Introduction of an electronic physiological early warning system: effects on mortality and length of stay

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Editor’s key points
- Early warning scores (EWSs) are used routinely to identify critically ill patients and allow early intervention.
- This study evaluated the use of an EWS with electronically captured data and automated alerting in an acute medical unit.
- Mortality and length of stay were reduced over the study period, but this was related to reduced severity of illness.
- The use of an electronic EWS with automated alerts had little effect on mortality in acutely ill medical patients.

Background. The Worthing physiological scoring system (PSS) was first validated in 2005 as a tool to predict hospital mortality on admission and was subsequently introduced into clinical practice at Worthing Hospital, UK. Five years on, this study was conducted to determine the effects on mortality and length of stay (LOS) after the introduction of electronic alerting software using the PSS. In addition, we investigated whether the Worthing PSS predictive ability could be improved by addition of further variables.

Methods. Prospective observational study conducted in the acute medical unit, Worthing Hospital, UK. Patient physiological data on admission and discharge/transfer were collected between February and July 2010 from the electronic alerting software VitalPACTM. Patient characteristics, co-morbidity, outcomes, and biochemistry data were taken from the hospital administration and pathology systems.

Results. The observed mortality reduction from 8.3% to 5.2% over 5 yr was not statistically significant after adjustment for admission Worthing PSS score. Median LOS was reduced from 4 to 2 days, but this reflected an increase in short stay admissions. Worthing PSS was not significantly improved with the addition of biochemical variables or patient co-morbidity. A score taken before admission to a medical ward showed an improved predictive ability when compared with the initial admission score, but further analysis found no additional clinical benefit.

Conclusions. The introduction of an electronic alerting PSS did not lead to a reduction in mortality when adjusted for severity of illness defined by physiological variables. Predictive performance was not enhanced by the addition of biochemical variables and co-morbidities.

Keywords: hospital mortality; length of stay; medicine; monitoring, physiological; patient admission

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After a recommendation by the Department of Health (DoH) in 2000, the use of physiological early warning scores (EWSs) is now common practice in acute NHS hospitals in order to aid identification of patients with potential or established critical illness so that management can be instigated from appropriately skilled staff in a timely manner.1 This recommendation led to the development of several scoring systems which prompted a systematic review, commissioned by the National Institute for Health Research Service Delivery and Organisation in 2007, to evaluate their performance.2 This concluded that there was a lack of evidence to identify any one best EWS model. Later that year, the Royal College of Physicians recommended that the physiological assessment of all patients should be standardized across the NHS and a working group be commissioned to develop an NHS Early Warning Score (NEWS).3 Locally, we had developed and validated the Worthing physiological scoring system (PSS) in 2005 based on data collected in a population-based, single-centre study.4 This predictive model was validated as a tool to predict patient hospital mortality from admission physiology and its simplicity made it ideal for a paper-based EWS. In response to the study, the Worthing PSS was introduced into clinical practice in Worthing Hospital, Worthing, UK, in 2008 with a view to conducting a post-Worthing PSS implementation observational study. The assumption was that by alerting the nursing and medical staff early to patients with a predicted high mortality,
early intervention would be triggered and mortality reduced in those patients where reversible pathology was present.

In 2010 Worthing Hospital implemented the electronic clinical data software system VitalPAC™ into the Acute Medical Unit (AMU) for a 6-month period. This automatically calculated the Worthing PSS and displayed an alert based on a local protocol. During this period, we conducted the post-Worthing PSS implementation study to determine whether this resulted in a reduction in mortality and LOS for patients admitted to AMU. The expectation was that this mortality prediction tool would change over time if the intervention was successful (i.e. the proportion of survivors with higher AMU admission EWS would increase over time). The discrimination achieved when the Worthing PSS was first validated in 2005 was fair with an area under the receiver operating characteristic (ROC) curve of 0.74 (95% CI 0.71 – 0.77). We, therefore, investigated whether the prediction tool could be improved through incorporating patient co-morbidity, biochemical data or both. Finally, for patients admitted to a hospital in-patient ward from the AMU, we investigated whether the Worthing PSS score recorded at AMU discharge improved the predictive ability of the tool. Patients discharged home from AMU were excluded from this analysis.

During the conduct of this study, Worthing Hospital merged with St Richard’s Hospital to form the Western Sussex Hospitals NHS Trust. It was decided that both hospitals should adopt the NEWS. Therefore, post hoc analysis was performed on this study database to determine whether NEWS was an appropriate mortality prediction tool for the West Sussex population. Further post hoc analysis was also performed to determine whether severity of illness (as defined by the Worthing PSS) differed between weekday and weekend admissions in view of the recent much published reports showing an increased mortality for weekend admissions enabling comparison. The Worthing PSS (Table 1) was automatically calculated from the physiology measurements by the VitalPAC™ software and an alert displayed.

The physiological variables recorded were:

- Systolic and diastolic blood pressure, heart rate, and oxygen saturation in air (measured with Vital Signs Monitor VS-800, Mindray Medical International Ltd or Dynascope DS-7100, Fukuda Denshi Co. Ltd)
- Whether supplemental oxygen was required
- Respiratory rate
- Temperature
- Level of consciousness (as per the AVPU score—alert, responsiveness to verbal command, pain or unresponsive)

Alerts displayed recommended intervention according to a set protocol. All therapeutic management was at the discretion of the attending doctor.

Physiological observations used to generate the Worthing PSS score on admission (Admission Worthing PSS score) and before discharge home, transfer into the hospital, or death in AMU (Final Worthing PSS score) were taken from VitalPAC™. Patient characteristic information was obtained through the hospital patient administration system (PAS) and patients were followed up to determine patient outcomes: mortality and length of stay (LOS). Patient admission biochemical data [serum creatinine, C-reactive protein (CRP) and bilirubin] were taken from the hospital pathology system. Twenty-eight co-morbidities, based on the Charlson Co-morbidity Index, were included in the analysis and were taken from the patients’ coded diagnoses entered onto the PAS.

### Data analysis

There were no exclusion criteria, but incomplete data sets were removed before statistical analysis. Data were entered onto an Excel® spreadsheet (Microsoft Corporation, Richmond, WA, USA) and the data were anonymized. Completeness of the data was independently verified. Anonymized data were

### Methods

This prospective observational study was conducted in the AMU of the Worthing site of the Western Sussex Hospitals Trust between 1 February 2010 and 31 July 2010, and was the continuation of work previously published. The Western Sussex Hospitals Trust is an 870-bedded affiliated university hospital. The Worthing site is a 500-bedded district general hospital with 25–35 acute medical admissions every 24 h. Approval had previously been obtained from the NHS Research Ethics Committee (REC No. 05/Q1911/62), which included the post-implementation study. Processes in place for the initial work including displaying information posters explaining the research in AMU were continued throughout the study period.

### Table 1  Worthing PSS as published in 2007—observations measured with corresponding scores

<table>
<thead>
<tr>
<th>Score</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory frequency</td>
<td>&lt;19</td>
<td>20–21</td>
<td>≥22</td>
<td></td>
</tr>
<tr>
<td>Pulse</td>
<td>&lt;101</td>
<td>≥102</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic blood pressure</td>
<td>≥100</td>
<td>≤99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>≥35.3</td>
<td>&lt;35.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen saturation in air</td>
<td>96–100</td>
<td>94 to &lt;96</td>
<td>92 to &lt;96</td>
<td>&lt;92</td>
</tr>
<tr>
<td>AVPU</td>
<td>Alert</td>
<td>Other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

...
analysed at the School of Computing, Mathematical and Information Sciences, University of Brighton. The Worthing PSS was revalidated to predict patient hospital mortality using data collected during this study period. Patient outcomes were compared between the data collected to initially develop and validate the Worthing PSS in 2005 (AMU admission PSS data collected only) and the data collected during the 2010 study period.

Statistical analysis

Poisson regression was used to compare the proportions of non-survivors in 2005 data and 2010 data while adjusting for Worthing PSS scores on admission. In the regression, the logarithm of the expected number of deaths was modelled as a linear function of dummy variables representing the class variables PSS score and phase. The logarithm of the number of patients with each Worthing PSS score was included as an offset. Multivariable logistic regression was used to investigate whether the ability of the Worthing PSS score to discriminate between survivors and non-survivors could be improved by including additional variables one at a time (co-morbidities (present or absent), admission creatinine, weekend admission, CRP, bilirubin—see Supplementary Table S1). The area under the receiver operating characteristics curves (AUC) was used to measure the level of discrimination achieved. The effect of day-of-the-week of admission on mortality and LOS was assessed using chi-squared and Kruskal–Wallis tests.

Post hoc analysis of the data comparing the Worthing PSS with the NEWS was possible as the NEWS comprised the physiological variables that were collected by VitalPACTM to calculate the Worthing PSS in the original data collection.

Results

Data were collected from 3601 patients and were complete for 3184 patients (3020 survived, 164 died) (Table 2). Of these patients, 1111 (34.9%) were discharged from AMU and 23 (0.7%) died in AMU. Of the remaining 2050 patients transferred into the hospital, 1909 survived (60%) and 141 died (4.4%) of whom 33 (1.6%) died within 72 h of admission.

Mortality and LOS changes between 2005 and 2010

The proportion of non-survivors was noticeably lower in 2010 data compared with 2005 with a mortality reduction from 8.3% to 5.2% (Table 2). Comparison of the distribution of the Worthing PSS scores on admission between 2005 and 2010 study data shows a greater proportion of patients with a score <3 in 2010 (83.6%) compared with 2005 (69.3%). Consequently, no significant difference (P=0.29) was seen between proportions of non-survivors after adjustment for the admission score.

The median LOS for survivors also reduced between 2005 and 2010 from 4 to 2 days. On further analysis of the 2010 data, the median LOS for all patients admitted to AMU was 20 h (range 0–719 h). The LOS of patients transferred from AMU into the hospital, who survived to discharge, with an initial Worthing PSS equal to 0 had the shortest median LOS (4 days). The median LOS tends to increase as the Worthing PSS increases with a sharp increase for scores ≥7 (see Supplementary Fig. S2).

Worthing PSS score on admission to AMU

The distribution of admission score and the corresponding mortality in 2010 is shown in Figure 1A. This is similar to the distribution seen in 2005, where scores above 2 were also associated with a mortality >10%. The discrimination of the Worthing PSS for the 2010 data gave an AUC of 0.74 (95% CI: 0.69–0.78), which is similar to the discrimination achieved when the score was first validated in 2005 (AUC 0.74, 95% CI: 0.71–0.77).

Worthing PSS plus co-morbidity and biochemical variables

The logistic regression analyses indicated that, in addition to the Worthing PSS score, only CRP was independently associated with mortality (P=0.013). However, CRP values were only available for 1084 patients (34% of total) and the improvement in discrimination was only slight, with an AUC of 0.78 (95% CI: 0.71–0.85). No significant improvement in discrimination was observed with serum creatinine, bilirubin, or the presence of a patient co-morbidity.

Admission AMU Worthing PSS score vs final AMU Worthing PSS score

Comparisons were made between admission and final AMU Worthing PSS scores for patients transferred into the hospital only. Patients who died 72 h after admission were excluded, thereby limiting analysis to early mortality. This was felt to reduce the number and extent of influencing factors that could alter the correlation between the Worthing PSS with mortality. Figure 2 shows that the discrimination between patients who died within 72 h and the rest was greater when using the final AMU scores with an AUC increase from 0.73 (95% CI: 0.63–0.83) to 0.88 (95% CI: 0.83–0.94). Note that the discrimination

| Table 2 | Baseline characteristics for 2005 and 2010 data sets |
|---------|----------------------------------------|--------|--------|------------|
|         | 2005 study                           |        | 2010 study                     |        |
|         | Survivors | Non-survivors | Survivors | Non-survivors |
| n (%)  |           |             |           |             |
| Female sex (%) | 3931 (91.7) | 355 (8.3) | 3020 (94.8) | 164 (5.2) |
| Age (range) | 71 (17–106) | 83 (32–99) | 69 (16–105) | 81 (20–102) |
| Median LOS (range) | 4 (0–240) | 7 (0–62) | 2 (0–217) | 7 (0–62) |
between admission Worthing PSS score for patients transferred into the hospital compared with the all-inclusive admission Worthing PSS score (i.e. including those who died after 72 h and who were discharged from or died in AMU) is similar (AUC 0.73 and 0.74, respectively).

**NEWS on admission to AMU**

The NEWS includes the provision of supplemental oxygen as an additional variable. Even with this additional variable, the discrimination achieved was similar (0.76, 95% CI: 0.72 - 0.80) to that of the Worthing PSS for the 2010 data set. Using this system, scores above 4 show a mortality rate above 10% (Fig. 1a).

**Weekend admission Worthing PSS score and mortality**

No significant difference in mortality was seen between weekday and weekend admissions during the study period. Even though the percentage of deaths was highest for Sunday admissions (7.7%), this was not statistically significant (P = 0.189) (Table 3). There was no significant difference between the mean weekday and the mean weekend admission Worthing PSS.

**Discussion**

In this study, we found that Worthing Hospital experienced a reduction in mortality and LOS between 2005 and 2010. However, the proportion of survivors with a higher admission score did not increase and the predictive ability of the Worthing PSS remained unchanged. After the addition of co-morbidity and biochemical variables, only CRP gave some improvement in the predictive ability of the Worthing PSS. Compared with the admission Worthing PSS score, the score recorded before transfer into the hospital appears to give a more accurate prediction of mortality. Post hoc analysis revealed the NEWS and Worthing PSS to perform similarly and there was no significant
Mortality and LOS reduction

Five years after the development of the Worthing PSS, and subsequent implementation of an electronic alerting PSS to Worthing hospital, hospital mortality fell from 8.3% to 5.2%. Average LOS also reduced from 4 to 2 days. However, after adjustment for the admission Worthing PSS score, this reduction in mortality is not statistically significant. This is because of a greater proportion of patients having less physiological derangement on admission. Therefore, the observed reduction in LOS is likely to reflect an increase in short-term admissions, thereby reducing average LOS. Interestingly, this phenomenon is not uncommon and is observed throughout the NHS. A Nuffield Trust report attempted to identify potential factors responsible for the increase in short stay emergency admissions and the artificial reduction in LOS that is observed. They concluded that this was a result of multiple factors and could not be explained by a single change in practice, such as the ‘Payment by Results’ policy or the 4-h maximum waiting time target in A&E.

Despite a complicated interplay of factors that may artificially improve LOS, the admission Worthing PSS score was shown to correlate with average LOS, nearly doubling with a score >4. This correlation is consistent with current studies and emphasizes the usefulness of an EWS as a predictor of LOS with potential to facilitate discharge planning.


difference between weekday and weekend admission scores and associated mortality.


each Worthing PSS scores for patients admitted into the hospital and who died within 72 h.

<table>
<thead>
<tr>
<th>Day</th>
<th>Admission number</th>
<th>Deaths (%)</th>
<th>Mean score (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
<td>480</td>
<td>20 (4.2)</td>
<td>1.26 (1.49)</td>
</tr>
<tr>
<td>Tuesday</td>
<td>525</td>
<td>29 (5.5)</td>
<td>1.32 (1.75)</td>
</tr>
<tr>
<td>Wednesday</td>
<td>475</td>
<td>26 (5.5)</td>
<td>1.23 (1.59)</td>
</tr>
<tr>
<td>Thursday</td>
<td>486</td>
<td>27 (5.6)</td>
<td>1.23 (1.58)</td>
</tr>
<tr>
<td>Friday</td>
<td>535</td>
<td>20 (3.7)</td>
<td>1.14 (1.38)</td>
</tr>
<tr>
<td>Saturday</td>
<td>319</td>
<td>14 (4.4)</td>
<td>1.52 (1.73)</td>
</tr>
<tr>
<td>Sunday</td>
<td>364</td>
<td>28 (7.7)</td>
<td>1.56 (2.05)</td>
</tr>
<tr>
<td>Total</td>
<td>3184</td>
<td>164 (5.2)</td>
<td>–</td>
</tr>
</tbody>
</table>


each day of the week

Unchanged mortality in patients with higher admission scores

After the implementation of the electronic alerting PSS, it was speculated that the proportion of survivors with higher admission Worthing PSS scores may increase over time because of earlier and ultimately more successful interventions being made preventing death (i.e. there would be a rightward shift of the mortality curve shown in Fig. 1a). However, in our study introduction of an electronic alerting PSS does not appear to have had any clinical impact and several factors may explain this. First, data collection was dependent upon the accuracy with which the ward staff measured and recorded clinical measurements of patients on admission to AMU, and so prone to measurement and recording errors. However, the computerized VitalPACTM system assisted data collection and has been shown to reduce incorrect entries and data omissions. Second, although the alert from the electronic EWS empowers an intervention, we have not currently measured the speed or appropriateness of this intervention such as compliance with clinical protocols and guidelines. Delays in intervention and a failure to deliver the appropriate treatment are likely to translate into poor outcomes. Thirdly, the failure of the Worthing PSS to improve mortality may be because of incorrect trigger thresholds. However, as highlighted in an editorial by Cuthbertson and Smith, the Worthing PSS was developed using statistical methods to derive and validate the score rather than being based upon expert consensus. Thus, the thresholds set to trigger a response are as accurate as we can possibly make them. Lastly, there was no feedback to nurses and clinicians during the study regarding timing and appropriateness of the intervention to outcomes such as mortality and LOS. Reporting these measures are likely to encourage improvements. These measurements and reporting tools are the subject of ongoing study.

Additional variables on mortality prediction

It is generally accepted that biochemical markers can be used as a marker of disease process and its severity; an increased serum creatinine or CRP generally suggests kidney injury or an acute infective/inflammatory process, while a low-grade
hyperbilirubinaemia has been implicated in poorer outcomes in critical illness. However, the lack of discriminatory improvement seen in our study with the addition of serum creatinine and bilirubin and only a slight improvement with CRP suggests that they do not improve predictive outcomes. These findings show some consistencies with the findings of a previous study where it was shown that serum albumin, creatinine, and electrolyte levels taken on admission to the Worthing accident and emergency department had no discriminatory ability when used as single predictors of mortality or LOS. One of the reasons our study may have failed to see any significant improvement in discrimination with biochemical markers could be the relatively small numbers of patients they were measured in and subsequent type II error. This highlights one of the problems of using biochemical variables in an EWS, as they are not routinely measured on admission unless clinically indicated.

Improved mortality prediction with final AMU score
The improvement seen in discrimination for the final AMU Worthing PSS score suggests that it is a better predictor of early mortality, compared with the admission AMU score. However, further analysis revealed that this subset mainly consisted of patients who were either very frail or appropriate for end-of-life care. Twenty-five of the 33 patients had notes available for analysis. Four patients were for full escalation of care and were admitted to the intensive care unit. Of those not for escalation of care, 5 were from a nursing home, 10 had end-stage cancer or cardiac disease, 3 were termed ‘medically frail’, and 1 was bed-bound because of a progressive neurodegenerative disease. Therefore, it could be argued that the Worthing PSS merely supported clinical judgement that these patients were unlikely to survive, thereby questioning its function as a predictive tool of mortality. At first, this may undermine the need for the Worthing PSS, but this study only used mortality as the common endpoint and intervention and subsequent improvement, after an alert, has not been measured. Previous studies demonstrate that implementing an EWS does reduce hospital mortality and improves clinical response to critically ill medical patients although other studies have highlighted little impact in specific patient populations. This aside, the Worthing PSS may be a useful tool in prompting clinicians to discuss and decide early on in the admission, patient resuscitation status, and limitations of care.

Similar mortality prediction for NEWS and Worthing PSS
The standardization of patient physiological monitoring across the NHS using the NEWS assumes that the population, in which it is initially validated, is representative of the whole UK patient population, so maintaining a high performance for mortality prediction. However, there are large patient characteristic variations not only in population age, but also in socio-economic status and disease states across the UK. In our study, the NEWS appeared to perform as well as the locally validated Worthing PSS. We feel this justifies its use in the Western Sussex Hospitals NHS Trust and may even start to justify its use across England and Wales.

No significant difference in weekend mortality or admission scores
Hospital mortality by day of admission was more than 2% higher for admissions on Sundays, but this was not statistically significant. This finding is not in accordance with recent published work highlighting growing concerns about weekend mortality, such as the Dr Foster Intelligence 2011 report. A theory described for the increased weekend mortality is a lower ratio of ‘senior staff : beds’ and it may be that during our study period this ratio was in favour of a lower mortality.

In summary, we have shown that after the introduction of an electronic alerting PSS, there was no reduction in mortality when adjusting for severity of physiological illness. Furthermore, the predicted mortality reduction in patients with higher admission scores was not seen. This highlights the need for further study to investigate the timing and appropriateness of interventions and introduction of reporting feedback tools. The addition of biochemical markers or patient co-morbidities did not enhance the mortality predictive performance of the Worthing PSS. In concordance with other EWS studies, the admission Worthing PSS score correlated with LOS. Our post hoc analysis confirms that the NEWS performs as well as the Worthing PSS in the West Sussex population, justifying our change to the standardized NHS mortality prediction tool.

Supplementary material
Supplementary material is available at British Journal of Anaesthesia online.

Authors’ contributions
L.G.F. and R. V. designed and co-ordinated this post-implementation study after the original study with R.W.D. J.W. co-ordinated collection of the physiological observations via VitalPACTM on AMU. M.D. collected and compiled all additional patient admission data. E.C. and V.B. performed all the statistical analyses. T.R.D. interpreted the data with L.G.F. and R.V. and compiled the manuscript. All of the authors were involved in reviewing the manuscript before submission.
Declaration of interest
None declared.

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