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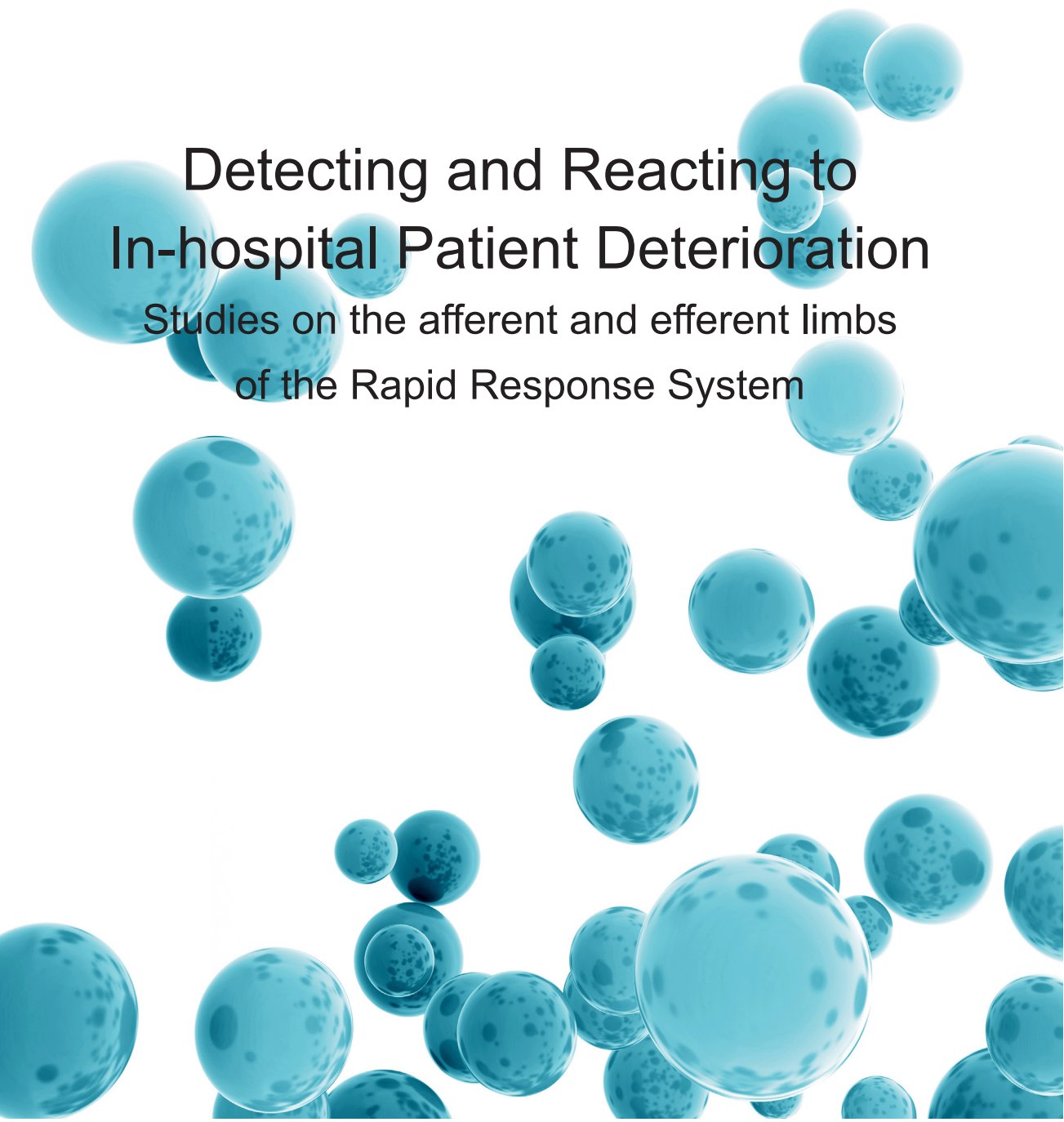
JOONAS TIRKKONEN

Detecting and Reacting to In-hospital Patient Deterioration

Studies on the afferent and efferent limbs of the Rapid Response System



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ACADEMIC DISSERTATION
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UNIVERSITY OF TAMPERE

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Contents

1 List of Original Publications

This thesis is based on the following original publications referred to in the text by their Roman numerals I to IV.

I. Tirkkonen J, Olkkola KT, Huhtala H, Tenhunen J, Hoppu S. Vital dysfunctions after intensive care discharge: prevalence and impact on patient outcome. Acta Anaesthesiol Scand 2013; 57:56-62.

II. Tirkkonen J, Ylä-Mattila J, Olkkola KT, Huhtala H, Tenhunen J, Hoppu S. Factors associated with delayed activation of medical emergency team and excess mortality: An Utstein-style analysis. Resuscitation 2013; 84:173-8.

III. Tirkkonen J, Olkkola KT, Huhtala H, Tenhunen J, Hoppu S. Medical emergency team activation: performance of conventional dichotomised criteria versus national early warning score. Acta Anaesthesiol Scand 2014; 58:411-9.

IV. Tirkkonen J, Nurmi J, Olkkola KT, Tenhunen J, Hoppu S. Cardiac arrest teams and medical emergency teams in Finland: a nationwide cross-sectional postal survey. Acta Anaesthesiol Scand 2014; 58:420-7.

2 Abbreviations

ACDU	Alert, confused, drowsy, unresponsive
AE	Adverse event
AHA	American Heart Association
ALF	Afferent limb failure
ALS	Advanced life support
APACHE II	Acute physiology and chronic health evaluation II
ASY	Asystole
AVPU	Alert, responds to voice, responds to pain and unresponsive
BLS	Basic life support
CAT	Cardiac arrest team
CCI	Charlson comorbidity index
CCO	Critical care outreach
CI	Confidence interval
CPR	Cardiopulmonary resuscitation
DNAR	Do not attempt resuscitation
ED	Emergency department
EMS	Emergency medical services
ERC	European Resuscitation Council
EWS	Early warning score
GCS	Glasgow coma scale
HDU	High dependency unit
HR	Heart rate
ILCOR	International Liaison Committee on Resuscitation
ICU	Intensive care unit
ICD 10	International Classification of Diseases 10
IHCA	In-hospital cardiac arrest
LOMT	Limitations of medical treatment
MET	Medical emergency team
MEWS	Modified early warning score

MODS	Multiple organ dysfunction syndrome
NEWS	National early warning score
NFR	Not for resuscitation
OHCA	Out-of-hospital cardiac arrest
OR (statistics)	Odds ratio
OR	Operating room
PART	Patient at risk team
PEA	Pulseless electrical activity
RCT	Randomized controlled trial
ROSC	Return of spontaneous circulation
RR	Respiratory rate
RR (statistics)	Relative risk
RRT	Rapid response team
RRS	Rapid response system
SAE	Serious adverse event
SAP	Systolic blood pressure
SAPS II	Simplified acute physiology score II
SCA	Sudden cardiac arrest
SpO_2	Peripheral arteriolar blood oxygen saturation
TAYS	Tampere University Hospital (Tampereen yliopistollinen sairaala)
VF	Ventricular fibrillation
VT	Ventricular tachycardia

3 Abstract

Aim: To study the components of the Rapid Response System (RRS) in Finland. Specific aims included studying the prevalence and relative performance of different activation criteria among general ward patients, describing the utilization of a Medical Emergency Team (MET) in a university hospital, studying the impact of a delayed MET activation on in-hospital mortality and investigating the characteristics of RRSs in Finnish hospitals.

Materials and Methods: The activation criteria were studied in two different prospective cohorts (Studies I and III). The first of these included ICU patients discharged to the Tampere University Hospital's (TAYS) general wards during a two months study period, who were attended 24 hours after discharge. All general ward patients in TAYS on two separate evenings were evaluated and formed the second cohort. Measured vital signs were classified as 'positive' or 'negative' activation criteria according to TAYS dichotomized criteria and the National Early Warning Score (NEWS), and tested against in-hospital serious adverse events and 30-day mortality, which were used as primary outcomes.

Characteristics of MET reviews and the impact of activation delays were investigated in a prospective cohort including all MET activations to the general wards of TAYS during a twelve month study period (Study II). MET activation was classified as delayed if positive activation criteria had been documented 0.33-6 hours before the activation.

In all three prospective cohort studies data on admissions and patient characteristics were obtained from patient records and multivariate logistic regression was used to adjust for confounding.

A cross-sectional postal survey was conducted to gather information on RRSs in Finland (Study IV). A questionnaire was sent to all heads of anaesthesia/intensive care departments of public hospitals providing adult anaesthetic services.

Results: The post-ICU cohort included 184 patients, and 24 hours after discharge both positive dichotomized activation criteria (prevalence 15%, OR 3.79, 95% CI 1.18-12.2) and the 'worried' criterion (19%, 3.63; 1.17–11.3) were associated with in-

hospital serious adverse events. In the cohort of 615 unselected general ward patients, however, the dichotomized activation criteria (prevalence 12%) were not associated with outcomes. NEWS was independently associated with both in-hospital serious adverse events and 30-day mortality on both suggested cut points (score $\geq$5 or an individual vital sign scoring three, and $\geq$7, prevalences 22% and 6.5%).

During the twelve month study of MET activations in TAYS, 569 general ward reviews were conducted. Characteristics of patients reviewed and MET interventions were comparable to international reports. A delayed activation was independently associated with increased in-hospital mortality (1.67; 1.02-2.72).

Fifty-one hospitals (93%) participated in the postal survey, and 16 hospitals reported having an RRS. Differences were noted, especially between the activation criteria used. The median MET activation rate in Finland was 2.3 (1.5, 4.8) per 1,000 hospital admissions.

Conclusions: NEWS detects general ward patients at risk of deterioration better than the commonly used dichotomized activation criteria, but it is reasonable to include the subjective 'worried' criterion as a MET activation method. Delays in MET activation increase the hospital mortality of severely ill general ward patients. In Finland uniform guidelines for RRS are required, as both the implementation and utilization are still suboptimal.

4 Tiivistelmä

Sairaalansisäiset vakavat haittatapahtumat, kuten sydämenpysähdykset tai hätäsiirrot vuodeosastoilta teho-osastolle, eivät ole ennakoimattomia hätätilanteita. Jopa 80 %:a tapauksista edeltävät tunteja jatkuneet peruselintoimintojen häiriöt. Ne ilmenevät yksinkertaisesti mitattavina ja havaittavina muutoksina potilaan verenpaineessa, syketiheydessä, perifeerisen veren happikyllästeisyydessä, hengitystiheydessä, ruumiinlämmössä ja tajunnantasossa. Hypoteettisesti suuri osa vakavista haittatapahtumista olisi estettävissä, mikäli peruselintoimintojen häiriöt tunnistettaisiin ja niihin reagoitaisiin ajoissa. Tätä varten alun perin Australiassa kehitettiin sairaalansisäinen ensihoitoketju, jonka tärkeimmät osat ovat osastohenkilökunnan käyttämät hälytyskriteerit sekä sairaalansisäinen ensihoitoryhmä (MET, medical emergency team). Konseptia ei ole suomalaisessa sairaanhoidossa tutkittu.

Tämän väitöskirjatutkimuksen tavoitteena oli tutkia erilaisten hälytyskriteerien esiintyvyyttä, ennustearvoa ja toimivuutta sairaalapotilailla kahdessa prospektiivisessa kohorttitutkimuksessa (osatyöt I ja III). Ensimmäinen kohortti muodostui kahden kuukauden aikana vuodeosastolle jatkohoitoon siirtyneistä teho-osaston potilaista, joiden peruselintoiminnot mitattiin 24 tuntia potilassiirrosta. Toisessa hälytyskriteereitä tutkivassa osatyössä kaikkien Tampereen yliopistollisen sairaalan (TAYS:n) vuodeosastopotilaiden peruselintoiminnot mitattiin kahtena eri iltana. Kolmannessa osatyössä tutkittiin ensihoitoryhmän hälytyksiä ja niihin liittyviä viiveitä 12 kuukauden ajalta TAYS:ssa. Osatyössä IV selvitettiin kirjekyselytutkimuksen avulla sairaalansisäisiä ensihoitoketjuja ja niiden eroja suomalaisissa anestesiapalveluita tuottavissa julkisissa sairaaloissa.

Ensimmäisessä osatyössä (184 potilasta) 12 % potilaista täytti peruselintoimintoihin perustuvat dikotomiset hälytyskriteerit, ja ’hoitaja huolissaan’ -kriteeri kirjattiin 19 %:lle potilaista. Molemmat kriteerit assosioituivat vakioinnin jälkeen myöhempiin sairaalansisäisiin haittatapahtumiin (ristitulosuhde 3.79; 95 % luottamusväli 1.18–12.2 ja 3.63; 1.17–11.3). Osatyössä II (615 potilasta) kaksijakoiset hälytyskriteerit eivät kuitenkaan ennustaneet vakioidusti myöhempiä haittatapahtumia tai 30 vrk:n kuolleisuutta. Sen sijaan Isossa-Britanniassa kansallisesti suositeltu aikaisen varoituksen pisteytysjärjestelmä (National Early

Warning Score, NEWS) assosioitui päätetapahtumiin myös vakioinnin jälkeen molemmilla hälytyksen laukaisevilla raja-arvoilla (≥5 tai yksittäinen vitaalielintoiminto 3, ja ≥7, esiintyvyys aineistossa 22 % ja 6.5 %). Kolmannessa osatyössä (569 ensihoitoryhmän hälytystä vuodeosastoille) kohortin piirteet olivat verrattavissa kansainvälisiin tutkimuksiin. Viiveet ennen ensihoitoryhmän hälytystä liittyivät itsenäisesti suurempaan sairaalakuolleisuuteen (1.67; 1.02–2.72). Kirjekyselytutkimukseen osallistui 93 % (51/55) sairaaloista. Kuudessatoista sairaalassa oli organisoitu sairaalansisäinen ensihoitoketju hälytyskriteereineen ja ensihoitoryhmineen. Sairaaloiden välillä oli suuria eroja erityisesti käytetyissä hälytyskriteereissä. Kansallinen ensihoitoryhmän hälytysmäärä oli keskiluvultaan 2.3 (1.5, 4.8) tuhatta sairaanhoitojaksoa kohden.

Väitöstyön päätelminä todetaan, että peruselintoimintoihin perustuvat hälytyskriteerit ennustavat sairaalansisäisiä haittatapahtumia ja kuolleisuutta, joskin aikaisen pisteytyksen hälytysjärjestelmä NEWS havaitsee riskipotilaat paremmin vuodeosastopotilaiden keskuudessa. Sairaalansisäisen ensihoitoryhmän hälytysten syyt ja tavatut potilaat ovat TAYS:ssa samankaltaisia kuin kansainvälisissä tutkimuksissa, ja viiveet hälytysten tekemisessä liittyvät kohonneeseen sairaalakuolleisuuteen. Kansallisella tasolla yhtenäiset hoitosuositukset sairaalansisäisestä hoitoketjusta tarvitaan, sillä tällä hetkellä ensihoitoryhmien käyttö on kansainväliseen tasoon nähden liian vähäistä.

5 Introduction

'The most sophisticated intensive care often becomes unnecessarily expensive terminal care when the system preceding ICU fails'

Peter Safar, Professor and Chairman, Department of Anaesthesiology, Director of Critical Care Medicine Program, University of Pittsburg 1974 (Safar 1974).

A majority of in-hospital serious adverse events (SAEs), defined as cardiac arrests, emergency intensive care admissions and unexpected deaths, are neither sudden nor abrupt incidents. Up to 80% of in-hospital SAEs are preceded by vital dysfunctions lasting hours before the actual event (Schein et al. 1990, Berlot et al. 2004). These vital dysfunctions are easily observed and include alterations in respiratory rate, SpO_2, heart rate, blood pressure and level of consciousness (Smith & Wood 1998, Hodgetts et al. 2002b, Nurmi et al. 2005). If these signs are not acted upon, the final manifestations of patient deterioration (the SAEs) are of poor prognosis (Franklin & Mathew 1994, Buist et al. 1999, Kause et al. 2004, Berlot et al. 2004, Nurmi et al. 2005, Skrifvars et al. 2006).

A rapid response system (RSS) was first introduced in Australia in 1990 to respond proactively in case of a patient deterioration being observed on any general ward in the hospital (Hillman et al. 2001). An RSS consists of an afferent limb (early detection of patient deterioration and immediate call for help by the ward staff) and an efferent limb (the responding unit; medical emergency team, MET) (Jones, DeVita & Bellomo 2011). Since then METs and RRSs have been widely internationally implemented (Devita et al. 2006, Peberdy et al. 2007). In an RRS, adequate efferent limb activation criteria and the actions of the ward staff (observation of vital signs, early detection of patient deterioration and immediate MET activation) are of utmost importance and today regarded as key factors when significant reductions in the incidence of SAEs are pursued (Winters et al. 2013).

The purpose of this thesis was to prospectively investigate the feasibility of different MET activation criteria, describe the characteristics of an RRS in Tampere University Hospital with special reference to delayed MET activations, and determine the current utilization of RRSs in Finland.

6 Review of the Literature

6.1 Adverse events

6.1.1 In-hospital adverse events

The very purpose of hospitals is to treat patients suffering from a variety of illnesses, if possible. This is becoming a task harder and harder to fulfill; ageing population, cumulative comorbidities and more advanced (and expensive) interventions face diminishing funding and resources (Hillman, Chen & Aneman 2010). At the same time, specialties inside the hospitals are transforming to ever narrower fields and wards of expertise (Hillman, Chen & Aneman 2010).

Iatrogenic illness resulting from conducted or neglected procedures and observations in hospital has been well documented since the 1950s, and is an ongoing challenge (Barr 1955, Moser 1956, Schimmel 1964, Steel et al. 2004). The reported incidence of adverse events (AEs) varies from 2.9 to 16.6 per 100 hospital admissions and depends on the definition of an AE; as high as 20 to 36 AEs per 100 admissions have been reported if all mild, but harmful occurrences have been included (Leape et al. 1991, Wilson et al. 1995, Thomas et al. 2000, Vincent, Neale & Woloshynowych 2001, Steel et al. 2004, Baker et al. 2004, Zwaan et al. 2010). The most extreme incidents, serious adverse events (SAEs), are defined as emergency intensive care unit (ICU) admissions, in-hospital cardiac arrests (IHCAs) and unexpected deaths (Buist et al. 1999, Peberdy et al. 2007).

Human decision-making is inevitably prone to miscalculations, especially in situations requiring rapid decisions (Gunn 2000, Smith & Ratcliff 2004, Bleetman et al. 2012, Yeung & Summerfield 2012). However, in recent decades it has been acknowledged that most potentially preventable AEs are rather the results of system-wide failures than mere errors of individuals (Gunn 2000, Manser 2009, El Bardissi & Sundt 2012, Segall et al. 2012). Prevention of in-hospital AEs and improving patient safety are today recognized as core elements of health care, surgical checklists being a good example of improvement procedures (Leape & Berwick 2005, Weiser et al. 2010, Clark et al. 2012, Bergs et al. 2014).

6.1.2 Out-of-hospital versus in-hospital cardiac arrest

According to the American Heart Association (AHA) and the European Resuscitation Council (ERC) a cardiac arrest (CA) refers to the loss of cardiac mechanical activity confirmed by the absence of signs of circulation (Field et al. 2010, Koster et al. 2010). Unless any obvious reasons for the CA are known (trauma, drug overdose, etc.), it is presumed to be of cardiac origin likely to be induced by myocardial infarction (Jacobs et al. 2004). This assumption is supported further if ventricular tachycardia or ventricular fibrillation (VF) is observed; these malignant arrhythmias are generally provoked by myocardial ischaemia (European Heart Rhythm Association et al. 2006).

Sudden cardiac arrest (SCA) is one of the leading causes of death in western countries, often portrayed in the media and therefore familiar to (though not comprehended by) the lay public (Myerburg, Kessler & Castellanos 1992, Harris & Willoughby 2009). The incidence of EMS-treated out of hospital cardiac arrests (OHCAs) is between 50 and 66 per 100,000 inhabitants, although lower incidence rates (38/100,000) have also been reported (Herlitz et al. 1999, Atwood et al. 2005). In Finland the incidence of OHCAs is annually of the order of 66-94/100,000 inhabitants (Kuisma & Määttä 1996, Herlitz et al. 1999, Kämäräinen et al. 2007, Hiltunen et al. 2012). OHCA usually occurs due to myocardial infarction caused by ruptured plaque in atherosclerotic coronary arteries leading to VT and VF (Davies & Thomas 1984, Lombardi, Gallagher & Gennis 1994, Zheng et al. 2001). Survival to hospital discharge from OHCA varies between counties and districts (1.4-23 %), the quality of Emergency Medical Systems (EMS) being one of the cornerstones in survival rate (Lombardi, Gallagher & Gennis 1994, Herlitz et al. 1999, Skogvoll et al. 1999, Bottiger et al. 1999, Atwood et al. 2005). In Finland the discharge rate from hospital after attempted resuscitation has been reported to be 12-20% (Kuisma & Määttä 1996, Kämäräinen et al. 2007, Hiltunen et al. 2012). Favorable outcome from OHCA is associated with a presumed cardiac origin and initial rhythms of either VT or VF (Bottiger et al. 1999, Herlitz et al. 1999, Skogvoll et al. 1999, Pell et al. 2003, Atwood et al. 2005, Kämäräinen et al. 2007). OHCA presumed or confirmed to be of non-cardiac origin is associated with poor outcome and initial rhythm of pulseless electrical activity (PEA) or asystole (ASY), though potentially being the result of reversible causes (hypoxia, hypothermia, hypovolemia, toxins etc.) (Desbiens 2008, Virkkunen et al. 2008, Field et al. 2010, Thomas et al. 2013).

In-hospital cardiac arrest refers to the cessation of cardiac activity in a hospitalized patient who had a pulse at the time of admission (Jacobs et al. 2004). It

is well documented that patients suffering an IHCA often have several comorbidities, with the current reason for hospitalization (infections, malignancies, electrolyte disturbances, conducted surgical interventions) making the situation even more precarious (Ebell 1992, Cohn et al. 1993, Nurmi et al. 2005, Nadkarni et al. 2006). Cardiac arrests resulting from hypoxemia, hypotension, cardiac tamponade and other reasons not directly associated with myocardial ischaemia are likely to produce PEA/ASY as the initial rhythm (Peberdy et al. 2003, Kause et al. 2004, Hess, Campbell & White 2007, Virkkunen et al. 2008). Therefore, as one would expect, in 69% to 77% cases of IHCA, the first analysed rhythm is non-shockable (PEA/ASY) (Gwinnutt, Columb & Harris 2000, Peberdy et al. 2003, Nurmi et al. 2005, Nadkarni et al. 2006, Meaney et al. 2010). The incidence of IHCAs varies from between 1 to 13 per 1,000 hospital admissions, with a mean estimate of 6.6/1,000 admissions (Peberdy et al. 2003, Sandroni et al. 2007, Merchant et al. 2011, Morrison et al. 2013).

The basic treatment protocol for an IHCA is similar to that for an OHCA. The methods of modern cardiopulmonary resuscitation (CPR) were first introduced by Zoll, Safar and Kouwenhoven in 1956-1960 including ventilation, defibrillation and closed chest cardiac massage (Zoll et al. 1956, Safar, Escarraga & Elam 1958, Kouwenhoven, Jude & Knickerbocker 1960). Today, resuscitation is divided into basic life support (BLS) and advanced live support (ALS): BLS constitutes of chest compressions, defibrillation and simple airway management while ALS is provided by professionals with advanced invasive airway management, resuscitation drugs and means to intervene in the possible underlying causes of the CA (Field et al. 2010, Nolan et al. 2010). Figure 1. presents the ALS cardiac arrest treatment algorithm according to ERC 2010 guidelines. In hospitals, BLS is expected to be provided by the general ward staff with automated external defibrillators (AEDs) while calling for help (Field et al. 2010, Nolan et al. 2014). ALS is usually considered to be provided by the hospitals cardiac arrest team (CAT). However, although widely implemented, there is practically no evidence to support the implementation of CATs, nor are they recommended (Field et al. 2010, Nolan et al. 2014). Recent studies have moreover questioned the distribution of AEDs to general wards as well; shockable rhythms in hospitals are rare and no survival benefit has been observed (Forcina et al. 2009, Chan et al. AHA 2010, Smith, Hickey & Santamaria 2011).

Though survival to discharge rates after IHCA as low as 1% to 2% have been reported, generally the estimates vary between 10% and 20%, but have not improved in the last 30 years (Hershey & Fisher 1982, Peberdy et al. 2003, Cohn et al. 2004, Cooper, Janghorbani & Cooper 2006, Nadkarni et al. 2006, Sandroni et al. 2007,

Franczuk et al. 2008, Meaney et al. 2010, Nolan et al. 2014). While developments in the treatment and response (therapeutic hypothermia, optimizing emergency dispatch centre and EMS performance) have yielded better outcomes from OHCA, the treatment of IHCA relies on scientific evidence presented over 60 years ago: early recognition, immediate chest compressions and defibrillation by first responders (Field et al. 2010, Nolan et al. 2010).

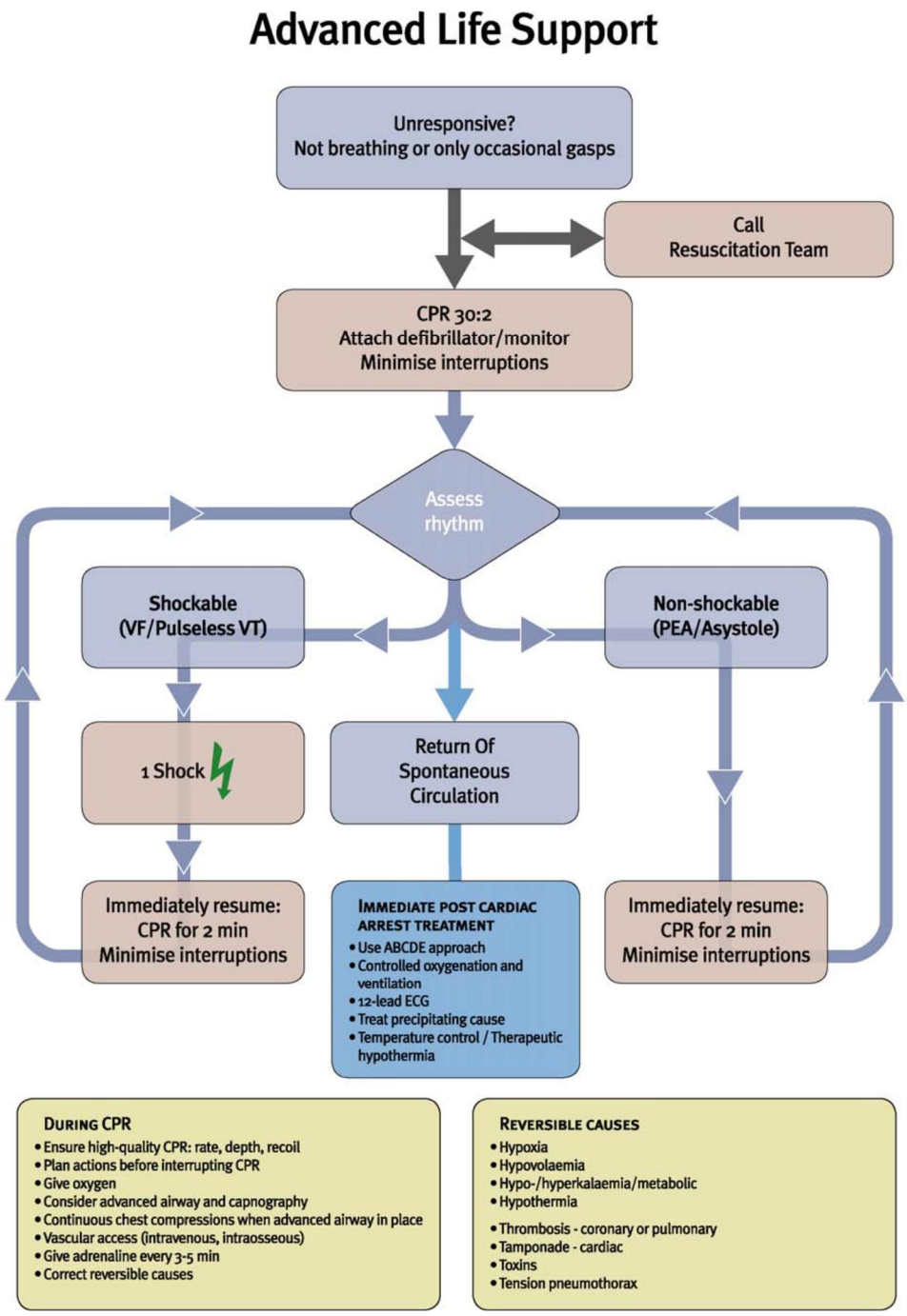


Figure 1. ALS algorithm according to ERC 2010 guidelines. Reprinted with the kind permission of Elsevier.

6.1.3 Emergency intensive care unit admission

Intensive care refers to temporarily provided artificial life support for the critically ill, until either medical/surgical interventions dispel the reason for illness or death occurs despite treatment (Hillman, Chen & Aneman 2010). The concept of intensive care is considered to have originated in the 1950s during the Copenhagen polio epidemic: continuous manual ventilation of patients suffering from respiratory failure decreased mortality from 80% to 40% (Lassen 1953). The idea of specialized wards for the critically ill was rapidly translated into reality, with physicians (mostly anaesthesiologists) developing skills to provide critical care and sustain life (Hillman, Chen & Aneman 2010). Modern intensive care requires huge resources compared to general ward care, and the costs rise linearly. Ethically sound but rational patient selection, cost effectiveness and aging population with a multitude of comorbidities create a dilemma our healthcare system is today forced to face (Angus et al. 2000, Dowdy et al. 2005, Wild & Narath 2005).

Intensive care units (ICUs) provide the most advanced care for the severely ill. They may operate as open units or closed units; in open units the admitting physician (surgeon, neurologist etc.) continues to be responsible for the patient, while in closed units specialized ICU physicians have the formal responsibility through the critical illness (Pronovost et al. 2002). Admission to intensive care may be planned (elective) or unplanned (emergency admission). An elective admission to the ICU may first sound absurd. However, many planned, but complex surgical interventions (neurosurgery, cardiothoracic surgery, sophisticated abdominal surgery) require post-operative stabilization and follow-up by means of intensive care (Pedoto & Heerdt 2009, Hillman, Chen & Aneman 2010, Bos et al. 2013, Hanak et al. 2014). Emergency transfers to intensive care form the vast majority of admissions (Goldhill & Sumner 1998, Vaara et al. 2012a, Vaara et al. 2012b, Bing-Hua 2014). Patients may be acutely admitted from emergency departments (EDs), operating rooms (ORs), from other hospitals or from the hospital's general wards (Hillman et al. 2002, Chalfin et al. 2007, Flabouris et al. 2012). Although a multitude of factors influence the mortality of patients admitted to ICU, an admission from the hospital's general wards is one of the variables associated with poor prognosis (Goldhill & Sumner 1998, Flabouris et al. 2012). Further, patients acutely readmitted to intensive care from general wards are at 2-10 times higher risk of hospital mortality than patients not requiring intensive care after the initial discharge to further recovery (Chen et al. 1998, Rosenberg & Watts 2000, Elliott 2006, Campbell et al. 2008, Kaben et al. 2008, Kramer, Higgins & Zimmerman 2012).

6.2 System failure

6.2.1 Patient monitoring

A recent consensus conference on appropriate patient monitoring defined 'monitoring' in the health care context as 'the ongoing assessment of a patient with the intention of (1) detecting abnormality, and (2) triggering a response if an abnormality is detected' (DeVita et al. 2010). This monitoring should be performed for all hospitalized patients, and entails measuring and recording of patients' vital signs (DeVita et al. 2010). The vital signs, today easily measured by any health care professional, are: respiratory rate (RR) (breaths/min), peripheral arteriolar blood oxygen saturation (pulse oximetry, SpO_2) heart rate (HR) (beats/min), (systolic) blood pressure (SAP), body temperature and level of consciousness (Tierney, Whooley & Saint 1997, Flaherty et al. 2007, DeVita et al. 2010, DeVita et al. 2011). Level of consciousness may be assessed in several ways, but commonly clinically used tools for the translation of the level of consciousness to objective numerical data are the Glasgow Coma Scale (GCS), the AVPU-scale (alert, responds to voice, responds to pain and unresponsive) and the ACDU-scale (alert, confused, drowsy, unresponsive) (Teasdale & Jennett 1974, McNarry & Goldhill 2004). The GCS is a score of 3-15 points and includes the scoring of three behavioural: eye opening, verbal performance and motor functions (Teasdale & Jennett 1974). AVPU/ACDU-scales divide the patient's behaviour and responses into four different categories (4-1), 'alert' signifying normal state of consciousness (McNarry & Goldhill 2004).

It is debatable how often the vital signs should be monitored in general wards (DeVita et al. 2010). Ideally all patients would be under continuous electronic automated monitoring; however resources for this step-down unit-like practice are simply not available, nor would the automated monitoring *per se* necessarily provide the desired benefits (increased vigilance and responses to detected abnormalities) (Drew et al. 2004, Atzema et al. 2006, Edworthy & Hellier 2006, Watkinson et al. 2006, Graham & Cvach 2010, Harris et al. 2011). The majority of hospital beds are on general wards where the available nursing staff, especially during on-call time, is limited. Several cross-sectional studies utilizing large data sets have shown the benefits of increased nursing staffing levels for patient care quality and safety, but these levels are rarely achieved in reality (Aiken et al. 2002, Needleman et al. 2002, Cho et al. 2003, Rafferty et al. 2007). Therefore the consensus conference suggested

that on general wards the frequency of vital signs monitoring should preferably be every six hours, but the absolute minimum is every 12 hours (DeVita et al. 2010).

Do the recommendations, for a tradition considered to be nearly 150 years old, meet the reality of vital signs monitoring (Hillman 2006)? According to retrospective observational studies, routine measurements of vital signs are commonly neglected on general wards (Leuvan & Mitchell 2008, McGain et al. 2008, Stevenson et al. 2014). RR is the least documented vital sign, though it has been shown to possess the highest sensitivity for detecting patient deterioration (Buist et al. 2004, Hogan 2006, Jacques et al. 2006, Chaboyer et al. 2008, Cretikos et al. 2008). A recent multicentre study from Australia reported that respiratory rate had not been recorded at all during the 24 hours preceding the events in a mean of 30% (from 2% to 80%) of the SAEs (Chen et al. 2009). The percentages for HR (13, 0-64) and SAP (11, 0-64) were almost identical. Most worryingly, however, in 9% (0%-64%) of the SAEs no vital signs had been measured during the preceding 24-hour period (Chen et al. 2009).

6.2.2 Vital dysfunctions

Many patients in the ICUs ultimately die of multiple organ dysfunction syndrome (MODS) (Deitch 1992, Murray & Coursin 1993, Livingston, Mosenthal & Deitch 1995). MODS is a sequential multiorgan failure resulting from the generalized inflammatory response, cytokine storm, triggered by impaired homeostasis (hypoperfusion and tissue deoxygenation, infection or major trauma) (Schlichtig, Kramer & Pinsky 1991, Deitch 1992, Murray & Coursin 1993, Livingston, Mosenthal & Deitch 1995, Wang & Ma 2008). For example, gut and cerebral metabolism are prone to suffer from the slightest perfusion defects long before the obvious clinical signs of organ-specific failure or MODS become apparent (Price et al. 1966, Schmoker, Zhuang & Shackford 1992, Murray & Coursin 1993, Landow & Andersen 1994).

The same physiological mechanisms apply on general wards. In the vast majority of cases, an SAE is the final stage of disturbed homeostasis, resulting, for example, from hypoperfusion and suboptimal tissue oxygenation lasting for hours before the actual collapse (Hershey & Fisher 1982, McQuillan et al. 1998, Buist et al. 1999, McGloin, Adam & Singer 1999, Hillman et al. 2002, Kause et al. 2004, Nurmi et al. 2005). Although SAEs on general wards are referred to as medical emergencies, deviations in the vital signs (vital dysfunctions) are recorded (but not necessarily

responded to) for up to 48 hours before the inevitable endpoint (Franklin & Mathew 1994, Smith & Wood 1998, Goldhill, White & Sumner 1999, Berlot et al. 2004, Harrison et al. 2005, Vlayen et al. 2012).

6.2.3 Antecedents of in-hospital cardiac arrests

In western countries, the classical antecedents of OHCA (chest pain, anxiety, cold sweat, syncope), are regularly played in televised drama and known to lay public (Graham et al. 2008, Harris & Willoughby 2009, Nishiyama et al. 2013). While IHCAs have been studied since the 1960s, the first report focusing on the clinical antecedents was published in 1990 (Sandoval 1965, Johnson et al. 1967, Hershey & Fisher 1982, Schein et al. 1990). The researchers wrote in the introduction-section: 'It has been our clinical impression that cardiopulmonary arrest occurring among hospital inpatients is frequently related to noncardiac processes, with the 'cardiac arrest' representing the common final pathway of a variety of disturbances' (Schein et al. 1990). In this tentative prospective observational study with retrospect case note analysis of a total of 64 patients, 84% of the IHCA patients had had recorded vital dysfunctions during the eight hour period preceding the event (Schein et al. 1990). Since then, these findings have been repeatedly confirmed in both unicentre and multicentre studies using similar methodology (Franklin & Mathew 1994, Buist et al. 1999, Berlot et al. 2004, Kause et al. 2004, Nurmi et al. 2005, Skrifvars et al. 2006). The most common objective vital dysfunctions preceding IHCAs are tachypnea, tachycardia, hypotension and alterations in the level of consciousness (Smith & Wood 1998, Buist et al. 1999, Berlot et al. 2004, Buist et al. 2004). Table 1 presents the incidence of clinical antecedents preceding IHCAs in eight observational studies on this subject. Often the documentation of vital signs had been neglected; thus the actual percentages of preceding vital dysfunctions were probably even higher (Smith & Wood 1998, Nurmi et al. 2005, Skrifvars et al. 2006, Chen et al. 2009).

Table 1. Studies of clinical antecedents of in-hospital cardiac arrests

Study	Site/hospital type	Cardiac arrests (n)	Studied time period preceding CA (hours)	Clinical antecedents (%)	Single most common antecedent (%)
(Schein et al. 1990)	Unicentre/Tertiary	64	0-8	84	Tachypnea (38)
(Franklin & Mathew 1994)	Unicentre/Secondary	150	0-6	66	-
(Smith & Wood 1998)	Unicentre/Tertiary	47	0-24	51	Tachypnea (58)
(Hodgetts et al. 2002b)	Unicentre/Secondary	118	0-24	62	Low SpO_2 (24)
(Berlot et al. 2004)	Unicentre/Tertiary	148	0-6	86	Dyspnea (23)
(Kause et al. 2004)	Multicentre/90 hospitals	141	0.25-24	79	Low SAP (31)
(Nurmi et al. 2005)	Multicentre/4 hospitals	56	0-24	54	Tachypnea (30)
(Skrifvars et al. 2006)	Unicentre/Secondary	220	0-8	47	Low SpO_2 (28)

6.2.4 Antecedents of emergency ICU admissions

In 1998 McQuillan et al. conducted a prospective confidential inquiry on the quality of preceding care of 100 patients admitted to the ICU from general wards in two hospitals (McQuillan et al. 1998). In 54% of the cases the care was regarded as suboptimal and in 37% cases the admission occurred late; the most common reasons were organizational failures and failure to comprehend the urgency of patient deterioration (McQuillan et al. 1998). This finding has since been confirmed by other

prospective observational studies assessing the care before ICU admissions (Goldhill, White & Sumner 1999, Hillman et al. 2002, Kause et al. 2004). Although measurement of vital signs during the hours preceding the ICU admission is suboptimal, when measured, vital dysfunctions are consistently recorded but in most cases no specific escalation of care occurs (Goldhill, White & Sumner 1999, Hillman et al. 2002). Antecedents are documented in 54% to 80% of emergency ICU admissions from general wards during the 8-24 hours preceding the admissions (Goldhill, White & Sumner 1999, Hillman et al. 2002, Kause et al. 2004). The most common vital dysfunctions are tachypnea, tachycardia, hypotension and decrease in the level of consciousness (Buist et al. 1999, Goldhill, White & Sumner 1999, Hillman et al. 2002, Kause et al. 2004). Of utmost concern is the association of a delayed ICU admission with higher ICU and in-hospital mortality detected by McGloin et al. in a prospective observational study of 98 ICU admissions (McGloin, Adam & Singer 1999).

6.3 The Rapid Response System

Figure 2. The Chain of prevention by Gary B Smith, 2010. Reprinted with the kind permission of Elsevier.

6.3.1 Concept and history

After concluding that patients in hospitals frequently deteriorate without rapid and adequate interventions, the concept of a rapid response system (RRS) was introduced (Devita et al. 2006, Peberdy et al. 2007). 'System' refers to the fact that the response requires coherent functioning across conventional organizational braches in a hospital. While the 'chain of survival' from cardiac arrest includes (1) early recognition and call for help, (2) early CPR, (3) early defibrillation and (4) post resuscitation care, the chain of prevention requires (1) education (of ward staff on vital signs and dysfunctions), (2) monitoring (of vital signs), (3) recognition (of patient deterioration), (4) call for help (without delay) and (5) response (medical emergency team) (Figure 2.) (Nolan et al. 2010, Smith 2010). The purpose of RRS is to proactively respond to patient deterioration which enables (1) stabilization with minor interventions, (2) timely admission to ICU if required and (3) implementing limitations of medical therapy (LOMT) if deemed appropriate (Peberdy et al. 2007).

The RRS can be divided to four elements, often referred to as limbs of the RRS. They include the afferent limb (identification of patient deterioration by the ward staff and triggering a response), the efferent limb (response team) and the feedback & administrative components (Jones, DeVita & Bellomo 2011). Figure 3. presents the elements of RRS.

A medical emergency team (MET) was first introduced in 1990 in Liverpool Hospital, Australia (Hillman et al. 2001). In 1995 Lee et al. published the first prospective observational report of MET activity over a one-year period: three quarters of the 522 MET activations were due to patient deterioration not involving/progressing to IHCAs (Lee et al. 1995). In 1997 a patient-at-risk-team (PART) was implemented in the Royal Hospital of London to facilitate early transfers from general wards to ICU if required (Goldhill et al. 1999). In retrospect, perhaps the most relevant finding of this first six-month prospective report from Europe was that although only 28% of the patients admitted to ICU from general wards were admitted after a PART activation, 81% of the patients admitted through the 'common' pathway also fulfilled the activation criteria (Goldhill et al. 1999).

At first the publications focused mostly on the efferent limb, the response teams (Jones, DeVita & Bellomo 2011). In Australia, New Zealand and Scandinavia the term MET is most commonly used; in the United States teams are often named RTTs (rapid response teams) (Bertaut, Campbell & Goodlett 2008). Critical care outreach (CCO) by definition is focused on the aftercare and follow-up of discharged ICU patients (Ball, Kirkby & Williams 2003). After comprehending the RRS more

as an intervention requiring the appropriate involvement of the whole hospital organization, the focus has turned towards the afferent limb and adequate implementation of the system (Devita et al. 2006, Jones, DeVita & Bellomo 2011, Winters et al. 2013).

Currently both the International Liaison Committee on Resuscitation (ILCOR, which includes representatives from AHA; the American Heart Association, ERC; the European Resuscitation Council and five other resuscitation organizations) and the ERC recommend the implementation of RRS as a strategy to prevent IHCAs (Bhanji et al. 2010, Nolan et al. 2010). Our national Finnish resuscitation guidelines (2011) likewise confirm the need for RRSs (working group set up by the Finnish Medical Society Duodecim, the Finnish Resuscitation Council, the Finnish Society of Anaesthesiologists and the Finnish Red Cross 2011). RRS is regarded as a patient safety strategy. Deploying RRSs in hospitals in the United States was recently one of the main goals in the *'Saving 100,000 lives in US hospitals'* -campaign led by the Institute for Healthcare Improvement, and in United Kingdom NICE (National Institute for Health and Clinical Excellence) published guidelines on 'Acutely ill patients hospitals - Recognition of and response to acute illness in adults in hospital' in 2007 (McCannon et al. 2006, NICE Short Clinical Guidelines Technical Team 2006).

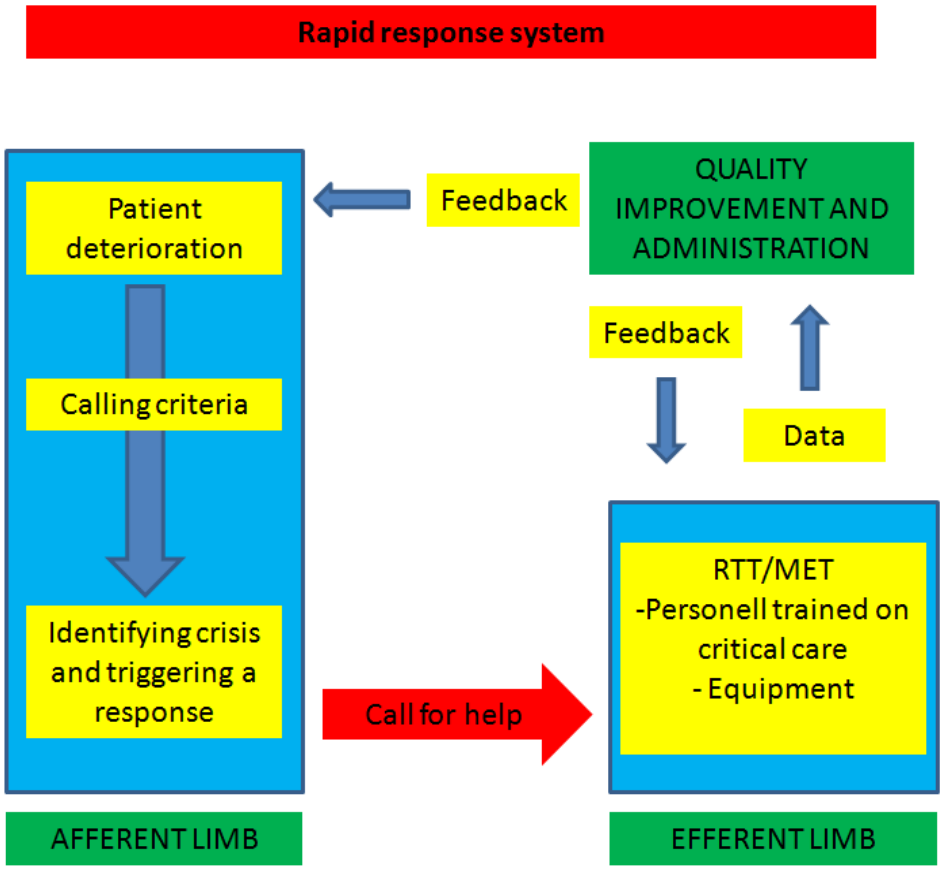


Figure 3. Components of the Rapid Response System. Adapted from *'Rapid response teams' NEJM 2011 by Jones et al.* (Jones, DeVita & Bellomo 2011).

6.3.2 Implementation

Since the earliest reports concerning the performance of RRSs one major problem has been the low activation rate of the efferent limb (Hillman 2006). Today it is underlined that a system-wide response is implemented, and adequate and continuous staff training is required (Winters et al. 2013). No formal guidelines exist for RRS implementation, but several hospitals have reported their implementation methodologies (Winters et al. 2013). The implementation period has varied from four to 12 months (Hillman et al. 2005, Dacey et al. 2007, Calzavacca et al. 2010).

During the implementation period, ward staff education has been organized using joint lectures, face-to-face meetings and simulations in smaller teams to improve group problem solving (Dacey et al. 2007, Calzavacca et al. 2010, Laurens & Dwyer 2011). Information reminding personnel about the calling criteria and MET has been disseminated using educational videotapes, booklets, posters, wallet-sized index cards and announcements in the hospital intra-net (Hillman et al. 2005, Dacey et al. 2007, Calzavacca et al. 2010, Konrad et al. 2010, Laurens & Dwyer 2011). Importantly, staff education has continued after the implementation period (Santamaria, Tobin & Holmes 2010).

Implementing an RRS requires additional resources to the efferent limb as well; the MET workload increases substantially after also responding to other medical emergencies than CAs (Jones, Bellomo & DeVita 2009, Jones, DeVita & Bellomo 2011). At the same time, ICU admission rates from the general wards can be expected to increase (Karpman et al. 2013). The actual or hypothesized amount of additional resources required and costs has been presented in three studies. A 700-bed hospital with 53,500 annual admissions reported that after RRS implementation four consultants, three fellows, nurse consultants and three additional beds were introduced to the ICU; these changes, however, were seen more as collective strengthening of the quality of care rather than mere consequences from increased workload (Kenward et al. 2004). To date only two studies have assessed the total costs of RRS. Simmes et al. used an analysis based on their earlier findings (including the costs of implementation and maintenance, training, nursing time spent on extended observations of vital signs, MET consults, and differences in the number of unplanned ICU days before and after RRS implementation) (Simmes et al. 2014). In the hypothesized scenario the RRS costs per patient day in their institution were 10.18€. Before the RRS the average costs for one hospital day were 594€, so the implementation of RRS increased the costs by 1.7% while the CAs and unexpected deaths decreased 50% (due to low initial incidence, these results were not statistically significant (Simmes et al. 2012, Simmes et al. 2014). Bonafide et al. estimated in a paediatric hospital, that potentially avoidable critical deterioration increases the costs of an admission on average by 100,000$ while the annual RRS costs were estimated to be 350,000$ (Bonafide et al. 2014). Thus, hypothetically by reducing 3.5 events/year the costs of the RRS would be covered.

Implementation of RRS may confront a multitude of purely social, political and hierarchical barriers which must be taken into account before and during the implementation phase (Azzopardi et al. 2011, Jones, DeVita & Bellomo 2011). Table 2. summarizes some of these barriers identified in a Consensus Conference in 2006

(Devita et al. 2006). According to a recent comprehensive thematic literature review, continuous education of general ward staff addresses and potentially dispels many of these barriers (Jones, King & Wilson 2009).

Table 2. Barriers to implementing a rapid response system. Adapted from 'Findings of the First Consensus Conference on Medical Emergency Teams' 2006 by DeVita et al. (DeVita et al. 2006).

Perceived confrontation with culture and professional role norms
• Doctor-patient relationship
• Hierarchies within current system
• Disengagement between doctors and nurses
• Professional resistance (practicing according to norms taught years ago)
Structure and tendency to work in professional "silos"
• Specialist training fosters focus within very narrow practice realms
• Work/budget; unwillingness to work on other disease processes
• Territorialism and turf battles
Adequacy and knowledge of evidence regarding medical emergency team
• Few studies on natural history and epidemiology of hospitalized and seriously ill patients
• Inadequate knowledge of outcome benefit of rapid response system
• Inadequate current evidence of best implementation strategy
• Inadequate evidence regarding effector arm structures and benefit
Resource constraints
• Staffing
• Financial
• Work-load concerns
• Implementation requirements: data, personnel, organization
• Sustaining and maintaining the system: data collection and analysis, personnel and organization
Lack of champions committed to a rapid response system (needed to promote cultural and practice change

6.3.3 Afferent limb

The afferent limb of the RRS includes predefined criteria for MET activation, measuring vital signs to detect deterioration and prompt MET activation if required (DeVita et al. 2006, Jones, DeVita & Bellomo 2011). In practical terms it means the actions of general ward staff leading to MET activation.

All hospital staff should be permitted and encouraged to activate the MET in case of a patient deterioration; in a situation where 'a disparity between what care a patient is receiving and what care he or she requires emergently' exists (DeVita et al. 2006). In reality, most of the MET activations are made by the general ward nursing staff (Parr et al. 2001, Kenward et al. 2004, Dacey et al. 2007). Whilst MET activation overtakes the normal consultation hierarchies, general ward nurses regarded MET as a useful and potentially beneficial system that improves patient safety and care in unicentre survey studies (Jones et al. 2006, Bagshaw et al. 2010). A majority of ward nurses comprehended the concept of a RRS, and reported that they appreciate the rapid escalation of care for patients they were worried about (Jones et al. 2006, Bagshaw et al. 2010). It has been speculated that implementation of RRS could actually reduce the skills required for treating acutely ill patients among general ward nurses even further (Jones, DeVita & Bellomo 2011). In surveys, however, most nurses clearly deny this effect and actually report that the MET offers valuable education in care of sick patients (Jones et al. 2006, Bagshaw et al. 2010).

Junior physicians are regarded as an important part of the afferent limb, since their knowledge and skills in acute care are inevitably deficient but as physicians they are above many of the hierarchical barriers delaying the MET activation (Smith & Poplett 2002, Jones, King & Wilson 2009). Junior physicians should be encouraged to both activate the MET and attend MET reviews; these situations provide the opportunity to develop critical care skills under the guidance of a MET physician (Jones, King & Wilson 2009).

6.3.4 Afferent limb failure

Afferent limb failure (ALF) refers to a delayed activation of the MET; even though ward staff have recorded positive activation criteria they do not activate the efferent limb (Trinkle & Flabouris 2011). This phenomenon was first documented by Hillman et al. in 2005; during the cluster-randomized controlled trial RRSs were implemented in 12 hospitals. After the implementation, positive MET activation criteria had still been recorded >15 minutes before the event in 51% of the

emergency ICU admissions and in 30% of IHCAs without activating the efferent limb (Hillman et al. 2005). Observational studies have defined the timeline for ALF variably: occurring from 0.25-1 h to 24h (or more) before an SAE (Hillman et al. 2005, Calzavacca et al. 2010, Trinkle & Flabouris 2011, Boniatti et al. 2014).

The most common reasons for ALF are hierarchical: in questionnaire studies 72% to 76% of the nurses reported that they would first alert the ward's physician responsible for the patient instead of activating the MET (Jones et al. 2006, Bagshaw et al. 2010). Worrying about being criticized for unnecessary activation inhibited the willingness for MET activation among one fifth of nurses, and sometimes home ward (physicians) may directly discourage alerting the MET (Jones et al. 2006, Jones, King & Wilson 2009, Bagshaw et al. 2010, Azzopardi et al. 2011). According to unicentre survey studies, if a patient seems well in spite of fulfilling the calling criteria, 30 to 40% of nurses reported feeling uncertain if MET activation was actually needed and/or would not alert the MET (Jones et al. 2006, Azzopardi et al. 2011). The attitude of the MET staff may affect nurses' decision-making positively or negatively; future activations are inhibited if MET members' comments cause the nurses giving the alert to feel incompetent (Jones, King & Wilson 2009).

Delays in adequate interventions are detrimental to the prognosis of the critically ill (Rivers et al. 2001, Jones, King & Wilson 2009, Cardoso et al. 2011, Bing-Hua 2014). Patients reviewed by the MET are no exception. In a cohort of 200 MET reviews triggered by a change in consciousness or arrhythmias ALF was documented in 30% of the activations, and was independently associated with hospital mortality (OR 3.1, 95% CI 1.4–6.6) (Downey et al. 2008). Another observational unicentre study including 251 office hours of reviews found ALF in 21% of the reviews, and similarly an independent association with hospital mortality (OR 2.53, 95% CI 1.2-5.3) (Calzavacca et al. 2008).

6.3.5 Efferent limb

The efferent limb of the RRS, RRT/MET/CCOT, within minutes deploys the equipment and the personnel with critical care skills in case of an alert call (Jones, DeVita & Bellomo 2011). The team composition depends on institutional and cultural factors; commonly the team includes a critical care physician with 1-2 dedicated nurses, but teams led by ICU nurses or respiratory therapists have also been implemented (Devita et al. 2006, Peberdy et al. 2007, Jones, DeVita & Bellomo 2011). MET, by consensus definition, refers to a physician-led team that (1) is able

to prescribe therapy, (2) has advanced airway skills, (3) can insert central vascular lines and (4) is able to begin ICU-comparable treatments at bedside (Devita et al. 2006). A recent systematic review concluded that the efferent limb seems to be more effective when it is physician-led, but no studies have directly compared the outcome benefits between nurse-led and physician-led teams (Jones, DeVita & Bellomo 2011, McNeill & Bryden 2013).

The experience level and specialization of MET physicians varies; in a recent questionnaire study from Australia including 39 of the 108 hospitals equipped with METs, an ICU physician invariably attended the MET activation in 79% of the teams; an ICU resident was most commonly the physician attending activations followed by internal medicine residents (ANZICS-CORE MET dose Investigators et al. 2012). Two unicentre observational studies have assessed the impact of physicians experience level on patient outcome, and no differences in survival were observed between resident and attending intensivist-led METs (Karvellas et al. 2012, Morris et al. 2012).

The escalation of care is not a routine intervention provided by MET; ethically sound limitations of medical treatment (LOMT), such as 'do not attempt resuscitation' (DNAR) or 'not for intensive care' are an integral part of RRSs (Parr et al. 2001, Hillman et al. 2005, Aneman & Parr 2006). Recent prospective observational unicentre and multicenter studies have reported that approximately one fifth of patients attended by the MET have LOMT, and the MET implements new LOMT for every tenth patient it reviews (Jones et al. 2012, Jaderling et al. 2013).

6.3.6 Critical care outreach

Prospective observational follow-up studies show that SAEs after intensive care are often related to suboptimal care on general wards (McLaughlin et al. 2007, Chaboyer et al. 2008). Critical care outreach (CCO) (also known as an ICU liaison nurse) services provide a continuum of care for discharged ICU patients (Endacott, Eliott & Chaboyer 2009). Generally an experienced ICU nurse visits discharged ICU patients at least once a day, measures vital signs, provides guidance in patient care, shares critical care skills with ward staff and activates further responses (e.g. MET) if required (Ball, Kirkby & Williams 2003, Leary & Ridley 2003, Endacott et al. 2010). Minor interventions commonly provided by the liaison nurse are related to tracheostomy management, suctions, guiding of management of continuous

positive airway pressure and similar tasks general ward nurses are unfamiliar with (Ball, Kirkby & Williams 2003).

Most studies evaluating the impact of CCO on patient outcome have been conducted in Australia and the United Kingdom, and the study design has been a before-after trial (Endacott, Eliott & Chaboyer 2009, McNeill & Bryden 2013). Although improved survival rates and ICU readmission rates have been reported after CCO implementation, these studies include residual confounding related to the before-after design (comparability of the cohorts, concomitant improvements in patient safety) and are poorly comparable with each other (Ball, Kirkby & Williams 2003, Garcea et al. 2004, Priestley et al. 2004, Endacott, Eliott & Chaboyer 2009). The current level of evidence supports the use of CCO, but high risk of bias exists (McNeill, Bryden 2013).

6.3.7 Level of current evidence

In 2002 Buist et al. published the results of a before-after trial evaluating the effect of MET implementation on the rate of IHCAs in a single 300-bed tertiary hospital (Buist et al. 2002). After adjusting for confounding factors, the deployment of the MET was associated with reduced rates of IHCAs (odds ratio (OR) 0.50, 95% confidence interval (CI) 0.35 to 0.73) for the first time in RRS literature (Buist et al. 2002). Subsequently, over 40 unicentre and multicentre studies using the before-after design have been published (Winters et al. 2013).

Two randomized controlled trials on rapid response systems have been published. The more cited one was published by Hillman et al. in 2005; in a large multicentre study including 125,000 patients, 23 hospitals were randomized to introduce a MET (n=12) or continue functioning as before (n=11) (Hillman et al. 2005). No differences between the intervention and control hospitals were observed. However, the MET hospitals suffered from ALF and the control hospitals were presumably contaminated because their existing cardiac arrest teams began to be activated for other medical emergencies as well. As a result, the incidence of IHCAs decreased in both the intervention and the control hospitals (Hillman et al. 2005). Priestley et al. published their results after randomizing 16 general hospital wards in a single-centre to RRS in 2004 (Priestley et al. 2004). A total of 2,900 patients were included, and introducing RRS was associated with decreased hospital mortality (OR 0.52, 95% CI 0.32-0.85). Since these two studies no RCTs have been conducted. A Cochrane review in 2007 evaluating RRSs excluded all but these two studies because

of deficient methodology and underlined the lack of solid evidence of RRSs (McGaughey et al. 2007).

Three meta-analyses and one supplementary review of RRSs with IHCAs and in-hospital mortality as outcome measures have been presented. Table 3 presents the results of these meta-analyses. The persistent problem is that most of the studies included are unicentre before-after trials (Winters et al. 2013). Although some studies have been adjusted for preintervention trends, confounding factors like institutional heterogeneity (differences between hospitals, implementation methodology, METs, activation criteria) and temporal trends (like possible other patient safety campaigns) make it difficult to draw conclusions about the effectiveness (Chan et al. 2010, McNeill, Bryden 2013). Further, while some of the before-after studies have adjusted their analyses for confounding factors like age and comorbidities, only in RCT studies can all potential confounding factors be 'controlled' (Mann 2003, Chan et al. 2010). In 2008 Chan et al. conducted a high quality meta-analysis including 18 studies, and Winters et al. supplemented this meta-analysis four years later in 2012 with 26 additional studies (Chan et al. 2010, Winters et al. 2013). All the additional studies used before-after design and the risk of bias was assessed to be high (Winters et al. 2013). Winters et al. presented the additional metadata but did not conduct actual meta-analysis. They estimated significant association with RRS and decreased incidence of both IHCAs and in-hospital deaths when a total of 44 studies were included as all the recent studies reported positive results; because of the data quality the strength of evidence was assessed to be 'moderate' (Winters et al. 2013).

A number of systematic reviews not using meta-analytical methods concur with the results of the meta-analyses; evidence from generally poor to moderate quality studies exist but large multicentre RCTs are required to confirm the hypothesis behind RRSs (Aneman & Parr 2006, Esmonde et al. 2006, McNeill & Bryden 2013). Both the most recent analysis with recent metadata and systematic review found that before-after trials conducted in recent years seemed to yield more positive results; one reason (among the confounding factors described above) may be the improved implementation methods and maturation of the systems (McNeill & Bryden 2013, Winters et al. 2013).

Table 3. Results of the 3 meta-analyses and 1 supplementary review of rapid response systems

Meta-analysis	Included studies published before	Number of included studies (designs)	Decrease in cardiac arrests (RR, 95% CI in comparison to control)	Decrease in mortality (RR, 95% CI in comparison to control)	Conclusions
(Winters et al. 2007)	6/2005	8 (2 RCT, 1 quasi-experimental, 5 before-after)	0.94 (0.79-1.13) in RCT and 0.70 (0.56-0.92 in before-after designs)	0.76 (0.39-1.48) in RCT and 0.87 (0.73-1.04) in before-after designs	Weak association with improved outcomes. Poor data quality.
(Ranji et al. 2007)	8/2006	13 (1 RCT, 12 before-after)	Not significant in RCT, 0.73 (0.65-0.83) in before-after designs)	Not significant in RCT, 0.82 (0.74-0.91) in before-after designs	No consistent association with improved outcomes. Poor data quality.
(Chan et al. 2010 Rapid Response Teams)	11/2008	18 (2 RCT, 1 quasi-experimental, 15 before-after)	Adults 0.66 (0.54-0.80), paediatric 0.62 (0.46-0.84)	Adults 0.96 (0.84-1.09), paediatric 0.79 (0.63-0.98)	No robust evidence of decreased hospital mortality in adults.
(Winters et al. 2013)	10/2012	44 (2 RCT, 1 quasi-experimental, 41 before-after)	Metadata presented only	Metadata presented only	Moderate strength evidence of reduced rates of cardiac arrests and mortality

6.4 Activation criteria

An important link in the 'chain of prevention' is the early recognition of patient deterioration triggering the response. By definition, RRS incorporates predefined activation criteria, which are used by ward staff to detect deterioration in patients' condition (Devita et al. 2006, Jones, DeVita & Bellomo 2011).

At least 71 different activation criteria have been reported in the literature (Gao et al. 2007, Smith et al. 2008, Smith et al. 2013). They are based on vital signs (objective criteria) but most of them also encourage MET activation by including a subjective 'worried' criterion. More complex subjective criteria (pain, colour change, lethargy, social factors) have also been reported (Gao et al. 2007, Smith et al. 2008). On the basis of the objective vital signs measurements, activation criteria can be categorized as single-parameter systems, multiple-parameter systems, aggregate weighted scoring systems or combination systems (Gao et al. 2007, Smith et al. 2008). Either a single parameter system (dichotomized activation criteria) or an aggregate weighted scoring system (early warning scoring system) is usually used (Gao et al. 2007, Jones, DeVita & Bellomo 2011).

Ideally, activation criteria would enable early detection of deteriorating patients (good sensitivity) and, on the other hand, not detect patients not requiring MET review (good specificity). Good positive predictive value means that the activation criteria recommend MET activation only for patients with high probability for SAEs in the studied population; negative predictive value means that the activation criteria assess patients correctly as 'healthy' in the setting (Saah & Hoover 1997). In 2007 Gao et. al conducted a meta-analysis including 15 activation criteria; most of the activation criteria evaluated had weak sensitivities and positive predictive values (respective medians 43% and 37%) as evaluated against SAEs occurring later during the hospitalization, but specificities and negative predictive values were acceptable (respective medians 90% and 94%) (Gao et al. 2007).

Initially the activation criteria were based solely on expert clinical intuition of the manifestations of patient deterioration (Lee et al. 1995, Hodgetts et al. 2002a, Morgan & Wright 2007). Because the aim of RRS is the reduction of IHCAs, emergency ICU admission and unexpected deaths, the performance of activation criteria was first studied using these outcomes as endpoints after measuring vital signs in different patient cohorts (Subbe et al. 2001, Duckitt et al. 2007). Recently electronic data gathering has enabled the comparison of large sets of vital signs against these endpoints, thereby potentially increasing the accuracy of new activation criteria (Prytherch et al. 2010). However, this method of defining the performance

of activation criteria as 'ability to predict SAEs' has also been criticized. In these analyses, the patients whose clinical course improved (and who were potentially 'salvaged' from deteriorating all the way to these SAEs) are not included (Tarassenko et al. 2011). In other words, activation criteria are meant to detect patient deterioration, not to predict SAEs (Morgan & Wright 2007). Therefore, when activation criteria are derived from a certain study population to reliably predict SAEs, they must at least be tested on different populations before drawing further conclusions (Pieringer & Hellmich 2013). Another defect, especially in studies using large datasets and/or including in-hospital mortality in the composite outcome of SAEs, is not excluding DNAR patients; predicting the deaths of these patients is by no means the aim of the activation criteria (Churpek, Yuen & Edelson 2013). Finally, multiple factors increase the risk for SAEs during hospitalization; these include age, comorbidities, admission characteristics and interventions conducted (Falcoz et al. 2007, Frost et al. 2009, Renton et al. 2011, Smith et al. 2013). The relative (adjusted for these confounding factors) performance of activation criteria has not been reported.

No robust evidence exists to unambiguously recommend either dichotomized criteria or early warning scores as activation criteria. In 2013 two systematic reviews concluded that EWSs may perform better than dichotomized criteria in both detecting deteriorating patients and preventing IHCAs and emergency ICU admissions (Churpek, Yuen & Edelson 2013, McNeill & Bryden 2013). This may partly be because EWSs inherently lead to measuring all vital signs (McNeill & Bryden 2013).

6.4.1 Dichotomized activation criteria

The dichotomized activation criteria (also known as single parameter system), commonly used in Australia, comprise a selected set of vital signs (ANZICS-CORE MET dose Investigators et al. 2012). For each vital sign, thresholds have been defined; if any of the included vital signs reaches its threshold, the criteria are 'positive' and the MET should be alerted. Otherwise the criteria are 'negative' and MET activation is not required (Gao et al. 2007, Jones, DeVita & Bellomo 2011). Table 4. presents the dichotomized criteria used in Tampere University Hospital (TAYS), Finland.

Generally included vital signs are RR, $Sp0_2$, HR, SAP and a fall in GCS, and the set thresholds for these vital signs vary between studies (Lee et al. 1995, Buist et al.

2002, Bellomo et al. 2003, Hillman et al. 2005, Bell et al. 2006, Jacques et al. 2006, Cretikos et al. 2007, Fuhrmann et al. 2008, ANZICS-CORE MET dose Investigators et al. 2012). The greatest variance occurs in the upper threshold for RR (25-40/min) and HR (120-140/min) (Hillman et al. 2005, Bell et al. 2006, Jones, DeVita & Bellomo 2011). Sensitivities (33-72%) and specificities (86-96%) for predicting SAEs/30-day mortality naturally differ, depending on the thresholds used (Bell et al. 2006, Cretikos et al. 2007, Gao et al. 2007, Fuhrmann et al. 2008). If the thresholds are restricted to avoid unnecessary triggering (fewer patients have 'positive' activation criteria), the already low sensitivity decreases further (Bell et al. 2006). The positive predictive values of dichotomized activation criteria are poor, varying from 6.5% to 44% (Bell et al. 2006, Cretikos et al. 2007, Gao et al. 2007, Fuhrmann et al. 2008). Negative predictive values are good (95-100%) (Bell et al. 2006, Cretikos et al. 2007, Fuhrmann et al. 2008). In accordance with these statistical values, Jacques et al. concluded in 2006 that the dichotomized criteria are 'late signs' of patient deterioration (Jacques et al. 2006). This phenomenon of late signs was documented in the RCT study by Hillman et al.; less than half of IHCA/unplanned ICU admission patients had positive criteria as late as <15 minutes before the call (Hillman et al. 2005).

One method to assess the true workload of activation criteria (if they were always complied with, i.e. positive criteria would always lead to MET activation) for the MET is to measure the prevalence of fulfilled activation criteria on general wards. Three studies (all with dichotomized criteria) have been presented, and positive activation criteria were observed in 3-18% of patients (Bell et al. 2006, Fuhrmann et al. 2008, Bucknall et al. 2013). Sensitivities (9-37%) and positive predictive values (13-25%) on 30-day mortality were poor (Bell et al. 2006, Fuhrmann et al. 2008, Bucknall et al. 2013).

Table 4. Tampere University Hospital's dichotomized medical emergency team activation criteria

Vital sign	Activation threshold
Heart rate (beats/min)	< 40/min or >140/min
Systolic blood pressure (mmHg)	< 90 mmHg
SpO_2	< 90 %
Respiratory rate (breaths/min)	< 5/min or > 24/min
A fall in Glasgow Coma Scale	≥ 2

If one (or several) of the vital signs meets the agreed activation threshold, the MET should be activated immediately. Otherwise vitals are considered normal and no MET activation is required.

6.4.2 Early warning scoring systems

Early warning scoring systems (also known as aggregate weighted scoring systems or aggregate weighted track and trigger systems) score each included vital sign, usually from 0 (normal) to 3 (extreme derangement), according to how much the measured vital sign deviates from the range considered as 'normal' (Smith et al. 2008). First presented in 1997, these activation criteria have been widely adopted in the United Kingdom, and in recent years most developments regarding activation criteria have concerned the EWSs (Morgan & Wright 2007, Prytherch et al. 2010, Smith et al. 2013). Usually vital signs in EWSs include RR, $Sp0_2$, HR, SAP, body temperature and AVPU scale, but many EWSs also incorporate urine output and supplementary oxygen usage (Gao et al. 2007, Smith et al. 2008).

Performance of EWS have been similarly assessed using SAEs as outcomes. Because EWSs are continuous variables, their performance in predicting these dichotomized outcomes (no/yes) correctly have been evaluated by the area under the receiver-operating characteristics (AUROC) curve (Hanley & McNeil 1982, Prytherch et al. 2010). A recent study by Smith et al., using all SAEs as a composite outcome for 36,000 medical patients admitted to hospital from the emergency department (ED), reported that the ability (percentage of cases) of different EWSs to predict the outcome (either occurring or not) correctly ranges from 74% (95% CI 73–75%) to 87% (87–88%) (Smith et al. 2013). However, although EWSs form a continuous score, an effective activation threshold, cut-point (the score that initiates MET activation) has to be included, which makes EWSs also dichotomized at a certain level (Cuthbertson 2008). Gao et al. studied the sensitivities and specificities of 10 different EWSs published before 2005, using the suggested cut-points for MET activation (Gao et al. 2007). With the suggested cut-points sensitivities for

SAEs varied from 25-100% and specificities from 14-99%. As logical, better sensitivity came with reduced specificity and vice versa (Gao et al. 2007). Improvements to these results have been recorded; with a cut point of scoring four or more Gardner-Trope et al. reported the modified early warning score (MEWS) to be 75% sensitive and 83% specific for later emergency ICU transfer (Subbe et al. 2001, Gardner-Thorpe et al. 2006). More recently, Churpek et al. published their results after testing four EWSs with their activation thresholds in a cohort of 59,600 general ward patients (Churpek, Yuen & Edelson 2013). Sensitivities ranged from 19% to 67% and specificities from 80% to 97%. The best sensitivity was observed with (MEWS) >3 (67%); with this activation threshold the specificity was 80% (Churpek, Yuen & Edelson 2013).

In 2012 the Royal College of Physicians in the United Kingdom, supported by the National Health Service, developed the 'National Early Warning Score' (NEWS) to standardize the assessment of the hospitalized patients nationwide (Royal College of Physicians 2012). Table 5. presents the NEWS with proposed activation thresholds. Although assessed relatively reliable in the study by Smith et al. (described above), it has not been validated for heterogeneous general ward patients (Smith et al. 2013). Most other EWSs have similarly been developed among ED patients or on selected wards (Gao et al. 2007).

Table 5. National Early Warning Score (NEWS) according to the Royal College of Physicians (Royal College of Physicians, 2012).

	3	2	1	0	1	2	3
Respiratory rate (breaths/min)	≤8		9—11	12—20		21—24	≥25
SpO_2%	≤91	92—93	94—95	≥96			
Any supplementary oxygen		Yes		No			
Temperature (°C)	<35.0		35.1—36.0	36.1—38.0	38.1—39.0	≥39.1	
Systolic blood pressure (mmHg)	≤90	91—100	101—110	111—219			≥220
Heart rate (beats/min)	≤40		41—50	51—90	91—110	111—130	≥131
A, V, P, U				A			V, P, U

Every vital sign is scored from 0 (normal) to 3 (extreme deviation). The total score is then added up, providing a discrete score. A score of five, or an individual vital sign scoring three should initiate an urgent review; a score of seven or more should trigger an immediate MET activation.

6.4.3 The 'Worried' criterion

According to survey studies, from 48% to 56% of general ward nurses would activate the MET if they were worried about their patient, even if that patient's vital signs were normal (Jones et al. 2006, Bagshaw et al. 2010). This 'worried' criterion has been included in the majority of activation criteria (both dichotomized and EWSs) from the beginning, and is also recommended for use in the consensus statement (Buist et al. 2002, Devita et al. 2006, Gao et al. 2007, Smith et al. 2008, Jones, DeVita & Bellomo 2011). In an Australian study including 39 hospitals with RRS, 94% had included the 'worried' criterion in their activation criteria (ANZICS-CORE MET dose Investigators et al. 2012). The 'worried' criterion encourages the ward personnel

to activate MET on a 'gut feeling' that something is wrong even if the patient's vital signs do not reach the activation threshold, which seems appropriate given the sensitivity of objective criteria (described above) (Jones, King & Wilson 2009, Santiano et al. 2009).

In prospective observational studies, from 5-32% of MET calls have reportedly been triggered because of 'concern about the patient' (Santiano et al. 2009, Boniatti et al. 2010, Calzavacca et al. 2010, Boniatti et al. 2014). In one third of the cases, respiratory dysfunction was the cause of concern, and among the specific verbal reasons 'chest pain' is often reported (Santiano et al. 2009, Boniatti et al. 2010). It has been suggested that the 'worried' criterion enables earlier recognition of patient deterioration (Santiano et al. 2009, Boniatti et al. 2010). No studies have investigated the statistical performance or feasibility of the ‘worried’ criterion.

6.5 Finnish guidelines

The latest Finnish national cardiopulmonary resuscitation guidelines were published on 2 February 2011 as part of the Current Care (Käypä Hoito) evidence-based guidelines series. Table 6. summarizes our national recommendations related to RRS (Working group set up by the Finnish Medical Society Duodecim, the Finnish Resuscitation Council, the Finnish Society of Anaesthesiologists and the Finnish Red Cross 2011).

Table 6. Recommendations of Finnish resuscitation guidelines on rapid response systems in hospitals (translated).

- Every staff member should be able to recognize a medical emergency and begin basic treatments while waiting for assistance.
- A majority of in-hospital cardiac arrests are preceded by altered vital signs (airway problems, respiratory rate, heart rate, blood pressure, $Sp0_2$, level of consciousness, diuresis).
- Early detection and effective treatment of critical illness may prevent some cardiac arrests, deaths and unplanned ICU admissions.
- Adequate treatment of critically ill ward patients requires a response system covering the whole hospital.
- Routine vital signs measurements help to find risk patients. Training and clear instructions (activation criteria) must be provided for ward staff.
- Whole hospital staff, regardless of occupation, must be encouraged to call for help for a deteriorating patient, and a uniform system for calling help should be provided.
- Hospitals must have a clearly defined response in case of a patient deterioration in general wards. Staff members included in this response should have critical care skills. The response may be a 'Medical Emergency Team' or a 'Rapid Response Team'.

6.6 RRS in Tampere University Hospital (TAYS)

TAYS is one of Finland's five university-level tertiary level referral centres with 700 somatic beds and approximately 75,000 annual admissions. It provides care as a secondary referral centre (central hospital) for 23 municipalities (catchment population 520,000). In addition, TAYS provides the most advanced care as a tertiary referral centre for 67 municipalities (population 1,100,000).

TAYS has a closed model, mixed surgical-medical, adult ICU with 24 beds and its own clinical information system (Centricity® Critical Care, GE Healthcare). Eight of these beds serve primarily as a high dependency unit (HDU) beds but can be and are used for severely ill patients as well.

An RRS was first implemented in TAYS for six months (February-July 2008) on trial as a part of an ICU nurse's advanced studies (Alanen 2008). It included two internal medicine wards, one surgical ward, dichotomized activation criteria and a

MET led by an ICU physician. As the results were promising, the RRS was expanded to include all hospital wards, ED and operating rooms (ORs) in January 2009. Implementation to the whole hospital included lectures for medical- and nursing staff, distribution of posters and wallet-sized index cards of the activation criteria (Appendix 1) and announcements in the hospital intra-net. Every hospital ward has a dedicated nurse who is responsible for ward-level training on patient deterioration and CPR. After the initial implementation phase, collective lectures (current guidelines and TAYS statistics/results on CPR/RRS) have been organized twice a year for these nurses. Additionally, ward staff has small-group training in a simulation laboratory, but the training frequency depends on the individual departments' management.

The MET consists of one ICU physician and two ICU nurses. The physician may be attending or resident. All residents must train at least one day in the simulation laboratory before their first on-call shift, and an attending ICU physician is always present in the ICU during on-call shifts. MET nurses train in the simulation laboratory from four to five days a year. When alerted, the MET nurses may attend the patient first and consult the physician by phone/ask the physician to attend the patient after their initial evaluation. A MET trolley is part of the team making it independent of emergency site equipment; the MET can independently provide CPAP, intubation, defibrillation, i.v. fluids, medication including vasoactive infusions and both obtain and analyze arterial blood gas samples. The MET responds to all medical emergencies including CAs, and MET nurses may conduct CCO for discharged ICU patients if deemed necessary by the discharging physician.

Dichotomized activation criteria were implemented in 2009 and are still used in TAYS. The objective criteria are presented in Table 3. In addition the criteria include: lifelessness, obstructed airway, prolonged seizures and the 'worried' criterion.

7 Aims of the study

The aim of this thesis was to investigate (1) the prevalence and subsequent consequences of vital dysfunctions among hospitalized general ward patients and (2) RRSs in Finland. Specific objectives were:

1. To evaluate the relative performance of MET activation criteria among discharged ICU patients (I) and all general ward patients (III).

2. To describe the core data of an RRS in a Finnish university hospital according to the Utstein-style scientific statement, with a special reference to delays in MET activations (II).

3. To observe the documentation frequency of vital signs and altered vital signs in general wards (II, III).

4. To determine the current status of RRSs in Finnish hospitals (IV).

8 Materials and Methods

8.1 Hypotheses and designs

This thesis is based on empirical, quantitative studies conducted according to the hypothetico-deductive model. The studies were planned in November 2009-February 2010 after the author, Dr. Joonas Tirkkonen, had completed his advanced studies on MET. Table 7. presents the study designs with general characteristics.

Before Studies I and III the following hypothesis (conjecture) was formed: vital dysfunctions, defined as positive MET activation criteria, predict independently SAEs. This hypothesis was compatible with previous (univariate) studies and logically contained no discrepancies. It also was relatively simple, informative and easily tested in a prospective cohort study with mathematical and statistical methods.

In Study II, the basic data reporting according to the Utstein-style Statement required no formal hypothesis as the premise was to publish descriptive core data on the utilization of the MET in Finland as recommended in the Statement (Peberdy et al. 2007). However, two specific hypotheses subject to testing in this study were formed: 1) increased monitoring intensity of vital signs itself may not decrease the prevalence of ALF and 2) ALF is independently associated with in-hospital mortality. As above, these premises fulfill the fundamental requirements for hypotheses, and were well suited for testing in a prospective cohort study.

The design process of the IV study contained the following hypothesis: there is a wide variety in the RRSs operational in Finland. A cross-sectional postal survey enabled the data elements to be gathered from dozens of participating hospitals simultaneously.

Table 7. Characteristics of the studies I-IV.

	Design and conduct time	Main objectives	Initial cohort	Exclusion criteria	Final cohort
Study I	Prospective cohort, 1st June - 31st July 2010	Prevalence and impact of vital dysfunctions recorded 24 h after ICU discharge	253 discharged ICU patients	Age < 18, discharged after an ICU readmission, LOMT, discharged to other hospital, death/readmission before the 24 visit, not present in the ward at the time of the visit	184 discharged ICU patients
Study II	Prospective cohort, 1st Jan - 31st Dec 2010	a) Utstein-style report of RRS in TAYS b) ALF: prevalence, risk factors and impact on in-hospital mortality	770 MET reviews for 641 patients	Reviews with CPR, non-general ward reviews, reviews to patients not present in the ward 0-6h prior the review	539 MET reviews for 428 general ward patients
Study III	Prospective cohort, on two separate days in Sep - Oct 2010	Performance of dichotomized MET activation criteria vs. NEWS in general wards	698 general ward patients	Age < 18, LOMT, non-citizen, present during the first study day, not present in the ward, visit assessed inappropriate, patient refusal	615 general ward patients
Study IV	Cross-sectional postal survey, April 2012	Prevalence and characteristics of CATs and RRSs in Finland	55 public hospitals with anaesthethic services	-	51 public hospitals with anaesthethic services

8.2 Data collection and exclusion criteria

8.2.1 Study I

This study was conducted between 1 June 2010 and 31 July 2010. All patients discharged from the 24-bed ICU in TAYS were visited approximately 24 hours after their discharge, with the following exceptions (the exclusion criteria): age under 18 years, discharged after readmission to ICU, discharged with LOMT and discharged directly to other hospital. Patients who had new treatment limitations 24h after the ICU discharge were further excluded. If a patient had died, been readmitted to ICU or transferred to other facility within the first 24 hours the visit was naturally not possible. If other reasons prevented the visit, these were recorded.

The 24 h visits were conducted by two trained medical students working as interns in the ICU. First, basic information regarding the discharged patient was recorded manually by the ICU nurse responsible for the patient (name, social security number, details of general ward to which patient was discharged, time of discharge, treatment limitations) and stored in a folder. The data in the folder was daily compared to computerized department statistics so that no discharges were missed. During the following day the interns attended the discharged patients if possible. They measured RR, $Sp0_2$, HR, SAP and documented GCS. The general ward nurse responsible for the patient was also briefly interviewed with the following question: Have you been more concerned than usual about your patient's condition? In case of a positive answer, the nurse was asked the reason for this. The measured vital signs were reported to these nurses, and they were asked if they deemed a MET review necessary; categorization to 'positive' or 'negative' MET activation criteria was performed later.

Patients' medical records were retrospectively reviewed for patient characteristics, hospital admission variables and outcome data. Intensive care admission data were obtained from the ICU's clinical information system.

8.2.2 Study II

In 2007 ILCOR published Utstein-style guidelines for uniform research on RRSs (Peberdy et al. 2007). Suggested core elements to be reported comprised hospital demographics, RRS characteristics (including implementation, team composition

and activation criteria), pre-event data, MET review data and outcome measurements. According to the 2007 guidelines, data on all MET activations were collected prospectively from 1 January 2010 to 31 December 2010. During all MET activations a standardized case form, designed according to the ILCOR guidelines, was completed by a MET nurse *in situ* (Appendix 2). A retrospective review of medical records was conducted, and patient and outcome data were obtained. To retrieve data on patients' vital signs before MET activation, time-labelled electronic nursing records were examined for the 6 h time period preceding the reviews. ALF was defined as positive TAYS MET activation criteria (Table 3), excluding a fall of GCS, recorded 0.33-6 h before the MET activation. In 2010 all electronic data was manually fed into the records, although 5.9% (45) of general ward beds were equipped with automated non-invasive patient monitors and better staffed (0.24 vs. 0.1 nurses/patient) to enable more frequent measurements and evaluations.

To report the actual annual number of MET activations due to medical emergencies other than CAs, MET activations where CPR was provided were excluded and reported separately. For further analyses concerning general ward patients, MET activations to ED, OR, ICU, HDU, diagnostic areas and public areas were excluded. Finally, for the sub-analyses regarding the preceding documentation of vital signs and ALF, newly admitted general ward patients had to be further excluded to avoid obvious reporting bias.

8.2.3 Study III

Two prospective point prevalence studies on vital dysfunctions had been published before this study was planned and the data gathered (Bell et al. 2006, Fuhrmann et al. 2008). One large methodological flaw in both studies was that 18% of the general ward patients were not evaluated for a number of reasons, and selection bias remained a question as the characteristics of these patients were unknown (Bell et al. 2006, Fuhrmann et al. 2008). Further, the study by Bell et al. included DNAR patients and did not include the measurement of SpO_2.

Power calculations based on the study by Fuhrmann et al. were conducted to obtain an estimate of the appropriate cohort size (variable being TAYS dichotomized criteria, outcome 30-day mortality) and are more specifically explained in the 8.5 Statistics (Fuhrmann et al. 2008). A total of 555 patients were required. From the hospital's beds, those in ED, OR, ICU, HDU, paediatric wards and obstetric wards were excluded leaving 538 general ward beds eligible for inclusion. The average

occupancy in TAYS was 75%; thus it was assumed that two separate evaluation days would provide the required cohort (538 beds x 0.75 x 2 = 807 patients).

Thirty fourth-year medical students were recruited. All students received training on vital signs, equipment usage and data recording before both occasions. Working in pairs, they measured RR, $Sp0_2$, HR, SAP, GCS and AVPU from each patient on TAYS's general wards between 4.00 and 7.00 p.m. on two evenings, first in September and then in October 2010. They also recorded the use of supplementary oxygen and possible treatment limitations. All measurements were documented on a template, and a duplicate was provided to the ward staff. Vitals were handled as raw numbers only. No interventions were conducted. Names and social security numbers were also collected from all ward patients not assessed by the students.

Cases of under-aged patients on adult general wards were excluded. Other exclusion-criteria were: being non-Finnish (no mortality data available in the Finnish Population Register Centre), being admitted during both study days, having a DNAR-order, refusing measurement of vital signs and if the ward personnel assessed the measurement of vital signs to be inappropriate. If other reasons prevented the evaluation (a patient was admitted to surgery / temporarily absent from the ward etc.), the reasons were recorded.

Retrospectively, patient records were checked for patient and admission characteristics. Mortality up to 360 days was retrieved from the Finnish Population Register Centre. Nursing records were also reviewed: patients' body temperatures from the study evening were noted, and data on the measurements of the vital signs from the 24 hours preceding the review was collected. Based on the measured vital signs, patients were categorized to those with 'positive' or 'negative' TAYS MET criteria. NEWS scores were also calculated for every patient, and then categorized as being 'positive' or 'negative' according to the two suggested cut-points ($\geq$5 or an individual vital sign scoring three, and a score of $\geq$7) (Royal College of Physicians 2012).

8.2.4 Study IV

A questionnaire was compiled to gather information on CATs and RRSs in public Finnish hospitals providing anaesthetic services. Hospitals providing care for paediatric patients only were excluded. The university hospital of the densely populated metropolitan area has eight satellite hospitals for adults, which provide care as separate units. These hospitals were considered as individual hospitals in this

study. Four hospitals were further classified as secondary referral centres as they have adult ICUs and a *de facto* central hospital function; the other four hospitals were classified as 'specialized units of a university hospital'.

A draft questionnaire was produced and evaluated by a TAYS ICU physician (not involved in the study) and a biostatistician, and revised accordingly. The questionnaire included 47 closed-ended questions with options for open-ended answers. Five questions elicited data on hospital demographics, 14 questions on CATs, 23 questions on RRSs and five questions were related to CCO activity (Appendix 3).

In April 2012 55 questionnaires were sent to the directors of anaesthesia/ICU departments. In the covering letter recipients were requested to forward the questionnaire to a physician directly responsible for resuscitation/RRS activity, if appropriate. Two reminder letters were sent, after which the respondents were contacted by telephone or e-mail.

8.3 Outcome measures

8.3.1 Study I

Vital dysfunctions were defined as positive objective TAYS MET activation criteria (Table 3), excluding a fall of GCS as a trend in the level of consciousness could not be measured. If the patient's nurse answered 'yes' to the question 'Have you been more concerned than usual about your patient's condition?', it was recorded as a positive 'worried' criterion.

SAE was used as a composite outcome including any of the following occurring during the subsequent hospital admission: MET activation, readmission to ICU or death. A MET activation was regarded as an SAE because, as described in the literature review, this potentially enabled the inclusion of deteriorated patients 'salvaged' by minor intervention and not suffering the more severe SAEs. However, possible MET activations occurring immediately after the study visits were not considered as SAEs, as these would have been prompted by the visits.

8.3.2 Study II

First, the characteristics of MET reviews, preceding recording of vital signs and prevalence of ALF were reported and also compared between general ward patients monitored either 'automatically' or 'normally'. Second, ALF itself was used as an outcome measure and independent associations were investigated. The third outcome studied in the cohort was death during the subsequent hospital admission.

8.3.3 Study III

Five different outcomes were used to enable comparisons between previous and future studies with different outcome measures. The first was an SAE during the subsequent hospital admission defined as any of the following: MET activation, cardiac arrest, emergency intensive care unit admission or death. The second was an SAE excluding MET activations. Outcomes three to five were mortalities measured at different time points (30-, 60- and 180-days after the visit). The primary outcome measure was 30-day mortality as this had also been used in earlier studies.

8.3.4 Study IV

Prevalence of CATs and RRS. Variance in MET activation criteria and team composition. Recorded incidences of IHCAs and MET activations in Finland.

8.4 Ethical considerations

All studies were of observational design; no interventions were conducted. Studies I and III included non-invasive measurements of vital signs with equipment used in everyday nursing activities. Study II observed MET activity already implemented in TAYS. Study IV was a survey concerning healthcare professionals. All these studies were presented in a research plan to the Ethics Committee of Tampere University Hospital, and the requirement for informed consent was waived (Approval number R10111). The outcome frames were declared in a web-based trial registry (clinicaltrials.gov NCT01214460). In addition, permission from the Chief Medical Officer of TAYS was obtained for the access to patient records (Studies I-III).

8.5 Statistics

Data were first stored as Microsoft Excel 2010 worksheets (Microsoft Office Excel® 2010, version 14, for Windows). SPSS software, version 16.0, for Windows (SPSS Inc., Chicago, USA) was used for the statistical analyses of the data.

Demographic data are presented as numbers and percentages, continuous variables with normal distribution (both skewness and kurtosis between −1.0 and +1.0), as means (± standard deviations) and non-Gaussian variables as medians (quartiles; Q1, Q3). Ranges are used when informative.

In Study III a power analysis (with a power of 80% (probability to correctly reject false a null hypothesis) and probability for a type I error (incorrect rejection of a true null hypothesis) to be < 5%) was conducted for the 'primary hypothesis' that positive TAYS dichotomized activation criteria are associated with increased 30-day mortality in univariate analysis. The aim of the power analysis was to ensure adequate sample size for this univariate analysis also used in two earlier studies (Bell et al. 2006, Fuhrmann et al. 2008), after which further analyses, adjusted associations, could be conducted. On the basis of the study by Fuhrmann et al., we expected mortality to be 13% among patients with positive and 5% with negative dichotomized TAYS criteria (Fuhrmann et al. 2008). No studies on NEWS among general ward patients were available, so power analysis with TAYS dichotomized activation criteria only prepared the ground for univariate and multivariate comparisons between these MET activation methods.

The Chi-square test, Student's *t*-test, Mann–Whitney *U*-test, Spearman's rank correlation coefficient and Kruskal–Wallis test were used for comparisons between groups where appropriate. Univariate logistic regression was used for the calculation of ORs. Multivariate logistic regression, with a stepwise backward elimination model ($p < 0.05$ for entry and > 0.10 for stepwise removal), was applied for adjusted ORs in Studies I and II (Bewick, Cheek & Ball 2005). In Study III multivariate logistic regression was applied with 'enter' model, thus including all introduced covariates in the final model. All tests were two-sided; the statistical significance level was set at two-tailed p-value of < 0.05 and 95% confidence intervals were calculated where appropriate.

To report the fit of the model of the logistic regression analyses, the Hosmer-Lemeshow goodness-of-fit test was applied (Lemeshow & Hosmer 1982). Large Hosmer-Lemeshow goodness-of-fit Chi-square test (C^) and small p-value (< 0.05) suggests poor fit of the model. In Study III, where ORs were calculated for three different variables with five different outcomes, the Hosmer-Lemeshow goodness-

of-fit test was calculated for each model separately. In addition, in Studies I and II it was tested whether the forward inclusion model included the same covariates in the final step.

In Studies I and III, sensitivities and specificities were calculated for the tested activation criteria. Sensitivity was calculated according to the following formula:

> Patients with positive studied criteria and suffering an outcome (N) /
> (Patients with positive studied criteria and suffering an outcome (N) + Patients with negative studied criteria but suffering an outcome (N))

Specificity was calculated according to the following formula:

> Patients with negative studied criteria and no outcome (N) /
> (Patients with negative studied criteria and no outcome (N) + Patients with positive studied criteria no outcome (N))

as appropriate (Lalkhen & McCluskey 2008).

In Study I the covariates introduced into the multivariate logistic regression model were gender, age, CCI (Charlson comorbidity score, without age), type of hospital admission, background (surgical/medical), SAPS II (Simplified Acute Physiology Score) and APACHE II (Acute Physiology and Chronic Health Evaluation) scores on ICU admission, surgery performed before ICU discharge, length of ICU stay (days), mechanical ventilation in intensive care, renal replacement therapy in intensive care, discharge during out-of-office hours and discharge to monitored ward area. Age, CCI, SAPS II, APACHE II and length of ICU admission were inputted as continuous variables. CCI is a comorbidity score taking account of the cumulative effect of chronic illnesses (Charlson et al. 1987). APACHE II is a continuous score (0-71) calculated from the 14 variables during the initial 24 h in ICU (12 variables related to vital signs or laboratory markers, age and one variable related to chronic health status) (Knaus et al. 1985). SAPS II (0-163) is formed similarly (but with different thresholds) from 17 variables (12 physiology, age, admission type and three chronic illnesses) (Le Gall, Lemeshow & Saulnier 1993).

In Study II the variables studied were age, gender, non-elective hospital admission, medical/surgical background, days in hospital before the call, ICD II neoplasms, ICD VI nervous system, ICD IX circulatory system, ICD X respiratory system, ICD XIV genitourinary system, preceding ICU admission, DNAR before the review, supplementary O_2 usage before the review, opioid/sedative administered 0–6 h before the review, non-office-hours MET review, multiple triggers (multiple criteria for medical emergency team activation), ALF, patient in monitored bed, medication by MET, DNAR after the review and transfer to ICU by MET. Comorbidities were used as individual variables (classified according to ICD

classification, International Statistical Classification of Diseases and Related Health Problems 10th Revision 2) as this method was used in the only published study documenting the multiple variables associated with mortality among MET patients (Calzavacca et al. 2010).

Age, gender, admission type, background (surgical/medical), surgery within 48h of assessment, preceding ICU admission and CCI (without age) were introduced into the multivariate logistic regression model as covariates in Study III.

9 Results

9.1 Participiants

9.1.1 Study I

During the study period, 253 patients were discharged from the ICU to general wards. From this initial cohort 69 patients were excluded for the following reasons. Seven of these patients were discharged after a readmission and 15 were discharged with treatment limitations. Further excluded patients included one patient who suffered a CA and died during the first night on the ward, eight patients who were readmitted to ICU before the 24h visit and seven patients who had been discharged from the hospital. Finally, 31 patients were not assessed because they were visiting the canteen (17), they had new treatment limitations (6) or they had been admitted to OR (8). A total of 184 patients formed the final cohort.

The mean age of patients was 57 (± 15.6) years, 68% (125) were male, 79% (145) had CCI score 0-1 and 21% (39) ≥2. The reason for initial hospital admission was surgical in 71% (130) of the patients, 31% (57) were admitted electively, and according to the ICD 10 classification the most common reasons for admissions were neoplasm (21%, 38) or trauma/intoxication (21%, 39). Median SAPS II score on admission to ICU was 26.5 (17, 37), APACHE II score 15 (10, 21), 36% (66) of the patients were mechanically ventilated, 8.7% (16) required renal replacement therapy and median length of stay was 1 (1, 4) days (33%, 60, patients, had admission length ≥3 days).

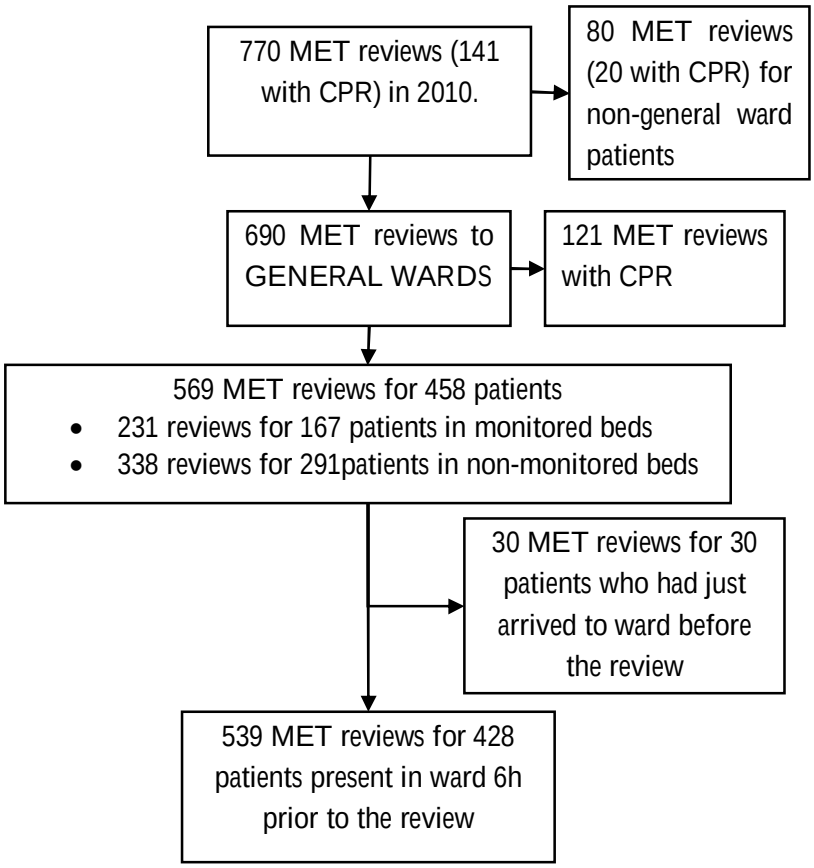
9.1.2 Study II

The MET was activated 770 times for 641 patients during the study period, and in 141 of these activations it was recorded that CPR was provided either by the ward staff or the MET (or both) (Figure 4.). Thus, the MET reviewed 629 patients because

of a medical emergency (no CPR) in 2010, which translates to 8.4 reviews per 1,000 hospital admissions.

The MET attended 458 general ward patients a total 569 times (111 general ward patients were reviewed more than once). The median age of patients was 70 (61, 79) years, 65% were male and 67% had a surgical background. Of the 569 reviews, 6.3% (36) concerned patients with treatment limitations and 34% (193) patients who had been discharged from the ICU (10%, 59 patients, had been discharged within 24 hours). Most calls took place during on-call hours (86%, 489 reviews) and the most common reasons for activation were respiratory distress (45%, 256 reviews) and hypotension (15%, 88 reviews). The MET admitted patients to ICU in 27% (155) of the reviews, and on the other hand issued treatment limitations in 7.4% (42) of the reviews. After the first MET review, 6.1% (28) of the patients died within the next 24 hours. Hospital mortality was 26% (118). For the regression analyses, only patients who had been in general wards 0-6h preceding the reviews could be included, and a further 30 patients were excluded: seven patients had still been in the ICU, four patients had been in surgery and 19 patients had been in the emergency department in this time window.

Figure 4. Flowchart of MET reviews during the Study II.

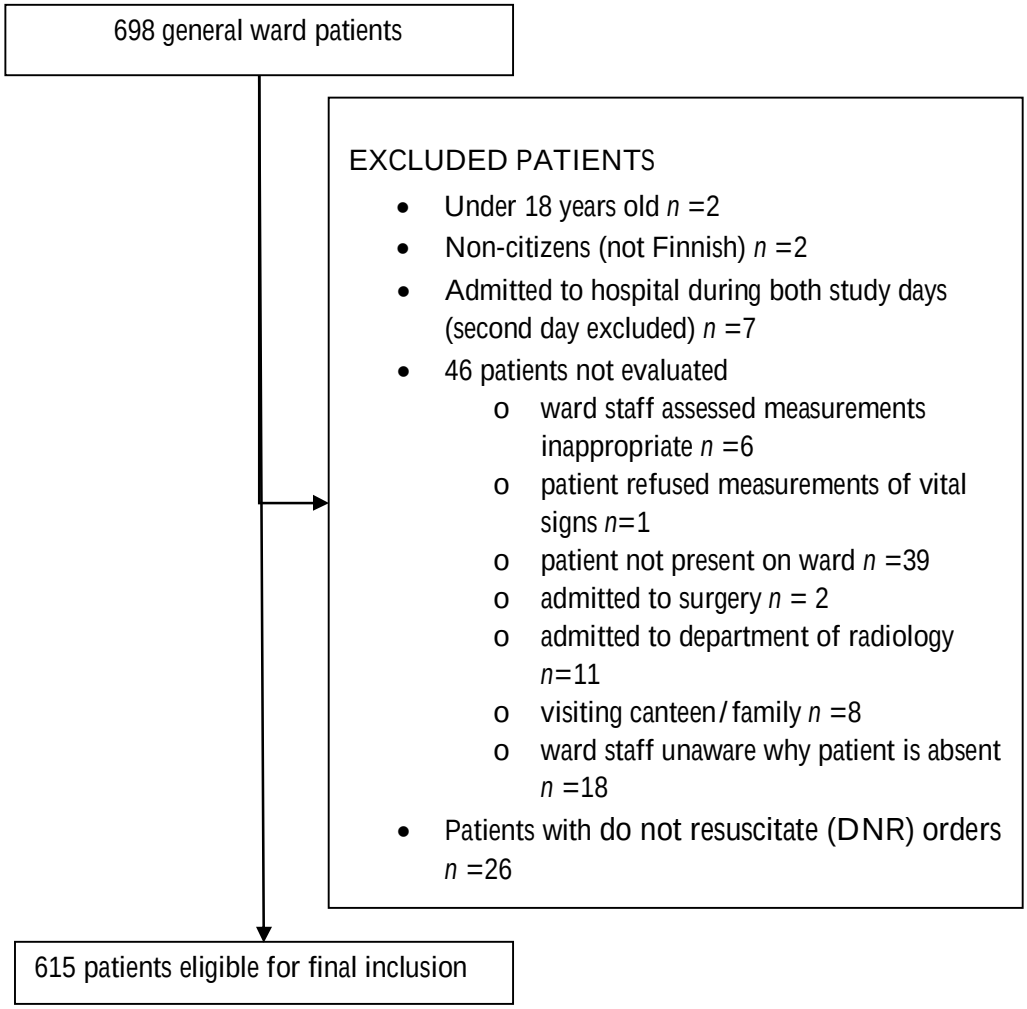


9.1.3 Study III

A total of 698 patients were admitted to the 538 beds during the two study days. Figure 5. presents the further excluded patients and the final cohort consisting of 615 patients. Apart from being younger (57 vs. 65 years, $p = 0.028$), the 46 patients 'not evaluated' did not differ from the evaluated patients. The median age in the final cohort was 65 (53, 76) and 53% (327) were male. CCI score 0-1 was calculated for 61% (347) of the patients; 22% (137) had a score of 2-3 and 17% (104) a score of ≥4. Forty percent (248) of the patients were admitted electively, 56% (347) for surgical reasons and median admission length of stay was 6 (3, 12) days. The most common reason according to the ICD 10 classification for hospital admission was

cardiovascular disease. Before the study review, 12% (72) of the patients had been admitted and discharged from the ICU, and for 22% (133) of the patients surgery had been performed during the preceding 48 hours. A record of body temperature was missing for 103 patients (17%) and inputted as 'normal' (36.1–38.0°C). Of these patients, 70% (72) were admitted because of cardiovascular or orthopaedic reasons. Their hospital mortality was 0% and 180-day mortality 5.8% (6).

Figure 5. Flowchart of participants in Study III.



9.1.4 Study IV

A total of 51 hospitals (93%) participated in this study: 29 hospitals returned the first round questionnaire, 16 hospitals answered after the first reminder and six heads of anaesthesia departments were interviewed by phone. All tertiary hospitals and secondary hospitals took part; 25/27 district hospitals and 2/4 of the metropolitan area's satellite hospitals returned the questionnaire.

9.2 Documentation of vital signs on general wards (II, III)

Preceding documentation of vital signs was noted from patient records among two different cohorts; patients who were reviewed by the MET and all adult general ward patients (Studies II and III). The data presented here from Study III has not been published before, but is of the utmost relevance.

In Study II 539 MET reviews concerned general ward patients who had been on the ward during the preceding six hours. No notes on RR, SpO_2, SAP or HR were found for 17% (91) of the patients. RR was the least documented vital sign; 40% (228) of the patients had at least one documentation of it.

In Study III, 484 patients (79% of the cohort) were admitted at least one day before the study visit. In 95/484 of the cases (19%) patients had no documentation of RR, SpO_2, SAP or HR in the 24 hours preceding the study visit. All vital signs had been documented at least once for 5.0% (24) of the patients. RR was the least documented vital sign; 5.6% (27) of the patients had at least one recording in their records. Table 8. presents the preceding documentation of RR, SpO_2, SAP and HR in both Studies II and III.

Table 8. Table 8. Percentage of individual vital signs documented at least once (Study II) 0.33-6h before MET activation to general wards and (Study III) 0-24h before the review conducted by medical students (patients admitted on review day excluded).

	Respiratory rate	SpO_2	Systolic blood pressure	Heart rate
Study II	40	72	75	76
Study III	6	43	78	79

9.3 Prevalence of MET activation criteria on general wards (I, III)

In Study I, 15% (28/184) of the discharged ICU patients fulfilled the objective dichotomized MET activation criteria. RR was the most common individual vital sign exceeding its thresholds (in 23/28 of the cases). The nurse responsible for the patient at the time of the visit reported in 19% (35/184) of the reviews that he/she had been unusually worried about the patient. MET activation was never deemed necessary by ward staff.

In Study III, 12% (72/615) of the general ward patients had positive dichotomized MET activation criteria of TAYS. RR exceeded its thresholds in 7.8% (48/615) of the cases. NEWS score $\geq$5 or an individual vital sign scoring three was calculated for 22% (136/615) of the patients and 6.5% (40/615) of the patients had NEWS score $\geq$7.

9.4 Incidence of SAEs on general wards (I, III)

In Study I, 9.8% (18/184) of the discharged ICU patients who had survived the first 24h on general wards experienced an SAE during their subsequent hospital stay. A total of 16 patients were reviewed by the MET, and 10 were readmitted to the ICU and four were stabilized but died later during their hospital stay. Two patients had a MET review only, one patient was readmitted to the ICU after an emergency relaparothomy and one died without notes of a MET activation. MET was activated at median 2.0 days after ICU discharge (1.75, 6.25). ICU readmission was at median 2.0 days (1.75, 6.75) after the initial discharge.

In Study III, A serious adverse event occurred in 2.9% (18/615) of the patients during their subsequent hospital stay. The MET reviewed 10 patients: five patients had a MET review only (two CAs), three patients were admitted to the ICU and two patients were left on the general ward but died later during their stay. In addition, five patients were urgently admitted to the ICU by direct consultation and three died later during their hospital stay without records of MET activation. Three SAEs occurred during the first 24 h following the patient evaluation; the first was a MET activation because of CA 6 h after the vital signs measurements and other two occurred the following day. Four patients suffered SAEs 24–48 h after the evaluation, and two patients 48–72 h after the evaluation.

In Studies I and III, the MET was never immediately activated by ward staff due to study protocol visits.

9.5 Logistic regression models (I-III)

In Study I, the following variables were introduced into the final model (total 11 steps): type of hospital admission, renal replacement therapy in intensive care, discharge to monitored ward area, positive TAYS MET activation criteria and the 'worried' criterion. Hosmer-Lemeshow goodness-of-fit Chi-square test for this model was 2.71 with a *p*-value of 0.75. The forward inclusion model included only three variables in the final step (discharge to monitored ward area, positive TAYS MET activation criteria and the 'worried' criterion).

In Study II the following variables were introduced into the final model (total 14 steps): age, non-elective hospital admission, days in hospital before the call, ICD II neoplasms, ICD XIV genitourinary system, ALF, DNAR after the review and transfer to ICU by MET. Hosmer-Lemeshow goodness-of-fit Chi-square test for this model was 12.8 with a *p*-value of 0.12. The forward inclusion model included the same variables.

In Study III the 'enter' model was applied. For the multiple conducted analyses, Hosmer-Lemeshow goodness-of-fit Chi-square test values ranged from 4.35 to 13.4 with *p*-values from 0.10 to 0.83.

9.6 Performance of MET activation criteria (I, III)

After adjusting for confounding factors, the dichotomized criteria of TAYS (OR 3.79; 95% CI 1.18–12.2) and the 'worried' criterion (3.63; 1.17–11.3) were independently associated with SAEs in a cohort of discharged ICU patients in Study I. If the vital signs (RR, SpO_2, SAP and HR) were introduced into the multivariate model as individual variables ('positive' or 'negative'), the factors independently associated with SAEs were respiratory rate < 5/min or > 24/min (6.54; 2.00–20.5), the 'worried' criterion (4.41; 1.42–13.7), non-elective hospital admission (10.8; 1.09–107) and receiving renal replacement therapy in ICU (4.96; 1.22–20.1).

After adjustments, the positive dichotomized MET criteria of TAYS were independently associated only with the latest of outcomes (180-day mortality, OR 1.96; 95% CI 1.02–3.74) in Study III. NEWS score with both cut points (≥5 or an

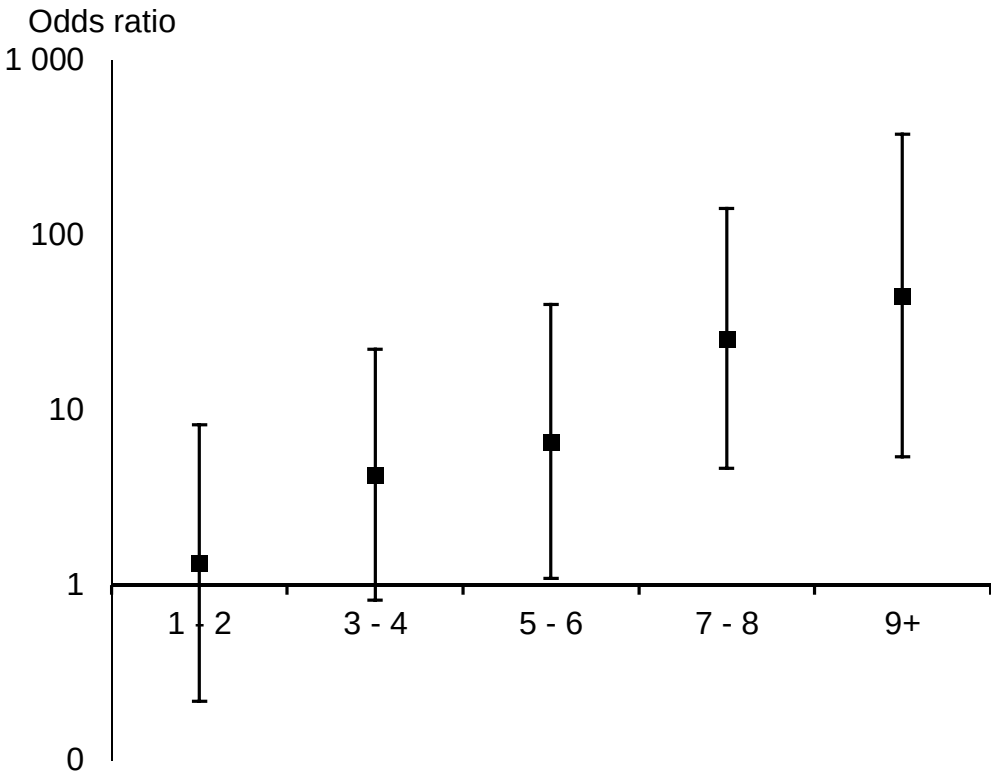
individual vital sign scoring three, and ≥7) were associated with all outcomes (ORs with 95% CIs presented): SAEs (including MET activations) 14.7 (4.32–50.2) and 7.45 (2.39–23.3), SAEs (excluding MET activations) 18.1 (4.51–72.8) and 11.5 (3.40–38.6), 30-day mortality 11.8 (4.26–32.6) and 11.4 (4.40–29.6), 60-day mortality 5.55 (2.91–10.6) and 6.42 (2.92–14.1) and 180-day mortality 4.50 (2.58–7.86) and 6.15 (2.83–13.4). Figure 6. presents the ORs of increasing NEWS for 30-day mortality after adjustments. A score of 7–8 increased the OR for death at 30 days independently 25-fold; a score of 9–10 increased the OR 45-fold (compared to that of patients scoring 0).

Table 9. presents the sensitivities and specificities of the activation criteria studied to SAEs (Studies I and III) and 30-day mortality (Study III). Data presented here from Study III have not been published before, but are of utmost relevance to this thesis.

Table 9. Sensitivities and specificities of different activation criteria.

	SAE		30-day mortality	
	Sensitivity	Specificity	Sensitivity	Specificity
Study I				
Positive dichotomized MET criteria	50%	89%	-	-
'Worried' criterion	26%	84%	-	-
Study III				
Positive dichotomized MET criteria	22%	89%	39%	89%
NEWS ≥5 or an individual vital sign score 3	72%	87%	83%	87%
NEWS ≥7	33%	94%	61%	95%

Figure 6. ORs with 95% CIs of different NEWS values for 30-day mortality compared to those of patients scoring 0.



9.8 ALF and hospital mortality among patients reviewed by the MET (II)

Of the MET reviews on general wards, 41% (231/569) concerned patients in monitored beds. After excluding 30 patients just admitted to the ward before the review, 41% (219/539) of the MET reviews concerned patients attached to automated monitors. All vital signs were more frequently documented 0.33-6 hours before the MET call among the monitored patients; however, all vital signs were more frequently also documented abnormal (Table 10). The ratio comparing patients with abnormal vital signs to patients with some vital signs measured at all in the presented time window was higher among monitored ward patients (81% vs. 53%, p<0.001). Altogether in 55% of MET reviews (299/539) ALF was documented.

Factors independently associated with documented ALF were non-elective hospital admission (OR 1.64, 95% CI 1.01–2.66), antecedent MET –review (2.73; 1.60–4.66), supplementary O_2 0–6 h before the review (4.82; 2.64–8.81) and being in a monitored bed (3.81; 2.52–5.76).

In a cohort of general ward patients reviewed by the MET, ALF was independently associated with increased in-hospital mortality (1.67; 1.02-2.72).

Table 10. Documentation of vital signs and ALF 0.33-6h before the MET activation.

	Patient in monitored bed (N=219)	Patient in non-monitored bed (N=320)	*p*-value
Vitals documented 0.33-6 h before call			
Respiratory rate	75 %	17 %	<0.001
SpO_2	90 %	60 %	<0.001
Heart rate	90 %	65 %	<0.001
Systolic blood pressure	91 %	66 %	<0.001
NO vitals documented	3.7 %	26 %	<0.001
Vitals documented abnormal 0.33-6 h before the call (afferent limb failure, ALF)			
Respiratory rate (<5 or >24/min)	50 %	11 %	<0.001
SpO_2 (<90%)	33 %	21 %	<0.001
Heart rate (<40 or >140/min)	13 %	3.4 %	<0.001
Systolic blood pressure (<90 mmHg)	22 %	13 %	<0.001
ALF documented	78 %	40 %	<0.001

9.9 RRSs in Finnish hospitals (IV)

All university tertiary referral centres (5/5) and 53% (10/19) of secondary referral centres had a RRS. One of the 25 district hospitals and neither of the metropolitan district's satellite hospitals had an RRS. CATs were in use in every tertiary hospital, in 84% (16/19) of secondary hospitals, in 24% (6/25) of district hospitals and in both participating satellite hospitals. Altogether 16 hospitals had RRSs, and one of these hospitals reported having a separate MET and CAT. Overall reported incidence of IHCAs was median 1.48 (0.93, 1.93) events per 1,000 hospital admissions (24/29 hospitals with CATs had recorded the events). Fifteen hospitals had recorded data on MET activations. MET was activated (IHCAs excluded) median 2.3 times (1.5, 4.8) per 1,000 hospital admissions (range 0.65–11), or 1.5 (0.96, 4.0) times per every attended IHCA (range 0.33–7.1).

The RRSs had been implemented median 3.3 (1.5, 7.3) years before April 2012. In 14 cases the MET operated from the ICU (from the OR in two hospitals) and was available 24/7 (during office hours only in two hospitals). METs were physician-led (in 15/16 cases led always by an ICU physician), but in half of the systems physicians attended MET patients only when required. In only 3/16 hospitals RRSs operated in all hospital areas; OR (13/16), ED (10/16) and paediatric wards were the most common excluded departments. In half of the hospitals non-medical staff were able to alert the MET; in only one hospital patients and visitors were allowed to activate the team. Table 11. presents the activation criteria with used thresholds in Finnish hospitals using RRSs.

Table 11. MET activation criteria (n) in 16 Finnish hospitals with RRSs.

Cardiac arrest	15
Respiratory arrest	15
Threshold for low respiratory rate	15
< 5	4
< 6	3
< 8	7
< 10	1
Threshold for high respiratory rate (breaths/min)	16
> 24	2
> 25	2
> 28	2
> 30	10
Threshold for low SpO_2 (all < 90 %)	15
Threshold for low systolic blood pressure (all < 90 mmHg)	15
Threshold for high systolic blood pressure (>200 mmHg)	1
Threshold for low heart rate (beats/min)	16
< 30	1
< 40	14
< 45	1
Threshold for high heart rate (beats/min)	16
> 120	2
> 125	1
> 130	4
> 140	9
Glasgow Coma Scale	10
Fall in GCS above two points	7
Fall in GCS above two points or GCS < 12	1
Fall in GCS above two points or GCS < 9	1
Fall in GCS above two points or GCS < 8	1
Low urine output	2
'Staff worried'-criterion	15
In addition to normal MET criteria, early warning scoring system implemented	3

10 Discussion

10.1 Internal validity

Studies I-III were of prospective cohort study design. As in single cohort studies, patients not encountering the outcome formed the internal controls. This design enabled investigation of multiple outcomes simultaneously after the initial observed exposure. Study IV used cross-sectional design; this methodology is generally best suited to measuring the prevalence of a variable or variables at a certain time. Although Study III was primarily considered to be a prospective cohort study, the initial assessment used cross-sectional methodology and also produced information on prevalence. One major problem in observational studies may be the usage of rare outcomes that require enormous sample groups; however, given the literature, outcomes used in Studies I-IV were not expected to be rare. Thus, the validity of used study designs seemed plausible.

It should be acknowledged that several factors related to appropriate measuring could have negatively influenced the internal validity of these Studies. In Study I the measurements of vital signs were conducted with one set of equipment including standard electronic blood pressure- and SpO_2 meters used by the MET nurses. These meters were not calibrated during the study period, which may have led to systematic error in the values of vital signs. In Study III, medical students utilized the electronic blood pressure and SpO_2 meters of the general wards. In this case, random error from meters not calibrated with each other may have biased the results. All meters were, however, accepted and used on a daily basis in the normal clinical work. Further, in Study III we did not measure the inter-rater agreement between the students; the measurements of RR, GCS and AVPU scale were especially prone to variability though training was provided and fourth-year students were already familiar with clinical work. Finally, in Study III body temperatures were obtained from the patient records (measured by ward staff, not medical students) and missing in 17% of the cases. For these patients the body temperature was scored as normal (NEWS: 36.1-38.0 °C); this, however, was just a conjecture.

After the vital signs were measured in Studies I and III, the results were provided to the ward staff. Further, in Study I the nurse responsible for the patient was both

interviewed and asked if he/she felt that a MET review was required. While there were no cases with immediate MET activations in either Study, later MET activations could have been prompted because of these protocol visits; the ward staff were (or should have been) aware of the MET criteria in TAYS. In both studies an inevitable risk for the 'Hawthorne Effect' existed, which decreases the internal validity of the results (McCarney et. al 2007).

In both Studies I and III the performance of dichotomized activation criteria already implemented in TAYS were investigated. In theory, positive criteria should not exist among general ward patients at all, as they should be observed and the MET alerted immediately. However, in light of the existing literature and clinical knowledge it was clear that dichotomized criteria were not observed or followed as suggested. Further, the same methodology was used in an Australian multicentre study as well (Bucknall et al. 2013). Nevertheless, it is possible that in both studies on average one to two patients having positive criteria were missed because MET had already attended these patients.

The questions in the postal survey (Study IV) were formulated mostly as closed ended questions, so obscure answers would not be possible (e.g. yes/no options or numbers of incidences). Further, the questions were formulated to elicit the data deemed necessary by the Utstein-Statement and to enable comparisons to one earlier study from Australia (Peberdy et al. 2007, ANZICS-CORE MET dose Investigators et al. 2012). With an external review of the questionnaire (conducted by a biostatistician and an ICU physician not participating in the study) a further attempt to improve the internal validity was made. However, questionnaire studies always involve risk for response bias, as they are self-reports that are not validated by an independent third party.

Follow-up was possible for all patients reviewed by the medical students (I, III) or MET (II). However, in Study I 17 patients were not reviewed because they were visiting the canteen. While it can be speculated that these patients were 'well enough' to be omitted in any case, outcomes of these patients remained unknown. In Study III the aim was to improve internal validity further by retrieving characteristics and outcome data on all patients 'not evaluated'. With a 93% response rate, and including all ICU equipped hospitals, response rate was not a limiting factor in Study IV.

Since data on event, patient, hospital admission and outcome characteristics were all extracted from case forms, patient records and the Finnish Population Register, the possibility of both random and systematic error was present in each study. Random error can never be completely controlled for. In Studies I and III the medical students may have incorrectly documented erroneous values of vital signs

or misclassified, for example, patients' DNAR status. In Study II similar errors may have occurred during the documentation of the MET reviews. However, the influence of random error decreases in larger cohorts. Patients' DNAR status and outcomes were documented and double-checked from the patient records; as all outcomes used were SAEs, it is highly unlikely that these would have been documented neither in nurses' nor in doctors' electronic records. The mortality data of the Finnish Population Register Centre is updated with a time lag of a couple of months. Therefore this data was retrieved two years after the initial data was gathered. Random and systematic error during the data tabulating may have occurred in all Studies I-IV. While random errors are single misstabulations, some variables may have been systematically incorrectly tabulated. However, as most variables and all outcomes were dichotomized, these tabulations should have been noted during the statistical analyses as strange distributions when compared to the existing literature and general clinical knowledge.

A confounding variable is associated with both the exposure (variable studied) and outcome, increasing or decreasing the risk to the outcome (Mann 2003). For example, risk of death (outcome) is increased if one has cancer (variable); however risk of death is also increased with increasing age (confounding variable) that itself increases the risk of contracting cancer. All confounding variables can be eliminated only in RCTs (Mann 2003). In prospective cohort studies, the possibility of unknown confounding factors always exists (residual confounding), but adjustment for known confounding variables is possible via multivariate logistic regression (when the outcome is dichotomous as in Studies I-III). In Studies I and III all included confounding variables had been confirmed to be associated with the outcome in previous studies. In Study II some of the confounding variables included had only once been studied in a similar cohort, and were based more on clinical intuition.

In Studies I and II both the backward and forward stepwise multivariate logistic regression models yielded similar results and the variables studied were independently associated with the outcomes. In all three studies with logistic regression models, the Hosmer-Lemeshow test indicated that goodness-of-fit of the models was acceptable. However, several limitations to the used methodology exist. First, the Hosmer-Lemeshow test has low power in cohorts with small sample sizes and the developers recommend sample sizes greater than 400; in Study I the cohort was only 184 patients (Lemeshow & Hosmer 1982, Bewick, Cheek & Ball 2005). Second, in Study I collinearity between two or three continuous variables may have existed and was not investigated. Age was inputted as an independent variable but is also included in the SAPS II and the APACHE II scores. Further, SAPS II and

APACHE II scores are partly comprised of similar variables with different cut-off values. Third, it is proposed that in logistic regression the model should be used with a minimum of 10 outcome events per included covariate, although this 'rule' has been suggested to be relaxed to five per included covariate (Vittinghoff & McCulloch 2006). In Studies I and II multiple covariates were introduced into the model, and while in Study II the outcome was also common (1:4), in Study I the cohort was smaller and the outcome more rare (1:10); thus the 'rule' was 'violated' and results should be interpreted with caution.

10.2 External validity

Studies I-III were conducted in a Finnish tertiary level university hospital providing the most advanced care for a population of 1.1 million people. This fact sets the frames for the overall generalizability of these studies; the results may not apply in smaller institutions or hospitals/countries with different clinical practices and standards of healthcare.

Study I concerned discharged ICU patients only. As ICU-settings vary between institutions, neither the cohort nor the results may be extrapolated to hospitals with, for example, dedicated ICUs or separate HDUs (Kaben et al. 2008). Further, our cohort was relatively small and the sample may have simply been biased because of temporal trends. For example, Campbell et al. reported the characteristics of 4,535 patients discharged alive from a closed model, mixed medical and surgical ICU in the United Kingdom; compared to our cohort patients in this study were more often female (41%) and had higher APACHE II- and SAPS II-scores at admission (mean 18 and 34) (Campbell et al. 2008).

In Study II, the external validity is limited to RRSs using comparable activation criteria and METs as the efferent limb. Further, we studied our RRS one year after implementation with a MET activation rate of 8.4 per 1,000 hospital admissions, and ALF was documented in 55% of the reviews. It has been suggested that in mature and well integrated RRSs the activation rate of the efferent limb is 26-56.4 calls per 1,000 hospital admissions (Jones, Bellomo & DeVita 2009). Calzavacca et al. reported in 2010, that ALF was first documented in 40% of MET activations but the percentage decreased to 22 during the following five years (Calzavacca et al. 2010). Because ALF is defined as the presence of positive activation criteria before the activation, the fact that institutions use different activation criteria further

decreases the comparability (Downey et al. 2008, Calzavacca et al. 2010, Boniatti et al. 2014).

In both Studies II and III the subjective 'worried' criterion was excluded as it means ‘attending nurse’s additional worry about patient’s condition’, which could not be determined by the medical students visiting the patient (III) or retrospectively reliably assessed from the patient records (II). While this increased the internal validity of these studies, it decreased the generalizability of the results to practice because most activation criteria include this method for alerting help. However, no studies have included this criterion in a composite variable ('positive' or 'negative' criteria) either. Similarly we had to exclude the important 'fall in Glasgow Coma Scale' from the dichotomized activation criteria in Studies I-III, thereby decreasing the external validity further (Cretikos et al. 2007).

Finally, in Studies I and II the outcomes studied were in-hospital SAEs (I, including mortality) and mortality. Although this enabled comparisons to some earlier studies, a fixed endpoint (like 30-day mortality in Study III) is today recommended (Glance & Szalandos 2002, Calzavacca et al. 2008, Calzavacca et al. 2010).

10.3 Interpretation of the Results

10.3.1 Documentation of vital signs

First it should be stated that 'not documented' does not automatically translate into 'not measured'. Vital signs may be measured more frequently than recordings made, especially in cases when the values are considered normal and there are more urgent matters to attend to. Also, specific wards may still use non-electronic sheets and only input the most relevant information with occasional routine values to the computerized system. However, documentation is expected because this enables information to be relayed, trends to be formed and in the most extreme situations it also provides legal documentation on appropriate care.

Overall documentation of vital signs on general wards was poor, only 5.0% of general ward patients had all vital signs measured at least once when observed retrospectively from a random time point. Nothing so far is known about the documentation of vital signs in an unselected general ward population, although some conclusions may be drawn from a study by Fuhrmann et al. (Fuhrmann et al.

2008). They reported that when abnormal vital signs were detected in their point prevalence study of unselected ward patients, in half of the cases ward staff were totally unaware of abnormal vital signs (Fuhrmann et al. 2008). While the 5.0 percent may sound depressing, it seems logical, as severe deficiencies also exist in acknowledged high risk cohorts: two studies reported that only 52-58% of ED patients had all vital signs measured 15 minutes after arrival, although severely ill (category 'red') patients were also included (Alcock, Clancy & Crouch 2002, Armstrong et al. 2008). As the minimum standard for the assessment of all vital signs is every 12 hours (in expert opinion), it is safe to say that TAYS, as a university level tertiary referral center, scored far from satisfactory (DeVita et al. 2010).

Documentation of vital signs during the six hours before a MET activation was more frequent than documentation of vital signs in general. This conclusion is, however, biased because 41% of the patients attended by the MET in general wards were automatically monitored. Nevertheless, documentation of RR and SpO_2 were more frequent in non-monitored areas as well, even though 86% of the calls occurred during on-call hours with limited staffing. This may suggest that nurses were indeed more concerned about the patients later reviewed by MET, and increased the frequency of respiratory measurements, which are commonly neglected (Cretikos et al. 2008, McGain et al. 2008). In fact, Chen et al. reported that over 65% of patients reviewed by the MET had RR, SAP and HR documented 0.25-24 hours before the MET activation. Similarly, Nurmi et al. reported that 89% of IHCA patients on general wards had some vital signs measured 0-8 hours prior to the arrest, although in this cohort only 25% had recordings of objective respiratory measurements (only one documentation of RR) (Nurmi et al. 2005). RR is the least documented vital sign on general wards, as also confirmed by Studies II and III.

The results of Studies II and III together suggest that while the documentation of the vital signs is poor, the frequency increases before a MET activation. The reasons for this may only be speculated on, but in case of increased concern, measuring without interventions does not improve outcome and the threshold for MET activation seems high.

10.3.2 Prevalence and performance of the activation criteria

The positive dichotomized activation criteria of TAYS were observed in 15% of discharged ICU patients and 12% of general ward patients. Further, nurses reported they were 'more worried that usual' regarding every fifth discharged ICU patient.

While the measured vital signs were reported to the nurses, visits never resulted in a direct MET activation. It is highly unlikely that the dichotomized criteria were misinterpreted. Rather the results indirectly suggest that the criteria are not deemed feasible among general ward staff. This seems plausible given the sensitivities and specificities of the dichotomized criteria; in the post -ICU cohort not more than acceptable values were calculated with independent association with poorer outcome, but this was a high risk cohort with a three times higher incidence of SAEs than in the general ward cohort. In the latter cohort, dichotomized criteria performed poorly with no relative association with SAEs.

'The gut feeling that something is wrong', the 'worried' criterion, was indeed independently associated with poorer outcome, but with a very poor sensitivity. According to our results this criterion does not help to detect the patients at risk of deterioration very well, rather it should raise further concern and awareness. In 2010 we recorded the MET activation rate to be far below the rate considered 'effective' with high ALF ratio in TAYS, and in Study IV the activation rate was poor nation-wide (Jones, Bellomo & DeVita 2009). Therefore albeit the discouraging statistical analyses of the 'worried' criterion, this criterion prompts activations that must not be considered futile. It remains to be seen whether objective activation criteria with reliable triggering thresholds are validated; until then the 'worried' criterion should be included in every hospital with an RRS.

Is it appropriate to simply conclude that general ward staff do not comply with instructions? As discussed above, measuring vital signs is indeed deficient. But what if the MET had been activated immediately when the students reported the vital signs and nurses would have observed that some patients fulfilled the dichotomized criteria? In Study I, every seventh discharged ICU patient would have been reviewed by the MET 24 hours later, which seems practicable in a high risk cohort. In Study II, however, the MET should have immediately attended 72 patients in a cohort where undesirable outcomes are more rare. If at any given time point almost every tenth general ward patient fulfills the dichotomized activation criteria in a 700 -bed hospital, they can be considered impractical in clinical usage, even without the sensitivity/relative performance analyses. This leads to ignorance even when high risk patients (Study I) fulfill these criteria (cf. to the ancient tale of 'The Boy Who Cried Wolf', Aesop 5th century BCE).

In Study III, NEWS score $\geq$5 or an individual vital sign scoring three was observed in 22% (136) of the patients and 6.5% (40) of the patients had NEWS score $\geq$7. NEWS score $\geq$5 or an individual vital sign scoring three had a better combination of sensitivity and specificity for both SAEs and 30-day mortality, but

both cut points for the NEWS were independently clearly associated with both outcomes. A cut off value of score ≥5 or an individual vital sign scoring three for MET activation may not be clinically feasible (at least in TAYS) due to high the percentage of patients fulfilling this cut off value, but neither is it recommended by the developers (Royal College of Physicians 2012). Rather, this value should raise concerns and escalate the level of care urgently, which could include immediate notification of the ward physicians, for example. A threshold of ≥7, recommended for immediate MET activation, was observed in only 40 patients, which might be more realistic to achieve. Activation rates might be prompted with the knowledge that compared to patients scoring 0, patients scoring 7-8 had an independent 25-fold OR for 30-day mortality.

The results of Studies I and III suggest that while dichotomized activation criteria were associated with SAEs in a high risk group, NEWS should rather be used on general wards. Well-functioning RRS offers ward staff feasible activation criteria on which they can rely. For the first time, the relative performance of activation criteria was studied in a heterogeneous general ward population, and the results confirmed that NEWS is statistically applicable. Furthermore, when the nature of these two activation patterns is observed, NEWS also seems more practical than dichotomized criteria for follow up. With a continuous variable, trends for better or worse can be detected (Kellett et al. 2013).

10.3.3 Afferent limb failure

The purpose of monitoring is to enable early interventions in case of a detected deterioration, which was not observed in Study II. While vital signs were more frequently documented among automatically monitored patients, ALF was more frequently recorded even when the increased documentation *per se* was taken into account for. As almost half of the MET calls concerned monitored patients who constituted approximately 6% of the general ward population, it can be concluded that potentially unstable patients were correctly admitted to these beds. We may only speculate the reasons behind increased delays among monitored ward patients with the variables we have measured, but a system failure (rather than just incorrect actions by ward staff) seems plausible. First, a preceding MET review was associated to ALF. If the first activation was based on positive dichotomized criteria, but the patient was left on the ward, how can further deterioration be objectively determined by the ward staff? Second, intense monitoring may have also been regarded as a

sufficient intervention itself, although the treatment options did not actually change. Automated monitoring capabilities are increasingly implemented, and operating protocols must be adapted accordingly (Graham & Cvach 2010). While being admitted to monitored bed was not associated with increased mortality, ALF was, and efforts to prompt timely interventions are required.

While this study was being planned, two other studies reported the effect of ALF on mortality in small, selected cohorts with some adjustments for confounding (Calzavacca et al. 2008, Downey et al. 2008). Our results confirmed this relative association in an unselected, prospective and large cohort after rigorous adjustments. Since then, two additional studies have reported similar results (Calzavacca et al. 2010, Boniatti et al. 2014). RRS in TAYS was immature at the time the study was conducted, but the results underline the importance of reducing activation delays.

10.3.4 RRSs in Finland

The characteristics of patients attended by the MET in a Finnish university hospital were comparable to those reported in the international literature. MET was frequently utilized during on-call hours because of hypotension and respiratory distress, one fourth of patients were repeatedly reviewed and one fourth were admitted to the ICU (Dacey et al. 2007, Calzavacca et al. 2010, Konrad et al. 2010). On the other hand, the MET also participated in the care of patients with treatment limitations, and implemented new limitations of medical treatment (Jones et al. 2012, Jaderling et al. 2013). Patients attended by the MET were severely ill in a Finnish hospital setting as well; one fourth died during their hospital stay. Knowing this, the MET should be activated more frequently than for every hundredth of the twentieth admitted patient. These results underline that patients indeed do deteriorate and suffer potentially avoidable SAEs in Finnish hospital as in other western countries; acknowledging this fact is the first step towards improvements in patient safety.

The MET activation rate was in fact low nation-wide and well below the suggested 'effective dose' (at least 26 calls per 1,000 admissions) (Jones, Bellomo & DeVita 2009). Although in a well-established RRS in Scandinavia adjusted reduction in hospital mortality was observed with just 9.3 calls per 1,000 admissions, it can safely be stated that median 2.3 calls per 1,000 admissions is below the required frequency for mortality reduction (Konrad et al. 2010).

As in the place where RRS originated, Australia, dichotomized activation criteria and physician-led METs as efferent limbs were commonly utilized in Finland

(ANZICS-CORE MET dose Investigators et al. 2012). There were differences in the activation thresholds set for vital signs, especially with RR and HR, but the 'worried criterion' was included in all but one of the Finnish RRS hospitals. All these findings were in line with previous nation-wide questionnaires from Australia and New Zealand (ANZICS-CORE MET dose Investigators et al. 2012, Psirides, Hill & Hurford 2013). Because the evidence regarding an optimal RRS structure is inconclusive, no uniform recommendations have been made. However, more consistent and precise national guidelines as part of the Current Care Evidence-based guidelines series (Resuscitation) could prompt RRS implementation and simplify the detection and treatment of critically ill ward patients across national centres with the same basic RRS structures. While translating evidence based guidelines to clinical practice is challenging, Nurmi et al., for example, reported in 2006 significant improvements in resuscitation practices after the publication of resuscitation guidelines (Grol & Grimshaw 2003, Bosse, Breuer & Spies 2006, Nurmi et al. 2006).

Importantly, CATs were implemented in 13 hospitals with no RRS. If resources are utilized to organize a team attending patients suffering an IHCA (no benefit evidence), these teams should proactively attend the deteriorating patients as well (moderate benefit evidence).

11 Conclusions

This thesis investigated vital dysfunctions and components of Rapid Response Systems in Finland. In light of the results, the following conclusions can be presented:

1. A recently introduced early warning scoring system (NEWS) is based on simple measurements of vital signs. It is able to detect general ward patients at risk of deterioration better than the commonly used dichotomized activation criteria. The dichotomized criteria used in TAYS were associated with poorer outcome only among discharged ICU patients.

2. Patients seen by the MET in TAYS are comparable in their characteristics to those in other countries. Delays in MET activation are associated with increased hospital mortality.

3. Documentation of vital signs on general wards is negligent. If altered vital signs are recorded, the threshold in seeking advice through the MET remains high.

4. Implementation and utilization of RRSs are suboptimal in Finnish hospitals. The characteristics of the RRSs are diverse, and more concrete guidelines are required.

12 Errata

II. Page 175, Fig. 1, fourth text box '569 MET reviews for 458 patients'. The sentence '291 reviews for 338 patients' should read '338 reviews for 291 patients'.

IV. Page 422, Fig. 1, bottom text box in the left corner: '6/27 equipped with CAT' should read '6/25 equipped with CAT' and '1/27 equipped with MET' should read '1/25 equipped with MET'

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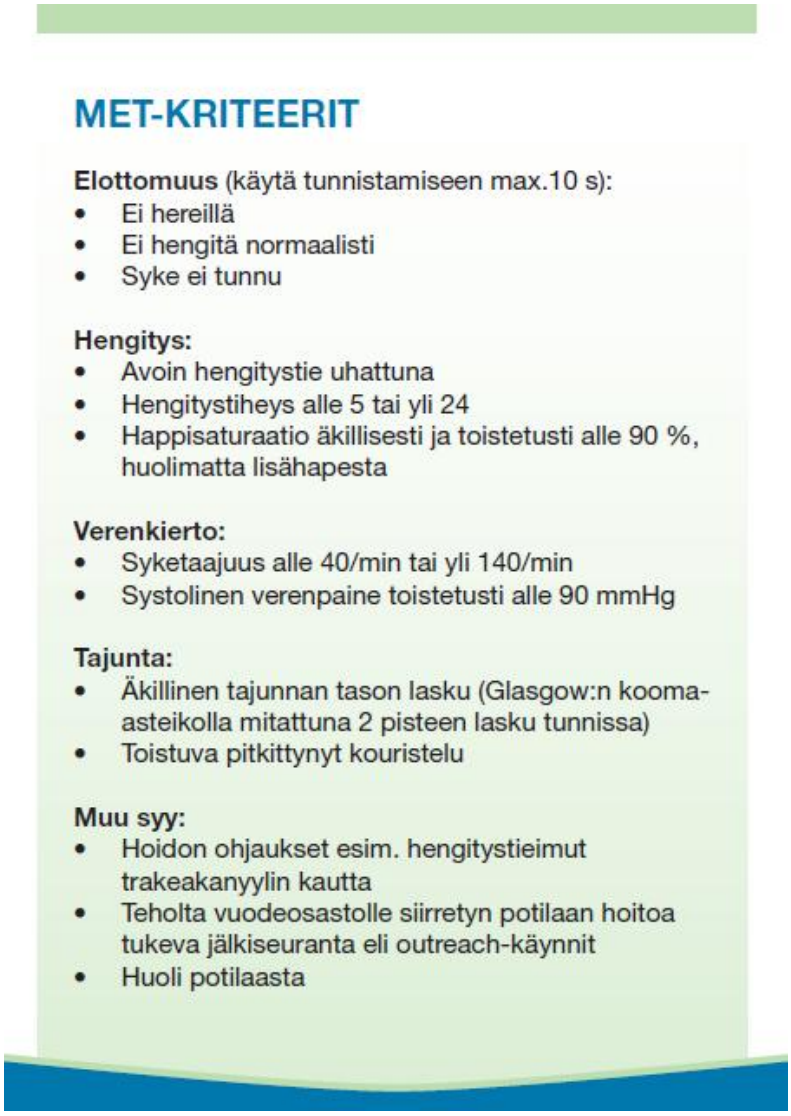
15 Appendices

Appendix 1. Dichotomized activation criteria used in TAYS.



MET-KRITEERIT

Elottomuus (käytä tunnistamiseen max.10 s):
- Ei hereillä
- Ei hengitä normaalisti
- Syke ei tunnu

Hengitys:
- Avoin hengitystie uhattuna
- Hengitystiheys alle 5 tai yli 24
- Happisaturaatio äkillisesti ja toistetusti alle 90 %, huolimatta lisähapesta

Verenkierto:
- Syketaajuus alle 40/min tai yli 140/min
- Systolinen verenpaine toistetusti alle 90 mmHg

Tajunta:
- Äkillinen tajunnan tason lasku (Glasgow:n kooma-asteikolla mitattuna 2 pisteen lasku tunnissa)
- Toistuva pitkittynyt kouristelu

Muu syy:
- Hoidon ohjaukset esim. hengitystieimut trakeakanyylin kautta
- Teholta vuodeosastolle siirretyn potilaan hoitoa tukeva jälkiseuranta eli outreach-käynnit
- Huoli potilaasta

Jos olet huolissasi potilaasta: mittaa hengitystaajuus, happisaturaatio, syketaajuus ja verenpaine. Arvioi potilaan tajunnantaso esim. Glasgow:n kooma-asteikkoa apuna käyttäen

Ilmoita osaston päivystävälle lääkärille potilaan voinnin huononemisesta ja soita MET-ryhmälle **p. 64691**

- Jos kyseessä on hoidon ohjaus tai muu hoitajakonsultaatio ei lääkärille välttämättä tarvitse soittaa.

Kun soitat elvytys/MET –puhelimeen **64691**, kerro onko kyseessä elvytys tai MET-käynti. Ryhmän tullessa paikalle, ole potilaan luona ja kerro ryhmälle potilaan taustoista ja tilanteesta.

Sydänpysähdystilanteessa hälytä lisäapu ja aloita peruselvytys. Kytke AED, noudata ohjeita, ja käytä selkälevyä.

TEHO-OSASTON ELVYTYS –JA MET -RYHMÄ

Appendix 2. Template for core data recording on MET activations.

Pirkanmaan sairaanhoitopiiri
TAMPEREEN YLIOPISTOLLINEN SAIRAALA
Yhdessä terveyttä

ELVYTYS/MET-TIEDOT

Pvm _____ Osasto _____

Nimi / Henkilötunnus

Elottomuus
Nähty ☐
Kuultu ☐
klo ___ : ___
Viimeksi nähty hereillä
klo : :

Hälytyssoitto
___ : ___
Elvytysryhmä paikalla
___ : ___
Elvytysryhmä poistui
: :
Potilassiirto ___
TEHO ___ : ___
HDU ___ : ___
Jää osastolle ☐
Elvytys lopetettu
: :
DNR ☐ ___
___ : ___

Hälytyksen syy
☐ Sydänpysähdys monitoroitu
☐ Sydänpysähdys ei monitoroitu
☐ Hengitysvajaus
☐ Hypotensio
☐ Tajunnanlasku
☐ Muu

Alkurytmi
☐ ASY
☐ PEA
☐ VF
☐ VT
☐ SR

ROSC
___ : ___
___ : ___
___ min

Kuolinaika
: ___

Totesi
_____
_____
_____

Tapahtumakuvaus
Elvytys / MET ☐ Käynti ☐ Konsultaatio

KLO	DCJ	ADR.	CORD	Muut lääk.	HR	Rytmi	RR	HF	SaO_2	$Etco_2$	GCS	Pupill. O/V

Hengitys
intubaatio
: ___ ___
syvyys ___
koko ___
O_2 lisä ___

Nesteet
iv. yhteys
: ___ ___

Muuta (vs. lämpö, kipu, hät:t)

Hoitajat:
_____
_____
_____

Lääkäri:

TAYS mo LP0564 2.06

Pirkanmaan sairaanhoitopiiri
TAMPEREEN YLIOPISTOLLINEN SAIRAALA
Yhdessä terveyttä

ELVYTYS/MET-TIEDOT

Pvm _____ Osasto _____

ELVYTYSKÄYNNIN ARVIOINTI

☐ Elvytys ☐ MET

Arvioi elvytystapahtumaa seuraavilla alueilla

	Ei ongelmia	Hieman ongelmia	Jonkin verran ongelmia	Paljon ongelmia
Ryhmän toiminta				
Johtaminen				
Välineiden toiminta				

Tarkenna tarvittaessa: _____

_____

_____

Debriefing ☐ Keskusteltu ☐ Halutaan keskustella myöhemmin

Arvio osaston henkilökunnan toiminnasta

PPE aloitettu ☐ ☐ ei
Laatu tehokasta ☐ ☐ ei
Ei nähty ☐

Yleistä osaston toiminnasta: _____

_____

_____

Silmien avaus
4 = pitää silmänsä auki, katselee
3 = avaa puhuteltaessa
2 = avaa kipuärsykkeelle
1 = ei avaa
t = silmät turvonneet umpeen

Puhevaste
5 = selkeä
4 = sekava, lauseita
3 = sanoja, kiroilua ym.
2 = äänteleyä
1 = ei ääntä
i = intuboitu / trakeostomia

Liikevaste
6 = noudattaa kehoituksia
5 = paikallistaa kivun
4 = torjuu kipua, vetäytyy kipuärsykkeestä
3 = koukistus kivulle
2 = ojennus kivulle, reagoi kipuun
1 = ei liikettä
im = raajat immobilisoitu

Pupillat __ / __

Valoreaktio __ / __

Appendix 3. Questionnaire to the hospitals (translated)

Contact information of the respondent:

Hospital

Name and title
E-mail address
Phone number

I. Background information

1. Hospital level:
1) University hospital
2) Satellite unit of a university hospital
3) Central hospital
4) District hospital

2.
1) Bed capacity of the hospital (n)
2) Admissions (n) / year

3. Does your hospital have any of the following intensive care units (ICUs)? Please tick all that apply.

ICU type	No	Yes	If yes, number of beds (n)
Mixed	0	1	
Medical	0	1	
Surgical	0	1	
Cardiac	0	1	
Pediatric	0	1	
High dependency unit (HDU)	0	1	
No ICU in the hospital	0		

4. Does your hospital have monitored beds on general wards? Please tick all that apply.

Ward specialty	No	Yes	If yes, number of beds (n)
Medical	0	1	
Surgical	0	1	

Neurology	0	1
Cardiac	0	1
Pediatric	0	1
No monitored beds in general wards	0	

5. Presence of an anesthesiologist
1) Always
2) During office hours
3) Other hours, please explain
4) Never

II. Cardiac arrest teams

1. Does your hospital have a cardiac arrest team? If the answer is no, please go to chapter III.
1) Yes, operational 24/7
2) Yes, operational during office hours only
3) Yes, operational during other limited times, please specify
4) No

2. From which department does the cardiac arrest team operate?
1) Intensive care unit
2) Emergency department
3) Other department, please specify

3. Cardiac arrest team leader is
1) Anesthesiologist
2) Internal medicine physician
3) Surgeon
4) Nurse
5) Other health care professional, please specify

4. If the cardiac arrest team leader is a physician, is the team physician-led
1) 24/7
2) During office hours
3) During other limited times, please specify

5. Mechanical equipment of the cardiac arrest team. Please, tick all that apply.
1) Automated external defibrillator (AED)
2) Manual defibrillator
3) Backboard
4) CPR measurement and feedback device (e.g. Philips MRx QCPR®, CPRMeter®, Zoll Real CPR Help®)
5) Load-distributing band (e.g. AutoPulse®)
6) Other equipment, please record all

6. Does your hospital have an appointed person responsible for resuscitation training?
1) Yes, a physician
2) Yes, a nurse
3) No

7. Are data on cardiac arrest team activations documented to a specialized form?
1) Yes
2) No

8. Are these forms archived?
1) Yes
2) No

9. Are statistics compiled using the collected data?
1) Yes, according to the Utstein recommendations
2) Yes
3) No

10. If statistics have been compiled, how many cardiac arrests occurred (please, answer to all sections if possible)
1) In 2011 (n)
2) In 2010 (n)
3) During the last six months (n)

11. Is structured debriefing organized after resuscitation events?
1) Yes

2) No

III. Do not attempt resuscitation (DNAR) decisions

1. Do you have uniform guidelines on DNAR orders in your hospital?
1) Yes
2) No
3) I don't know

2. Do you have uniform style to document DNAR orders in patient records??
1) Yes,
    1. A combination of characters (e.g. DNAR)
    2. A symbol
3. Other, please specify
2) No

3. Healthcare professionals who can make the decision to terminate unsuccessful resuscitation attempts and resuscitation attempts regarded as futile. Please tick all that apply.

	No	Yes
Ward nurse	0	1
Ward physician	0	1
Cardiac arrest team nurse	0	1
Cardiac arrest team physician	0	1
No one	0	1

IV. Medical emergency teams

1. Are you aware, that most in-hospital cardiac arrests are preceded by vital dysfunctions?
1) Yes
2) No

2. Does your hospital have a dedicated response team reacting for patient deterioration in general wards? (e.g.*"Medical Emergency Team" (MET), "Rapid Response Team (RTT)", "Critical Care Outreach Team" (CCOT*)).If the answer is no, please go to chapter V.

1) Yes
2) No

3. When did the response team become operational? (e.g.1/2009)

4. From which department does this team operate?
1) Intensive care unit
2) Emergency department
3) Other, please specify

5. Is this team the same team as hospitals cardiac arrest team?
1) Yes
2) No, but it operates from the same department
3) No, and it operates from a different department

6. Does this dedicated medical emergency team operate
1) 24/7
2) During office hours only
3) During other limited times, please specify

7. Please tick below all team members and their numbers

	No	Yes	Number
Anesthesiologist	0	1	
Internal medicine physician	0	1	
Surgeon	0	1	
Intensive care unit nurse	0	1	
Nurse of a different specialty	0	1	
Other health care professional (please specify)			

8. The team physician is
1) Always attending (consultant)
2) Always resident (senior house officer)
3) Attending or resident
4) Team has no physician

9. Do all team members react immediately in case of team activation?

1) Yes

2 No, depending on the case nurses may go in advance. However, physician will always participate at some point.

3) No, depending on the case nurses may go in advance. Physician participates if assessed appropriate.

4) Yes, because team as no physician.

10. Operational areas of hospitals medical emergency team. Please tick all that apply.

	No	Yes
Medical wards	0	1
Surgical wards	0	1
Monitored areas of medical wards	0	1
Monitored areas of surgical wards	0	1
Intensive care units	0	1
Pediatric wards	0	1
Operating room and post anaesthetic care unit	0	1
Emergency department	0	1
Diagnostic areas (laboratory etc.)	0	1
Public areas of the hospital	0	1

11. Individuals that are able to activate medical emergency team. Please tick all that apply.

	No	Yes
Physicians	0	1
Nurses	0	1
Other staff members	0	1
Patients	0	1
Visitors/Non-patients	0	1

12. Has education regarding vital dysfunctions and medical emergency team been organized to general ward staff?

1) Yes, all staff members have been educated

2) Yes, part of the staff members has been educated

3) No

13. Do predefined calling criteria for MET exist?

1) Yes
2) No

14. Medical emergency team calling criteria in your hospital. Please tick all that apply. Please also record activation thresholds where appropriate.

	No	Yes	Thresholds
Cardiac arrest	0	1	
Respiratory arrest	0	1	
Respiratory rate	0	1	< /min > /min
Spo2	0	1	< %
Systolic blood pressure	0	1	< /mmHg > /mmHg
Heart rate	0	1	< /min > /min
AVPU/ACDU-score	0	1	below 4 3 2 1
Glascow Coma Scale	0	1	score< / score change ___ units
'Staff worried'	0	1	
Early Warning Score (If yes, please provide a copy of used EWS)	0	1	

15. Is medical emergency team able to implement treatment limitations?

1) Yes, independently
2) Yes, but only after consulting ward physician
3) No

16. Interventions that medical emergency team can implement independently. Please tick all that apply.

	No	Yes
Intravenous fluids	0	1
Supplementary oxygen therapy	0	1
Intravenous vasoactive infusions (e.g. noradrenaline)	0	1
Arterial blood gas sample	0	1
Analysing arterial blood gas sample	0	1

Invasive (intra-arterial) blood pressure (IBP) monitoring	0	1
Defibrillation	0	1
CPAP –treatment	0	1
Intubation	0	1

17. Is a special form for note keeping used during team activations?
1) Yes
2) No

18. Are these forms archived?
1) Yes
2) No

19. Are statistics compiled using the collected data?
1) Yes
2) No

20. If statistics have been compiled, how many medical emergency team activations (including cardiac arrests) occurred (please, answer to all sections if possible)
1) in 2011 (n)
2) in 2010 (n)
3) during the last six months (n)

21. Have you received additional funding for MET implementation?
1) Yes
2) No

22. Structured training days per year for MET members (average)? (n)

23. In your opinion, have the following areas of in-hospital emergency medicine improved in your hospital during the last five years?

	No	Yes
Resuscitation	0	1
Prevention of in-hospital cardiac arrests	0	1
DNAR –decision policies	0	1

V. Critical care outreach: follow-up of discharged ICU patients

1. If assessed appropriate, follow-up visits to discharged ICU patients can be initiated.

If your answer is no, we thank you for your co-operation.

1) Yes
2) No

2. Follow-up visits are initiated for

1) All discharged ICU patients
2) All patients that fulfill the used selection criteria. Please tick all that apply.

	No	Yes
Prolonged ICU stay	0	1
Discharged to monitoredarea	0	1
Other, please specify		
Other, please specify		
Other, please specify		

3) No criteria. Follow-up initiated when assessed appropriate by ICU physician

4. How many follow-up visits per day?

1) Always (n)
2) Depending on the case from (n) to (n)

5. The results of the conducted visit are reported to ICU physician

1) Always
2) If assessed appropriate

16 Original Publications

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Vital dysfunctions after intensive care discharge: prevalence and impact on patient outcome

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Background: Patients discharged from the intensive care unit (ICU) are at increased risk for serious adverse events (SAEs). Recording vital functions and comprehending the consequences of altered vitals on general wards may be suboptimal. This potentially endangers recovery after successful intensive care. We aimed to determine the prevalence of vital dysfunctions after ICU discharge and their effect on patient outcome.
Methods: A prospective observational study. Adult patients discharged from a tertiary referral hospital ICU to general wards without treatment limitations were visited 24 h afterwards; their vitals were measured and reported to ward staff. Attending ward nurse responsible for patient was interviewed.
Results: The cohort consisted of 184 patients who had survived the first 24 h on the ward without complications (age: 57 ± 16 years; male: 68%). The prevalence of objectively measured vital dysfunctions was 15%, and the attending nurse had been unusually concerned about the patient in 19% of cases. Of the 184 patients, 9.8% subsequently suffered an SAE. In a multivariate logistic regression model, only vital dysfunctions (odds ratio 3.79; 95% confidence interval 1.18–12.2) and nurse concern (3.63; 1.17–11.3) were independently associated with an increased incidence of SAE. Medical emergency team (MET) assistance was never considered necessary by ward staff. Sensitivity of observed altered vitals on SAEs was 50% and specificity 89%. Sensitivity of nurse concern was 26%, specificity 84%.
Conclusions: Simple vital function measurement and attending ward nurse's subjective assessment facilitate early detection of post-ICU patients at risk. The threshold in seeking assistance through MET remains high.

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Patients discharged from intensive care units (ICUs) without treatment limitations are at increased risk of serious adverse events (SAE) resulting in medical emergency team (MET) review, readmission to ICU or even death. In spite of the initial recovery from the critical illness, nearly 10% of ICU patients transferred to general wards die and approximately 7% to 10% are acutely readmitted to ICU.[1–5]

There are multiple risk factors associated with increased morbidity and mortality among post-ICU patients. These factors are related to hospital/ICU admission type, patient characteristics and several variables related to the disease, the patient and the treatment.[3,6–8] At the same time, recent studies on METs and prevalence of MET activation criteria on general wards suggest that the ward-level care in hospitals is often suboptimal.[9–11] Basic vital functions (or dysfunctions) are not recorded or treated as would be expected.[12,13] If this applies to post-ICU patients too, recovery from critical illness may be compromised even after successful intensive care and discharge from the ICU.

This observational study aimed to investigate the prevalence of altered vitals among discharged ICU patients remaining on the ward for the first 24 h after discharge without complications. We also wanted to study whether the likelihood of SAEs in post-ICU patients was independently associated with observed vital dysfunctions on the ward.

Materials and methods

The study was conducted according to the revised Declaration of Helsinki and approved by Tampere University Hospital's Ethics Committee (approval

no: R10111). Written informed consent procedure was waived as no interventions were conducted and the design was entirely observational. The study was registered to Clinical Trials registry (clinicaltrials.gov NCT01214460).

Study setting

Tampere University Hospital is one of the five tertiary referral centres in Finland, serving a population of 1,200,000 inhabitants. It has 820 beds with 75,000 somatic admissions annually. Mixed ICU has a total of 24 beds, eight of which serve primarily as high dependency beds, but which can also be used for severely ill patients. In this study, all 24 beds were regarded as ICU beds. Medical and surgical wards have dedicated rooms with patient monitors facilitating more intensive observation. In 2010, we had 2016 ICU admissions, 5.7% ($n = 116$) of which were readmissions. ICU mortality was 6.1%, and overall hospital mortality of patients admitted to intensive care was 12%.

MET has been active in our hospital since 2009 and responds both to resuscitation calls and other medical emergencies. The MET calling ratio in 2010 was 8.4 calls/1000 hospital admissions. Current MET activation criteria include: threatened airway, heart rate < 40/min or > 140/min, systolic blood pressure < 90 mmHg, peripheral arteriolar oxygen saturation < 90%, respiratory rate < 5/min or > 24/min, acute fall of Glasgow Coma Scale (GCS) by at least two and/or situations where according to the attending nurse the patient requires a MET activation. The last subjective rule was included in our MET activation criteria because recent evidence suggests that it allows the identification of many critically ill patients not otherwise fulfilling the objective criteria.[12,14] It should also be noted that we deliberately chose to use a significantly lower upper threshold limit for respiratory rate than some other institutions using rapid response systems, where limits varying from 30 to 36 breaths per minute have been used.[13,15,16]

Inclusion criteria and data collection

Every adult patient (over 18 years) discharged from ICU to a general ward without treatment limitations between 1 June 2010 and 31 July 2010 was included in the study. Discharges after ICU readmissions were excluded. Twenty-four hours after the discharge, trained fourth-year medical students working as interns in the ICU visited every discharged patient. Patients with new treatment limitations, already readmitted to the ICU, admitted to the operating theatre or visiting the canteen with family were further excluded. Patients who had died, been transferred to another facility or discharged from the hospital were likewise not assessed. Figure 1 provides an overview of the patients included and the final cohort.

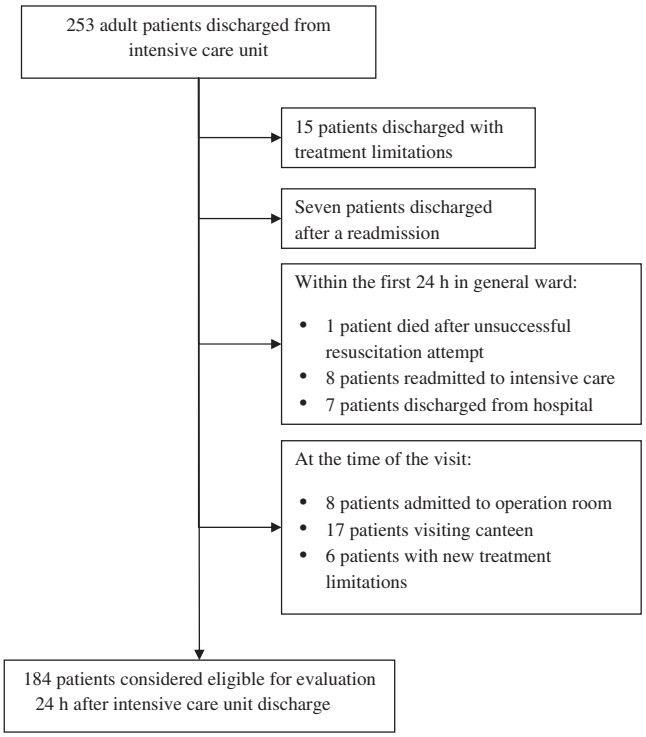

Fig. 1. An overview of recruited patients and final cohort.

During the visits, the interns measured each patient's heart rate, systolic blood pressure, peripheral arteriolar oxygen saturation and respiratory rate. As an acute fall in GCS could not be objectively evaluated, we did not include it in the analysis. Before reporting the four measured vitals, the ward nurse responsible for the patient was also interviewed briefly with the following questions: Have you been more concerned than usual about your patient's condition? In case of a positive answer, the nurse was asked the reason for this. Finally, the results of the vital measurements were reported to the nurse, and he/she was asked if he/she felt that a MET review was required.

Data regarding ICU stay were obtained from a clinical information system (Centricity Critical Care, GE Healthcare) introduced in 2006. Data on hospital admission and possible SAEs were obtained from patient records and the MET activation database recorded in the Utstein style.[17] An SAE was defined as any of the following occurring during subsequent

hospital stay: (1) deterioration causing MET to be activated by ward staff, (2) readmission to intensive care or (3) death during hospitalisation. If MET was activated by a ward nurse due to the reported vitals measured by the interns, activation was not included as an adverse event. The Charlson Comorbidity Index (CCI) score was calculated on the basis of the patients' International Classification of Disease, tenth revision diagnoses preceding current hospitalisation. CCI is used to evaluate the confounding effect of comorbidities such as diabetes, ischaemic heart disease, chronic lung diseases, chronic renal failure and cancer in clinical research.[18,19] We also recorded the Simplified Acute Physiology Score (SAPS II) and Acute Physiology and Chronic Health Evaluations (APACHE II) scores calculated within the first 24 h of ICU admission. SAPS II and APACHE II are severity of illness scoring systems used in intensive care and based on physiologic measurements, patient characteristics and previous health status.[20,21]

Statistical analysis

Data were analysed using SPSS 17.0 for Windows (SPSS Inc, Chicago, IL, USA). The data are presented as percentages and numbers, mean ± standard deviations or median and quartiles (Q_1, Q_3), as appropriate. A multivariate logistic regression analysis was performed on the study population with any subsequent SAE during hospital stay (yes/no) as a dependent variable. Covariates included in this analysis were gender, age, CCI (score without age), type of hospital admission, background (surgical/medical), SAPS II and APACHE II scores on ICU admission, surgery performed before ICU discharge (yes/no), length of ICU admission (days), mechanical ventilation in intensive care (yes/no), renal replacement therapy in intensive care (yes/no), discharge during out-of-office hours (yes/no), discharge to monitored ward area (yes/no), altered vital signs observed 24 h after ICU discharge (yes/no) and ward nurse worried about patient 24 h after ICU discharge (yes/no). Regression analysis was also repeated after introducing the four measured vitals as individual variables instead of a composite variable. 95% confidence intervals (95% CI) were reported, and the statistical significance level was set at two-tailed *P*-value of < 0.05.

Results

Characteristics of the patients, comorbidities and hospital/ICU admissions are presented in Table 1.

Table 1

Characteristics of 184 patients evaluated 24 h after their intensive care unit (ICU) discharge.

	%	*n*
Patient characteristics		
Age (years) (mean, SD)	57 ± 15.6	
Sex (male)	68	125
Comorbidity score*		
0	59	109
1	20	36
≥ 2	21	39
Previously diagnosed comorbidities		
Ischaemic heart disease	8.1	15
Congestive heart failure	5.4	10
Peripheral vascular disease	3.8	7
Cerebrovascular disease	3.8	7
Chronic obstructive pulmonary disease	3.8	7
Diabetes	19	34
Cancer (malignant tumour)	12	22
Current hospital admission characteristics		
Elective hospital admission	31	57
Surgical reason for admission	71	130
Length of hospitalisation (days) median (Q_1, Q_3)	8 (5, 15)	
Primary reason for hospitalisation		
Cardiovascular disease	18	33
Cerebrovascular disease	12	22
Infectious disease	8.2	15
Respiratory disease	2.2	4
Gastrointestinal disease	6.5	12
Neoplasm	21	38
Trauma/poisoning	21	39
Other	11	21
Intensive care admission characteristics		
Surgical procedure before/during admission	55	101
SAPS II at time of ICU admission (score) median (Q_1, Q_3)	26.5 (17, 37)	
APACHE II at time of ICU admission (score) median (Q_1, Q_3)	15 (10, 21)	
Mechanical ventilation required	36	66
Renal replacement therapy required	8.7	16
Length of ICU admission (days) median (Q_1, Q_3)	1 (1, 4)	
Admission length ≥ 3 days	33	60
Office hours discharge (8:00–15:00 h)	81	149
Discharged to monitored ward	38	69
Discharged with CPAP	4.3	8

Second column indicates percentages and third the absolute number, if not otherwise indicated in the first column.
*The Charlson Comorbidity Index score.
APACHE II, Acute Physiology and Chronic Health Evaluations; CPAP, continuous positive airway pressure device; SAPS II, Simplified Acute Physiology Score; SD, standard deviation.

SAEs occurred subsequently in 18 patients (9.8%) during their hospital stay. A total of 16 patients required a MET review. Ten patients had a MET review and were readmitted to the ICU (one patient was readmitted after an emergency relaparothomy). Five patients died in the hospital and four of them

Table 2

Data on visits conducted to 184 patients 24 h after intensive care unit discharge.

Vital functions	%	*n*
Heart rate (beats/min) (mean ± SD)	83 ± 16	
Systolic blood pressure (mmHg) (mean ± SD)	139 ± 23	
Peripheral arteriolar oxygen saturation (%) (median (Q_1, Q_3))	97 (95, 98)	
Respiratory rate (breaths/min) (mean ± SD)	19 ± 6.0	
Heart rate < 40/min or > 140/min	0	0
Systolic blood pressure < 90 mmHg	1.1	2
Peripheral arteriolar oxygen saturation < 90%	2.7	4
Respiratory rate < 5/min or > 24/min	13	23
Altered vitals observed*	15	28
Interview of ward nurse responsible for the patient		
Nurse has been unusually worried about patient	19	35
Specific reason for concern		
Respiratory function	29	10
Cardiovascular function	14	5
Disorientation	37	13
Other	20	7
Nurse feels that rapid response team activation is required	0	0

The second column indicates percentages and third the absolute number, if not otherwise indicated in the first column.
*One patient had both low SpO_2 (peripheral arteriolar oxygen saturation) and high RR (respiratory rate).
SD, standard deviation.

had also had a previous MET review. Thus, the total of patients with any/multiple SAEs was 18. MET was activated at median 2.0 days after ICU discharge (1.75, 6.25). ICU readmission was at median 2.0 days (1.75, 6.75) after the initial discharge.

The recorded vitals at ICU discharge were: heart rate 88 ± 15/min, systolic blood pressure 138 ± 23 mmHg, peripheral arteriolar oxygen saturation 97 (94.25, 98.75)% and respiratory rate 18 ± 4.8/min. At discharge, five patients had altered vitals according to our MET criteria. The day after visit took place 24 ± 4 h after the initial ICU discharge. After 24 h, the number of patients with altered vitals was 28. In 35 cases, the ward nurse reported being more concerned than usual about the patient. Despite the reported altered vitals and additional concern about the patient, MET activation was never deemed necessary by the ward staff. Data on the visits are presented in Table 2.

Table 3 presents the results of the multivariate logistic regression analysis. The only factors showing an independent statistical association with poorer outcome were: presence of abnormal vitals

Table 3

Multivariate logistic regression analysis for factors independently associated with increased risk for serious adverse events 24 h after intensive care unit (ICU) discharge.

Factor	Multivariate analysis		
	Odds ratio	95% CI	*P*-value
Altered vitals observed 24 h after ICU discharge (yes/no)	3.79	1.18–12.2	0.025
Ward nurse worried about patient 24 h after the discharge (yes/no)	3.63	1.17–11.3	0.026

Results of multivariate logistic regression analysis with backward model. Other variables introduced to multivariate analysis: gender, age, comorbidity score, type of hospital admission, background (surgical/medical), surgery performed before ICU discharge (yes/no), length of ICU admission (days), mechanical ventilation in intensive care (yes/no), renal replacement therapy in intensive care (yes/no), discharge outside office hours (yes/no), discharge to monitored ward area (yes/no), and Simplified Acute Physiology Score and Acute Physiology and Chronic Health Evaluations Score at time of intensive care admission.

24 h after ICU discharge (OR 3.79; 95% CI 1.18–12.2) and nurse's heightened concern about the patient (3.63; 1.17–11.3). Sensitivity of altered vitals in predicting SAEs was 50% and specificity 89%. Sensitivity of nurse concern was 26%, specificity 84%. If the four measured vitals were inserted into the multivariate regression analysis as individual variables, the factors showing an independent statistical association with SAEs were: respiratory rate < 5/min or > 24/min (6.54; 2.00–20.5), nurse's heightened concern (4.41; 1.42–13.7), non-elective hospital admission (10.8; 1.09–107) and receiving renal replacement therapy in ICU (4.96; 1.22–20.1).

Discussion

The present prospective observational study in discharged ICU patients surviving the first 24 h on a general ward demonstrates that it is not the diagnosis or the characteristics of ICU care that determine the likelihood of SAEs. Rather, the incidence of SAEs is related to the absence or presence of abnormal vital functions while on the general ward.

Recent evidence suggests that the severity of the illness at ICU admission, accumulating comorbidities, age, length of stay in the ICU, inappropriately timed discharge, and abnormal vitals and laboratory markers recorded in the ICU are associated with a poor outcome after ICU discharge.[3–8] Unfortunately, this information does not allow the identification of individual patients who will develop

SAEs.[1,2] It is therefore crucial to try to recognise patient deterioration as early as possible on general wards and initiate the appropriate therapy.

In our cohort, approximately 10% of patients suffered a subsequent SAE during their hospital stay. In addition, nine primarily recruited patients were excluded as one had died after an unsuccessful resuscitation attempt and eight had been readmitted to the ICU after a MET call within 24 h of ICU discharge. Although these SAEs occurring so soon after ICU stay may be explained by factors related to inappropriate early discharge, it can be concluded that post-ICU patients do indeed require intensive observation and the threshold for seeking advice on wards should be low.

The prevalence of fulfilling objective MET activation criteria among post-ICU patients in the present study was 15%. In addition, in 19% of the visits, nurses were more than normally concerned about their patients. Despite these findings, MET activation was not deemed necessary by ward staff in any of the cases. This concurs with earlier studies reporting that altered vitals may be tolerated up to 24 h before MET call is actually made.[12,13] Ward staff may be inexperienced in ICU patient aftercare and unaware of early signs of patient deterioration. Appropriate recordings of vital signs on general wards are often lacking or the information is misinterpreted, although it has been recorded.[22]

Some of the reasons for a delayed or missing response to an observed deviation in vital signs have been the limited time nurses have per patient and the traditional approach of initially consulting attending physicians.[23,24] Attending physicians may ignore the abnormalities, as junior physicians are often inexperienced in acute care.[25–27] Further, if a patient is discharged with already altered vitals, meaning that MET activation criteria were present at the very time of transferring the patient to the general ward, timely MET activation may not be feasible given the limited resources on general wards. In our study, however, only five patients had altered vitals at the time of ICU discharge. In our hospital, MET activation criteria are presented as posters in every ward, and regular training has been organised for ward staff. Most nurses reporting concern about their patients were able to specify the reason for such concern, which indicates that potential problems had at least been identified to a certain degree. Underestimation of the relevance of positive MET activation criteria and subjective concern seemed to be the key reasons for deeming MET activation unnecessary. We moreover conducted the visits on daytime. As ward physicians were available at hospital during the visit, this may have further discouraged nurses from considering a MET review after the visit of the interns.

In our multivariate logistic regression analysis, only altered vitals and ward nurses' additional concern about the patient 24 h after ICU discharge were associated with SAEs. These SAEs occurred at median 2 days after ICU discharge, approximately 1 day after the visit by the interns. Thus, observed vital deviations and nurse concern can be linked to these worse outcomes. It should be acknowledged, however, that our study population was relatively small and in a larger cohort, other covariates might have also been associated with patient outcome. Although it was not associated with worse outcome in our study population, we found that nearly one fifth of the patients were discharged from the ICU outside office hours, indicating perhaps insufficient resources in our ICU setting.

Respiratory rate over 24/min was by far the most commonly observed vital dysfunction. It was also the only individual vital deviation that was independently associated with poorer outcome. Interestingly, in a recent study by Chaboyer et al., respiratory rate over 24/min in the intermediate care unit was also one of the two significant predictors of adverse events after intensive care discharge.[28] Although MET criteria have been criticised for their on/off nature and relatively low sensitivity and specificity as regards the occurrence of SAEs, the criteria used in our hospital appeared to show acceptable sensitivity and fairly good specificity despite the lower upper threshold limit for respiratory rate compared with some earlier reports.[11,29] In light of our and Chaboyer et al.'s findings, it seems that the lower limit may indeed be feasible. Because our study underlines the finding of other reports recognising deviating respiratory rate as a strong predictor for SAEs,[16,28,30] future educational efforts should emphasise the importance of measuring respiratory rate on general wards.

Nurse concern about the patient appeared to be independently associated with SAEs in the present study. In a questionnaire study by Jones et al., 56% of the ward nurses reported that they would activate MET regardless of objective criteria if they were concerned about the patient.[24] Santiano et al. reported the 'nurse worried' criterion to be the most frequent reason for MET activation in a study evaluating over 3000 calls from six centres. In this study, 'abnormal breathing' was the most common reason for 'nurse worried' activations.[14] One reason for this

may be the relatively high trigger level used for respiratory rate, which prompts the staff to use alternative triggers. In our cohort, nurse concern was present in 19% of the cases compared with 15% prevalence of objectively observed altered vitals, and the most common reason for the nurse concern was the level of consciousness. However, our cohort consisted of post-ICU patients who differed from general hospital population requiring MET assistance. Interestingly, none of the worried nurses judged the condition of the patient to necessitate MET activation. As post-ICU patients may have more complex needs on a general ward, the decision to contact MET on nurse's subjective judgment should be encouraged.

Our study suffers from a number of limitations. The small number of patients might not have allowed the identification of all covariates associated with poor outcome of post-ICU patients. Because of the single-centre and single-ICU nature of the study, our findings may not be extrapolated to hospitals with multiple dedicated ICUs and step down units. Further, the MET calling ratio at the time this study was conducted was below the average reported in institutions with MET,[31] which may indicate that our MET is still immature. Our study protocol of presenting vital signs for the nurse after the visit may have also altered her/his actions and prompted a subsequent MET call. We also excluded the assessment of decreasing level of consciousness from the MET activation criteria, although a fall in GCS has been shown to be independently associated with higher mortality in MET populations.[14,29,32] This was due to the fact that for logistic reasons, acute fall in GCS could not be objectively recorded by study personnel because of the point-prevalence study setting.

Conclusions

The results from the present study show that prevalence of abnormal vital signs, recognised as positive MET criteria, was worryingly high among patients discharged from intensive care. When presented to ward staff, altered vitals were not regarded as early signs of deterioration requiring intervention even though MET has been active in our hospital since 2009. After the first 24 h on the general ward, recorded vital deviations and attending nurse's concern about patient were the only factors independently associated with SAEs among discharged ICU patients. Additional education on recognising early signs of critical illness and the importance of not tolerating presented MET criteria should be conducted on wards treating post-ICU patients.

Conflicts of interest: Jyrki Tenhunen is a co-founder, medical director and shareholder of Sensem Technologies Ltd (Tampere, Finland). The other authors declare no conflicts of interest.

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Factors associated with delayed activation of medical emergency team and excess mortality: An Utstein-style analysis☆

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ABSTRACT

Aim: We used the Utstein template, with special reference to patients having automated patient monitoring, and studied the factors which are associated with delayed medical emergency team (MET) activation and increased hospital mortality.
Design and setting: A prospective observational study in a tertiary hospital with 45 of 769 general ward beds (5.9%) equipped with automated monitoring.
Cohort: 569 MET reviews for 458 patients.
Results: Basic MET review characteristics were comparable to literature. We found that 41% of the reviews concerned monitored ward patients. These patients' vitals had been more frequently documented during the 6 h period preceding MET activation compared to patients in normal ward areas (96% vs. 74%, $p < 0.001$), but even when adjusted to the documentation frequency of vitals, afferent limb failure (ALF) occurred more often among monitored ward patients (81% vs. 53%, $p < 0.001$). In MET population, factors associated with increased hospital mortality were non-elective hospital admission (OR 6.25, 95% CI 2.77–14.11), not-for-resuscitation order (3.34, 1.78–6.35), ICD XIV genitourinary diseases (2.42, 1.16–5.06), ICD II neoplasms (2.80, 1.59–4.91), age (1.02, 1.00–1.04), preceding length of hospital stay (1.04, 1.01–1.07), ALF (1.67, 1.02–2.72) and transfer to intensive care (1.85, 1.05–3.27).
Conclusions: Documentation of vital signs before MET activation is suboptimal. Documentation frequency seems to increase if automated monitors are implemented, but our results suggest that benefits of intense monitoring are lost without appropriate and timely interventions, as afferent limb failure, delay to call MET when predefined criteria are fulfilled, was independently associated to increased hospital mortality.

1. Introduction

Serious adverse events (SAE) like cardiac arrests (CA) and emergency intensive care unit (ICU) admissions are common among hospitalized patients.[1–3] These are often preceded by altered vital functions, which manifest in clinical signs such as tachy- and bradyarrhythmias, tachypnea, low peripheral arteriolar oxygen saturation, low systolic blood pressure and sudden drowsiness.[4–10] Medical emergency teams (METs) have been implemented in many hospitals to facilitate timely interventions in case of patient deterioration.[11–13,1]

The afferent limb, early detection of a critically ill patient by nursing and medical staff in the wards, is required for MET to deliver required interventions in time. A delayed MET activation, failure of ward staff to call MET immediately when vital dysfunctions are detected, has been reported to jeopardize patient safety and the efficacy of MET systems (also referred as afferent limb

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failure, ALF).[14,15] Some known reasons for ALF are the hierarchy and fear of false alarms among the staff, and ignoring the MET criteria because of own subjective assessment.[16,17]

Patient monitors are increasingly implemented in general wards.[18,19] The very idea is to facilitate more intense observation of the vital functions of the patients which in turn would allow early interventions in case of the deterioration. However, intensive monitoring may also compromise patient safety, if, for example, alarm fatigue (because of too sensitive alarm thresholds) leads to ignoring the deteriorating vital functions.[18–22] In a MET system, this can result in delayed activations.

Recent consensus conference addressed factors associated with ALF, and frequency and timing of appropriate patient monitoring.[23] Little is known how different monitoring intensity levels inside general wards reflect on the appropriate use of MET. We have used the Utstein template, recommended for uniform reporting on MET by international scientific statement,[24] and studied the documentation of vitals and vital dysfunctions before a MET call, with special reference to patients having automated patient monitoring in general wards. We have also identified factors which are associated with a delayed MET activation and increased hospital mortality in a MET population in a tertiary referral center in Finland.

2. Methods

2.1. Ethics committee and study approval

This study was approved by the Ethics Committee of Tampere University Hospital (Approval number R10111; clinicaltrials.gov NCT01214460). Informed consent was waived because of the observational nature of the study.

2.2. Hospital

Tampere University Hospital is one of Finland's five tertiary referral centers and admits approximately 75,000 somatic patients annually (total hospital mortality 1.4%). ICU and high dependency unit (HDU) combined have 24 beds with over 2000 admissions annually. ICU and HDU operate as a combined unit, and only ICU physicians can prescribe therapy.

The hospital has 769 beds on general wards, 45 beds (5.9%) of which have patient monitors which facilitate automatic noninvasive monitoring of vital functions. Each patient has his/her own monitor which is continually attached to the patient. These beds are located in dedicated two to six bed rooms and they consist of eight surgical and 37 primarily medical beds. The average staff number during non-office hours is 0.24 nurses/patient in these areas, primarily designed to increase the frequency of observations, compared to 0.1 nurses/patient in normal ward areas. Patient selection to these beds is based on attending ward physicians' or emergency room physicians' subjective assessments, who are also responsible for these beds same as for other ward areas.

2.3. Medical emergency team

MET system was introduced in January 2009. In 2010 the MET covered all adult and pediatric somatic wards, including the emergency room, operation rooms and diagnostic areas. The team consists of one ICU physician and two ICU nurses, and is available 24/7. MET members, physicians and nurses, rehearse advanced cardiac life support and medical emergencies six days per year in a simulation center. MET nurses work as team members in approximately every fifth shift in ICU. Our MET responds both to resuscitation calls and medical emergencies. Any member of hospital staff/visitor can activate the MET when pre-defined calling criteria are fulfilled. Every general ward has a dedicated nurse responsible for acute care education in their ward, and these nurses have two lecture days every year, where new institutional data, feedback and training is given. In addition, data regarding MET activations are reported to each ward individually for internal evaluation. Ward staff members operating also in emergency room have received training in simulation center, but otherwise training has been conducted with normal manikins by MET members in wards. Posters and pocket cards presenting MET criteria are present in every ward.

2.4. Study setting and inclusion criteria

The study was conducted as a prospective observational study in a single academic tertiary hospital. All MET activations in the wards during year 2010 were included. MET activations to the emergency room, operation rooms, intensive care unit, high dependency unit and diagnostic areas were excluded. As suggested by the Utstein-style scientific statement,[24] MET activations resulting in cardiopulmonary resuscitation (CPR) were analyzed, but reported separately from actual MET calls.

2.5. Data collection

A MET nurse at site recorded detailed data of each MET review. Additional data concerning the patient demographics and outcome was obtained from the patient records. The data regarding vital functions before MET activation were retrospectively obtained from an electronic database, where nurses document the observed vital functions. Each documentation was time labeled. Automated patient monitors dedicated to more active observation in general wards were not attached to any database. Thus, vitals observed with automated monitors had to be documented manually as in other ward areas.

Two recent studies on ALF have classified vital signs as normal or abnormal before the MET activation according to the used activation criteria.[14,15] Our activation criteria used in this study were: heart rate <40/min or >140/min, systolic blood pressure <90 mmHg, peripheral arteriolar oxygen saturation <90% and respiratory rate <5/min or >24/min. Glasgow Coma Scale was not used by general ward staff, and we therefore excluded the estimate of acute change in the state consciousness from analysis as it was prone to misinterpretation.

Low frequency of documentation of vital signs in general wards is not unusual,[23] and this may bias the analysis of ALF. We therefore aimed to report also the ALF/vitals documented-ratio. We compared the number of documented ALFs to the actual number of cases when vitals were documented in the first place. If a MET criterion was documented at 20–360 min before the MET activation, it was recorded as a delayed MET activation and ALF.

2.6. Statistical analysis

SPSS software, version 16.0, for Windows (SPSS Inc., Chicago, USA) was used for the statistical analyses of the data. Data were reported as percentages or median and quartiles (Q_1, Q_3) when appropriate. Chi-square test and Mann–Whitney *U*-test were used for the comparisons between groups. As some patients had multiple MET activations, we only included the first activation for the analyses of patient characteristics and hospital mortality. Multivariate logistic regression with 95% confidence intervals was used to determine factors independently associated with ALF and increased hospital mortality. Statistical significance level was set at $p < 0.05$ and two-tailed *p*-values were reported.

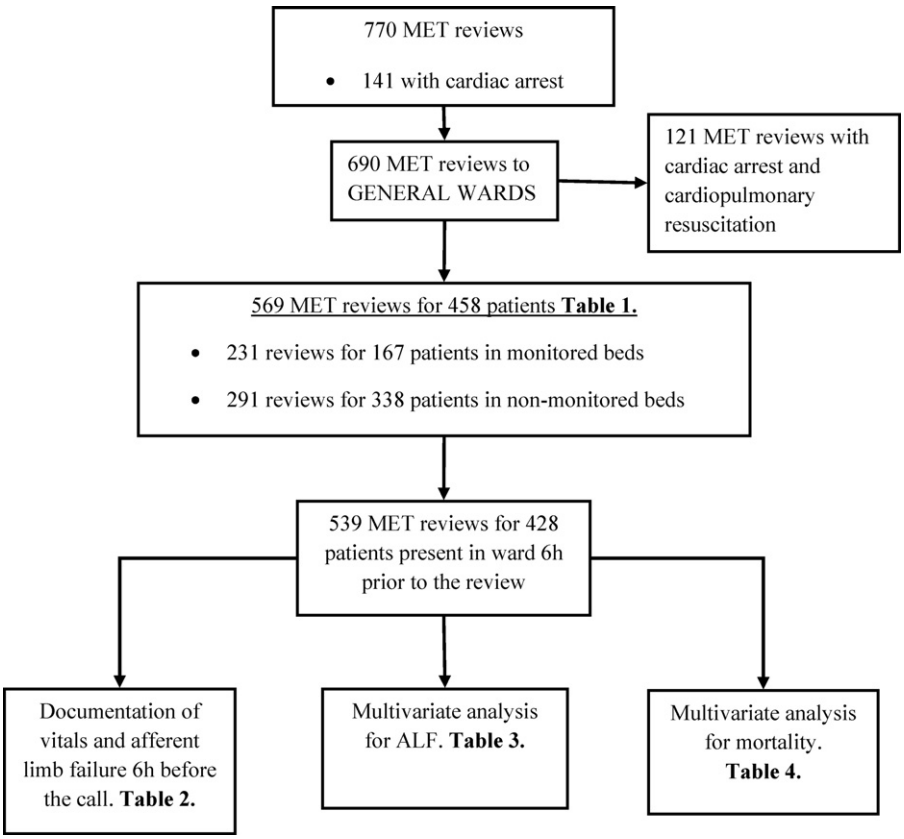

Fig. 1. Medical emergency team activations during the study period. In flowchart is also described how analyses presented in Tables 1–4 were performed.

3. Results

3.1. Characteristics of the MET activations and reviewed patients

During the study period we had 770 MET activations in our hospital, 141 of which were cardiac arrests. MET review frequency (excluding CAs) was 8.4 calls per 1000 hospital admissions. 690 MET activations concerned general ward patients, 121 of which were cardiac arrest reviews. Thus we had total 569 medical emergency reviews for 458 patients in hospitals general wards during the study period (Fig. 1).

Median age of patients reviewed in general wards due to medical emergency was 70 (61, 79) years, 65% were male, 67% had surgical background, 34% had a preceding ICU admission and 6.3% an existing not for resuscitation (NFR) order. New NFRs were issued in 7.4% of the reviews. Hospital mortality in MET population was 26% (22% if NFR patients were excluded). In 30 occasions the patient requiring MET review had arrived at the ward from other locations immediately prior to call: 17 times from the emergency room, six times from the operation room and seven times from ICU/HDU. The data from these visits were not included in ALF analysis because the patients had not been in the ward prior to the call. This left us with 539 reviews where the delay to MET call could have occurred in ward.

3.2. MET reviews to monitored vs. non-monitored patients

41% of the MET activations in general wards concerned patients in beds equipped with automated monitoring. The monitored patients were more likely male, medical, non-electively admitted to hospital and had longer hospital stays (Table 1) than non-monitored patients. The monitored patients had more frequently a preceding ICU admission, and their MET reviews occurred less often during office hours. Monitored patients were more often transferred to ICU as a result of the review. There were no statistically significant differences in the frequency of prior NFRs, or new NFRs issued by MET. There were no differences in hospital mortality, even when NFR patients were excluded.

Table 2 shows the documentation of vitals and possible vital dysfunctions by the ward staff during the 6 h period before the call. The vital functions had been more often documented at least once if the patient was attached to monitor prior to MET activation ($p < 0.001$). ALF was documented twice more often if the patient was in a monitored bed in comparison to non-monitored beds ($p < 0.001$). This was the case also with ALF documented/vitals documented-ratio ($p < 0.001$). If ALF was documented, the delay to contact MET seemed longer if the patient was monitored, but statistical difference was not observed ($p = 0.061$).

3.3. Cardiac arrest activations in general wards

In 121 MET activations for 105 patients CPR was initiated by ward staff or by MET. In 74% (90) of these calls the reason for MET activation was CA, and 26% of the calls were made due to deviating vitals.

49% (59/121) of the CAs concerned monitored patients. Monitored patients requiring CPR were more often on medical than on surgical ward ($p = 0.003$). Eight patients (three monitored) had a preceding NFR order but ward staff attempted resuscitation nevertheless. In 114 occasions the patient had been in the ward for the preceding 6 h. ALF was documented in 52% (59/114) of the cases. 73% (40/55) of the monitored patients had ALF as compared to 32% (19/59) in non-monitored ward patients ($p < 0.001$) and ALF documented/vitals documented-ratio was 75% (39/52) vs. 45% (19/42) ($p = 0.003$.)

Table 1
Characteristics of 569 medical emergency team (MET) reviews to 458 patients.

	Monitored bed	Non-monitored bed	*p*-value
Patient characteristics	*N* = 167	*N* = 291	
Age (years)	69 (60,78)	71 (62, 80)	0.107[d]
Sex (male)	73%	61%	0.012[e]
Surgical patient	60%	71%	0.014[e]
Medical patient	40%	29%	0.014[e]
ICD II neoplasms	20%	32%	0.005[e]
ICD VI nervous system	20%	26%	0.115[e]
ICD IX circulatory system	67%	69%	0.692[e]
ICD X respiratory	19%	22%	0.410[e]
ICD XIV genitourinary system	11%	11%	1.000[e]
Elective hospital admission	16%	25%	0.022[e]
MET review characteristics	*N* = 231	*N* = 338	
NFR before	5.6%	6.8%	0.427[e]
Antecedent ICU admission	43%	28%	<0.001[e]
- Two or more	12%	2.4%	<0.001[e]
Patient in ICU 0–24 h before	14%	7.8%	0.046[e]
Patient in surgery 0–24 h before	7.8%	13%	0.073[e]
Additional opioid or/and sedative administrated 0–6 h before the call	48%	37%	0.011[e]
Review during office hours[a]	15%	23%	0.017[e]
Reason for MET activation	*N* = 231	*N* = 338	
Respiratory distress	51%	41%	
Hypotension	16%	15%	
Neurologic derangement	8.7%	17%	0.045[e]
Multiple reasons	13%	13%	
Other	12%	14%	
MET intervention/aftercare	*N* = 231	*N* = 338	
NFR issued	5.2%	8.9%	0.099[e]
Transferred to ICU	35%	22%	<0.001[e]
LOS in ICU (days)[b]	3 (2, 6)	2.5 (2, 4)	0.059[d]
ICU mortality of transferred patients	16%	10%	0.234[e]
Patient outcome	*N* = 167	*N* = 291	
Hospital LOS (days)[c]	14 (8, 30)	10 (6, 20)	0.004[d]
Hospital LOS after 1st. MET review[c]	10 (6, 18)	7 (3, 14)	<0.001[d]
24h mortality	4.2%	7.2%	0.193[e]
Hospital mortality	29%	24%	0.235[e]

For continuous variables median and quartiles (Q_1, Q_3) are given.
ICD: International statistical classification of diseases and related health problems 10th revision; LOS: length of stay; ICU: intensive care unit; NFR: not for resuscitation-order.
[a] MET review was conducted on Monday–Friday between 8.00 a.m. and 15.00 p.m.
[b] Patients who died in intensive care excluded.
[c] Patients who died in hospital excluded.
[d] Mann–Whitney test.
[e] Pearson Chi-square test

Table 2
Documented vitals and documented afferent limb failure (ALF) during the 6 h before a medical emergency team (MET) call was made.

	Monitored bed (*N* = 219)	Non-monitored bed (*N* = 320)	*p*-value
Vitals documented 0–6 h before call			
Respiratory rate	75%	17%	<0.001[a]
Peripheral O_2 saturation	90%	60%	<0.001[a]
Heart rate	90%	65%	<0.001[a]
Systolic blood pressure	91%	66%	<0.001[a]
NO vitals documented	3.7%	26%	<0.001[a]
Vitals documented abnormal 0–6 h before the call (afferent limb failure, ALF)			
Respiratory rate (<5 or >24/min)	50%	11%	<0.001[a]
Peripheral arteriolar O_2 saturation (<90%)	33%	21%	<0.001[a]
Heart rate (<40 or >140/min)	13%	3.4%	<0.001[a]
Systolic blood pressure (<90 mmHg)	22%	13%	<0.001[a]
ALF documented	78%	40%	<0.001[a]
Time (min) from first ALF to call	213 (101, 292)	168 (58, 284)	0.061[b]
Vitals documented abnormal 0–6 h before the call/vitals documented 0–6 h before the call –ratio			
Respiratory rate	67%	65%	0.824[a]
Peripheral O_2 saturation	37%	34%	0.581[a]
Heart rate	14%	5.3%	0.002[a]
Systolic blood pressure	24%	19%	0.278[a]
ALF/vitals documented-ratio	81%	53%	<0.001[a]

For continuous variables median and quartiles (Q_1, Q_3) are given.
[a] Pearson Chi-square test.
[b] Mann–Whitney test.

Table 3
Odds ratios for factors independently associated with documented afferent limb failure (ALF).

	Multivariate analysis		
	OR	95% CI	*p*-Value
Non-elective hospital admission (yes/no)	1.64	1.01–2.66	0.048
Antecedent MET-review (yes/no)	2.73	1.60–4.66	<0.001
Supplementary O_2 0–6 h before (yes/no)	4.82	2.64–8.81	<0.001
Monitored bed (yes/no)	3.81	2.52–5.76	<0.001

Multivariate logistic regression analysis (backward model). Other variables included in analysis: age, gender, medical/surgical background, preceding ICU admission (yes/no), surgery 0–24 h before (yes/no), not for resuscitation order before the review (yes/no), opioid/sedative 0–6 h before (yes/no), non-office-hours review (yes/no), multiple triggers (multiple criteria for medical emergency team activation) (yes/no), days in hospital before the call. OR: odds ratio; CI: confidence interval.

Table 4
Odds ratios for factors independently associated to increased hospital mortality.

	Multivariate analysis		
	OR	95% CI	*p*-value
Age	1.02	1.00–1.04	0.024
ICD II neoplasms (yes/no)	2.80	1.59–4.91	<0.001
ICD XIV genitourinary system (yes/no)	2.42	1.16–5.06	0.019
Non-elective hospital admission (yes/no)	6.25	2.77–14.11	<0.001
NFR after the review (yes/no)	3.34	1.78–6.35	<0.001
Transferred to ICU by MET (yes/no)	1.85	1.05–3.27	0.034
Days in hospital before the call	1.04	1.01–1.07	0.003
Documented afferent limb failure (yes/no)	1.67	1.02–2.72	0.041

Multivariate logistic regression analysis (backward model). Other variables included in analysis: gender, medical/surgical background, ICD VI nervous system (yes/no), ICD IX circulatory system (yes/no), ICD X respiratory system (yes/no), preceding ICU admission (yes/no), NFR before the review (yes/no), supplementary O_2 (yes/no), opioid/sedative administrated 0–6 h before the call (yes/no), non-office-hours MET review (yes/no), multiple triggers (multiple criteria for medical emergency team activation) (yes/no), medication by MET (yes/no), patient in monitored bed (yes/no). OR: odds ratio; CI: confidence interval; NFR: not for resuscitation-order; ICU: intensive care unit; ICD: International Statistical Classification of Diseases and Related Health Problems 10th Revision 2.

3.4. Risk factors for afferent limb failure and increased hospital mortality in the study population

Factors independently associated with ALF and higher hospital mortality are shown in Tables 3 and 4. Non-elective hospital admission, preceding MET review, receiving supplementary oxygen prior to call and automated monitoring increased the risk for ALF. Afferent limb failure remained as an independent risk factor for hospital mortality.

4. Discussion

The three main findings of this study were that (1) documentation of vital signs before MET activation was suboptimal. Documentation of respiratory rate was alarmingly low, especially in ward areas without automated monitors. (2) Documentation rate of vitals increased in areas equipped with automated monitors, but even when adjusted to this higher documentation rate, afferent limb failure occurred more often among monitored than non-monitored ward patients. (3) Our study confirms that in MET population, afferent limb failure is associated with increased hospital mortality.

General ward beds equipped with patient monitors are dedicated for potentially unstable patients. Based on this preselection by attending physicians' subjective assessment, it is comprehensible that 41% of the MET evaluations and 49% of the resuscitation attempts were to these areas. These patients were also more often medical, and admitted through emergency room, which suggests that their severity of illness was higher than of patients admitted to normal ward beds. Vitals were more often documented if a patient was monitored automatically, which speaks in favor of implementing automated monitors also in general wards. However, delayed MET activation occurred twice as often if a patient was attached to a monitor. The difference persisted even though delayed MET activations were normalized to the actual number of vitals observed during the 6 h-period preceding the reviews. This suggests that it was in fact more common of nursing staff to tolerate altered vitals in areas equipped with automated monitoring, if deviating vitals were detected. In our facility staff responsible for monitored patients in wards has not had any additional training by MET personnel regarding unstable patients, and this may partly explain the poor performance. Therefore it should be emphasized that in general wards vital dysfunctions must not only be monitored but interventions must be initiated whenever indicated by this intensive monitoring. As multiple studies report the importance of adequate repeated education,[17,25,26] it would be important to focus the training to the staff treating potentially unstable patients.

The reasons for the delay in MET activation are manifold. Ward staff may feel that current MET criteria do not apply to monitored patients. Attending physicians may also consider the intense monitoring per se as sufficient intervention, as especially junior doctors may be inexperienced in acute care.[27] In our study, administration of supplementary oxygen prior to MET call was an independent risk factor for ALF. Supplying oxygen may have been considered as an adequate intervention by ward staff triggered by deterioration. However, this potentially led to conclusion that starting supplementary oxygen was sufficient. Consequently MET criteria were ignored albeit the use of additional oxygen did not necessarily correct the vitals sufficiently. If the patient had been reviewed by MET previously, staff seemed to also tolerate the MET criteria before a new call. While we can only speculate on the reasons for this phenomenon, it should be underlined that clear instructions must be given to ward staff for further monitoring after a MET review, if a patient is not transferred to a higher level of care. The reasons for afferent limb failure merit further investigation, as ALF was independently associated to increased hospital mortality. In the light of our findings it seems logical, that eliminating afferent limb failure from a MET system would (1) improve patient outcome with timely interventions or (2) enable more appropriate evaluation earlier on. This is important for the deteriorating patients with potential treatment limitations. Minimizing and preventing futile ICU admissions and resuscitation attempts is essential for ethically sound system.

For the non-monitored ward patients, one quarter of the patients had no documented vitals for the 6 h preceding the call which makes the analysis of ALFs more difficult. Especially respiratory rate was poorly documented, although deviating values are recognized as strong predictors for hospital mortality.[28,29] As respiratory rate is basically one of the simplest clinical observations to conduct, educational efforts toward increasing measurements of respiratory rate in the general wards must indeed be enforced. We tried to avoid bias in the analysis of ALFs by reporting the ratio of ALFs to the number of vitals documented at all. Although the use of this ratio instead of just the prevalence of ALFs gave similar results, we recommend that also the ratio should be reported in future studies so ALF in varying time windows may be reliably assessed and possible comparisons made.

One third of MET patients had a preceding ICU admission. Potential reasons for this may have been an inadequately early discharge from ICU or suboptimal aftercare. ICU liaison nurse services, utilized in some hospitals,[30,31] might reduce MET activations to post-ICU

patients, because adequate guidance to general ward level is given automatically after the ICU discharge. As the impact of liaison nurse services on ICU readmissions and hospital mortality of post ICU patients remain inconclusive,[32] our results suggest, that this ICU-based follow-up care may at least be beneficial from the aspect that it simultaneously would enable ward staff education and more professional evaluation of vitals among recovering post-ICU patients.

To our knowledge, there are only few studies which have investigated ALFs preceding CAs in a hospital already equipped with a MET.[14,33] Interestingly, we observed ALFs in half of the CAs. This is five times more than reported by Trinkle and Flabouris[14] but in agreement with Vetro et al.[33] However, we used much lower upper threshold limit for respiratory rate and higher limit for systolic blood pressure in our calling criteria than Trinkle and Flabouris[14] which obviously increases the prevalence of ALF prior to both resuscitation and MET reviews in our hospital. Regardless of varying threshold limits, fact remains that MET is suboptimally used as long as ALFs are documented before cardiac arrests. Assessing the incidence of ALFs before cardiac arrests may be of great value when developing local MET system and encouraging staff to avoid delays when contacting MET.

Because of a single center design, our findings may not be fully generalizable to other hospitals. However, we believe that our results are of value in many countries implementing MET, because the general level of health care and patient safety is comparable to that in Finland. Another weakness is related to the MET calling ratio which was 8.4 per 1000 hospital admissions. This is below the average reported ratio in mature MET systems,[34] and indicates that MET in our hospital is still immature, especially as this study was initiated just one year after MET implementation.

5. Conclusions

Characteristics of MET reviews in a Finnish tertiary referral center were comparable to those reported in the literature. Documentation of vital signs before a MET activation was suboptimal. The use of automated patient monitoring was associated with more frequent documentation of vital signs, but with higher incidence of ALF before MET activation, also when compared to the actual number of reviews when vitals documented at all. A delayed MET activation was independently associated to higher hospital mortality. When patients are attached to monitors, it should always be emphasized that technology does not replace the need for a thorough understanding of physiology as well as knowledge and skills to respond to critical illness.

Conflict of interest statement

Jyrki Tenhunen is a cofounder, Medical Director and shareholder of SenSem Technologies Ltd. (Tampere, Finland). Other authors declare no conflicts of interests.

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Medical emergency team activation: performance of conventional dichotomised criteria versus national early warning score

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Background: To activate the hospital's medical emergency team (MET), either conventional dichotomised activation criteria or an early warning scoring system may be used. The relative performance of these different activation patterns to discriminate high risk patients in a heterogenic general ward population after adjustment for multiple confounding factors has not been evaluated. We aimed to evaluate the dichotomised activation criteria used at our institution and the recently published national early warning score (NEWS, United Kingdom).

Materials and Methods: Prospective point prevalence study at a university hospital in Finland. On two separate days, the vital signs of all adult patients without treatment limitations were measured. Data on cumulative comorbidity (Charlson comorbidity index), age, gender, admission characteristics and subsequent mortality were collected. Univariate and multivariate logistic regression models were used for unadjusted and adjusted performance testing.

Results: The cohort consisted of 615 patients. The dichotomised activation criteria were not associated with in-hospital serious adverse events (odds ratio 1.87, 95% confidence interval 0.55–6.30) or 30-day mortality (2.13, 0.79–5.72) after adjustments. For a NEWS of seven or more (the suggested trigger level for immediate MET activation), the adjusted odds ratios for the above mentioned outcomes were 7.45 (2.39–23.3) and 11.4 (4.40–29.6), respectively. Unlike the dichotomised activation criteria, NEWS was also independently associated with a higher 60- and 180-day mortality after adjustments.

Conclusions: NEWS discriminates high risk patients in a heterogenic general ward population independently of multiple confounding factors. The conventional dichotomised activation criteria were not able to detect high risk patients.

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Medical emergency teams (METs) have been implemented to prevent in-hospital cardiac arrests preceded by vital signs abnormalities, but the evidence of a beneficial impact on mortality remains inconclusive.[1–8] This may be due to the failure of the afferent limb of the rapid response system, i.e., a lack of appropriate monitoring, and/or a delayed or absent response (the MET activation) to abnormal parameters among the hospital's general ward staff.[9]

The activation of the MET by ward staff is based on an agreed threshold set for basic vital signs.[10] However, the activation criteria vary greatly in different centres.[11,12] Dichotomised 'track and trigger' criteria are commonly used for the activation of the MET. They require that at least one of the included vital signs deviates from the agreed threshold set individually for each vital sign.[3,7,11,13,14] In such a case, the criteria are 'positive' and a MET activation should occur.[3,7,11,13,14] If all vital signs are within their individual limits, the criteria are regarded as 'negative'. In addition to physiological parameters, these dichotomised track and trigger systems often encompass a subjective 'worried' criterion.[11] Early warning scores, on the other hand, are derived by weighting the extent of each vital sign's deviation from an agreed 'normal' range on a scale from 0 (normal) to 3 (extreme deviation), and then adding

the weightings for all vital signs.[12,15] Compared with the dichotomised criteria, the early warning score provides a discrete score.

Three prospective point prevalence studies on general ward patients have evaluated the performance of the local hospital-specific dichotomised activation criteria.[16–18] Two included patients with do-not-resuscitate (DNR) orders[16,18] and two others adjusted the performance evaluation either for age and gender[17] or for age together with the nature of the parent unit.[18] The performance of early warning scores has been studied in accident and emergency departments and selected general wards.[12,19–25] Most studies[12,20–25] include patients with DNR orders and none adjust for important covariates. There appears to be relatively little information on the relative performance of dichotomised activation criteria and early warning scores among general ward patients.

This prospective point prevalence trial aimed to evaluate the ability of our hospital's dichotomised activation criteria and NEWS (the national early warning score recently introduced in the United Kingdom to standardise the risk assessment of general ward patients)[26,27] to discriminate 'at risk' patients in a heterogenic population of hospitalised general ward patients without treatment limitations after adjustment for multiple covariates known to affect patient outcome.

Methods

Ethics

The Ethics Committee of Tampere University Hospital (TAYS) approved the study protocol (Approval number R10111; 9 September 2010; http://clinicaltrials.gov NCT01214460). Informed consent was waived as no interventions were made.

Hospital

TAYS is one of the five tertiary referral centres in Finland admitting 75,000 somatic patients annually. Excluding the intensive care and high dependency units, the accident and emergency department, and the paediatric and obstetric wards, the hospital has 538 somatic general ward beds. The intensive care and high dependency units operate as a combined unit with 24 beds and have over 2000 admissions annually. The MET was implemented in January 2009. It operates 24/7 from the intensive care unit (ICU) and is led by an intensive care physician. In 2010, the MET activation frequency was 8.4 calls per 1000 hospital admissions.[28]

Table 1

Tampere University Hospital's dichotomised medical emergency team activation criteria.

Vital sign	Activation threshold
Heart rate (beats/min)	< 40/min or > 140/min
Systolic blood pressure (mmHg)	< 90 mmHg
SpO_2	< 90%
Respiratory rate (breaths/min)	< 5/min or > 24/min
A fall in Glasgow Coma Scale	≥ 2

If one or more of the vital signs meets the agreed activation threshold, MET should be activated immediately. Otherwise, vitals are considered normal and no medical emergency team activation is required.

Dichotomised activation criteria and NEWS

At the time of this study, dichotomised activation criteria were applied in TAYS. They are presented in Table 1. The criteria are simply classified as 'positive' or 'negative'. When one or more criteria are positive, the MET should be activated. A fall in Glasgow Coma Scale (GCS) of two or more could not be measured in this point prevalence study, and this dichotomised activation criterion was excluded from the TAYS criteria. Furthermore, the subjective 'worried' criterion was not used in this study as it was predisposed to misinterpretation. Table 2 presents the NEWS currently recommended for use in all hospitals in the United Kingdom.[26] It is recommended that an urgent patient review should occur if the cumulative score is 5 or more, or if the weighted score for any individual vital sign is 3. If the score is 7 or more, an immediate MET review is required.[26] The NEWS also encompasses a 'worried' criterion (concern about a patient's clinical condition should override the NEWS), which was not used in this study.[26]

Study protocol

On two separate days (first in September and then in October 2010) all patients over 18 years in general wards were examined in a point prevalence manner by 15 pairs of fourth-year medical students between 16:00 and 19:00 h. The patients' heart rate, systolic blood pressure, SpO_2, respiratory rate, AVPU (alert, voice, pain, unresponsive), and GCS were measured once. Use of supplementary oxygen and DNR orders were recorded. All data were documented on a separate template, and a copy was provided to ward staff following the clinical examination. Students recorded the data as raw values only (e.g. respiratory rate 18/min) and did not interpret or classify the values in any way. No interventions

Table 2

National early warning score (NEWS) according to The Royal College of Physicians.[26]

	3	2	1	0	1	2	3
Respiratory rate (breaths/min)	≤ 8		9–11	12–20		21–24	≥ 25
SpO_2	≤ 91	92–93	94–95	≥ 96			
Any supplementary oxygen		Yes		No			
Temperature (°C)	< 35.0		35.1–36.0	36.1–38.0	38.1–39.0	≥ 39.1	
Systolic blood pressure (mmHg)	≤ 90	91–100	101–110	111–219			≥ 220
Heart rate (beats/min)	≤ 40		41–50	51–90	91–110	111–130	≥ 131
AVPU				A			V, P, U

Every vital sign is scored from 0 (normal) to 3 (extreme deviation). The total score is then added up, providing a discrete score. A score of 5 or 6, or an individual vital sign scoring 3 should initiate an urgent review; a score of 7 or more should trigger an immediate MET activation.[26] AVPU, alert, voice, pain, unresponsive; A, alert; P, pain; U, unresponsive; V, voice.

were made by the students. Prior to the examination days, all students received training on examining vital signs, equipment usage and data recording.

Data on patient and admission characteristics were noted from patient records and from the ICU's MET database. The existence of a DNR order, or lack thereof, was noted for each patient. Body temperature was obtained from the electronic nursing record containing all procedures and measurements conducted by nursing staff. Where body temperature had not been measured in the study evening, it was scored as 'normal' (36.1–38.0°C). To include the cumulative impact of concomitant diseases as a single covariate, the Charlson comorbidity index was applied.[29] The Charlson comorbidity index is extensively used and approved as a continuous variable for risk adjustment in clinical research.[30,31] A serious adverse event during the subsequent hospital stay was defined as any of the following: if the MET was later activated by ward staff for the patient, the patient suffered a cardiac arrest, the patient was acutely admitted to the ICU or the patient died.

As patients may suffer multiple serious adverse events (e.g. a MET activation leads to an emergency ICU admission), the first one to occur was considered a serious adverse event for each patient. MET activation was included as a serious adverse event as it enabled the inclusion of deteriorated patients 'salvaged' by appropriate, minor intervention and thus not progressing to other serious adverse events.[32] However, we also repeated the analysis where serious adverse events were used as an outcome so that MET activations not progressing to other serious adverse events were not defined as serious adverse events at all. This enabled a better comparison with previous studies. The 180-day mortality data was retrieved from Finnish Population Register Centre.

Statistics

Our primary outcome measure was 30-day mortality. Based on the study by Fuhrmann *et al*.[17], we expected mortality to be 13% among patients with positive and 5% with negative dichotomised TAYS criteria. The ratio between group sizes was assumed to be 1 : 4 based on the prior study.[17] To achieve a statistical power of 80% and type a I error of 5%, 111 patients with positive criteria and 444 patients with negative criteria (a total of 555) were required. As the average occupancy in TAYS was 75% (400/538 beds), we estimated that over 2 separate evaluation days, the medical students would meet 800 patients.

Demographic data are presented as numbers and percentages, continuous variables with normal distribution (both skewness and kurtosis between –1.0 and +1.0), as means (± standard deviations) and non-Gaussian variables as medians (quartiles; Q_1, Q_3). The chi-square test, Student's *t*-test and Mann–Whitney *U*-test were used for comparisons between groups as appropriate. Univariate logistic regression was used for crude odds ratios (ORs), after which multivariate logistic regression was applied for adjusted ORs. All tests were two-sided; $P < 0.05$ was considered significant and 95% confidence intervals were calculated where appropriate. The software used was SPSS, version 16.0, for Windows (SPSS Inc., Chicago, IL, USA).

Results

Study cohort and subsequent adverse events

Of the general ward beds, 66% ($n = 355$) were occupied during the first study day and 64% ($n = 343$) during the second day. The initial patient population was 698 patients. However, 11 patients were excluded because of age ($n = 2$), nationality ($n = 2$) or because they were admitted to hospital during both

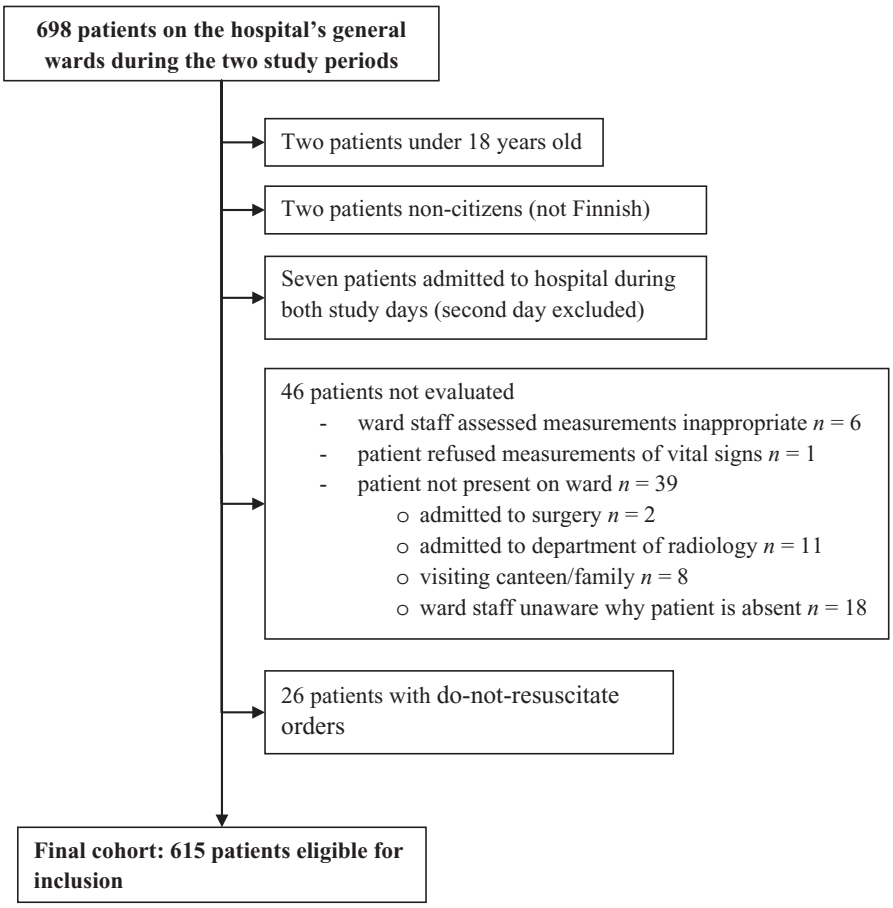

Fig. 1. Recruitment and the final study cohort.

study days ($n = 7$) (see Fig. 1). The vital signs of an additional 46 patients were not evaluated for a range of additional reasons (see Fig. 1). None of these 46 patients had DNR orders, and they were younger (57 vs. 65 years, $P = 0.028$) than the 641 evaluated patients. There were no statistically significant differences in gender, type of admission, surgical/medical background, Charlson comorbidity index score, length of admission, incidence of serious adverse events during hospitalisation or mortality at any evaluated time point (in-hospital, 30-, 60-, 180-days) between the evaluated and non-evaluated patients.

Patient and hospital admission characteristics of the final cohort are presented in Table 3. A record of body temperature was missing for 103 patients (17%). Of these patients, 70% ($n = 72$) were admitted because of cardiovascular or orthopaedic reasons. Their hospital mortality was 0% and 180-day mortality 5.8% ($n = 6$), respectively.

A total of 72 patients (12%) had 'positive' dichotomised activation criteria of TAYS (Table 3). The most common vital sign classified as 'positive' was respiratory rate (48 patients, 7.8%). Ten patients had multiple vitals fulfilling the TAYS dichotomised criteria. According to NEWS, 136 patients would have required an urgent MET review and 40 patients immediate team activation. There were no differences between the two study days in prevalence of positive criteria (11.9% vs. 11.5%, $P = 0.895$). The median (Q_1, Q_3) NEWS score was 1 (0, 3). There was a statistically significant difference in the distribution of NEWS scores between the 2 study days: median 1 (0, 3) vs. 2 (0, 3), $P = 0.003$.

A serious adverse event occurred in 2.9% ($n = 18$) of the patients during their subsequent hospital stay. The MET was activated for a total of 10 patients: three patients had a MET review only, and no other serious adverse events; two patients had a MET review because of a cardiac arrest; three patients were admitted to intensive care as a result of a MET review; and two patients were left on ward with instructions (treatment limitations were not issued in either case) after a MET review, but died later during their hospital stay. In addition, five patients were urgently admitted to intensive care by direct

Table 3

Patient and hospital admission characteristics with the results of the conducted measurements.

Patient demographics	
Age (years), median (Q1,Q3)	65 (53, 76)
Gender (male)	327 (53)
Charlson comorbidity index, median (Q1,Q3)	1.0 (0.00, 2.0)
score 0–1	347 (61)
score 2–3	137 (22)
score ≥ 4	104 (17)
COPD	41 (6.7)
Diabetes	100 (16)
Malignancy	122 (20)
Chronic renal failure	46 (7.5)
PAD	26 (4.2)
Coronary artery disease	92 (15)
Hospital admission characteristics	
Elective hospital admission	248 (40)
Length of hospital admission (days) median (Q1, Q3)	6 (3, 12)
Surgical diagnosis for admission	347 (56)
Patient requires regular haemodialysis	24 (3.9)
Primary reason (diagnostic category in ICD-10) for hospitalisation	
Cardiovascular disease	100 (16)
Gastrointestinal disease	92 (15)
Neoplasm	91 (15)
Infectious disease	71 (12)
Trauma/intoxication	63 (10)
Preceding ICU admission during hospitalisation	72 (12)
Surgery conducted 0–48 h before	133 (22)
Patient review results	
Heart rate (beats/min) mean, SD	75 ± 15
Systolic blood pressure (mmHg) mean, SD	135 ± 22
Diastolic blood pressure(mmHg) mean, SD	77 ± 13
SpO2 median (Q1,Q3)	97 (95, 98)
Respiratory rate (breaths/min) median (Q1,Q3)	16 (14, 20)
AVPU	
Alert	570 (93)
Voice	31 (5.0)
Pain	12 (2.0)
Unresponsive	2 (0.33)
Body temperature [degree of Celsius (°C)] mean, SD	36.8 ± 0.6
Patient requires supplementary oxygen	103 (17)
Positive dichotomised activation criteria of TAYS	72 (12)
Heart rate < 40/min or > 140/min	0 (0)
Systolic blood pressure < 90 mmHg	6 (1.0)
SpO2 < 90%	28 (4.6)
Respiratory rate < 5/min or > 24/min	48 (7.8)
NEWS score ≥ 5 or individual vital score 3	136 (22)
NEWS score ≥ 7	40 (6.5)

Data are presented as numbers (percentages) if not otherwise indicated. COPD, chronic obstructive pulmonary disease; malignancy, malignant solid tumour, lymphoma or leukaemia according to the ICD-10, International Statistical Classification of Diseases and Related Health Problems 10th Revision (C00-C97, ICD-10). PAD, peripheral arterial disease; neoplasm, ICD-10 Chapter II: C00 – D48. ICU, intensive care unit; NEWS, national early warning score[26]; SD, standard deviation; TAYS, Tampere University Hospital.

consultation between physicians, and three patients died later during their hospital stay; no records exist of attempted resuscitation by MET.

Three serious adverse events occurred during the first 24 h following the patient evaluation; the first was a MET activation because of a cardiac arrest approximately 6 h after the vital signs measurements and other two occurred the following day. Four patients had serious adverse events 24–48 h after the evaluation, and two patients 48–72 h after the evaluation. The 30-day mortality in the study cohort was 4.2% ($n = 26$), the 60-day mortality was 8.5% ($n = 52$) and the 180-day mortality was 14% ($n = 85$).

The predictive performance of the hospital's dichotomised activation criteria and NEWS before and after adjustment for covariates

Table 4 shows the ORs for in-hospital serious adverse events (separately as first including and then excluding a MET activation as a serious adverse event) and mortality before adjustment, and after adjustment for age, gender, admission type (elective/emergency), background (surgical/medical), surgery within 48 h of assessment, preceding ICU admission and Charlson comorbidity index. Positive TAYS's dichotomised activation criteria were faintly associated with 180-day mortality after adjustments. Both suggested trigger levels of NEWS[26] were independently associated with worse outcomes. Figure 2 presents the ORs of increasing NEWS for 30-day mortality after adjustment to all previously mentioned covariates. A score of 7–8 increased the risk for death at 30 days independently 25-fold; a score of 9–10 increased the risk 45-fold.

Discussion

Key findings

The current prospective point prevalence trial shows that after adjusting for confounding factors, conventional dichotomised activation criteria were not associated with outcome and discriminated high risk patients poorly. However, NEWS[26] was able to detect high risk ward patients regardless of multiple factors affecting patient outcome.

Strengths and limitations related to internal validity

The very environments where METs are meant to operate are hospital general wards, where patients may deteriorate without anyone noticing or reacting, especially during non-office hours.[10] In the

Table 4

The value of the dichotomised activation criteria of Tampere University Hospital (TAYS) and national early warning score (NEWS)[26] in predicting serious adverse events and mortality in general ward patients at TAYS as judged by odds ratios calculated with univariate and multivariate logistic regression.

	Serious adverse event: I	Serious adverse event: II	30-day mortality	60-day mortality	180-day mortality
Univariate logistic regression without adjustment for covariates					
Positive dichotomised activation criteria of TAYS	2.22 (0.71–6.95)	1.92 (0.53–6.99)	2.97 (1.20–7.34)*	2.51 (1.25–5.06)*	3.08 (1.74–5.76)*
NEWS score ≥ 5 or if the weighted score for any individual vital sign is 3	13.6 (4.40–42.1)*	15.3 (4.27–55.3)*	13.6 (5.34–34.6)*	6.44 (3.56–11.7)*	5.11 (3.16–8.27)*
NEWS score ≥ 7	8.28 (2.93–23.4)*	11.1 (3.73–33.0)*	14.2 (5.98–33.6)*	7.61 (3.67–15.8)*	6.20 (3.17–12.2)*
Multivariate logistic regression with adjustment for covariates					
Positive dichotomised activation criteria of TAYS	1.87 (0.55–6.30)	1.68 (0.43–6.61)	2.13 (0.79–5.72)	1.72 (0.81–3.66)	1.96 (1.02–3.74)*
NEWS score ≥ 5 or if the weighted score for any individual vital sign is 3	14.7 (4.32–50.2)*	18.1 (4.51–72.8)*	11.8 (4.26–32.6)*	5.55 (2.91–10.6)*	4.50 (2.58–7.86)*
NEWS score ≥ 7	7.45 (2.39–23.3)*	11.5 (3.40–38.6)*	11.4 (4.40–29.6)*	6.42 (2.92–14.1)*	6.15 (2.83–13.4)*

Numeric values are calculated odds ratios with 95% confidence intervals.
Serious adverse event I: any of the following during the subsequent hospital stay: medical emergency team activation, cardiac arrest, emergency intensive care unit admission or death.
Serious adverse event II: any of the following during the subsequent hospital stay: cardiac arrest, emergency intensive care unit admission or death.
In the multivariate logistic regression, the following variables were introduced as covariates: age, gender, admission type (elective/emergency), background (surgical/medical), surgery within 48 h of assessment, preceding intensive care unit admission and Charlson comorbidity index.
*$P < 0.05$

Fig. 2. Odds ratios of different National early warning score (NEWS)[26] values with 95% confidence intervals for 30-day mortality as compared with patients with a total score of 0. All odds ratios are adjusted for patient age, gender, admission type (elective/emergency), background (surgical/medical), surgery within 48 h of assessment, preceding intensive care unit admission and Charlson comorbidity index. The scale of odds ratios (left) is logarithmic.

chain of prevention, a well-performing afferent limb (i.e. the ward staff responsible for detecting and reacting to deviating vital signs) is of the utmost importance.[9] Activation criteria – dichotomised or early warning scores – are the tools we offer to general ward staff to facilitate appropriate reviews and possible timely intervention.

We used the same method as two previous single-centre studies in university hospitals[16,17] and one multicentre study[18] used when evaluating their hospital-specific dichotomised activation criteria. However, we excluded patients with DNR orders as subsequent death was presumed unavoidable. We excluded the 'worried' criterion both from the TAYS dichotomised criteria and the NEWS as they were severely predisposed to misinterpretation. In each of the three previous studies, approximately 20% of the patients were not evaluated because of patient refusal or because the patient was absent, and the characteristics of these patients remained unclear.[16–18] In our study, the percentage was 6.6, and besides being younger, these patients did not differ from the evaluated patients. As patient outcome is dependent on a multitude of factors, we included several known or potential covariates to be able to control their confounding effect on outcome and survival.[33]

To our disappointment, body temperature was not recorded for all patients. Although taking into

account the statistical distribution of measured body temperatures and characteristics of patients without measured temperature, we cannot be certain that all these patients would have scored 'normal' for body temperature. The point prevalence study design was used to enable comparisons with previous studies; however, vital signs may fluctuate despite the severity of illness and this method only records the patient's status at a certain moment. Because of this study design, we also had to exclude 'a fall in GCS of 2 or more' – criterion from the TAYS dichotomised criteria; this in fact limits both internal and external validity of our results. A further limitation related to internal validity is the fact that we did not evaluate inter-rater agreement between the 15 pairs of medical students on the vital sign measurements, although training was provided before both occasions.

Interpretation of study results

In 2006, Jacques *et al*.[34] suggested that the thresholds used in a large variety of conventional dichotomised activation criteria are 'late signs' recognising patients already too far into the spiral of physical deterioration, and that thresholds should be lowered to increase sensitivity. This is quite understandable when comparing the thresholds of the dichotomised activation criteria used at our hospital with early warning scoring systems.[19,24–26] The thresholds set for individual vital signs in dichotomised activation criteria are the extreme deviations from values scored as normal in early warning scoring systems.[19,24–26] However, if the thresholds of dichotomised criteria are lowered, multiple patients fulfil the activation criteria and specificity may be lost, as many patients may have individual vital signs exceeding the threshold without ever suffering a serious adverse event.[16,34,35] Therefore early warning scores potentially create a more comprehensible picture of the patient's prevailing physical state; oxygenation, ventilation and tissue perfusion.

Our current results show that the dichotomised activation criteria used in our hospital discriminated poorly between no event and event, regardless of the chosen outcome. They were only associated with higher 180-day mortality with a realistic confidence interval. However, this late outcome is influenced by countless unknown covariates and should be interpreted with extreme caution. It seems that the dichotomised activation criteria are able to recognise patients at the extremes of clinical deterioration, or whose age and comorbidities mostly explain the deviation of an individual vital sign (e.g. chronic pulmonary obstructive disease). In other words, possible MET activation may come too late.

NEWS[26] was independently associated with all outcomes after adjustments, as tested with score limits suggested triggering a response. The use of covariates did not change the values for ORs and confidence intervals remarkably. This is consistent with the idea that it is not the extreme deviation of a single vital sign that describes the state of patient's body systems, as assumed if dichotomised criteria are used. It is rather the careful assessment of all vital signs available pieced together that permits detection of the silent onset of deterioration. Based on our results, we recommend the implementation of NEWS[26] as suitable MET activation criteria. The strength of NEWS is that, compared with the TAYS dichotomised activation criteria (positive or negative), they also enable the follow-up of even slight changes in each ward patient's overall vital functions.[36]

Strengths and limitations related to external validity

This is a single-centre study from Scandinavia including unselected patients at a university-level tertiary referral hospital. Thus, we believe that our results are generalisable to similar institutions with a comparable level of health care. The important limitation to be considered is that our hospital had already implemented a MET with dichotomised activation criteria, although during the study period the usage was highly suboptimal.[28,37] This may decrease the external validity of our results to otherwise comparable institutions with no MET system or with well-established, mature systems. Secondly, as the exclusion of the 'worried' criterion increased the internal validity, it limits the external validity of our results, as this criterion is often included and used in dichotomised 'track and trigger' systems and is also included in the NEWS.

Conclusions

Staff at general wards of hospitals must be offered validated tools for patient monitoring. We have confirmed that NEWS detects patients at risk, regardless of patient or admission characteristics in a population without treatment limitations. The conventional dichotomised MET activation criteria used in our hospital were not able to discriminate high risk patients.

Acknowledgements

Conflicts of interest: Jyrki Tenhunen is a cofounder, Medical Director and shareholder of Sensem Technologies Ltd (Tampere, Finland). The other authors declare that they have no conflicts of interest.

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Cardiac arrest teams and medical emergency teams in Finland: a nationwide cross-sectional postal survey

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Background: The implementation, characteristics and utilisation of cardiac arrest teams (CATs) and medical emergency teams (METs) in Finland are unknown. We aimed to evaluate how guidelines on advanced in-hospital resuscitation have been translated to practice.
Methods: A cross-sectional postal survey including all public hospitals providing anaesthetic services.
Results: Of the 55 hospitals, 51 (93%) participated in the study. All hospitals with intensive care units (university and central hospitals, $n = 24$) took part. In total, 88% of these hospitals (21/24) and 30% (8/27) of the small hospitals had CATs. Most hospitals with CATs (24/29) recorded team activations. A structured debriefing after a resuscitation attempt was organised in only one hospital. The median incidence of in-hospital cardiac arrest in Finland was 1.48 ($Q_1 = 0.93$, $Q_3 = 1.93$) per 1000 hospital admissions. METs had been implemented in 31% (16/51) of the hospitals. A physician participated in MET activation automatically in half (8/16) of the teams. Operating theatres (13/16), emergency departments (10/16) and paediatric wards (7/16) were the most common sites excluded from the METs' operational areas. The activation thresholds for vital signs varied between hospitals. The lower upper activation threshold for respiratory rate was associated with a higher MET activation rate. The national median MET activation rate was 2.3 (1.5, 4.8) per 1000 hospital admissions and 1.5 (0.96, 4.0) per every cardiac arrest.
Conclusions: Current guidelines emphasise the preventative actions on in-hospital cardiac arrest. Practices are changing accordingly but are still suboptimal especially in central and district hospitals. Unified guidelines on rapid response systems are required.

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The incidence of in-hospital cardiac arrest varies between one and five events per 1000 hospital admissions, and survival to hospital discharge remains poor (approximately 20%).[1,2] A majority of in-hospital cardiac arrests are related to non-cardiac reasons preceded by impaired physiology that persists hours before the cessation of cardiac activity.[3–5]

Cardiac arrest teams (CATs) inside hospitals provide promptly required advanced skills in cases of cardiac arrest,[6] but there is no evidence on the beneficial effect of CATs on survival. Finnish national guidelines and international resuscitation guidelines (American Heart Association, European Resuscitation Council) stress the importance of early recognition, adequate chest compressions and early defibrillation by ward staff in cases of in-hospital cardiac arrest.[7–9] However, because of the preventable nature of in-hospital cardiac arrests, current guidelines emphasise the need for a proactive approach.[7–10] This means systematic education on patient deterioration, consistent use of pre-defined calling criteria, and a rapid and effective clinical response (of the efferent limb) to detected deterioration.[7–10] Medical emergency teams (METs), rapid response teams or comparable teams with acute care skills are suggested to serve as the 'efferent limb' in a system-wide response to patient deterioration.[7–10] A MET usually includes an intensive care unit (ICU) physician and nurse(s), and it can be rapidly activated by hospital's general ward staff in cases of patient deterioration.[8,10]

The nationwide implementation, team composition and usage of CATs and METs have not been studied in Finland. More importantly, to our knowl-

edge, there is little or no information from other Nordic or European countries. Concurrently, the International Liaison Committee on Resuscitation consensus statement[10] and two recent systematic reviews[11,12] underline the need for further research to unify reporting and practices regarding METs.

This study describes the characteristics and determines the utilisation of CATs and METs in Finnish hospitals and thereby provides vital information on how guidelines have been transcribed into clinical practices in and outside university level (i.e., tertiary referral centre) hospitals.

Methods

Ethics

The Ethics Committee of Tampere University Hospital (Approval number R10111; 9 September 2010) approved the study protocol.

Country and hospital organisation

Finland is a Nordic country with 5.4 million inhabitants and 55 public sector adult hospitals providing anaesthetic services. The private sector offers 5% of hospital-level bed-days.

In addition to 27 district hospitals (primary referral centres), there are 15 hospitals officially serving as central hospitals (secondary referral centres). Five university teaching hospitals (tertiary referral centres) provide the most advanced diagnostic care in Finland while also serving as secondary referral centres for the local population.

The university hospital of the densely populated capital district has eight satellite hospitals for adults, which provide care as separate units. Four of these units were considered as central hospitals in this study, as they have adult ICUs and a de facto central hospital function. The remaining four units were classified as specialised units of a university hospital.

For the subanalyses, the adult ICUs of 24 hospitals were classified in the same way as in two recent Finnish studies evaluating the impact of ICU size on the quality of sepsis and renal replacement therapy.[13,14] Therefore, six hospitals were considered to have university-level ICUs, 10 hospitals to have large central hospital ICUs, and eight hospitals to have small central hospital ICUs.

Study design and implementation

A nationwide cross-sectional descriptive postal survey was conducted. The authors of this study compiled a questionnaire to gather information on CATs and METs according to the recent national and international guidelines on the treatment and prevention of in-hospital cardiac arrest.[7–10] The questionnaire included 47 closed-ended questions. Five questions gathered data on hospital demographics, 14 questions on CATs, 23 questions on METs and five questions were related to possible post-intensive care follow-up. An independent ICU physician and a biostatistician evaluated the feasibility of the questionnaire, and after appropriate revisions, 55 questionnaires were sent to the directors of anaesthesia departments in April 2012. Where feasible, questionnaires were referred to the ICU chief physician or senior physician directly responsible for the CAT/MET activity. If necessary, two reminder letters were sent after which physicians were contacted by telephone or e-mail.

Statistics

Data are presented as numbers (percentages) or plain numbers, if not otherwise indicated. For continuous variables, the median with both quartiles (Q_1, Q_3) and range (min–max) are presented. The chi-square test, Mann–Whitney *U*-test, Spearman's rank correlation coefficient and Kruskal–Wallis test were used, where appropriate. Statistical significance level was set at $P < 0.05$. SPSS software, version 16.0, for Windows (SPSS, Inc., Chicago, IL, USA) was used for the statistical analyses.

Results

Hospitals

Of the 55 hospitals, 51 (93%) participated in the study. All university hospitals ($n = 5$) and central hospitals, including the four university hospital units regarded as central hospitals in the analysis ($n = 19$), returned the questionnaire. Two district hospitals and two independent units of a university hospital from the capital district did not participate. The responder was the chief anaesthetic physician in 33 hospitals. Ten responders were chief physicians of ICUs, and eight were senior physicians directly responsible for resuscitation activity.

The median (Q_1, Q_3) annual hospital admission rates according to hospital type were: 58,000 (48,000, 64,000) in university hospitals, 20,000 (17,000, 31,000) in central hospitals, 4000 (1800, 4400) in district hospitals and 15,000 (12,000, 15,000) in specialised units of a university hospital.

All university hospitals and 84% ($n = 16$) of the central hospitals reported having CATs. METs with pre-defined activation criteria had been implemented at all university hospitals and at 53% ($n = 10$) of the central hospitals.

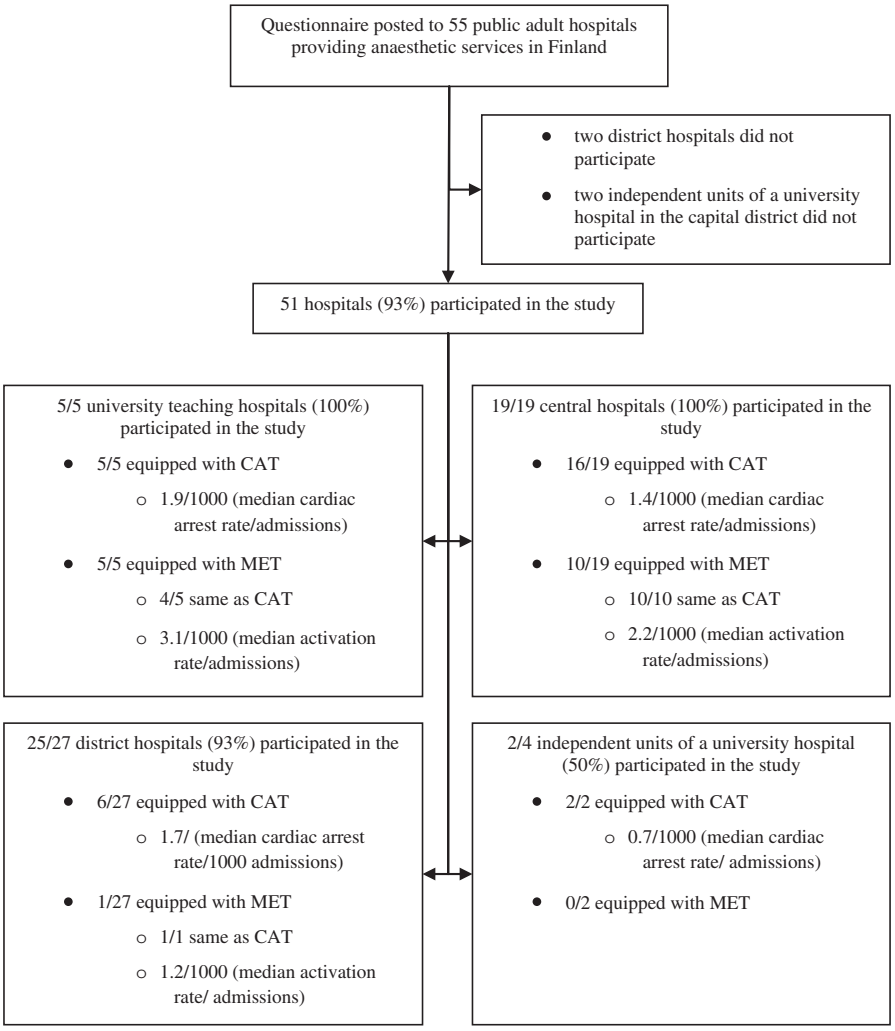

Fig. 1. Participating hospitals with prevalence of cardiac arrest teams (CATs) and medical emergency teams (METs) according to hospital classification.

Six district hospitals reported having CATs and one a MET. The two independent units from the capital district had CATs; neither had implemented a MET. Figure 1 shows the participating hospitals with the key results.

CATs

Of the participating hospitals, 29 (57%) reported having an organised CAT. The overall median incidence of in-hospital cardiac arrests in Finland was 1.48 (0.93, 1.93) per 1000 hospital admissions. Table 1 presents the characteristics and documented usage of the CATs separately for large hospitals with ICUs ($n = 21$) and small hospitals (district hospitals and two independent units of university hospital) without ICUs ($n = 8$).

The incidence of in-hospital cardiac arrests per 1000 hospital admissions was significantly lower in university hospitals' satellite units ($P = 0.025$) when compared with other hospital types, but the ICU classification of the hospital, a possible presence of MET, operational years of the MET or the MET calling ratio per 1000 hospital admissions had no statistically significant effect on the incidence of in-hospital cardiac arrests.

METs

Sixteen hospitals (31%) reported having a MET. This equals 55% (16/29) of the hospitals with CATs. Table 2 presents the characteristics and documented usage of the METs. Table 3 shows the activation criteria and thresholds of vital signs in the 16 institutions.

There was no statistically significant association between MET activation rate and hospital type, ICU level, operational years of the MET, or possible start-up funding of the MET. Higher upper threshold for respiratory rate was significantly

Table 1

Characteristics of 29 cardiac arrest teams in the 51 participating Finnish hospitals.

	Large hospitals with ICUs ($n = 21$)*	Small hospitals without ICUs ($n = 8$)†
Hours of operation		
24/7	21 (100)	6 (75)
During office hours only‡	0 (0)	2 (25)
Team operates from		
ICU	18 (86)	–
Emergency department	2 (10)	5 (63)
Operating theatre	1 (5)	0 (0)
Intermediate care unit	0 (0)	3 (37)
Team leader		
Always physician	21 (100)	7 (88)
Nurse outside office hours‡	0 (0)	1 (12)
Specialty of physician		
Always anaesthesiology and intensive care	17 (81)	2 (25)
Always internal medicine	1 (5)	2 (12)
Office hours anaesthesiology and intensive care, internal medicine outside office hours‡	3 (14)	3 (37)
Surgeon	0 (0)	1 (12)
On-board equipment§		
CPR measurement and feedback device	12 (57)	2 (25)
Backboard (to reduce mattress effect)	9 (43)	2 (25)
CPR measurement and feedback device and backboard	7 (33)	0 (0)
Load-distributing band CPR device	2 (10)	0 (0)
Dedicated person responsible for resuscitation training		
Physician	18 (86)	6 (75)
Nurse	2 (10)	2 (25)
No	1 (5)	0 (0)
Structured debriefing organised after resuscitation events	0 (0)	1 (12)
Data on resuscitation events recorded		
According to Utstein template	13 (62)	1 (12)
Other template	7 (33)	3 (37)
No	1 (5)	4 (50)
The annual incidence of in-hospital cardiac arrests	34 (22, 79) (11–162)	6.5 (1, 14) (1–15)
Incidence of in-hospital cardiac arrest per 1000 hospital admissions	1.54 (1.10, 2.15) (0.40–3.34)	0.78 (0.06–1.84) (0.06–1.96)

Data are presented as numbers (percentages). For continuous variables, both median with quartiles (Q_1, Q_3) and range (min–max) are given.
*Large hospitals with ICUs = university hospitals and central hospitals.
†Small hospitals without ICUs = district hospitals and specialised units of university hospitals.
‡Office hours = Monday to Friday 8:00 to 15:00 h.
§In addition to defibrillator, endotracheal intubation, intravenous cannulation equipment and basic recommended resuscitation medication (adrenaline, amiodarone).
CPR, cardiopulmonary resuscitation; ICU, intensive care unit.

associated with the activation rate of MET (r –0.58, $P = 0.025$).

Discussion

Key findings

Altogether, 88% of the ICU equipped hospitals and 30% of the small hospitals had CATs. METs had been implemented in 31% of the participating hospitals with a median of 3.3 operational years in April 2012. In only 55% of the hospitals with CATs were clear proactive functions taken regarding in-hospital cardiac arrest, even though both national and international guidelines specifically stress the prevention of cardiac arrests.[7–10] The median incidence of in-hospital cardiac arrests was equivalent to international reports,[1,7] but the national median MET calling rate of 2.3 per 1000 hospital admissions was below the level generally reported to be effective in the prevention of in-hospital cardiac arrests.[11,15,16]

CATs

Our study revealed several issues worthy of discussion. First, all university hospitals and most of the central hospitals had chosen to implement, maintain and use CATs. This has been considered feasible since these hospitals have ICUs, the supporting infrastructure and the human resources for such a

Table 2

Characteristics of medical emergency teams in Finnish hospitals ($n = 16$).

Additional funding for MET implementation received	7
Years MET had been operational on 1 April 2012	3.3 (1.5, 7.3) (0.25–17)
MET is the same team as cardiac arrest team in hospital	15
Structured training days per year for MET members	
0	3
1–2	6
≥ 3	7
MET operates from	
ICU	14
Emergency department	0
OT and PACU	2
MET operates	
24 h/day, 7 days/week	14
During office hours only*	2
Specialty of physician (all teams physician-led)	
Always anaesthesiology and intensive care	15
Office hours anaesthesiology and intensive care, internal medicine outside office hours	1
Level of physician's experience	
Always attending (consultant)	14
Always resident (senior house officer)	0
Attending or resident	2
Nursing staff	
Two ICU nurses	6
One ICU nurse	8
Two OT and PACU nurses during office hours, two emergency department nurses outside office hours	2
Involvement of physician with team activation	
Always	8
When assessed to be appropriate	8
MET covers all hospital departments	3
Departments commonly excluded	
OT and PACU	13
Emergency department	10
Paediatric wards	7
Data on MET activations recorded	15
The annual incidence of MET activations†	96 (33, 146) (4–666)
MET activations per 1000 hospital admissions†	2.3 (1.5, 4.8) (0.65–11)
MET activations per one cardiac arrest event	1.5 (0.96, 4.0) (0.33–7.1)

Data are presented as numbers. For continuous variables, both median with quartiles (Q_1, Q_3) and range (min–max) are given.
*Office hours: Monday to Friday 8:00 to 15:00 h.
†Medical emergency team activations because of cardiac arrests are not included.
ICU, intensive care unit; MET, medical emergency team; OT, operating theatre; PACU, post-anaesthesia care unit.

Table 3

Medical emergency teams: staff education and activation criteria in Finnish hospitals ($n = 16$).

Education regarding MET organised for general ward staff	
All staff members educated	9
Some of the staff educated	7
No staff education conducted	0
Individuals allowed to activate MET in hospital	
Physicians	16
Nurses	16
Non-medical staff	8
Patients	1
Visitors	1
Pre-defined calling criteria for MET	
Cardiac arrest	15
Respiratory arrest	15
Threshold for low respiratory rate	15
< 5	4
< 6	3
< 8	7
< 10	1
Threshold for high respiratory rate (breaths/min)	16
> 24	2
> 25	2
> 28	2
> 30	10
Threshold for low SpO_2 (all < 90%)	15
Threshold for low systolic blood pressure (all < 90 mmHg)	15
Threshold for high systolic blood pressure (200 mmHg)	1
Threshold for low heart rate (beats/min)	16
< 30	1
< 40	14
< 45	1
Threshold for high heart rate (beats/min)	16
> 120	2
> 125	1
> 130	4
> 140	9
Glasgow coma scale	10
Fall in GCS above two points	7
Fall in GCS above two points or GCS < 12	1
Fall in GCS above two points or GCS < 9	1
Fall in GCS above two points or GCS < 8	1
Low urine output	2
'Staff worried'-criterion	15
In addition to normal MET criteria, early warning scoring system implemented	3

Data are presented as numbers.
GCS, Glasgow coma scale; MET, medical emergency team; SpO_2, peripheral arteriolar blood oxygen saturation.

centralised service. At the same time, there is no evidence for survival benefit associated with centralised CATs per se. On the other hand, all guidelines underline the importance of adequate timely actions, most of all preventive actions (early recognition of deterioration or lifelessness) and high-quality cardiopulmonary resuscitation (CPR) (high-quality chest compressions and rapid defibrillation)

conducted by first responders in general wards.[7–9,17] If indeed resources are targeted to organise, train and maintain a team consisting of staff skilled in acute care, according to current guidelines, all these teams should be available not only for late measures (CPR) but rather and most importantly for preventive early interventions in cases of acute patient deterioration with agreed 'track and trigger' activation criteria.[7–10]

Second, structured debriefing after a resuscitation attempt was organised by only one hospital's CAT. One of the key elements of improving a team's CPR quality is focused 'discussion after a cardiac arrest event in which individual actions and team performance are reviewed'.[7,8,18] Considering the proven benefits to CPR quality with the minimal effort of organising these debriefings,[7,8,18,19] the number of hospitals using this method is disappointing. Another shortcoming was the fact that nearly 20% of hospitals with CATs did not record the events attended by the team.

Third, one third of the CATs in ICU equipped hospitals had utilised both backboards and CPR point-of-care feedback devices. While evidence of these tools to overall survival does not exist,[18] adequate chest compression depth and rate are essential for high-quality CPR, and the quality has been shown to improve in both manikin studies and in actual resuscitation attempts with CPR point-of-care feedback devices.[18–21] Therefore, the implementation of these tools seems justified, although our national guidelines are neutral regarding this matter.[9]

METs

While to date not more than moderate evidence exists to scientifically support the usage of METs,[12] it is reasonable to assume that early-risk recognition should be encouraged, is ethically sound and potentially cost-effective, and minimises adverse events for hospitalised patients. According to guidelines, proactive, preventive actions on in-hospital cardiac arrests are expected in all health-care organisations,[7–9] and it is therefore reasonable to state that large hospitals with ICUs should all have a MET service in addition to a CAT. Currently, only half of the central hospitals with ICUs have an organised response for deteriorating ward patients, although as discussed earlier, CATs were quite consistently implemented.

As is also the case in Australia,[22] all Finnish METs were physician-led, compared with 57% in the Netherlands,[23] and indeed moderate evidence for the benefit of including a physician in a MET currently exists.[24] Compared with 82% of Australian physicians having advanced airway skills, all MET physicians in the present study possessed advanced airway skills.[22] METs covered all hospital departments in only 3 out of 16 hospitals. Operating theatres (OTs) with their post-anaesthetic care units are staffed with physicians with advanced airway skills, but emergency departments rely on intensivists and OT anaesthesiologists in cases where advanced airway management is required. However, skilled nursing staff and proper equipment are otherwise available in emergency departments. It is therefore important to underline that the paediatric population was excluded in almost half of the hospitals. Among paediatric patients, respiratory failure is the most common cause of in-hospital cardiac arrests requiring rapid intervention and advanced airway skills.[25] The strongest evidence for the effectiveness of rapid response systems is from paediatric studies.[11,12] We do not have data on the reasons for exclusion, but paediatric patients potentially benefit the most from MET intervention in cases of rapid deterioration.

All 16 hospitals used single parameter 'track and trigger' systems as activation criteria; three hospitals reported using early warning scoring systems as well (aggregate weighted scoring systems). Threshold values for vital signs used in 'track and trigger' systems varied greatly, especially the upper and lower limits for respiratory rate and heart rate, which is in accordance with previous studies.[22,26] The values for the upper threshold for respiratory rate were lower in Finland than those used in both Australia and New Zealand.[22,26] There is evidence that suggests that the upper threshold for respiratory rate should be lower[4] and, indeed, the lower upper threshold limit was the only factor associated with a higher MET activation rate in our study, although the high activation rate itself is not considered a direct performance measure. It is worth discussing that there are no uniform national or international guidelines for MET activation criteria, although they are regarded as one of the key elements in the prevention of in-hospital cardiac arrests.[7–9] Furthermore, a recent systematic review on rapid response systems acknowledged the international variability in activation criteria.[12] The problem is that no evidence exists to enable the recommendation of one specific activation method. However, a recent systematic review by McNeill and Bryden concluded that unlike the 'track and trigger' methods, implementation of early warning

scoring systems improves hospital survival and reduces the incidence of cardiac arrests probably because they inherently require more comprehensive and frequent observation of all vital signs (level of evidence 2++, the Scottish Intercollegiate Guidelines Network grading system).[24,27] Defining unified activation criteria, at least in the national guidelines on prevention of in-hospital cardiac arrests, could prompt the monitoring of vital signs and adequate usage of activation criteria in general wards. After all, the 'afferent limb' (the general ward staff) is recognised as perhaps the most critical part of the system-wide response to patient deterioration.[24,28]

The median MET activation rate of 2.3 per 1000 hospital admissions or 1.5 per every in-hospital cardiac arrest was below the level generally reported to be effective for the prevention of in-hospital cardiac arrests.[11,15,16] Although no clear limits for 'effective calling rate' exist, it is comprehensible that if almost every other emergency event in general wards is a cardiac arrest, the MET is too rarely utilised.

Strengths and limitations

We had a response rate of 93%. All ICU equipped larger hospitals, and most regional hospitals participated in the study thus enabling a representative view of current national practices. The main limitations are related to the general reliability and external validity of questionnaire studies; results may be biased because they are self-reports that are not validated by an independent third party. Furthermore, the reported incidence of in-hospital cardiac arrests may be an underestimate, as it only includes events recorded by the CATs.

Conclusions

CATs have been more frequently implemented in central hospitals and district hospitals compared with METs, although current guidelines emphasise the methods preventing in-hospital cardiac arrests when considering advanced resuscitation. Documentation of in-hospital cardiac arrests and structured debriefings among CAT members after resuscitation attempts should be standard procedures. There is a large variation in the MET activation criteria used. The average usage of METs in Finland is at a suboptimal level.

Conflicts of interest: Jyrki Tenhunen is a cofounder, Medical Director and shareholder of Sensem Technologies Ltd (Tampere, Finland). The other authors declare that they have no conflicts of interest.

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