Design errors in vital sign charts used in consultant-led maternity units in the United Kingdom

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ABSTRACT

Background

Paper-based charts remain the principal means of documenting the vital signs of hospitalised pregnant and postnatal women. However, poor chart design may contribute to both incorrect charting of data and clinical responses. We decided to identify design faults that might have an adverse clinical impact.

Methods

One hundred and twenty obstetric early warning charts and escalation protocols from consultant-led maternity units in the United Kingdom and the Channel Islands were analysed using an objective and systematic approach. We identified design errors that might impede their successful use (e.g., generate confusion regarding vital sign documentation, hamper the recognition of maternal deterioration, cause a failure of the early warning system or of any clinical response).

Results

We found 30% (n=36/120) of charts contained at least one design error with the potential to confuse staff, render the charts difficult to use or compromise patient safety. Amongst the most common areas were inadequate patient identification, poor use of colour, illogical weighting, poor alignment and labelling of axes, and the opportunity for staff to 'game' the escalation.

Conclusions

We recommend the urgent development of an evidence-based, standardised obstetric observation chart, which integrates 'human factors' and user experience. It should have a clear layout and style, appropriate colour scheme, correct language and labelling, and the ability for vital signs to be documented accurately and quickly. It should incorporate a suitable early warning score to guide clinical management.

KEYWORDS:

Women's health; patient safety; standards of care; patient record; design; error.

BACKGROUND

Maternal clinical deterioration can usually be identified by monitoring and charting key vital signs (e.g. respiratory rate, oxygen saturation (S_pO_2), blood pressure (BP)).[1] Paper-based charts remain the principal means of documenting vital signs, despite a drive to introduce electronic automated systems.[2] These charts are intended to track maternal physiology temporally, highlight vital sign deviations and 'signpost' the need for a prompt clinical response. They employ a range of approaches to improve the recognition of abnormal physiology.[3] Some charts use colour-coded shading, often yellow and red, to highlight 'mildly' and 'markedly' abnormal parameter ranges.[4] Others incorporate an aggregate early warning scoring system that allocates points to each vital sign measurement based on the extent of their derangement from predefined 'normal' ranges.[5]

However, observations are not always charted correctly, and appropriate and timely clinical responses to abnormal physiology do not always occur.[1,4,6] Poor chart design may contribute to such failures.[7,8,9] In 2007, the UK Confidential Enquiry into Maternal and Child Health (CEMACH) proposed that a single maternal observation chart should be used for all obstetric admissions in all settings.[4] At the time, the 'CEMACH ' chart was no more than an example of good practice, being neither evidence-based nor validated. It has not been universally used in UK midwifery or obstetric units.[10,11] Recently, researchers in Australia have used an evidence-based approach, and an emphasis on 'human factors' and user experience, to design improved, 'standardised' vital signs charts for general patient use.[8,9,12-15]

During an analysis of paper vital sign charts in consultant-led UK maternity units,[3] design errors were commonly noted. Therefore, we decided to investigate this by focusing on common design faults that might hamper the charts' safe and successful use.

METHODS

In July 2014, as part of a survey of obstetric early warning systems used in consultant-led maternity units in the UK and the Channel Islands,[3] we wrote to 194 lead consultant anaesthetists registered with the Obstetric Anaesthetists' Association (OAA). We requested a copy of the obstetric early warning chart and associated escalation protocol used in their unit. Where necessary, non-responders were contacted again between July 2014 and October 2014 via telephone (once), follow-up letter (three times) and email (three times). We used existing recommendations for chart design[14,15] to identify faults that might lead to undesirable clinical impacts. Whilst acknowledging the importance of avoiding over-medicalisation of the management of pregnant and postnatal women, this article will often use the term 'patient' to refer to women as is practice in this journal.

Two members of the research team (GS and RI) analysed each chart independently. Charts were scrutinised for design errors that might impede their successful use by maternity staff (e.g., generate confusion regarding vital sign documentation, hamper recognition of maternal deterioration, cause a failure of the early warning system or of any clinical response). All errors were recorded on a single spreadsheet. The following design aspects of the charts were evaluated:

- A. Identification of the patient
- B. Chart style and layout
    - B1. Use of colour
    - B2. Graphical versus tabular layouts/displays
    - B3. Integration of early warning score (EWS) systems in the observation chart
    - B4. Alignment of axes and their labelling; row and column shift
    - B5. Illogical ranges

B6. Opportunities for ‘gaming’ the escalation of care

Research Ethics

In line with guidance from the NHS Health Research Authority, this study did not require ethical review by an NHS Research Ethics Committee or management permission through the NHS R&D office. Approval for the initial survey was obtained from the OAA Audit Subcommittee.

RESULTS

We received 120 usable charts. We identified many examples of good design, however 30% contained at least one design error with the potential to confuse staff, render the charts difficult to use or compromise patient safety. Examples of some errors have been recreated (for clarity and unit anonymity) and are presented in Figures 1-10 and Supplementary Figures 1-12.

A. Identification of the patient

All patient records should contain patient identifiers (i.e., first name, surname, date of birth, unique identifier [e.g., hospital number]).[16] However, only 55/120 (46%) charts included space for a patient identification label, with a further 62/120 (52%) providing space for hand-written patient details. Three charts (2%) contained no such allocated space.

B. Chart style and layout

An observation chart should display data to facilitate the prompt detection of clinical deterioration. Charts did not always display critical information in order of importance, or use colour and lines thoughtfully. There was often data duplication and the display of unnecessary information. Additionally, some charts failed to display the measurement units of some vital signs. We also noted charts where vital sign documentation and the scoring guide/escalation instructions spanned two sides of paper, thereby requiring temporary data memorization and potentially risking error. The design of other charts was such that considerable training seemed necessary for their correct use.

B1. Use of colour

Colour can be a powerful tool for improving chart usability.[14,15] However, several charts were over-complicated by its use, or demonstrated that poor colour choice or use leads to errors. One chart (Figure 1) used white, yellow, pink, red and purple for the weighting of respiratory rate, with a weighting of two being applied to respiratory rates in both the red and pink zones. Another chart (Figure 2) used colours inconsistently, with the following scheme for the weighting of respiratory rate: white=0, blue=1 and 2, and red=3, but a different scheme for temperature: white=0, blue=1, 2 and 3. Supplementary Figure 1 shows a typical chart employing a 0-3 aggregate EWS system and a pink shaded area to highlight abnormal physiological values. However, the whole of the row used to document S_pO_2 values is shaded pink, i.e. all documented S_pO_2 values appear abnormal. The chart shown in Supplementary Figure 2 uses unnecessary graduated, grey shading.

The lack of colour standardisation is highlighted when considering the numerous schemes used to represent ‘mildly’ and ‘markedly’ abnormal respiratory rate ranges (e.g., red and orange, red and yellow, red and amber, orange and yellow, and pink and yellow, with the exact shades used differing to varying degrees).

Supplementary Figure 3 demonstrates that coloured EWS weightings superimposed with good intention on vital sign ranges could distract users. Similarly, Supplementary Figure 4 demonstrates how a lack of attention to detail can lead to errors in colour shading and weighting values (here for pulse rates of 81-90). We also found examples of charts using red and green concurrently - a potential hazard for staff with red-green colour-blindness.

B2. Graphical versus tabular layouts/displays

Displaying data in a graphical or pictorial form facilitates its understanding and aids detection of abnormality.[7,17] In one chart, the physiological trend would be undetectable because of the lack of granularity of the ordinate scale. In Figure 3, although yellow shading is used to identify abnormal values, without appropriate training staff might simply tick the ‘>38’ or ‘<36’ box if the patient’s temperature exceeds the normal ranges, rather than documenting actual values.

We also found examples of several vital signs being plotted on the same chart section. This cluttered the display and could slow data interpretation, obscure deterioration and/or lead to vital signs being mixed up (Figure 4 and Supplementary Figure 2). In addition to the use of graduated, grey shading, Supplementary Figure 2 includes a thick, horizontal black line that relates to a temperature of 37°C and/or a BP of 180mmHg. However, both design aspects have the potential to conceal that a systolic BP (sBP) >160mmHg is abnormal and scores 3 points, as the value lies within the chart’s unshaded zone and below the thick horizontal black line.

B3. Integration of EWS systems in the observation chart

Disparities between the physiological values used to reflect normal physiology in different areas of the chart and policy occurred frequently. On one chart (Figure 5), the normal ranges for respiratory rate and S_pO_2 were identified as 11-20bpm and 95-100%, respectively, whereas the chart’s escalation plan used different values. Moreover, a S_pO_2 value of 91% lies within a red (i.e., markedly abnormal) zone on the chart but, according to the escalation plan, would not require a referral to the obstetric team. In contrast, a respiratory rate of 27bpm lies within a yellow (i.e., mildly abnormal) zone on the chart, yet on its own does warrant a referral. A similar chart (Supplementary Figure 5), using a yellow/red scheme to highlight ‘mildly’/’markedly’ abnormal ranges, used different ‘normal’ heart rate values on the chart and accompanying weighting table.

Disparities become more prominent when charts attempt to incorporate both the yellow/red approach to escalation and an EWS weighting table. For example, in Figure 6, the shaded white, yellow and red zones on the chart bear little relationship to the weightings in the EWS table. A temperature of 37.6°C lies in a 'white' (i.e., normal) zone on the chart but scores one point in the EWS table, whereas a value of 38.4°C also scores one point but lies in the chart's 'red' (i.e., markedly abnormal) zone. Another error is illustrated in Supplementary Figure 6, where the scoring system assigns two and four points to vital signs in the 'yellow' and 'red' ranges, respectively, making a score of five in the escalation algorithm impossible.

B4. Alignment and labelling of axes; row and column shift

To record physiological measurements accurately and quickly, a chart's axes and their labelling must be clear and precise. We found numerous examples of poorly aligned axes, which could delay chart completion and introduce error when tracking values temporally (Figure 7). There were also charts with different weightings on the left and right vertical axes (Supplementary Figure 7); different pain score ranges on the left (0-4) and right (0-5) (Supplementary Figure 8); and where a range referred to the wrong parameter (i.e. respiratory rate instead of SpO_2) (Supplementary Figure 9). Another chart (Supplementary Figure 10) doubled the vertical scale width for the temperature range from 36°C to 38°C, which magnified the visual impact of temperature changes in the 'normal' range.

'Row shift' and 'column-shift 'occur when users accidentally 'jump' into the wrong row or column when recording or reading vital signs data.[12,14,15] Traditionally, vertical chart axes are labelled on the left. Good practice suggests that the vertical axis should be labelled on both sides of the chart to reduce the risk of 'row shift' and that placing thicker vertical black lines every three columns reduces the risk of 'column shift'.[15] Labelling vertical chart axes on both sides also assists left-handed staff whose left hand may cover the left-hand scale during documentation. Many charts did not incorporate such features.

Labelling graphs may also prove problematic, ranging from the obvious omission of a legend for sBP (Supplementary Figure 11) to the use of language for, specifically, abbreviations and measurement units. For example, we observed the use of several terms for the same physiological parameter: 'maternal heart rate', 'heart rate', 'pulse rate', 'pulse', 'HR', 'PR' and 'P'. Sometimes charts used two different abbreviations (e.g., 'pulse rate' and 'HR'), for the same parameter, even though HR (heart rate) and pulse rate are different parameters and may not have the same value.

B5. Illogical ranges

A common error involved the use or omission of 'less than' (<) and 'more than' (>) symbols within scoring ranges, making it impossible for staff to know which weighting value to apply to a parameter, e.g., how to handle respiratory rates of 20bpm and 30bpm (Figure 8), sBP values of

90mmHg, 100mmHg and 150mmHg (Figure 9) and SpO_2 values of 85% (Supplementary Figure 12).

B6. Opportunities for 'gaming' the escalation of care

Illogical vital signs ranges have the potential to provide staff with the opportunity to 'choose' a 'desired' escalation pathway by 'manipulating' the measured value that is documented. We describe this as 'gaming'. One factor that encourages 'gaming' is the use of EWS weighting boundaries where minimal variation in a measured physiological value results in a large step in vital sign weighting. For example, in Figure 10, a sBP value of 149mmHg is considered 'normal', scoring zero, whereas a value of 150mmHg scores three points and requires staff to summon immediate help. Therefore, staff can 'elect' whether to escalate care or not simply by manipulating the sBP value that they record.

DISCUSSION

Whilst it is beyond the scope of this article to describe them, we found many examples where chart design adhered to the 'good design practice' outlined in the referenced documents.[14,15] However, 30% of maternal observation charts contained at least one significant design error. The most common faults included inadequate patient identification, poor use of colour, illogical weighting and escalation ranges, poor alignment and labelling of axes, and the opportunity for staff to 'game' the escalation. Overall, the usability of some charts appeared poor. Such errors could lead to delays or difficulties in chart completion, inaccurate scoring and incorrect use of the clinical escalation protocol, resulting in the summoning of immediate support when not required, or, manifestly worse, failure to escalate care when an urgent clinical response is necessary.

These findings imply a lack of attention to detail in the development of charts. Chart design is often undertaken by 'interested' individuals or by those perceived as having some experience in this regard. However, constructing a chart on the subjective judgements of health professionals is not ideal,[7,18] especially if they lack design, ergonomics and human factors knowledge. Many of the charts surveyed had used the CEMACH-endorsed chart as their foundation,[4] implementing it in an unchanged or slightly modified way.[3,10] Consequently, we found that charts often contained similar design errors, probably arising from a practice of copying charts from one organisation to another.

For over a decade, there have been calls to introduce a national obstetric early warning system and chart for the UK,[1,4,19] similar to those used for non-pregnant adults. Given our findings, it seems time for a single body to show leadership by developing a properly designed, standardised obstetric observation chart, as has been done for non-pregnant adults by the Australian Commission on Safety and Quality in Health Care (ACSQHC).[14,15,20]

Standardisation in healthcare brings many benefits, including reduced error rates, consistent clinical decision-making, opportunities for uniform staff training, better quality of care and improved patient safety.[21] However, standardised systems may be perceived as a challenge to professional autonomy and jurisdiction.[22] Therefore allowing focused, directed variation of a basic 'standard' chart, as is done by the ACSQHC, may be a way of engaging staff and facilitating improved care.[23]

Our study has several strengths and weaknesses. It is the first to consider design errors in obstetric vital signs charts and to highlight their possible impact. Two researchers used a common, objective, systematic approach to interrogate the charts independently. However, not all maternity units in the UK and the Channel Islands are represented by the OAA audit database and this may have led to selection bias. In addition, our data may be subject to non-response and volunteer bias since only 65.5% of invited lead anaesthetists returned charts. Nevertheless, our findings would probably be unchanged (other than in magnitude) by charts from additional units.

Our results mirror the ACSQHC findings that general observation charts frequently have substantial usability problems that may affect the ability of clinical staff to record observations accurately or recognize patient deterioration. We believe that there must be a multi-pronged response to the issues that our work raises. We recommend that individual units urgently and carefully scrutinise their own obstetric observation charts and remedy any design errors. In addition, we recommend that a UK body urgently develops an evidence-based standard obstetric observation chart, which integrates the lessons learned from the scientific study of 'human factors' with user experience. This should be underpinned by research and consensus regarding: (a) 'normal' vital signs ranges in pregnancy and postnatally, (b) a preferred aggregate-weighted EWS, and (c) the EWS value at which care escalation occurs. Such a chart must have a clear layout and style, an appropriate colour scheme, correct language and labelling, and the ability to record vital signs accurately and quickly. It should incorporate a suitable escalation score to guide clinical management.

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LEGENDS FOR FIGURES:

Figure 1

Chart using white, yellow, pink, red and purple for the weighting of respiratory rate, with a value of two being applied to respiratory rates in both the red and pink zones of the chart.

Figure 2

Chart using the following scheme for the weighting of respiratory rate values: white=0, blue=1 and 2, and red=3, whilst a different scheme is used on the same chart for weighting temperature values, i.e., white=0, blue=1, 2 and 3.

Figure 3

Chart that uses yellow shading to identify abnormal values. Without appropriate training, staff might simply tick the '>38' or '<36' box if the patient's temperature exceeds the normal ranges, rather than documenting actual values.

Figure 4

Chart where several vital signs are documented on the same section, cluttering the display or potentially obscuring deterioration.

Figure 5

Chart using a yellow/red colour scheme where the normal ranges for respiratory rate and S_pO_2 are identified as 11-20bpm and 95-100%, respectively, but the chart's escalation plan uses different values.

Figure 6

Chart where normal physiological ranges used on the chart differ from those in the EWS table. The shaded white, yellow and red zones on the chart bear little relationship to the weightings. For example, a temperature of 37.6°C lies in a 'white' (i.e., normal) zone on the chart but scores one point in the EWS weighting table, whereas a value of 38.4°C lies in the chart's 'red' (i.e., markedly abnormal) zone and also scores one point.

Figure 7

Chart with a poorly aligned axis for heart rate values.

Figure 8

Chart with poor use of the 'less than' (<) and 'more than' (>) symbols within scoring ranges, making it impossible for staff to know which weighting value to apply to respiratory rates of 20bpm and 30bpm.

Figure 9

Chart with poor use of ranges, making it impossible for staff to know how to handle systolic blood pressure values of 90mmHg, 100mmHg and 150mmHg.

Figure 10

Chart that facilitates ‘gaming’, in which staff can ‘choose’ a ‘desired’ escalation pathway by minor ‘manipulation’ of the documented physiological value. In this example, the small change in documented systolic blood pressure between 149mmH and 150mmHg results in large changes in vital sign weighting and clinical actions.

SUPPLEMENTARY FILE LEGEND

Supplementary Figures 1-12 demonstrating a range of design errors in vital sign charts used in consultant-led maternity units in the United Kingdom

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COMPETING INTERESTS

GBS was a member of the following groups: Royal College of Physicians of London’s National Early Warning Score Development and Implementation Group; National Institute for Health and Care Excellence Guideline Development Group on ‘Acutely ill patients in hospital. Recognition of and response to acute illness in adults in hospital’; National Patient Safety Agency Observatory group considering ’Deterioration not recognised or not acted on’; Department of Health Emergency Care Strategy Team’s ‘Competencies for Recognising and Responding to Acutely Ill Patients in Hospital’.

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FUNDING

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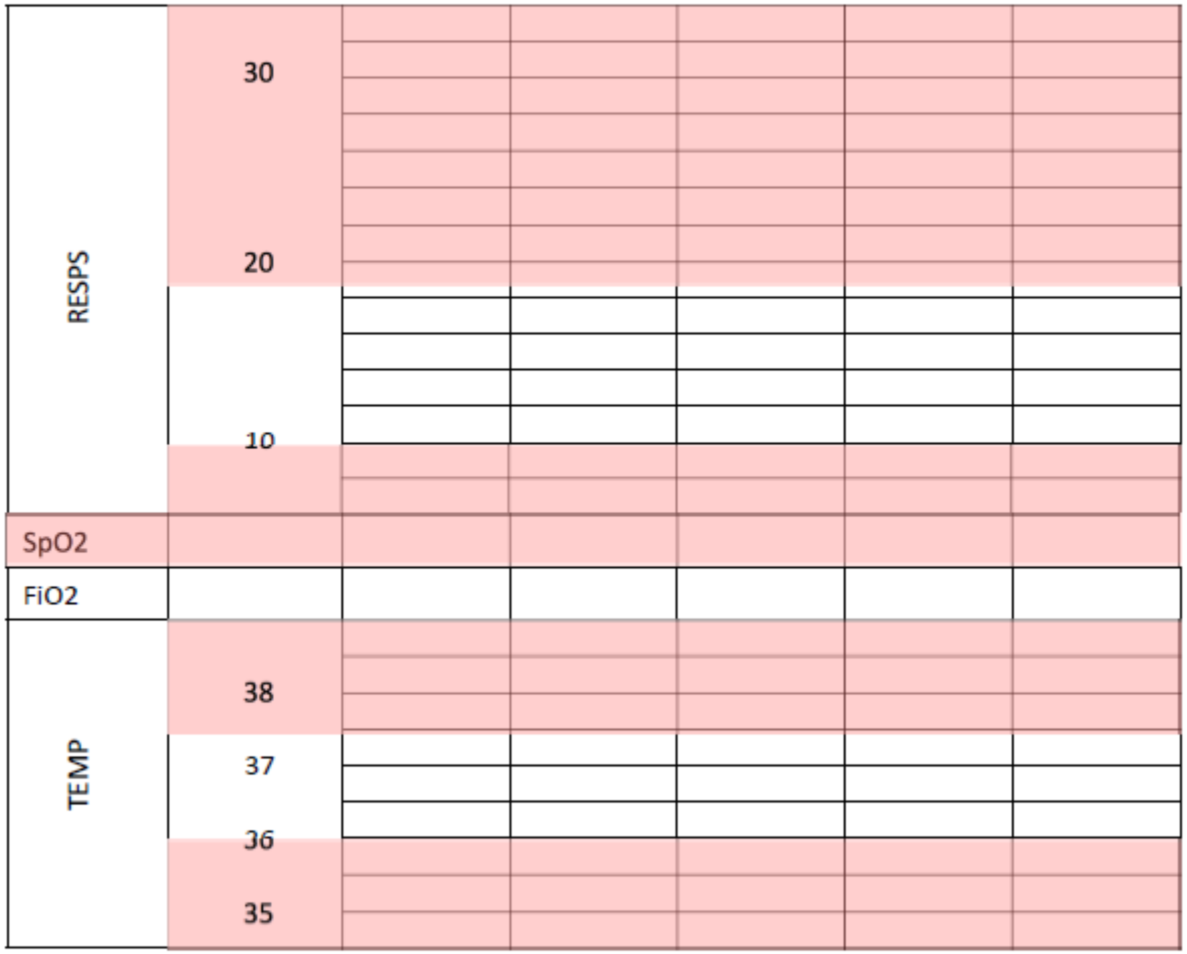
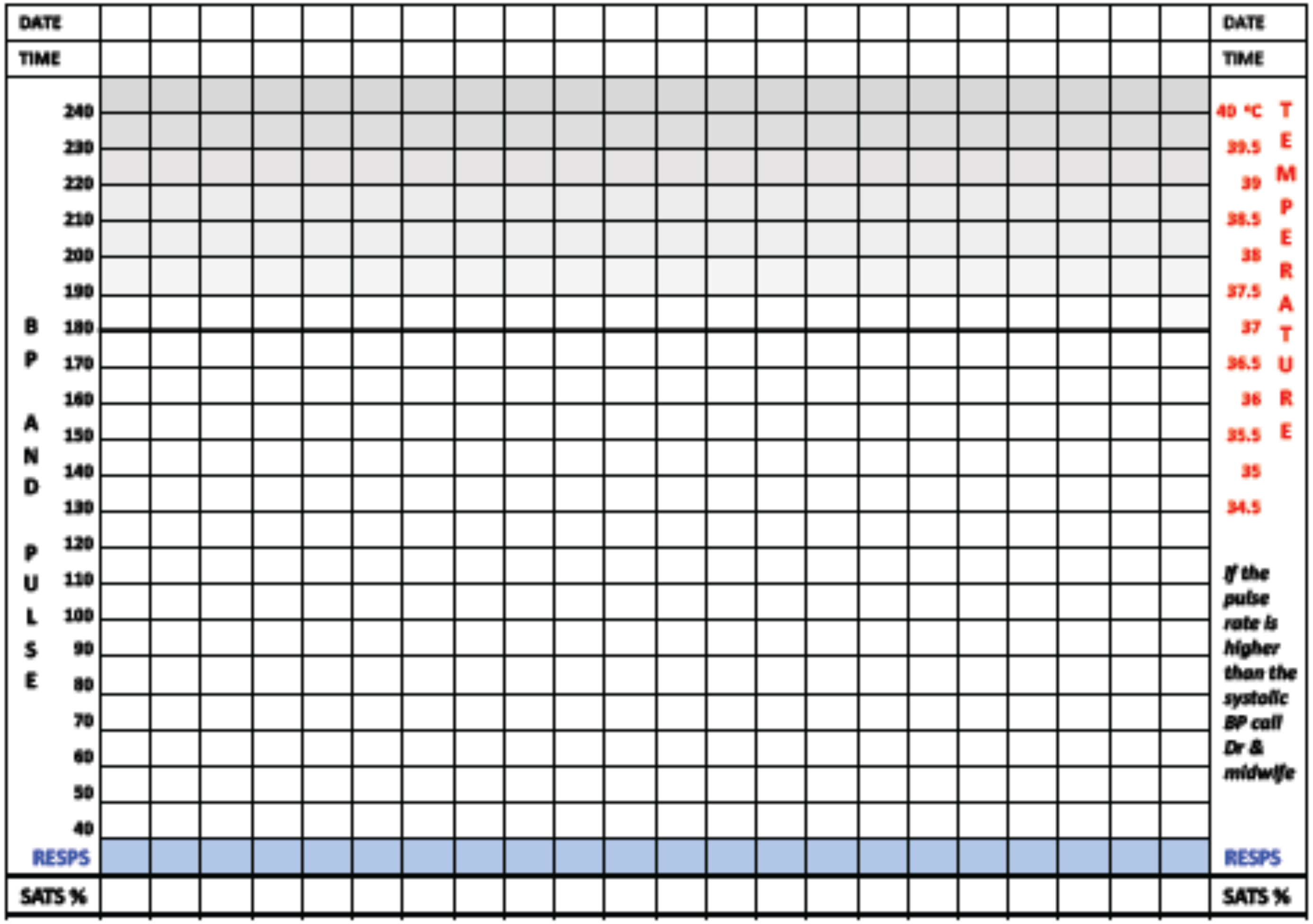
Supplementary Figure 1



Supplementary Figure 2



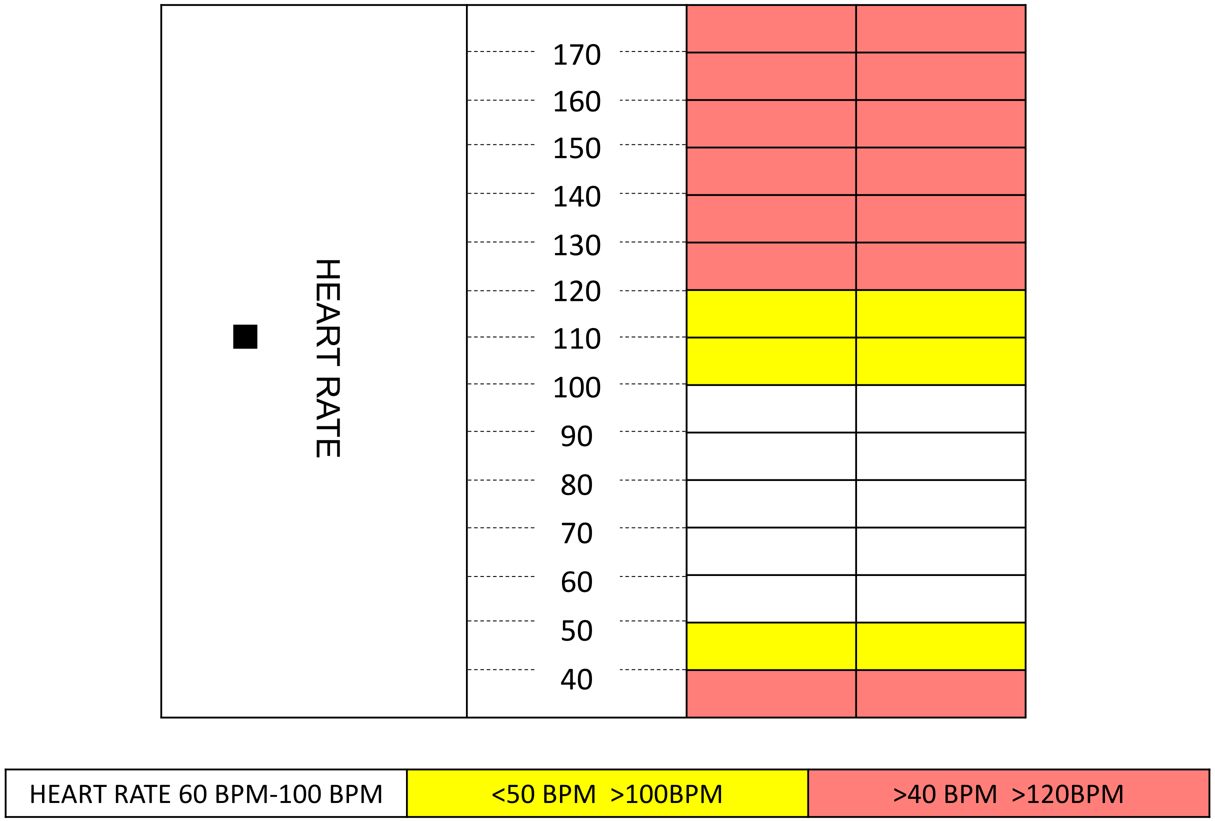
Supplementary Figure 3

	3	2	1	0	1	2	3
TEMP		<35.0		35.0-37.4		37.5-39	>39 C
BP Systolic	≤70	71-79	80-89	90-139	140-149	150-159	≥160
BP Diastolic			≤45	46-89	90-99	100-109	≥110
PULSE		≤40	41-50	51-100	101-110	111-129	≥130
RESPS		≤8		9-14	15-20	21-29	U30
AVPU				ALERT	VOICE	PAIN	UNCON
URINE mls/hour	<10	<30		Not measured			

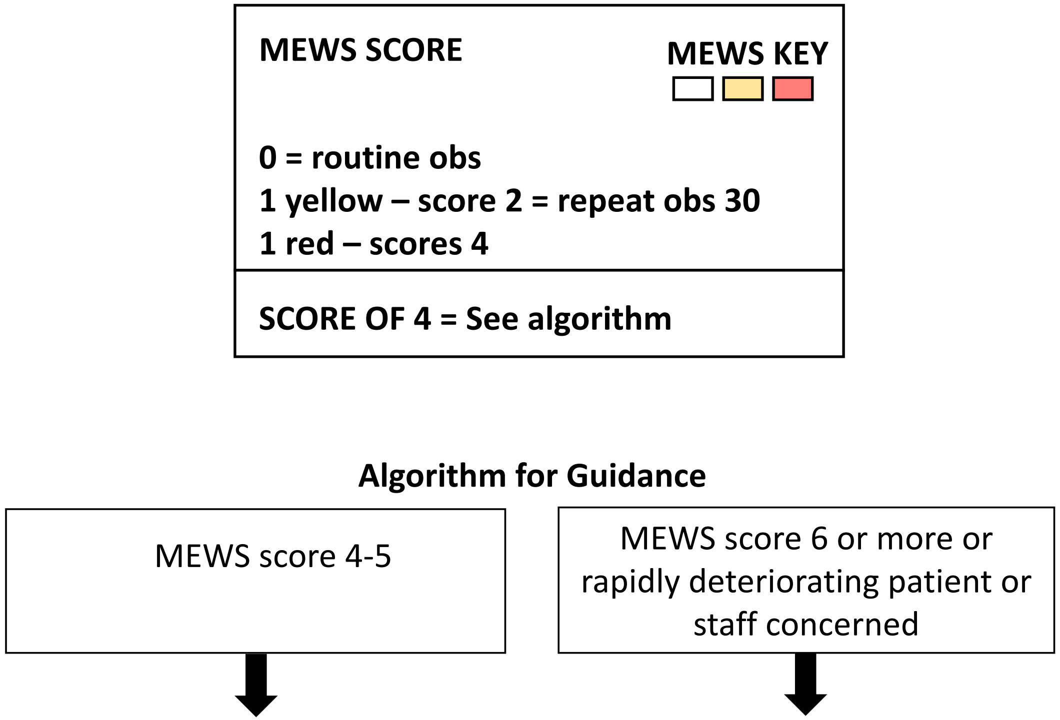
Supplementary Figure 4

101-110	1	
91-100	1	
81-90	0	
71-80	0	
61-70	0	
51-60	0	

Supplementary Figure 5



Supplementary Figure 6

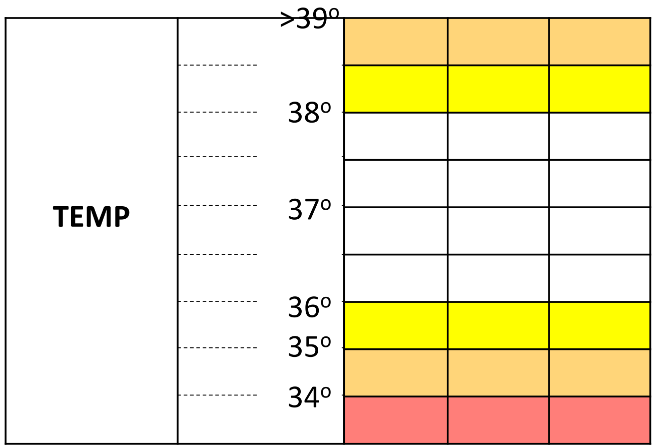


Supplementary Figure 7

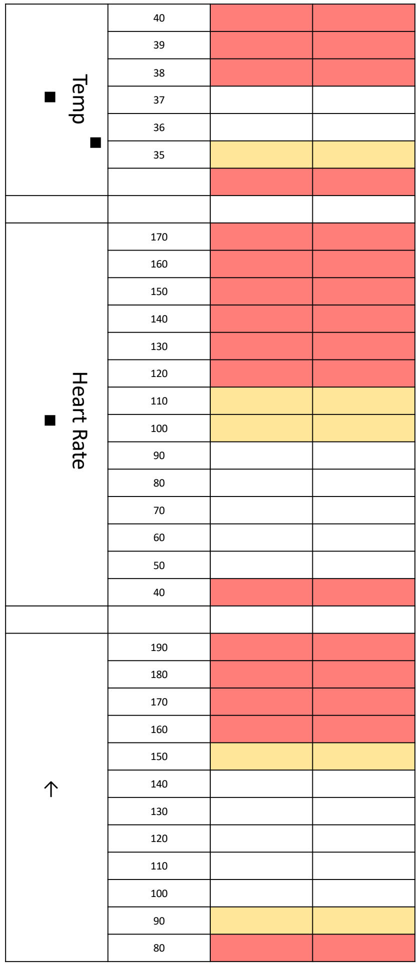
RESP rate (write rate in corresp. box)	>30			
	21-30			
	11-20			
	0-10			
Saturations	95-100%			
	<95%			

			>30
			21-30
			11-20
			0-10
			11-20
			<95%

Supplementary Figure 8



Supplementary Figure 9



Supplementary Figure 10

MEOWS score system	3	2	1	0	1	2	3
Temp		<35		35-37.4	37.5	>38	
Heart rate/min		<40	40-50	51-100	101-110	111-129	>129
BP (Syst)	<70	71-80	81-100	101-109	140-159	>160	>180
BP (Diast)		<50		50-99		>100	>110
Resps/min		<8		9-16/min	17-20	21-29	>30
AVPU			Agitated	Alert	Voice	Pain	Unresponsive
Urine (cath) (no cath)	<10/h	<100ml/hr		>100ml/hr	NPU/4hrs	NPU/6hrs	NPU/10hrs
O2 sats (in air)	<85	86-89	90-94	>95			