The identification of risk factors for cardiac arrest and formulation of activation criteria to alert a medical emergency team

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Abstract

Aim: (1) To identify risk factors for in-hospital cardiac arrest; (2) to formulate activation criteria to alert a clinical response culminating in attendance by a Medical Emergency Team (MET); (3) to evaluate the sensitivity and specificity of the scoring system. Methods: Quasi-experimental design to determine prevalence of risk factors for cardiac arrest in the hospitalised population. Weighting of risk factors and formulation of activation criteria to alert a graded clinical response. ROC analysis of weighted cumulative scores to determine their sensitivity and specificity. Setting: An acute 700 bed district general hospital with 32 348 adult admissions in 1999 and a catchment population of around 365 000. Subjects: 118 consecutive adult patients suffering primary cardiac arrest in-hospital and 132 non-arrest patients, randomly selected according to stratified randomisation by gender and age. Results: Risk factors for cardiac arrest include: abnormal respiratory rate (P = 0.013), abnormal breathing indicator (abnormal rate or documented shortness of breath) (P < 0.001), abnormal pulse (P < 0.001), reduced systolic blood pressure (P < 0.001), abnormal temperature (P < 0.001), reduced pulse oximetry (P < 0.001), chest pain (P < 0.001) and nurse or doctor concern (P < 0.001). Multivariate analysis of cardiac arrest cases identified three positive associations for cardiac arrest: abnormal breathing indicator (OR 3.49; 95% CI: 1.69–7.21), reduced pulse oximetry (OR 4.07; 95% CI: 2.08–8.31) and abnormal systolic blood pressure (OR 19.92; 95% CI: 9.48–41.84). Risk factors were weighted and tabulated. The aggregate score determines the grade of clinical response. ROC analysis determined that a score of 4 has 89% sensitivity and 77% specificity for cardiac arrest; a score of 8 has 52% sensitivity and 99% specificity. All patients scoring greater than 10 suffered cardiac arrest. Conclusion: Risk factors for cardiac arrest have been identified, quantified and formulated into a table of activation criteria to help predict and avert cardiac arrest by alerting a clinical response. A graded clinical response has resulted in a tool that has both sensitivity and specificity for cardiac arrest. © 2002 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Cardiac arrest; Risk factors; Medical emergency team; Activation criteria

Resumo

Objectivo: (1) Identificar os factores de risco para a paragem cardíaca intra-hospitalar; (2) formular critérios de activação dum Equipa de Emergência Médica (MET); (3) Avaliar a sensibilidade e especificidade do sistema de score. Métodos: Desenho “quasi-experimental” para determinar a prevalência de factores de risco para paragem cardíaca (PCR) na população hospitalizada. Avaliar a importância de factores de risco e a formulação de critérios de activação clínica escalonada. Análise ROC de scores cumulativos para determinar a sua sensibilidade e especificidade. Contexto: Hospital distrital com 700 camas de agudos com 32348 admissões de adultos em 1999 e servindo uma população de cerca de 365000 indivíduos. População: 118 adultos que sofreram PCR primária intra-hospitalar e 132 indivíduos que não pararam, selecionados de forma randomizada de acordo com randomização estratificada por sexo e idade. Resultados: Os factores de risco para paragem cardíaca incluem: frequência respiratória anormal (P = 0.013),...
indicador de respiración anormal (frecuencia anormal o documentado encurtamento da respiração) \( P < 0.001 \), pulso anormal \( P < 0.001 \), reducción da pressão arterial sistólica \( P < 0.001 \), temperatura anormal \( P < 0.001 \), reducción de valores na oximetría de pulso \( P < 0.001 \), dor torácica \( P < 0.001 \) e preocupación por parte da enfermagem ou do médico \( P < 0.001 \). Uma análise multivariante das PCR, identificou três associações positivas para PCR: indicador de respiración anormal \( OR = 3.49; 95\% CI: 1.69 - 7.21 \), pulso anormal \( OR = 4.07; 95\% CI: 2.0 - 8.31 \) e pressão arterial sistólica anormal \( OR = 19.92; 95\% CI: 9.48 - 41.84 \). Os factores de risco foram ponderados e tabulados. Os scores agregados determinam o grau de resposta clínica. Análise de ROC determina que um score de 4 tem 89% de sensibilidade e 77% de especificidade para a paragem cardíaca; um score de 8 tem uma sensibilidade de 52% e especificidade de 99%. Todos os doentes com scores superiores a 10 sofreram PCR.

Conclusa˜o: Foram identificados factores de risco para paragem cardíaca, quantificados e formulados numa tabela de critérios de activação para ajudar a prever e evitar a PCR através da activação precoce do MET. Uma resposta clínica escalonada constitui um instrumento com elevada sensibilidade e especificidade para a identificação de PCR.

**Palavras chave:** Paragem Cardíaca; Factores de risco; Equipa de Emergência; Critérios de activação

**Resumen**

**Objetivos:** (1) Identificar factores de riesgo de paro cardíaco intrahospitalario; (2) formular criterios de activación para alertar una respuesta clínica que culmine en la atención por el Equipo de Emergencia Médica (MET); (3) evaluar la sensibilidad y especificidad del sistema de puntaje. **Métodos:** diseño cuasi experimental para determinar la prevalencia de factores de riesgo de paro cardíaco en la población hospitalizada. Sopesar los factores de riesgo y formulación de criterios de activación para alertar una respuesta clínica graduada. Ambiente: Un hospital general distrital de 700 camas de agudos con 32348 admisiones de adultos en 1999 y una población asignada de alrededor de 365000 personas. Sujetos:118 pacientes adultos consecutivos que sufren paro cardiorrespiratorio primario intrahospitalario y 132 pacientes que no presentan paro cardíaco, seleccionados al azar de acuerdo a la estratificación randomizada por edad y sexo. **Resultados:** Los factores de riesgo de paro cardíaco incluyen: frecuencia respiratoria anormal \( P = 0.013 \), indicador de respiración anormal (frecuencia anormal o dificultad respiratoria) \( P < 0.001 \), pulso anormal \( P < 0.001 \), presión sistólica reducida \( P < 0.001 \), temperatura anormal \( P < 0.001 \), oximetría de pulso reducida \( P < 0.001 \), dolor de pecho \( P < 0.001 \), e inquietud del doctor o de la enfermera al respecto de ese paciente \( P < 0.001 \). El análisis de las múltiples variables de paro cardíaco identificó tres asociaciones positivas con paro cardíaco: indicador de respiración anormal \( OR = 3.49; 95\% CI: 1.69 - 7.21 \), pulso anormal \( OR = 4.07; 95\% CI: 2.0 - 8.31 \) y presión sistólica anormal \( OR = 19.92; 95\% CI: 9.48 - 41.84 \). Los factores de riesgo fueron evaluados y tabulados. El puntaje total determina el grado de respuesta clínica. El análisis ROC determinó que el puntaje de 4 tiene 89% de sensibilidad y 77% de especificidad para paro cardíaco; un puntaje de 8 tiene 52% de sensibilidad y 99% de especificidad. Todos los pacientes con puntaje mayor que 10 sufrieron un paro cardiorrespiratorio. **Conclusión:** Se han identificado, cuantificado los factores de riesgo, y han sido formulados en una tabla de criterios de activación para ayudar a predecir y prevenir un paro cardíaco a través de alertar una respuesta clínica. Una respuesta clínica graduada ha resultado ser una herramienta que tiene tanto sensibilidad como especificidad para paro cardíaco.

**Palabras clave:** Paro cardíaco; Factores de riesgo; Equipo de emergencias médicas; Criterios de activación

1. **Introduction**

Two-thirds of in-hospital cardiac arrests are potentially avoidable [1]. Poor survival [2] and international recognition that cardiac arrest is frequently avoidable [3–6] has resulted in the development of acute response teams that aim to avert cardiac arrest [7–10]. These teams predominantly rely upon predetermined changes in physiological parameters to trigger a clinical response. United Kingdom central government supports the extension of acute response teams as part of its prevention of illness strategy [11–13].

The root scoring system for the MET from Australia was developed empirically, and has been subject to further empirical modifications in Australia [7,8] and the UK [9,10]. The development of these systems has been related to the prevalence of individual abnormal signs without knowing their predictive value for cardiac arrest [14,15]. In the simpler systems, where no methodology is described, they are presumed to be entirely experience based. Failure to validate existing MET scoring systems has been identified as a weakness [14,16].

2. **Methods**

2.1. **Setting**

An acute 700 bed district general hospital with 32 348 adult admissions in 1999 and a catchment population of around 365 000.

2.2. **Definitions**

Adult patients were defined as > 16 years of age.
2.3. Patients and case-note analysis

About 118 consecutive adult patients suffering primary cardiac arrest where resuscitation was attempted and a comparative sample formed from the chart records of 132 non-arrest adult patients present on acute wards on the day of investigation. Chart records of controls were chosen randomly by stratified randomisation according to gender and age; patients were tracked for 2 weeks to detect cardiac arrest or unexpected ICU admission.

2.4. Identification of risk factors for cardiac arrest

Risk factors were identified from detailed retrospective case-note review of cardiac arrest cases. Abnormal physiological variables were compared with the non-arrest control sample.

2.5. Formulation of activation criteria to alert a MET

Risk factors for cardiac arrest were formulated into a table of activation criteria. Consideration was given to published risk factors and clinically relevant factors that did not reach statistical significance. Factors were weighted, with a higher weighting given to increasing physiological or biochemical deterioration. The weighted factors were applied to both cardiac arrest and non-arrest patients to determine sensitivity and specificity of cumulative activation scores to predict cardiac arrest.

2.6. Statistical analysis

The Statistical Package for Social Sciences (spss version 10.0) was used for data analysis. The association between cardiac arrest and normal or abnormal characteristic was assessed by the Pearson chi-squared test for contingency table or Fisher’s test where appropriate. For a further evaluation of this association, the risk of a characteristic being present in the arrest population compared with the control group was estimated by the odds ratio (OR) and 95% confidence interval (CI). All tests of significance were two-tailed and are reported with the exact P-value [17,18]. Corrections for Type I errors were made using a modified Bonferroni’s procedure. According to this procedure, the level of significance \( \alpha \) is adjusted to \( \alpha = \alpha^*/k \), where \( \alpha^* \) is the probability of committing at least one type I error in a number of \( k \) tests [18–20]. In addition, since this procedure tends to be rather conservative, a more generous value (\( > 0.10 \)) is often used. For quantitative measurements, group differences were assessed by the t-test or the non-parametric Mann–Whitney U-test [17,18]. The independent influence of all related factors were analysed by means of unconditional maximum likelihood regression analysis to determine whether or not an individual factor had a significant positive association with the risk of cardiac arrest [21]. This method was used in a backward stepwise fashion. The operating characteristics (sensitivity and specificity) of the cumulative scoring system for the activation of MET were calculated together with the receiver operator characteristic (ROC) [22].

2.7. Study limitations

The 118 cardiac arrest cases consisted of both general ward and critical care patients who would have received different levels of monitoring and intervention. However, this is made clear in the preceding paper (1) and provides an overview of the incidence of avoidable events across a group of hospitals. The control sample of chart records of patients did not include a detailed review of cases and was limited to physiological criteria and new symptoms.

3. Results

The two groups were of comparable age (cardiac arrest patients median age 72.7 years, range 22–93 years; non-arrest patients median age 69.2 years, range 18–98 years) and gender distribution (proportions of females 46.6% for cases and 49.2% for controls).

3.1. Identification of risk factors for cardiac arrest

Using the Bonferroni procedure with \( \alpha^* = 0.20 \) and \( k = 9 \), the following factors were identified as significant (\( P < 0.022 \)) predictors of cardiac arrest when arrest cases were compared with non-arrest controls: abnormal respiratory rate (\( P = 0.013 \)), abnormal breathing indicator (\( P < 0.001 \)), abnormal pulse (\( P < 0.001 \)), reduced systolic blood pressure (\( P < 0.001 \)), abnormal temperature (\( P < 0.001 \)), reduced pulse oximetry (\( P < 0.001 \)), chest pain (\( P < 0.001 \)) and nurse or doctor concern (\( P < 0.001 \)). The associated risk of cardiac arrest, as calculated by the odds-ratio, was significantly greater than one for all above factors. A summary comparison of characteristics is given in Table 1.

Logistic regression identified three significant independent positive associations with the risk of cardiac arrest: abnormal breathing indicator (abnormal rate or shortness of breath) (OR 3.49; 95% CI: 1.69–7.21); abnormal pulse (OR 4.07; 95% CI: 2.0–8.31) and reduced systolic blood pressure (OR 19.92; 95% CI: 9.48–41.84).
3.2. Formulation of activation criteria to alert a MET

Activation criteria for MET were grouped as new symptoms, physiological changes, and biochemical changes. The expert panel decided on the weighting criteria for each parameter (Table 2). The cumulative scoring system (relating to the clinical cascade scheme) was applied to cases and controls and assessed for sensitivity and specificity; Table 3. A score of 8 activates the MET (99% specificity and 52% sensitivity); therefore a score of 8 or higher will detect 52% of patients who deteriorate to cardiac arrest, 48% will have arrested at a lower score. Only 1% of patients who do not arrest score 8 or higher. All patients scoring 10 or more proceeded to cardiac arrest.

4. Discussion

This study represents the first evidence-based approach to providing activation criteria for an acute response team rather than relying upon extrapolations from empirical models. The clinical antecedents to fatal deterioration identified in this study are consistent with the findings of other studies. The key difference is the quantification of these antecedents into a structured and weighted response. Assessment of sensitivity and specificity confirms the need for a graded clinical response that encourages the identification of ‘at risk’ patients earlier.

This study demonstrated that nurse or doctor concern was a significant finding in the arrest group compared with the controls. This concurs with Franklin and Matthew’s finding where there was a documented deterioration (by a doctor or nurse) in 99/150 cases in the 6 h preceding arrest [5]. ‘Nurse concern’ appears as a ‘new symptom’ within our activation criteria and during MET training staff are told to include ‘new sweating’ and ‘new pallor’ within this assessment of concern. Whilst not entirely objective, ‘concern’ encompasses the subtle cues that arouse nurses and doctors suspicion but find difficult to quantify, and is a phenomenon that has been recommended worthy of further study [23].

Chest pain was much more likely in the arrest patients than the controls. In one year’s experience in Perth, Western Australia, chest pain was the commonest reason for MET activation [8]. Abdominal pain was not statistically significant but clinical judgement identified 3/73 (unanimity criterion) potentially a predictor of significant deterioration has been identified in numerous studies [24–27] and was 4 times more likely in our cardiac arrest sample. Fieslemann et al [24] found 54% of patients with a respiratory rate of greater than 27 breaths per min in the hours preceding arrest. Fieslemann et al [24] also used a control group of non-arrest patients and found only 17% had abnormal respiratory rate during admission, confirming the significance of respiratory rate as a predictor of potentially fatal deterioration.

Evidence of the predictive nature of a change in blood pressure is conflicting in existing studies, although most observers have found a fall in systolic blood pressure in a proportion of patients prior to arrest [5,27,28]. Our study identifies a change in systolic blood pressure...
(SBP) as an independent predictor of cardiac arrest. Within the graded activation criteria for SBP there is an assessment of the absolute value (for example, ‘falls to <90 mmHg’), an assessment of the degree of change (for example, ‘falls by 30–40 mmHg’) and an assessment of the early changes that often precede a fall of SBP in shock, which is a narrowing of pulse pressure (for example, ‘pulse pressure narrows >10 mmHg’). Within the education programme staff are instructed to count the highest scoring of these parameters.

The physiological factors that achieved statistical significance were not surprising. The importance of reliable, and regular basic nursing observations (pulse, blood pressure, respiration, temperature) that are recognised as abnormal and acted upon was highlighted. Pulse oximetry can now be added as a ‘basic’ observation, but it does not replace measuring the respiratory rate.

A change in mental status was present in 37% of arrest patients and none of the controls. Schein et al. [26] recorded a change in 42% of arrest patients, and a common failure by the nurse to communicate the change to the doctor. Although the observed value in this study just failed to reach statistical significance, it is considered clinically significant and therefore incorporated into the activation criteria.

Table 2
Activation criteria for a medical emergency team

<table>
<thead>
<tr>
<th>symptoms</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nurse concern</td>
<td>NEW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAA Pain</td>
<td>NEW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Physiology</th>
<th>Physiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse</td>
<td>&lt;45</td>
</tr>
<tr>
<td>Temp-core (rectal tympanic)</td>
<td>&lt;34</td>
</tr>
<tr>
<td>RR (adult)</td>
<td>&lt;8</td>
</tr>
<tr>
<td>SpO2 (%)</td>
<td>&lt;88</td>
</tr>
<tr>
<td>SpO2 (%)</td>
<td>&lt;85</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>Falls to</td>
</tr>
<tr>
<td>or</td>
<td>&lt;90</td>
</tr>
<tr>
<td>GCS changes</td>
<td>&lt;13</td>
</tr>
<tr>
<td>Urine output</td>
<td>&lt;10 mis/hr for 2 hrs</td>
</tr>
<tr>
<td>Biochemistry</td>
<td>K+</td>
</tr>
<tr>
<td>Na+</td>
<td>&lt;120</td>
</tr>
<tr>
<td>pH</td>
<td>&lt;7.21</td>
</tr>
<tr>
<td>pCO2 (acute changes)</td>
<td>&lt;3.5</td>
</tr>
<tr>
<td>Hb</td>
<td>&lt;80</td>
</tr>
<tr>
<td>Urea</td>
<td>&lt;2</td>
</tr>
</tbody>
</table>

Table 3
Graded clinical response for medical emergency team and sensitivity and specificity of scores (see Fig. 1)

<table>
<thead>
<tr>
<th>Score</th>
<th>Action</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Observe</td>
<td>100</td>
<td>17</td>
</tr>
<tr>
<td>2–3</td>
<td>Repeat TPR, BP, SpO2, GCS, calculate urine output last 2 h (if known) Now recalculate (if same, observe closely)</td>
<td>98–94</td>
<td>36–61</td>
</tr>
<tr>
<td>4</td>
<td>Bleep patient’s SHO (to attend within 30 min)</td>
<td>89</td>
<td>77</td>
</tr>
<tr>
<td>5–7</td>
<td>Confirm with senior nurse then fasts bleep SHO of patient’s speciality</td>
<td>84–64</td>
<td>89–96</td>
</tr>
<tr>
<td>8</td>
<td>Inform senior nurse then call MET</td>
<td>52</td>
<td>99</td>
</tr>
</tbody>
</table>
There were too few recordings of serum potassium to make an interpretation of statistical significance. However, within the expert panel review severe hypokalaemia was believed in anecdotal cases to be contributory to potentially avoidable cardiac arrest. Importantly, Rich [27] found 13% of 100 patients had abnormal serum potassium in the 8 h preceding arrest. Serum sodium was added as a parameter to the activation criteria and as a treatment guideline because, although severe derangements are rare, they are clinically recognised to be associated with high mortality. In support of this, Lee et al [29] found 1.7% (2/121) MET interventions were related to abnormal serum sodium.

Hourly urine output could not be evaluated from the retrospective study of case-notes. A reduced urine output is a recognised feature of decreased renal perfusion in shock, and for this reason falling urine output is included as a physiological parameter within the activation criteria.

There are similarities between this model and earlier models regarding the nature of physiological activation criteria. However, the stratification and weighting of these abnormalities provides a more objective assessment tool. Earlier models have an ‘all or nothing’ response [7,8,29]. The presence of physiological changes in the control group, who did not proceed to arrest, demonstrates the difficulty of an ‘all or nothing’ response that will result in over-activation of the MET. A 100% predictive scoring system is unlikely given the natural variation in physiology. However, a graded clinical response addresses both resource concerns about over-activation of the MET with high specificity, whilst maintaining high sensitivity to deliver a clinical response when a lower score is reached. At a score of only 2-3, nurses are alerted to be more vigilant: this has high sensitivity, but low specificity (Table 3). A score of 5 appears ideal to alert the MET (sensitivity 84% and specificity 89%), however, practically this would result in over activation of the Team and therefore the Senior House Officer is fast bleeped.

The MET system has resource saving implications; it aims to avert cardiac arrests but may also identify deteriorating patients before they require critical care by providing timely ward-based intervention. Additionally, nurses are empowered to provide the appropriate response for their patients’ clinical condition and are better able to quantify the deterioration, thus improving communication between health care professionals.

Getting skilled personnel to the bedside is only part of the solution. As the most consistent clinical failure is inadequate treatment [1] there must be confidence that the clinical team will make the right decisions and perform the right interventions to retrieve the situation once at the bedside. To help address this problem evidence-based guidelines for the management of the common antecedents to cardiac arrest were devised. Evidence-based guidelines promote standardised and best clinical practice.

Composition of the Medical Emergency Team will be partly determined by local resources, but ideally should have sufficient seniority and confidence to manage acute clinical deterioration and the continuing care. The system developed has clear application within the study hospital, but may require modification to suit local needs and available resources. The relatively small sample of cardiac arrest and control patients is a limitation and suggests the need for wider evaluation in multiple centres.

5. Conclusion

This study has quantified the importance of new symptoms, physiological changes and biochemical changes as risk factors for in-hospital cardiac arrest. A graduated clinical response begins to address the concerns regarding sensitivity and specificity of scoring systems. Activation criteria that quantify deterioration and provide a graduated and appropriate clinical response are a risk management tool that will assist in managing system failures within our hospitals.

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References