mortality and of preventable cardiac arrest and death on introduction of a pediatric medical emergency team*

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Objective: **To determine the effect of a medical emergency team (MET) on the incidence of unexpected cardiac arrest and death.**

Design: **Comparison of retrospective data (pre-MET) before introduction of MET with prospective data after introduction of MET system (post-MET).**

Setting: **Tertiary care pediatric hospital.**

Patients: **A total of 104,780 admissions during a 41-month period pre-MET; 138,424 admissions during 48 months post-MET.**

Interventions: **Introduction of a MET.**

Results: **Total hospital deaths decreased from 4.38 to 2.87/1000 admissions (risk ratio 0.65, 95% confidence interval [CI] 0.57–0.75, $p < 0.0001$). Ward unexpected death decreased from 13 (0.12/1000) to 6 (0.04/1000) (risk ratio 0.35, 95% CI 0.13–0.92, $p = 0.03$) but unexpected cardiac arrests did not change from 0.19/1000 to 0.17/1000 (risk ratio 0.91, 95% CI 0.50–1.64, $p = 0.75$). Thirty-four hospital deaths, including three unexpected deaths (1 out of 72 MET calls), were prevented each year of MET operation. Preventable cardiac arrest (children whose symptoms or signs fulfilled MET calling criteria) decreased from 17 (0.16/1000) to 10 (0.07/1000) (risk ratio 0.45, 95% CI 0.20–0.97, $p = 0.04$) and in whom death decreased from 12 to 2 (0.11/1000 to 0.01/1000) (risk ratio 0.13, 95% CI 0.03–0.56, $p = 0.001$). Non-preventable cardiac arrest (children whose symptoms or signs did not fulfill MET calling criteria) increased from 3 to 14 (0.03/1000 to 0.10/1000, $p = 0.03$) but death did not increase. Survival from cardiac arrest increased from 7 of 20 patients to 17 of 23 (risk ratio 2.11, 95% CI 1.11–4.02, $p = 0.01$). Annual calls for urgent assistance were 202 in the post-MET era and 46 during the pre-MET era (ratio 4.4:1).**

Conclusions: **Introduction of a MET was associated with reduction of total hospital death and reduction of preventable cardiac arrest and death with increased survival in wards of a pediatric hospital. MET calling criteria identified some but not all children at risk of unexpected cardiac arrest and death. (Pediatr Crit Care Med 2009; 10:306–312)**

Key Words: medical emergency team; cardiac arrest; death; children

Cardiac arrest in hospitalized children has a poor prognosis. In a meta-analysis of most retrospective reports (1), only 24% of 544 children were discharged from hospital after cardiac arrest and in a North American study (2) involving 156 hospitals, only 27% of 880 arrested children survived to hospital discharge. Death from unexpected but foreseeable cardiac arrest is an adverse event which may be preventable with timely intervention.

***See also p. 403.**

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In some hospitals with rapid response systems, specialized teams of doctors and nurses aim to treat critically ill patients before cardiac or respiratory arrest occurs. These teams are variously termed medical emergency teams (MET), rapid-response teams (RRT), or intensive care unit (ICU) outreach teams or services. Typically, a call for immediate assistance can be made by any ward-staff member when a child's clinical status attains predetermined clinical criteria.

A MET system was adopted by the Patient Safety Committee of The Royal Children's Hospital in 2002 after a review of unexpected patient deaths in general wards indicated that some cardiac arrests may have been foreseeable and possibly preventable. The perceived reasons for these cardiac arrests were sometimes the inability of both medical and nursing staff of all levels of training to recognize the signs of serious illness, lack of empowerment of junior staff to obtain assistance, delay in calling for help and in arrival of assistance, lack of readily available medical staff, or a combination of these factors.

A major feature of a MET service is the empowerment of junior staff, particularly nurses, to autonomously summon urgent assistance without deferring to senior nurses or medical members of the treating team, who may in any case, be unavailable. Nonetheless, even in hospitals with a well-established MET service with proven benefit, an allegiance to the traditional hierarchical approach may remain a barrier to calling the MET (3, 4).

Although 24% of 181 hospitals with >50 acute pediatric beds in United States and Canada have established activation criteria for immediate-response teams and have introduced some sort of rapid response system (5), reports of the outcomes of MET or RRT systems for children are few (6–10). A preliminary report of our pediatric MET service in 2005 (6), after the service had operated for 12 months following an analysis of cardiac arrest and death over the preceding 3½ years, suggested that the risk of unexpected cardiac arrest and death had decreased, but not significantly. This is a follow-up report of the effect of a MET service on unexpected cardiac arrest and death in a pediatric hospital after 4 years of operation.

MATERIALS AND METHODS

This study was conducted at the Royal Children's Hospital, Melbourne, Australia. It is a 215-bed inpatient tertiary care pediatric institution which serves a population of approximately six million, of whom approximately 1.5 million are children. It has 16 pediatric intensive care unit (PICU) beds and 22 neonatal intensive care unit beds. Sixty percent of the inpatient beds (including PICU and neonatal intensive care unit) have monitoring capability. We had already recorded the activity of a "code blue" (cardiorespiratory arrest) team, patient management, and outcomes (cardiac arrest and death) over the period from April 1999 to August 2002 (41 months). Then, after a 3-month period of staff education and introduction, we recorded activity of a MET service and patient outcomes over a similar period of time (48 months) from December 2002 until November 2006.

It was hypothesized that intervention on attainment of any call criteria would prevent subsequent cardiac arrest. The pediatric MET calling criteria were adapted from adult MET calling criteria with the addition of age-related abnormal recordings of heart rate, respiratory rate, and blood pressure. The full MET calling criteria are given in Figure 1 and differ only from our previous report (6) in that parents may also initiate a MET call. The MET system was introduced to all junior and senior hospital medical officers by mail in early September 2002. Then followed an extensive day and nighttime educational program for nurses and doctors over a period of 3 months. Informal open teaching for nurses and medical staff were held and additional educational sessions offered. "Sick child" workshops were introduced to reinforce the clinical features of serious illness and the MET calling criteria. The number of places in Advanced Pediatric Life Support courses was increased. A series of clinical practice reviews, open to all staff, were conducted in which the rationale and criteria for calling MET were presented with illustrative cases. This period was a transition from the previous pre-MET (code blue) era in which medical assistance was summoned urgently only when a patient was in cardiac or respiratory arrest.

Two additional nurses but no additional medical officers were appointed to the full-time staff of the ICU. The service was directed by the hospital's resuscitation officer (already appointed) and a nurse MET coordinating part-time position was created. The composition of the MET was initially five members comprising an ICU physician (consultant/registrar) and nurse, emergency department doctor, and nurse and medical registrar. After operation of the system for 6 months, the emergency department nurses withdrew from the service with the realization that four personnel were sufficient.

A key aspect of the system is that any staff member, irrespective of rank, may summon the MET without having to inform senior colleagues, and nurses may initiate a call without having to discuss the patient with physicians.

To summon MET, a staff member calls switchboard on a dedicated internal phone number. The MET team members are immediately notified of the location of the call by personal pagers, via an announcement on the public address system and by a telephone call from switchboard to the PICU. The response system is single tier, that is, it is not differentiated according to severity of the patient's condition, for example to regard cardiorespiratory arrest as a more urgent condition than respiratory distress alone. The MET members do not know the condition of the patient until their arrival at the scene. The MET members give immediate emergency treatment as required and then communicate with physicians otherwise responsible for the patient to formulate further management. The MET system operates 24 hrs/day, every day with no reduction of capability at any time.

We compared the occurrence of hospital death and the outcomes of cardiac arrest during eras of similar duration: 1999–2002 (41 months) when a code blue system (pre-MET) operated, with that during 2002–2006 (48 months) when MET operated (post-MET). We defined cardiac arrest as any need to give external cardiac compression (6, 11) and applied this to any child admitted to hospital irrespective of the duration of admission. We retrospectively examined the symptoms and signs of patients in the 6 hours before cardiac arrest (6) to determine whether they had fulfilled the MET calling criteria. We regarded cardiac arrest in children who had attained the calling criteria as "preventable" whereas arrests which had occurred in children without attaining calling criteria were "nonpreventable" by the MET system. To determine the effect of MET on unexpected cardiac arrest, we excluded non-inpatients, patients in the neonatal and PICUs, patients who arrested under anesthesia, and patients who were subject to a "do not resuscitate" order or subject to palliative care before cardiac arrest. Results were analyzed with Stata 9.0 (StataCorp, College Station, TX). Risk ratios of cardiac arrest and death before and after introduction of the MET service were analyzed with the two-sample test of proportion. Survival was defined as discharge from hospital. Permission was granted by our Human Ethics Committee for this study as a quality improvement exercise.

RESULTS

Pre-MET (code-blue era). In the code-blue era, total hospital deaths totaled 459 (4.38/1000 admissions) among 104,780 admissions including 266 deaths among 4666 admissions to ICU (5.7%). There were 166 ward calls for emergency assistance of which 28 were for unexpected cardiac arrest. Of these, five were for children who had arrived in the emergency department already in cardiac arrest, one was for an adult visitor and two were for children who had cardiac arrests in the operating theater. These eight were excluded from our analysis because their prearrest status was either unknown or not relevant to the issue of prevention, leaving 158 calls for inpatients. Thus, 20 children, mean age 3.6 years (range, 2 weeks–17 years), had unexpected cardiac arrests in this era (0.19/1000 admissions). Among these, preventable cardiac arrest occurred in 17 patients whose clinical condition fulfilled MET calling criteria and nonpreventable cardiac arrest in three whose condition did not fulfill MET calling criteria in the 6 hours before arrest (Table 1). Of the 13 patients (0.12/1000 admissions) who died (0.12/1000 admissions), 12 had fulfilled MET calling criteria and one had not. Seven patients (35%) survived. The initial cardiac rhythms at the time of arrest in these 20 patients were hypotensive–bradycardia 8 (40%), asystole 7 (35%), pulseless electrical activity 3 (15%), ventricular fibrillation 2 (10%). Outcomes from these dysrhythmias are shown in Table 2. The management of these arrests (and two more in the operating theater) is described elsewhere (11).

Post-MET Era. During this era, admissions to hospital totaled 138,424 with 398 deaths (2.87/1000 admissions) (average 100 per annum) including 228 deaths among 5753 ICU admissions (3.96%). Twenty-four unexpected cardiac arrests occurred in a total of 23 ward children with a mean age 3.5 years (range, 2 weeks–16 years). This yields an unexpected cardiac arrest rate of 0.17/1000 admissions. Preventable cardiac arrest occurred in 10 children whose condition had triggered a MET call, whereas nonpreventable cardiac arrest occurred in 14 children whose conditions had not been preceded by attainment of MET calling criteria (Table 1). Six children subsequently died (0.04/1000 admissions) of whom two had fulfilled MET calling criteria, whereas four did not. Seventeen patients (74%) survived. The initial cardiac rhythms were hypotensive–bradycardia 15 (63%), asystole 6 (25%), ventricular fibrillation 2 (8%), *any* ONE or more of:

1. Staff member or parent *worried* about clinical state
2. Airway threat
3. Hypoxaemia: SpO_2 <90% in any amount of oxygen
   SpO_2 <60% in any amount of oxygen (cyanotic heart disease)
4. Severe respiratory distress, apnoea or cyanosis
5. Tachypnoea

Age	Respiratory rate/min
Term-3 months	>60
4-12 months	>50
1-4 years	>40
5-12 years	>30
12 years+	>30

6. Tachycardia or bradycardia:

Age	Bradycardia beats/min	Tachycardia beats/min
Term-3 months	<100	>180
4-12 months	<100	>180
1-4 years	<90	>160
5-12 years	<80	>140
12 years+	<60	>130

7. Hypotension:

Age	BP (systolic mmHg)
Term-3 months	<50
4-12 months	<60
1-4 years	<70
5-12 years	<80
12 years+	<90

8. Acute change in neurological status or convulsion
9. Cardiac or respiratory arrest

- Some of the values for respiratory rate, heart rate and blood pressure are outside the normal ranges for age: they represent concerning levels that may indicate serious illness, and that require expert review.
- It is also important to look for worsening trends in vital signs and report these.
- If a child fulfils any of these criteria, notify the treating medical team and the MET service (via switchboard).

Figure 1. Criteria for activation of medical emergency team (*MET*). *BP*, blood pressure.

and pulseless electrical activity 1 (4%). Outcomes are shown in Table 2.

In this era, a total of 956 calls were made for emergency medical assistance. Of these, 809 were for inpatients and 147 were for visitors, staff, or outpatients. There were more MET calls during the day hours (0700–1900 hours) compared with the "out of hours" period (64% vs. 36%, $p < 0.001$) (Fig. 2). The ratio of calls for inpatients in the post-MET era compared with the pre-MET code blue era is 4.4:1. The children's ages were: <4 months, 161 (20%); ≥4 to <12 months, 124 (15%); ≥1 to <5 years, 206 (26%); ≥5 to <12 years, 132 (16%); ≥12 years, 184 (23%). The ages of two children are unknown.

Over this period, the principal triggers (nonexclusive) to call MET were low SpO_2 (46%); respiratory distress, apnea, or cyanosis (40%); "staff/parent worried (concerned) about patient" (26%); airway threat (23%); change in neurologic status (14%); tachycardia (14%); tachypnea (12%); seizures (12%); bradycardia (8%); hypotension (5%); cardiac arrest (2%); and respiratory arrest (1%). Sixty-four percent of calls for assistance were made by a nurse alone, 16% by a nurse and a doctor together, 10% by a doctor alone, and 10% by other personnel, including one call by a parent.

The principal therapies (nonexclusive) provided by the MET were oxygen (30%), resuscitative fluids (23%), bag-mask ventilation (19%), peripheral venous cannulation (17%), basic airway support (9%),

Table 1. Preventable and nonpreventable cardiac arrests before and after introduction of MET (preventable cardiac arrest: preceded by attainment of MET calling criteria within 6 hrs before arrest)

	Pre-MET	Post-MET
Preventable	(n = 17) Hypoxemia ● Two lung disease Airway obstruction ● One laryngotracheobronchitis ● One aspiration Hypotension ● Three septic shock ● Three postcardiac surgery ● One hypovolemic shock Tachypnea ● Four postcardiac surgery ● One mitochondrial disorder ● One septic shock-immune deficiency	(n = 10) Hypoxemia ● Two postcardiac surgery ● One lung disease ● One unoperated congenital heart disease ● One blocked tracheostomy tube Hypotension ● One posthypoxic-ischemic injury (near drowning) Tachycardia ● One sepsis ● One posthypoxic-ischemic injury Bradycardia ● One postcardiac surgery (pacemaker dysfunction) Neurological deterioration ● One cerebral hemorrhage
Nonpreventable	(n = 3) Sudden dysrhythmia ● Two postcardiac surgery ● One cerebral palsy	(n = 14) Sudden dysrhythmia ● Four postcardiac surgery ● Two cardiomyopathy ● One hypothyroidism (insertion of nasogastric tube) Sudden hypoxemia ● Three cerebral palsy aspiration ● Three postcardiac surgery Sudden loss of consciousness ● One cerebral hemorrhage

MET, medical emergency team.

Table 2. Initial dysrhythmias and outcomes (survivors, %)

	Pre-MET	Post-MET
Hypotensive–bradycardia	8 (6, 75)	15 (14, 93)
Pulseless dysrhythmias	12 (3, 25)	9 (3, 38)[a]
Asystole	7 (1, 14)	6 (2, 40)[a]
Ventricular fibrillation/ tachycardia	2 (0, 0)	2 (1, 50)
Pulseless electrical activity	3 (1, 33)	1 (0, 0)

MET, medical emergency team.
[a]One child experienced asystole twice, dying after the second.

endotracheal intubation (8%), continuous positive airway pressure or bilevel positive airway pressure (7%), and resuscitative drugs (4%). Infrequently needed therapies were external cardiac compression (2%), intraosseous cannula insertion (1%), and direct current shock (0.5%). In 16% of calls, only advice was required.

Overall, 47% of patients subject to a MET call were transferred directly to the ICU after stabilization on the ward. A further 26% were later reviewed on the ward by a MET member, 23% remained on the ward without further review, and 4% were transferred elsewhere, for example to the operating theater, to another ward, emergency department (for example from the day surgery unit), or who died at the time of the MET call on a ward (five patients).

Changes in Risk of Hospital Death and Ward Unexpected Cardiac Arrest and Death. The incidence of hospital death decreased from 4.38/1000 admissions to 2.87/1000 admissions (risk ratio 0.65, 95% confidence interval [CI] 0.57–0.75, $p < 0.0001$) with an average reduction of 34 deaths per annum (Table 3). The incidence of unexpected in-hospital ward deaths decreased from 0.12/1000 in the pre-MET era to 0.04/1000 in the post-MET era (risk ratio 0.35, 95% CI 0.13–0.92, $p = 0.03$) whereas the incidence of total unexpected ward cardiac arrest did not change from 0.19/1000 to 0.17/1000 (risk ratio 0.91, 95% CI 0.50–1.64, $p = 0.75$). One unexpected death was prevented for approximately every 12,400 admissions, which equates to three deaths per annum or one death every 72 MET calls. Among patients whose condition fulfilled MET calling criteria (preventable cardiac arrest), the incidence of arrest decreased from 0.16/1000 in the pre-MET era to 0.07/1000 in the post-MET era (risk ratio 0.45, 95% CI 0.20–0.97, $p = 0.04$) whereas the incidence of subsequent death decreased from 0.11/1000 to 0.01/1000 admissions (risk ratio 0.13, 95% CI 0.03–0.56, $p = 0.001$). Among patients whose condition did not fulfill MET calling criteria (nonpreventable cardiac arrest), the incidence of arrest increased from 0.03/1000 in the pre-MET era to 0.10/1000 in the post-MET era (risk ratio 3.53, 95% CI 1.02–12.3, $p = 0.03$) but the incidence of subsequent death did not change from 0.01/1000 to 0.03/1000 (risk ratio 3.03, 95% CI 0.34–27.09, $p = 0.30$). Survival from cardiac arrest increased from 7 of 20 patients to 17 of 23 (risk ratio 2.11, 95% CI 1.11–4.02, $p = 0.01$).

DISCUSSION

The aim of MET and similar services is to prevent unexpected in-hospital ward cardiac arrest with subsequent death. For this purpose, MET calling criteria aim to identify patients at risk, but the reliability of these criteria is unknown and may explain why our MET service reduced but did not eliminate unexpected cardiac arrest. Nonetheless, the introduction of a MET service seems to have significantly reduced the hospital total ward unexpected death rate by an approximate factor of three from 0.12 to 0.04/1000 admissions. Although the rate of total unexpected ward cardiac arrest was only slightly reduced from 0.19 to 0.17/1000 admissions, in the subgroup of patients whose condition fulfilled MET calling criteria ("preventable arrest group"), there was both a significant reduction in cardiac arrest (two-fold) and death (eight-fold). This suggests that our MET call criteria are effective in detecting and preventing unexpected cardiac arrest in most but not all children at risk.

Not only was there a reduction in preventable cardiac arrest but survival from unexpected cardiac arrest on wards increased from 35% to 74% after introduction of a MET service. This is in stark contrast to commonplace survival rates of <30% from hospital pediatric cardiac arrest (1, 2). We ascribe this to early recognition of the warning signs of cardiac arrest with prompt and capable intervention in early arrest when the patients were hypotensive but not pulseless. This is supported by the higher proportion of cases with initial hypotensive–bradycardia in the post-MET era (63%) compared with the pre-MET (40%). Of all

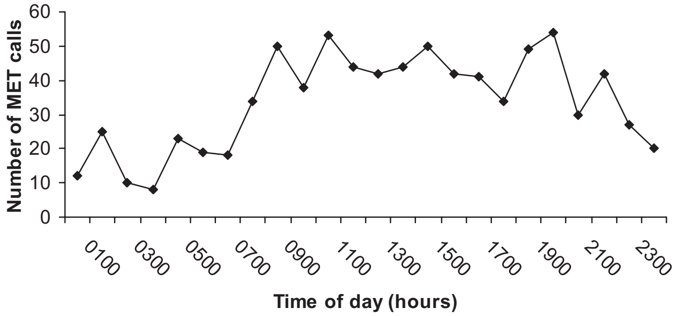

Figure 2. Diurnal-nocturnal occurrence of 809 medical emergency team (*MET*) calls over 4 years.

Table 3. Cardiac arrest and death (per 1000 admissions) and survival

	Pre-MET	Post-MET	Risk Ratio (95% Confidence Interval), p
Total hospital deaths	459 (4.38)	398 (2.87)	0.65 (0.57–0.75), <0.0001
Intensive care unit deaths	266 (57.0)	228 (39.6)	0.70 (0.58–0.83), <0.0001
Unexpected			
Cardiac arrest	20 (0.1909)	24[a] (0.1734)	0.91 (0.50–1.64), 0.75
Pulseless dysrhythmias	12 (0.1145)	9 (0.0650)	0.57 (0.24–1.35), 0.19
Hypotensive–bradycardia	8 (0.0763)	15 (0.1083)	1.42 (0.60–3.35), 0.42
Death	13 (0.1241)	6[a] (0.0433)	0.35 (0.13–0.92), 0.03
Survival	7	17[a]	2.11 (1.11–4.02), 0.01
Preventable			
Cardiac arrest	17 (0.1622)	10 (0.0722)	0.45 (0.20–0.97), 0.04
Death	12 (0.1145)	2 (0.0144)	0.13 (0.03–0.56), 0.001
Nonpreventable			
Cardiac arrest	3 (0.0286)	14 (0.1011)	3.53 (1.02–12.3), 0.03
Death	1 (0.0095)	4 (0.0289)	3.03 (0.34–27.09), 0.30

MET, medical emergency team.
[a]One child had two cardiac arrests and died after the second.

cardiac arrest dysrhythmias, hypotensive–bradycardia has the best survival at 60% compared with 27% for pulseless dysrhythmias (2).

During the study periods, the total hospital mortality declined 34% from 4.38/1000 admissions to 2.87/1000 admissions with deaths decreasing from an average 134 to 100 deaths per annum. Meanwhile, deaths in the PICU decreased from 5.70% to 3.96%, implying that the reduction of death on wards is not explained by transferral of patients to die in the PICU. Because of the long period of study, we cannot fairly claim that the entire reduction in total hospital deaths (average 34/annum) was due to introduction of a MET service as another institution has fairly claimed on a short-term basis (8), but we do claim that reduction of unexpected deaths preventable by the MET system has made a contribution. However, because a MET service involves not only a rapid response to defined clinical signs but also ongoing education, analysis of critical events, and feedback to ward staff (12), it is quite possible that the MET system has improved the overall standard of clinical care and prevented more cardiac arrests than detected by our analysis.

Although the MET system has improved outcomes, further improvements may be attainable. Because MET calling criteria are late manifestations of serious illness, it may be worthwhile identifying early the categories of children at risk of sudden deterioration. We have observed (13) that critical events in our institution, such as cardiac arrest, endotracheal intubation on the ward, reversal of opiate analgesia, need for fluid resuscitation, hypo/hypernatremia, hypoglycemia, and severe metabolic acidosis, are more likely to occur in children after recent surgery. We have not yet altered our original MET calling criteria (6) to include these factors, which may reduce further the incidence of unexpected cardiac arrest.

Our suite of MET calling criteria is based upon age-related physiologic variables, clinical signs, and clinical judgment and are more extensive than those in other pediatric studies (7–10). Although the rate of cardiac arrest and subsequent death was significantly reduced among patients whose clinical status triggered a MET call, there remained a cohort of patients whose cardiac arrest and death was not prevented, and a small percentage of calls required no active intervention. Sometimes cardiac arrest in children, as in adults, cannot be predicted, but the lack of complete elimination of these adverse events and the incidence, albeit small (16%), of calls requiring no intervention, underlines the important problem of the unknown sensitivity and specificity of our calling criteria.

Although other early pediatric warning scores or tools (calling criteria) have been described (14–16), their effects on the incidence of cardiac arrest have not been adequately evaluated. One prospective study (14) attempted to validate a suite of calling criteria but unsatisfactorily because it did not consider cardiac arrest and death in patients not activating a MET call and thus disallows calculation of true sensitivity and specificity (17). Another study likewise did not consider patients who did not activate a MET call but who may have required urgent assistance (15). Yet, another study (16) evaluated a combination of measured clinical data, previous patient history, and staff issues in matched cases to predict need for a code blue for cardiac arrest and yielded high sensitivity and specificity but its effect has not yet been evaluated.

The majority of MET calls (64%) occurred during day hours which is similar to that noted in a study of over 4000 MET calls in a large U.S. teaching hospital when 63% ($p < 0.001$) occurred during day hours (18). In contrast, another study from an Australian adult teaching hospital reported that a greater number of calls (53% of 2568 calls) occurred "out of hours" (19) although the time period was shorter (1800 to 0800 hours). The increased use of MET during the day time may be due to the greater number of operations and other invasive procedures occurring during this period. Alternatively, patient deterioration may be more likely to be detected when there is a greater presence of family members and more medical and nursing staff available (18).

It is possible that factors other than the operation of MET have altered the incidence of hospital death and of unexpected cardiac arrest and death in our institution. Foremost is better education of staff in recognition of critically ill children which is required on introduction of a MET service. Indeed, better education alone has been suggested as the real reason for better outcomes of MET services

(20). If this is the reason, it is an acceptable one, because the aim is to reduce unexpected preventable cardiac arrest and death whether by better education, better treatment or both, all of which are components of a MET system. Our study has been conducted over an approximate 8-year period. In that time, the pattern of admissions has not changed but staff turnover may have been an important and unknown factor. Initiatives other than introduction of MET may have improved the standard of ward care resulting in a reduction of cardiac arrest and mortality. These may include changes to contingency medical orders for administration of naloxone in cases of suspected therapeutic opiate overdose, increased frequency of pain service rounds, introduction of an ICU liaison nurse position (21), increased participation in Advanced Pediatric Life Support courses and Web-based availability of clinical practice guidelines on wards.

Bias may have been introduced into our study by our definition of cardiac arrest as the application of external cardiac compression rather than a state of pulselessness. At the risk of making a diagnosis based on treatment, we prefer the former functional definition because it is based on absent signs of circulation in addition to inability to feel a pulse. Furthermore, a diagnosis of cardiac arrest based on examination of the pulse alone by nurses and doctors in our institution is unreliable (22): in a study of simulated cardiac arrest (patients on extracorporeal life support), the pulse palpation test specificity was 0.64 and sensitivity 0.86, implying that rescuers are more likely to conclude that cardiac arrest is present when truly absent than to conclude it is absent when truly present. Accordingly, because hypotensive–bradycardia is defined as cardiac arrest under our definition, it is possible that its inclusion may yield different outcomes from cardiac arrest compared with other studies which focus on pulseless cardiac arrest (2). Nonetheless, we feel its inclusion is justified because it is not a benign condition. At our institution, it had an overall survival of 38% when including its occurrence in ICU (11), but in this study of ward arrests it had a survival of 75% in the pre-MET era and 93% in the post-MET era. Indeed, in another study of outcomes from cardiac arrest, hypotensive–bradycardia had a 60% survival (2). Another source of bias of outcomes from cardiac arrest may have been different treatments applied to the postarrest victim. We have not formally analyzed this possibility but add that we applied therapeutic hypothermia and extracorporeal life support when indicated to victims in both eras.

Yet, another source of bias may have been the 6-hour time period of analysis of clinical data before cardiac arrest to determine whether an arrest was preventable or not. The same period, however, was used in both pre-MET and post-MET analyses. This period was chosen because in adult studies (23, 24), the majority of patients experienced instability for this duration before cardiac arrest. Subsequently, a pediatric study determined that cardiac arrest may be predicted from 1 to 25 hours before cardiac arrest (16), but the optimum predictive time has not yet been determined.

This study supports literature on the utility of pediatric MET and similar services. Sharek et al (8) from Stanford University Lucile Packard Children's Hospital observed a significant 18% reduction in total mortality and an approximately 72% reduction in code rate (cardiac or respiratory arrest) 19 months after introduction of an RRT. At Stanford, the program prevented 21 deaths per annum compared with our 34 total deaths including 3 unexpected deaths per annum. Although the calling criteria for the RRT at Stanford are similar to our MET calling criteria, the total hospital death rate at our institution is considerably smaller at approximately 0.3% compared with approximately 1% thus making valid comparisons difficult. Brilli et al (7) from Cincinnati reported a pediatric study of shorter MET operation (8 months), which likewise showed reductions, although not significant, in cardiac arrest and death after introduction of a MET service. In other studies, introduction of a MET service did not decrease cardiac arrests but did decrease ward respiratory arrests (9); however, on BRT consisting of nurses only and operating separately from a code team (which only attends cardiac or respiratory arrests) was not associated with any change in respiratory arrest (10).

The published pediatric studies (6–10), all before- and after-cohort comparisons, provide a low level of evidence in support of adoption of a MET service, but it is the highest level available. The highest level study would require randomization of hospitals rather than randomization of wards within a hospital because crossover effects would be difficult to avoid. A journal editorial, entitled "Walk, Do Not Run," in part, questioning the necessity of a MET, sensibly suggested more study was needed (25) but ironically, if MET calling criteria are valid, the clinician can indeed afford to walk, not run because the patient is unlikely to be in cardiac arrest on his/her arrival at the scene.

Numerous adult hospitals have adopted MET services, some with astounding reductions in the incidences of unexpected cardiac arrest and death. For example, at the Austin Hospital in Australia, there was a 4-year sustained reduction in cardiac arrest from 4.06 to 1.90/1000 admissions and a suggestion that one cardiac arrest is prevented for every 17 MET calls (26). At the University of Pittsburgh Medical Center (27), there was a 17% decrease in the incidence of cardiac arrest but no reduction in the incidence of death after introduction of a MET service.

Despite enthusiastic uptake of MET services in adult hospitals, perhaps as a "bandage on a bigger problem" (28), the only randomized trial conducted between hospitals thus far, the Medical Emergency Response Intervention Trial study, concluded that the system did not substantially affect the incidence of unexpected cardiac arrest and death (29). However, that study seems to have had major methodologic problems because the incidences of cardiac arrest and death decreased significantly in both study and control hospitals, suggesting crossover effects, and the implementation of MET in the study hospitals was poor (30). A meta-analysis of adult studies (31), including the MERIT study, found weak evidence that rapid response systems are associated with reduction in hospital mortality and cardiac arrest rates.

CONCLUSIONS

This before-and-after study of a systems solution to reduce unexpected cardiac arrest shows an association with a large reduction in total hospital death including the incidence of preventable cardiac arrest and death and increased survival from cardiac arrest in wards of a pediatric hospital. Additional study of children experiencing adverse events may help identify other factors predictive of cardiac arrest and may suggest additional preventive strategies.

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