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# BMJ Open

## Validation of oxygen saturations measured in the community by emergency medical services as a marker of clinical deterioration in patients with confirmed COVID-19

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Complete List of Authors:	Inada-Kim, Matthew; Hampshire Hospitals NHS Foundation Trust, Department of Acute Medicine Chmiel, Francis P.; University of Southampton Boniface, Michael; University of Southampton Burns, Daniel; University of Southampton Pocock, Helen ; South Central Ambulance Service NHS Foundation Trust; University of Warwick Black, John; South Central Ambulance Service NHS Foundation Trust; Oxford University Hospitals NHS Foundation Trust, Emergency Department Deakin, Charles ; South Central Ambulance Service NHS Foundation Trust; University Hospital Southampton NHS Foundation Trust
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5 2 **Validation of oxygen saturations measured in the community by emergency medical**  
6 3 **services as a marker of clinical deterioration in patients with confirmed COVID-19**  
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12 6 Matthew Inada-Kim<sup>[1]</sup>

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14 7 Francis P. Chmiel<sup>[2]</sup>

15  
16 8 Michael J. Boniface<sup>[2]</sup>

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18 9 Helen Pocock<sup>[3,4]</sup>

19  
20 10 John J. M. Black<sup>[3,5]</sup>

21  
22 11 Charles D. Deakin<sup>[3,6]</sup>

23  
24  
25 13 [1] Acute Medical Unit, Department of Acute Medicine, Hampshire Hospitals NHS Foundation Trust, Winchester, United  
26 14 Kingdom.

27 15 [2] School of Electronics and Computer Science, University of Southampton, Southampton, SO17 1BJ, UK

28 16 [3] South Central Ambulance Service NHS Foundation Trust, Otterbourne, SO21 2RU, UK

29 17 [4] Warwick Clinical Trials Unit, University of Warwick, Coventry, CV4 7AL, UK

30 18 [5] Emergency Department, Oxford University Hospitals NHS Foundation Trust OX3 9DU.

31 19 [6] Southampton Respiratory Biomedical Research Unit, National Institute for Health Research, University Hospital  
32 20 Southampton, SO16 6YD

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24 **ABSTRACT**

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26 **Background** The early identification of deterioration in COVID-19 patients managed at home enables  
27 a more timely clinical intervention, which is likely to translate into improved outcomes. We  
28 undertook an analysis of COVID-19 patients conveyed by emergency medical services (EMS) to  
29 hospital to investigate how oxygen saturation and measurements of other vital signs correlate to  
30 patient outcomes, to ascertain if clinical deterioration can be predicted with simple community  
31 physiological monitoring.

32 **Methods** A retrospective analysis of routinely collected clinical data relating to patients conveyed to  
33 hospital by EMS was undertaken. We used descriptive statistics and predictive analytics to  
34 investigate how vital signs, measured in the community by EMS staff, correlate with patient  
35 outcomes. The primary study outcome was admission to ICU within 30-days of conveyance. ROC  
36 analysis was performed to evaluate, in a retrospective fashion, the efficacy of different variables in  
37 predicting patient outcomes.

38 **Results** We identified 1,080 adults with a COVID-19 diagnosis who were conveyed by EMS to either  
39 Basingstoke & North Hampshire Hospital or the Royal Hampshire County Hospital (Winchester)  
40 between March 1<sup>st</sup> and July 31<sup>st</sup>. Vital signs measured by EMS staff at first point of contact in the  
41 community correlated with patient 30-day ICU admission and mortality. Oxygen saturations were  
42 the most predictive of 30-day ICU admission (AUROC 0.753 (95 % CI: 0.668-0.826)), followed by the  
43 NEWS2 score (AUROC 0.731 (95 % CI: 0.655-0.800)), temperature (AUROC 0.720 (95 % CI: 0.640-  
44 0.793)), and respiration rate (AUROC 0.672 (95 % CI: 0.586-0.756)).

45 **Conclusions** Initial oxygen saturation measurements (on air) for confirmed COVID-19 patients  
46 conveyed by EMS correlated with short-term patient outcomes, demonstrating an AUROC of 0.753  
47 (95% CI: 0.668-0.826) in predicting 30-day ICU admission. We found that even small deflections in  
48 oxygen saturations confer an increased risk of adverse outcome in those with confirmed COVID at  
49 their initial community assessments.

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3 51 **KEY MESSAGES**  
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5 52 **What is already known on this subject**  
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7 53 COVID-19 has high morbidity and mortality and earlier recognition enabling timely hospital  
8 54 admission, particularly in the light of recent discoveries of effective disease modifying treatments, is  
9 55 very likely to improve outcomes. Complex scoring system tools have been proposed to predict those  
10 56 at highest risk of deterioration but these are not always practical in community settings. Home self-  
11 57 monitoring of COVID-19 patients using pulse oximetry to detect early desaturation and enable timely  
12 58 hospital care is unproven but may have potential to improve mortality rates and a range of other  
13 59 clinical outcomes.

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16 60 **What this study adds**  
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18 61 This is the first study to report that baseline (community) oxygen saturation measurements (on air)  
19 62 for confirmed COVID-19 patients conveyed by EMS to hospital for further management correlated  
20 63 with short-term (30-day) ICU admission and/or mortality. Oxygen saturations alone correlate with  
21 64 the need for ICU admission and early death. Small deflections in oxygen saturations below 96% (i.e.  
22 65 low normal range in adults) also confers an increased deterioration risk in patients with confirmed  
23 66 COVID-19 at the time of their initial community assessment by EMS.  
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## 67 INTRODUCTION

68 COVID-19 presents the biggest global healthcare challenge of our generation. As of February 2021,  
69 COVID-19 associated mortality stands at over 110,000 in the UK [1]. COVID-19 presents a number of  
70 challenges in identifying optimal management pathways, not only in terms of the clinical care itself,  
71 but also identifying the stage at which hospital admission is necessary. Traditional management  
72 pathways involving paramedic assessment and conveyance to the Emergency Department (ED) for  
73 further review have proven impractical, not only because of the large numbers of patients involved,  
74 but because of the need to minimise contact of COVID-19 patients with others. Most patients who  
75 become symptomatic do so in a home environment where the majority will remain. In terms of  
76 optimising outcome, there is a need to understand which symptoms and signs in this environment  
77 are prognostic indicators of potential deterioration. The national recommendation for the  
78 implementation of COVID virtual wards recently announced by NHS England,[2] ushers in a novel  
79 approach of empowering patients through providing symptomatic, at risk patients a pulse oximeter  
80 and a toolkit for self-monitoring at home. It is hoped that this will enable the earlier recognition of  
81 deterioration in COVID-19 patients and potentially improved outcomes.

82 In most cases of bacterial and non-COVID pneumonia, breathlessness appears relatively early in the  
83 disease and ahead of any significant hypoxia. The challenge with assessing COVID-19 severity is that  
84 asymptomatic hypoxia often precedes breathlessness and by the time symptoms of breathlessness  
85 occur, patients have developed advanced disease and hypoxia may be significant.[3] The ability to  
86 detect this asymptomatic hypoxia before patients experience shortness of breath is critical for  
87 preventing respiratory involvement progressing to a life-threatening state. The key is to be able to  
88 detect this initial drop in oxygen saturation levels so that patients infected with COVID-19 who begin  
89 to suffer from pulmonary complications in the community can be detected early and conveyed to  
90 hospital for further treatment.[4] Although some studies have reported the relationship between  
91 oxygen saturation and outcome on presentation to the ED, we are not aware of any studies that  
92 have reported the relationship between oxygen saturations measured in the community by EMS and  
93 outcome. Patients who on assessment are severely hypoxic are clearly in need of emergency  
94 conveyance and hospital treatment, but by far the majority of patients with Covid-like symptoms  
95 seen and assessed by the EMS have relatively normal or near-normal oxygen saturations. These  
96 patients have generally not been conveyed and have been managed at home, but it has become  
97 apparent that even relatively minor derangements in oxygen saturations may be an early warning  
98 indicator for disease progression and the subsequent need for critical care. Use of oxygen saturation  
99 as an indicator of disease severity may therefore underestimate the risk of leaving patients at home  
100 after assessment by the EMS. National case fatality rates (CFR) (ratio of deaths to total cases) have

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3 101 shown a strong inverse correlation between target oxygen saturation levels of 90-98% [5] suggesting  
4 102 that even mild derangements in oxygen saturation untreated can be detrimental to outcome.

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7 103 Understanding the prognostic implications of oxygen saturation when first measured by EMS  
8 104 clinicians would enable safe and effective triage and potentially improve outcome through early  
9 105 identification of those most at risk of disease progression. Two small studies have suggested the  
10 106 utility of home oxygen monitoring for COVID-19 patients discharged from hospital,[6, 7] but no  
11 107 studies to our knowledge have used out-of-hospital oxygen saturation measurements as a trigger for  
12 108 initial hospital assessment. With second waves of COVID-19 sweeping most European countries,  
13 109 there is an urgent need to establish the prognostic significance of initial oxygen saturation to enable  
14 110 effective triage and optimise the use of limited healthcare resources, not only for those with COVID-  
15 111 19, but for the far greater majority with non-COVID-19 illness who have been deprived of timely  
16 112 healthcare as a consequence.

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19 113 We therefore undertook a retrospective review of clinically confirmed COVID-19 patients accessing a  
20 114 regional UK ambulance service who were conveyed to hospital and correlated their initial oxygen  
21 115 saturations measured at home with their in-hospital outcome. These were compared with the  
22 116 standard NEWS2 patient score, as used by all UK ambulance services, to identify the deteriorating  
23 117 patient.[8]

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## 121 **METHODS**

### 122 **Study Design**

123 We conducted a retrospective cohort analysis of adult patients (aged 18 years of older) initially  
124 assessed and conveyed by personnel from South Central Ambulance Service (SCAS) to the  
125 Emergency Department at one of the two hospitals within north Hampshire; Basingstoke & North  
126 Hampshire Hospital, or the Royal Hampshire County Hospital (Winchester) at which the patients  
127 were subsequently admitted

128 All calls to the relevant EMS, both emergency (999) and urgent (111) are triaged using NHS Pathways  
129 telephone script (release 19). We analysed EMS conveyances occurring between 1<sup>st</sup> March to 31<sup>st</sup>  
130 July 2020, to determine suspect COVID-19 among conveyances at initial time of contact by the call  
131 taker or EMS staff, each patient record was reviewed for inclusion of at least one of the following  
132 four identifiers:

- 133 1. Those in who the EMS call taker had classified the call as 'COVID– Respiratory Distress'
- 134 2. Those where the Patient Clinical Record (PCR) listed the 'Presenting complaint' as 'Suspected  
135 COVID-19'.
- 136 3. Those where the PCR free text for the 'Presenting complaint' contained the word 'COVID'
- 137 4. Those where the PCR narrative in the free text field summarising the symptoms and their  
138 details completed by the paramedic contained the word 'COVID'.

139 Conveyances from these suspect COVID-19 patients were then linked to their subsequent hospital  
140 attendance. Of suspect cases, we then identified confirmed COVID-19 cases by selecting only those  
141 with a confirmed diagnosis in their discharge summary (i.e., the presence of a U07.1 or U07.2 ICD10  
142 code). These confirmed COVID-19 cases made up our study cohort.

143 All patients in known palliative care pathways were excluded from data analysis because their care  
144 did not follow standard care pathways.

### 145 **Study setting**

146 SCAS is a provider of emergency care in the counties of Hampshire, Berkshire, Buckinghamshire and  
147 Oxfordshire and covers a total of 3554 sq. miles (9205 km<sup>2</sup>). The service receives approximately  
148 500,000 emergency and urgent calls annually. SCAS covers a residential population of approximately  
149 4.0 million inhabitants in a mix of urban and rural areas. The north Hampshire region forms part of  
150 the area covered by SCAS and comprises a residential population of approximately 306,000.[9]

151

## 152 **Data collection**

153 The initial oxygen saturation reading (SpO<sub>2</sub>) on air recorded by the attending EMS staff (prior to any  
154 exercise or step test) and the NEWS2 score of patients fulfilling the inclusion criteria were collected  
155 from the EMS PCR. (NEWS2 score is calculated using the following seven variables: systolic blood  
156 pressure, heart rate, respiratory rate, temperature, oxygen saturation, supplemental oxygen  
157 administration, and level of consciousness - [https://www.england.nhs.uk/ourwork/clinical-  
158 policy/sepsis/nationalearlywarningscore.](https://www.england.nhs.uk/ourwork/clinical-policy/sepsis/nationalearlywarningscore))

159 Patient outcome was obtained by linking the SCAS and hospital clinical records by their NHS number.  
160 The primary outcome of our study was ICU admission within 30-days of conveyance and the  
161 secondary outcomes was mortality and a combined outcome (ICU admission and/or mortality)  
162 within 30-days of conveyance.

## 164 **Data analysis**

165 Analysis was performed in Python 3.7.2 [10], primarily making use of the statsmodels library [11].  
166 Confidence intervals on observed mortality rates were estimated using the Wilson score interval.  
167 Where relevant, significance of the difference between two observed adverse outcome rates were  
168 tested using a two-population proportions z-test with the null hypothesis that the two-population  
169 proportions are equal.

170 To evaluate how predictive individual variables (e.g., oxygen saturation) and combinations of  
171 variables (e.g., oxygen saturation with age) were of 30-day adverse outcomes, we performed  
172 Receiving Operator Characteristics curve analysis (Table 2 and Table 3). In the univariate analysis, we  
173 performed a complete case analysis (removing any patient with an incomplete record of vital signs,  
174 Table 1) and assume a patient's adverse outcome risk is a linear function of the respective variable  
175 (where negative or positive correlation with outcome is assessed by clinical judgement) and  
176 calculated the ROC curve corresponding to if this variable alone was used to predict a patients risk  
177 of an adverse outcome. We present both the sensitivity and specificity or the Area Under the  
178 Receiving Operator Characteristic curve (AUROC). The AUROC provides an estimate of the degree to  
179 which the predictor can discern between whether a patient has an adverse outcome within 30 days  
180 of conveyance or not, it can take values between 0.5 and 1.0. An AUROC of 0.5 corresponds to  
181 randomly guessing which patient have an adverse outcome within 30 days and an AUROC of 1.0  
182 corresponds to a perfect classifier - it can predict, without error, who will have an adverse outcome  
183 within 30-days of conveyance. Confidence intervals were estimated by performing 1000

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3 184 bootstrapping (sampling with replacement) iterations on the available data, calculating the AUROC  
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5 185 on each of the samples and then calculating the relevant percentiles.  
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7 186 **Patient and Public Involvement**  
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9 187 This research was done without patient involvement. Patients were not invited to comment on the  
10  
11 188 study design and were not consulted to develop patient-relevant outcomes or interpret the results.  
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13 189 Patients were not invited to contribute to the writing or editing of this document for readability or  
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15 190 accuracy.  
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17 191 **Governance and ethics approval**  
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19 192 Regulatory and ethical approval for the study were provided by the Health Research Authority (REC  
20  
21 193 reference 20/HRA/5445) and by the University of Southampton Ethics Committee (REF  
22  
23 194 ERGO/61242). NHS England and NHS Improvement have been given legal notice by the Secretary of  
24  
25 195 State for Health and Social Care to support the processing and sharing of information to help the  
26  
27 196 COVID-19 response under Health Service Control of Patient Information Regulations 2002  
28  
29 197 (COPI). This is to ensure that confidential patient information can be used and shared appropriately  
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31 198 and lawfully for purposes related to the COVID-19 response. Data were extracted from medical  
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33 199 records by clinicians providing care for the patients and an anonymised extract of the data were  
200  
201 provided to the team at the University of Southampton.  
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## 204 RESULTS

205 A total of 19,868 patients were assessed at home and subsequently conveyed by EMS to North  
206 Hampshire Hospitals during the study period. The call handler or EMS staff identified 2,257 suspect  
207 COVID-19 cases and of these we identified 1,209 adults as having a confirmed diagnosis of COVID-19  
208 (U07.1 or U07.2 coded in the patients discharge summary). Of the 1,209 confirmed cases we  
209 removed persons under palliative care (112 patients) and those with no initial oxygen saturation  
210 measurement on air recorded (17 patients). Overall, this left us with 1,080 confirmed COVID-19  
211 patient records all of whom had initial oxygen saturation measurements on air. Of these 1,080, the  
212 complete records of vital signs were recorded at home by paramedics for 892 of the patients (Table  
213 1). In our following discussions, we make use of all 1,080 patients, with the exception for our  
214 univariate analysis (discussed in Table 3) where we perform a complete case analysis and only use  
215 the 892 complete records.

216 Oxygen saturation was found to correlate with adverse outcome (Figure 2), with lower initial oxygen  
217 saturation readings being associated with a higher mortality rate. In Figure 2 we display the  
218 correlation between the observed 30-day adverse outcome rates and initial oxygen saturation in  
219 detail, which displays correlation to all outcomes. In Table 2 we display the breakdown of our  
220 retrospective ROC analysis for using measured oxygen saturation as a binary triage tool (i.e.,  
221 hospitalize or not) for different cut-offs (rows in Table 2). While the sensitivity vs specificity trade-off  
222 needs to be determined by the clinical context, this demonstrates that oxygen saturation is  
223 moderately discriminative for several cut-offs. For example, for a cut-off of 94 % or below, the  
224 sensitivity is 0.742 (95 % CI: 0.642-0.734) and the specificity is 0.706 (95 % CI: 0.678-0.734). Finally,  
225 we present comparisons of the results of ROC analysis for different variables measured in the  
226 community by EMS (Table 3). Across the three presented outcomes (30-day ICU admission,  
227 mortality, and combined outcome) correlations between variables and outcomes are broadly similar,  
228 with measured oxygen saturations and the NEWS2 score being the two most predictive of outcome.  
229 The notable differences are for the measured temperature which is moderately predictive of ICU  
230 admission (AUROC: 0.720 (95 % CI: 0.640-0.793)) but only weakly predictive of mortality (AUROC:  
231 0.597 (95 % CI: 0.523-0.678)) and for patient age which is strongly positively correlated to mortality  
232 but displays a negative correlation to ICU admission (Inspect Figure 1 a and b).

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Vital sign	Number missing	Percent missing
Heart rate	10	0.9
Systolic blood pressure	100	9.3
Respiration rate	120	11.1
Oxygen Saturation (on air)	0	0
Temperature	150	13.9
ACVPU	125	11.6
Complete Records	<b>892</b>	<b>83.0</b>

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**Table 1: Number of vital sign measurements missing and the number of complete records from 1,080 patient records.** ACVPU = alert, confused, responding to voice, responding to pain, unresponsive. Oxygen saturations were not missing for any patients as those with missing values had been excluded (n=17). Overall, records were complete for 83% of cases.

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		Sensitivity (95 % CI)	Specificity (95 % CI)	Number of observations	Cumulative sum of number of observations
Oxygen Saturation (on air) threshold (%)	85	0.294 (0.200-0.400)	0.947 (0.933-0.962)	8	76
	86	0.316 (0.216-0.421)	0.941 (0.927-0.955)	8	84
	87	0.320 (0.216-0.432)	0.935 (0.920-0.950)	6	90
	88	0.370 (0.261-0.476)	0.916 (0.899-0.933)	23	113
	89	0.413 (0.304-0.523)	0.894 (0.874-0.913)	25	138
	90	0.512 (0.411-0.615)	0.870 (0.849-0.890)	32	170
	91	0.590 (0.477-0.699)	0.841 (0.823-0.867)	31	201
	92	0.655 (0.544-0.761)	0.817 (0.796-0.841)	33	234
	93	0.706 (0.593-0.803)	0.776 (0.751-0.801)	45	279
	94	0.742 (0.642-0.840)	0.706 (0.678-0.734)	74	353
	95	0.808 (0.718-0.892)	0.634 (0.605-0.662)	76	429
	96	0.848 (0.767-0.921)	0.508 (0.477-0.538)	129	558
	97	0.898 (0.822-0.963)	0.357 (0.330-0.386)	156	714
	98	0.911 (0.841-0.973)	0.226 (0.201-0.254)	132	846
99	0.961 (0.913-1.0)	0.091 (0.075-0.109)	139	985	
100	1	0	95	1080	

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250 **Table 2: Evaluation of initial oxygen saturation measured by paramedics in COVID-19 patients in**  
 251 **the community used as a binary classifier for predicting 30-day ICU admission within 30 days of**  
 252 **conveyance.** Each row denotes a different threshold for determining those at risk of an adverse  
 253 outcome. We display the sensitivity and specificity for each threshold, equivalent to all possible  
 254 intersections of the receiving operator curve using thresholds between 85 % and 100 %. In total 68  
 255 patients had an oxygen saturation of 84 % or less (not shown). The column on the far right denotes  
 256 the cumulative sum of the number of observations of the given oxygen saturation (row) or below.  
 257 For example, 76 patients had an oxygen saturation of 85 % or less recorded (top row) and 429  
 258 patients had an oxygen saturation of 95 % or less recorded. Confidence intervals are estimated by  
 259 bootstrapping.

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Variable	AUROC (95 % CI)		
	ICU admission	Mortality	Combined
<b>Oxygen Saturation (on air)</b>	0.753 (0.668-0.826)	0.778 (0.704-0.843)	0.775 (0.727-0.829)
<b>NEWS2</b>	0.731 (0.655-0.800)	0.768 (0.709-0.823)	0.760 (0.708-0.807)
<b>Respiration rate</b>	0.672 (0.586-0.756)	0.668 (0.599-0.736)	0.677 (0.618-0.738)
<b>Temperature</b>	0.720 (0.640-0.793)	0.597 (0.523-0.678)	0.636 (0.69-0.700)
<b>Systolic blood pressure</b>	0.634 (0.560-0.706)	0.604 (0.529-0.680)	0.626 (0.568-0.684)
<b>Heart rate</b>	0.590 (0.506-0.672)	0.558 (0.486-0.631)	0.574 (0.514-0.633)
<b>Age band</b>	0.670 (0.611-0.734)	0.685 (0.626-0.738)	0.557 (0.495-0.615)

266 **Table 3: Ranked Area Under Receiver Operator Curves (AUROC) calculated for isolated**  
 267 **physiological variables and the composite NEWS2 score with each outcome.** AUROCS were  
 268 calculated using a complete case analysis (see Table 1) with 892 patients in total. Confidence  
 269 intervals are estimated by bootstrapping, with 95 % confidence intervals presented alongside the  
 270 mean validation AUROC across samples.

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**DISCUSSION**

Community assessment of patients with COVID-19 symptoms using a single initial oxygen saturation on air measurement correlates with 30-day clinical outcomes. Qualitatively, the observed 30-day adverse outcome rate is approximately constant between oxygen saturations of 100 - 96 % and then increase with decreasing oxygen saturation from 95 % to 90 %. Below 90 %, the mortality risk remains high. Although the therapeutic target range for oxygen saturations in the UK is 94-98%,<sup>[12]</sup> and in the USA is 92-96%,<sup>[13]</sup> this study suggests that patients at the lower end of this range are still at risk of deterioration in the context of COVID-like symptoms. For example, for patients in our cohort with presenting oxygen saturations in the range of 92-94 %, values often regarded as within this normal range, had a significantly ( $p=0.025$ ) higher risk of ICU admission within 30 days (5.9 %) compared to those presenting with oxygen saturations greater than 95 % (ICU admission rate 2.5 %). Outside this 'normal' range, our analysis suggests even relatively small decreases in oxygen saturation are markers of increased risk of death or ICU admission and suggest that a lower threshold for hospital conveyance may be necessary for patients who traditionally would be considered to have only minor physiological derangement and otherwise have been left at home. The sensitivity of home oxygen saturation measurements reflects the percentage of people correctly identified with adverse outcomes. The sensitivity of this parameter for adverse outcome decreased as oxygen saturation fell (Table 2). An oxygen saturation  $\leq 90\%$  was associated with a relatively low sensitivity of  $< 0.5$ . Specificity of identifying an adverse outcome, an indirect measure of unnecessary conveyance to hospital (but also including patients who survived and did not need ICU admissions), increased as oxygen saturations fell. However, it is important to ensure that patients at risk of deterioration are not missed and a degree of over-triage would be necessary to ensure that this was not the case. However, even oxygen saturations at the lower end of the normal range are associated with a risk of deterioration (sensitivity of 94% saturations = 0.713) and it therefore appears that oxygen saturation alone has significant limitations when it is within a normal range.

Although oxygen saturations as a risk factor for COVID-19 patients on presentation to the Emergency Department are widely reported,<sup>[14, 15,16]</sup> the ability of oxygen saturations measured in the community to indicate disease severity and the need for hospital conveyance has not been widely reported, presumably because of the challenges in equipping patients with pulse oximeters prior to the onset of any illness. Several studies have used oxygen levels in patients presenting in the ED as an indicator of the need for hospital admission and others have used the opportunity to send ED patients not requiring admission home with a pulse oximeter for self-monitoring. Oxygen saturations



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3 310 on presentation to the ED have also been shown to be strongly associated with outcome. The  
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5 311 strongest critical illness risk has been shown to be admission oxygen saturation < 88% (OR 6.99).[15]  
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7 312 Other studies have shown that even a relatively mildly deranged oxygen saturation of <92% is  
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9 313 strongly associated with an increased risk of in-hospital mortality.[17] Conversely, an ED resting SpO<sub>2</sub>  
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11 314 ≥ 92% as part of discharge criteria can achieve hospital readmission rates as low as 4.6%, [16]  
12  
13 315 suggesting that it may be a safe threshold for discharge in symptomatic patients with mild disease  
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15 316 after diagnostic workup .

15 317 Home oxygen saturation monitoring has been used for patients discharged from hospital, either  
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17 318 from the ED because their disease was not severe, or from intensive care for convalescence. A small  
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19 319 study of patients with COVID-19 discharged from an ED, reported similar results to ours using  
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21 320 subsequent home oxygen saturation monitoring. In these patients, resting home SpO<sub>2</sub> < 92% was  
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23 321 associated with an increased likelihood of re-hospitalization compared to SpO<sub>2</sub> ≥ 92% (relative risk =  
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25 322 7.0, 95% CI 3.4 to 14.5, p < 0.0001). Home SpO<sub>2</sub> < 92% was also associated with increased risk of  
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27 323 intensive care unit admission.[7]  
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29 325 Oxygen saturation is an integral variable in most critical illness tools that have been used to identify  
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31 326 COVID-19 patients requiring hospital admission.[18] NHS England has encouraged the use of the  
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33 327 NEWS2 scoring system to identify patients at risk of deterioration. This uses weighted physiological  
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35 328 variables of heart rate, systolic blood pressure, oxygen saturation (on air), respiratory rate,  
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37 329 temperature and level of consciousness to produce a score that is correlated with risk of  
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39 330 deterioration, not only as a general illness score, but specifically in patients with known COVID-  
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41 331 19.[19] We therefore compared the ability of isolated oxygen saturations with NEWS2 in our cohort  
42  
43 332 to identify patients at risk of ICU admission (and mortality) within 30 days. Using ROC analysis, the  
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45 333 AUROC for oxygen saturations at predicting ICU admission alone was 0.753 (95% CI 0.668-0.826) and  
46  
47 334 for NEWS2 was 0.731 (95% CI 0.655-0.800). These results are consistent with a previous study using  
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49 335 NEWS2 scores on hospital admission which has shown an AUROC of 0.822 (95% CI 0.690-0.953) to  
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51 336 predict risk of severe disease.[19] The lower observed AUROC of NEWS2 compared to oxygen  
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53 337 saturations may be the result of the NEWS2 score incorporating physiological variables less  
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55 338 predictive of COVID-19 outcomes than oxygen saturations, thereby reducing the discriminative  
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57 339 ability of the score, or because it uses discretized oxygen saturations which amounts to information  
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59 340 loss. Additionally, we have not assessed the reporting compliance of the NEWS2 scores and this may  
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341 have impacted the observed AUROCs. Interestingly, a recent review of 22 prognostic models showed  
342 that oxygen saturation on room air and patient age were strong predictors of deterioration and  
343 mortality among hospitalised adults with COVID-19 respectively, but no other variables added

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3 344 incremental value to these predictors.[18] We have shown the same for oxygen saturation as a  
4  
5 345 univariate predictor in the pre-hospital setting, and that predictive value does not increase by the  
6  
7 346 addition of other physiological variables. The PRIEST study using NEWS2, age, sex, and performance  
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9 347 status of patients in the ED predicted adverse outcome with good discrimination in adults with  
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11 348 suspected COVID-19 [20]. The discriminatory ability of this more complex scoring system was similar  
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13 349 to that demonstrated by simply measuring the oxygen saturations in the community and further  
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15 350 reinforces the utility of home oxygen saturations as a simple marker, not only for use by the EMS,  
16  
17 351 but by members of the public equipped with home oximetry.

17 352

19 353 A number of remote home monitoring models for patients with suspected COVID-19 have been  
20  
21 354 proposed, all of which aim to achieve early identification of deterioration for patients self-managing  
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23 355 COVID-19 symptoms at home.[21] It would be expected that the utility of home monitoring would  
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25 356 be improved by the ability to measure oxygen saturations, although not all models currently  
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27 357 integrate this into their protocols. Our results show that resting oxygen saturations measured in  
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29 358 patients with confirmed COVID-19 perform on a par with the same measurements taken in the ED.  
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31 359 They therefore suggest that the predictive value of oxygen saturations may be able to be effectively  
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33 360 moved to an earlier stage in the disease process and measured while the patient is still at home.  
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35 361 Although initial home SpO<sub>2</sub> may provide a useful marker of disease severity and the need for  
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37 362 hospital conveyance, it is clear that it has limited sensitivity and may need to be interpreted as part  
38  
39 363 of an overall assessment of the patient. Some authors have argued that pulse oximetry identified the  
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41 364 need for hospitalisation when using a cut- off of 92%,[7] but based on our data (Table 2),  
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43 365 approximately one-third of patients with an adverse outcome would be missed using this threshold.  
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45 366 We have demonstrated that even patients presenting with oxygen saturations of 92-94 %, which are  
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47 367 values often regarded as within a normal range, have a higher mortality than those with oxygen  
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49 368 saturations higher than 95 %. Even when measured in the ED, baseline median SpO<sub>2</sub> was as high as  
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51 369 95.0 % in those with an adverse outcome, compared to 97.0% in those without.[22] It is clear that  
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53 370 the relatively low sensitivity of oxygen saturation in those with mildly deranged values limits the  
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55 371 utility of this parameter alone in assessing risk of adverse outcome.

52 372 This is a relatively small retrospective cohort study with concomitant limitations of sample size. The  
53  
54 373 subjective nature of paramedic classification of symptoms consistent with COVID-19 may have  
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56 374 introduced some degree of bias into patients included in the study, as may have the presence of  
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58 375 known co-morbidities. Our dataset did not include patients who were reviewed by EMS but not  
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60 376 conveyed to hospital and this is arguably the most significant source of bias in our study. It is

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3 377 reasonable that for patients where a decision was made not to convey them, they were less likely to  
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5 378 deteriorate and more likely to have normal vital signs. If this is the case, this would result in a  
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7 379 reduction of the discriminative ability of recorded oxygen saturations. We did not specifically  
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9 380 compare the outcome data of COVID and Non-COVID patients with mildly deranged oxygen  
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11 381 saturations. However, our data suggests that mild derangement in COVID patients is a significant risk  
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13 382 factor for deterioration and this does not match the clinical progression witnessed in non-COVID  
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15 383 patients. Seventeen patients did not have initial oxygen saturations recorded on air (but did have  
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17 384 oxygen saturations recorded on oxygen) and were excluded from the data analysis. If this was  
18  
19 385 because they were so obviously hypoxic clinically that EMS staff immediately administered oxygen  
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21 386 without an initial reading on air (or were constantly on home oxygen treatment), the ability of  
22  
23 387 oxygen saturations to indicate risk of deterioration is likely to have been underestimated in this  
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25 388 study. Patients on palliative care pathways were also removed from the study cohort, but are likely  
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27 389 to be more susceptible to deterioration from COVID, irrespective of any alternative care pathway.

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28 391 With waves of COVID-19 regularly overwhelming EMS and hospital services, there is an urgent need  
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30 392 to optimise the identification of patients at risk of deterioration. We undertook this research to  
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32 393 ascertain the role simple physiological measures might have to inform clinical decision making.  
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34 394 While the results are hypothesis-forming (i.e., it shows oxygen saturations are predictive of clinical  
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36 395 outcomes within the care pathway studied in this manuscript), it has clinical utility as it helps inform  
37  
38 396 decisions made by clinicians at the point of conveyance. This will enable more patients to be safely  
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40 397 managed in the community and only referred to hospital once their clinical symptoms and  
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42 398 physiological signs suggest a risk of deterioration and the need for hospital care. This is particularly  
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44 399 needed for the majority of patients who have mild to moderate symptoms where it is not clear if  
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46 400 community or hospital management is appropriate. Home pulse oximetry is becoming relatively  
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48 401 cheap and easily accessible for the public and may be a relatively cost-effective tool in the safe  
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50 402 community management of these patients, perhaps focussed on those with significant co-  
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52 403 morbidities who are at higher risk. The utility of remote monitoring systems (or the COVID virtual  
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54 404 ward) has been an increasingly studied subject, and there is growing evidence that remote  
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56 405 monitoring can facilitate more streamlined approaches to the delivery of patient care, especially in  
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58 406 pulmonary disease.[6] The use of ICU admission as an endpoint identifies patients seen at home who  
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60 407 go on to deteriorate and the correlation of home oxygen saturation with a risk of severe  
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3 411 suggests that it may have the potential to significantly contribute to the safe and appropriate  
4 412 management of these patients in the community with timely referral to hospital when indicated.  
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## 9 414 **Conclusions**

10 415 We have demonstrated that even relatively minor derangements in peripheral oxygen saturation are  
11 416 an early warning of potential deterioration in confirmed COVID-19 patients conveyed by EMS to  
12 417 hospital and oxygen saturation would appear to have potential to be a key physiological variable  
13 418 that together with other clinical signs and clinical risk factors may be able to identify patients at risk  
14 419 of deterioration.  
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25

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29 427 of Health and Social Care.  
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35 428

## 36 429 **Competing interests**

37 430 M. I-K. is National Clinical Lead Deterioration & National Specialist Advisor Sepsis, NHS England and  
38 431 NHS Improvement. All other authors declare no competing interests.  
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## 44 432 **Data accessibility**

45 433 Due to information governance concerns, the data will not be made public. However, it will be made  
46 434 accessible via reasonable request to the corresponding author.  
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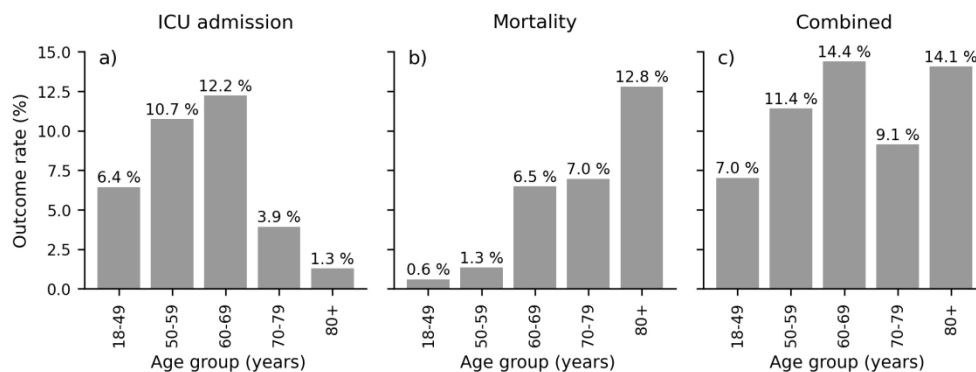


Figure 1: Observed a) ICU admission rate, b) 30-day mortality rate, and c) combined rates by age group for suspected COVID-19 patients conveyed by ambulance. Annotations (above bars) display the observed rates for the respective group.

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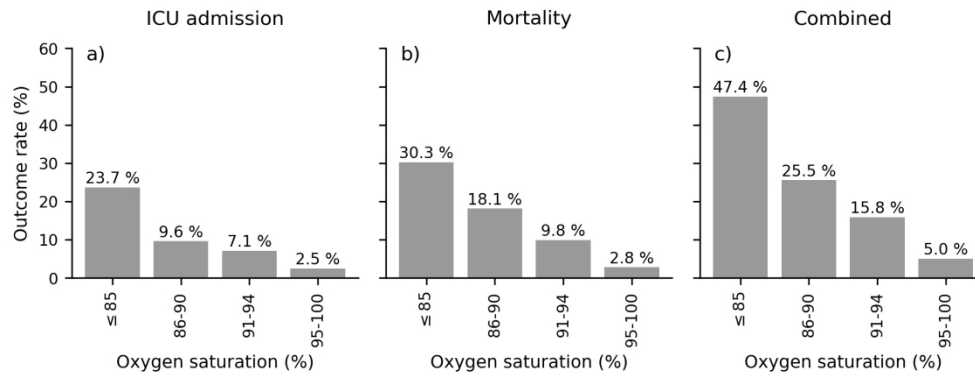


Figure 2: Observed a) ICU admission rate, b) 30-day mortality rate, and c) combined rates as a function of initial oxygen saturation (on air) measurement made by ambulance crews in the community. Annotations (above bars) display the observed rates for the respective group.

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STROBE Statement—Checklist of items that should be included in reports of *cohort studies*

	Item No	Recommendation	Page No
<b>Title and abstract</b>	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	6
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7, 8
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up (b) For matched studies, give matching criteria and number of exposed and unexposed	7, 8
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8, 9
Data sources/measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	8, 9
Bias	9	Describe any efforts to address potential sources of bias	16
Study size	10	Explain how the study size was arrived at	N/A
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8, 9
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) If applicable, explain how loss to follow-up was addressed (e) Describe any sensitivity analyses	8, 9, 10
<b>Results</b>			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage (c) Consider use of a flow diagram	7, 10
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (b) Indicate number of participants with missing data for each variable of interest (c) Summarise follow-up time (eg, average and total amount)	Figures 1, 2 Pages 11, 12, 13
Outcome data	15*	Report numbers of outcome events or summary measures over time	10

1	Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10
2			(b) Report category boundaries when continuous variables were categorized	
3			(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
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9	Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11, 12, 13
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12	<b>Discussion</b>			
13	Key results	18	Summarise key results with reference to study objectives	14, 15
14				
15	Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16, 17
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18	Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	18
19				
20	Generalisability	21	Discuss the generalisability (external validity) of the study results	16, 17
21				
22				
23	<b>Other information</b>			
24	Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	19
25				

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27 \*Give information separately for exposed and unexposed groups.

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29  
30 **Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at <http://www.strobe-statement.org>.

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# BMJ Open

## Validation of oxygen saturations measured in the community by emergency medical services as a marker of clinical deterioration in patients with confirmed COVID-19

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Keywords:	COVID-19, RESPIRATORY MEDICINE (see Thoracic Medicine), Epidemiology < INFECTIOUS DISEASES

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7 3 **Validation of oxygen saturations measured in the community by emergency medical**  
8 4 **services as a marker of clinical deterioration in patients with confirmed COVID-19**  
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13 7 Matthew Inada-Kim<sup>[1]</sup>

15 8 Francis P. Chmiel<sup>[2]</sup>

17 9 Michael J. Boniface<sup>[2]</sup>

19 10 Daniel K. Burns<sup>[2]\*</sup>

21 11 Helen Pocock<sup>[3,4]</sup>

23 12 John J. M. Black<sup>[3,5]</sup>

25 13 Charles D. Deakin<sup>[3,6]</sup>

26 14  
27 14  
28 15 [1] Acute Medical Unit, Department of Acute Medicine, Hampshire Hospitals NHS Foundation Trust, Winchester, United  
29 16 Kingdom.

30 17 [2] School of Electronics and Computer Science, University of Southampton, Southampton, SO17 1BJ, UK

31 18 [3] South Central Ambulance Service NHS Foundation Trust, Otterbourne, SO21 2RU, UK

32 19 [4] Warwick Clinical Trials Unit, University of Warwick, Coventry, CV4 7AL, UK

33 20 [5] Emergency Department, Oxford University Hospitals NHS Foundation Trust OX3 9DU.

34 21 [6] Southampton Respiratory Biomedical Research Unit, National Institute for Health Research, University Hospital  
35 22 Southampton, SO16 6YD  
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38 24 \* Corresponding author: d.burns@soton.ac.uk  
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3 26 **ABSTRACT**  
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6 27  
7 28 **Objectives** To evaluate oxygen saturation and vital signs measured in the community by emergency  
8 29 medical services (EMS) as clinical markers of COVID-19-positive patient deterioration.  
9

10 30 **Design** A retrospective data analysis.  
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13 31 **Setting** Patients conveyed by EMS to two hospitals in Hampshire, UK between March 1<sup>st</sup> and July 31<sup>st</sup>  
14 32 2020.  
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17 33 **Participants** A total of 1,080 patients aged  $\geq$  18 years old with a COVID-19 diagnosis who were  
18 34 conveyed by EMS to hospital.  
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20  
21 35 **Primary and secondary outcome measures** The primary study outcome was admission to ICU within  
22 36 30-days of conveyance with a secondary outcome representing mortality within 30-days of  
23 37 conveyance. ROC analysis was performed to evaluate, in a retrospective fashion, the efficacy of  
24 38 different variables in predicting patient outcomes.  
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28 39 **Results** Vital signs measured by EMS staff at first point of contact in the community correlated with  
29 40 patient 30-day ICU admission and mortality. Oxygen saturation was comparably predictive of 30-day  
30 41 ICU admission (AUROC 0.753 (95 % CI: 0.668-0.826)) to the NEWS2 score (AUROC 0.731 (95 % CI:  
31 42 0.655-0.800)), followed by temperature (AUROC 0.720 (95 % CI: 0.640-0.793)), and respiration rate  
32 43 (AUROC 0.672 (95 % CI: 0.586-0.756)).  
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37 44 **Conclusions** Initial oxygen saturation measurements (on air) for confirmed COVID-19 patients  
38 45 conveyed by EMS correlated with short-term patient outcomes, demonstrating an AUROC of 0.753  
39 46 (95% CI: 0.668-0.826) in predicting 30-day ICU admission. We found that threshold of 93% SpO<sub>2</sub> is  
40 47 prognostic of adverse events and of value for clinician decision making with sensitivity (74.2 % CI  
41 48 0.642-0.840) and specificity (70.6 % CI 0.678-0.734).  
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4 51 **ARTICLE SUMMARY**  
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7 53 **Strengths and limitations**

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9 54 • This is the first study to report that baseline (community) oxygen saturation measurements  
10 55 (on air) for confirmed COVID-19 patients conveyed by EMS to hospital for further  
11 56 management correlated with short-term (30-day) ICU admission and/or mortality.  
12 57 • This study assessed vital signs and demographics as predictive factors for short-term (30-  
13 58 day) ICU admission and/or mortality.  
14 59 • The study has a number of limitations due to data availability, as such we did not include  
15 60 data from patients who were reviewed by EMS but not conveyed, and do not consider the  
16 61 type of measurement device in our analysis  
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**63 INTRODUCTION**

64 Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is a highly transmissible and  
65 pathogenic coronavirus that causes coronavirus disease 2019 (COVID-19) [1]. COVID-19 presents the  
66 biggest global healthcare challenge of our generation. As of February 2021, COVID-19 associated  
67 mortality stands at over 110,000 in the UK [2] COVID-19 presents a number of challenges in  
68 identifying optimal management pathways, not only in terms of the clinical care itself, but also  
69 identifying the stage at which hospital admission is necessary. Traditional management pathways  
70 involving paramedic assessment and conveyance to the Emergency Department (ED) for further  
71 review have proven impractical, not only because of the large numbers of patients involved, but  
72 because of the need to minimise contact of COVID-19 patients with others. Most patients who  
73 become symptomatic do so in a home environment where the majority will remain. In terms of  
74 optimising outcome, there is a need to understand which symptoms and signs in this environment  
75 are prognostic indicators of potential deterioration. The national recommendation for the  
76 implementation of COVID virtual wards recently announced by NHS England,[3] ushers in a novel  
77 approach of empowering patients through providing symptomatic, at risk patients a pulse oximeter  
78 and a toolkit for self-monitoring at home. It is hoped that this will enable the earlier recognition of  
79 deterioration in COVID-19 patients and potentially improved outcomes.

80 In most cases of bacterial and non-COVID pneumonia, breathlessness appears relatively early in the  
81 disease and ahead of any significant hypoxia. The challenge with assessing COVID-19 severity is that  
82 asymptomatic hypoxia often precedes breathlessness and by the time symptoms of breathlessness  
83 occur, patients have developed advanced disease and hypoxia may be significant.[4] The ability to  
84 detect this asymptomatic hypoxia before patients experience shortness of breath is critical for  
85 preventing respiratory involvement progressing to a life-threatening state. The key is to be able to  
86 detect this initial drop in oxygen saturation levels so that patients infected with COVID-19 who begin  
87 to suffer from pulmonary complications in the community can be detected early and conveyed to  
88 hospital for further treatment.[5] Although some studies have reported the relationship between  
89 oxygen saturation and outcome on presentation to the ED, we are not aware of any studies that  
90 have reported the relationship between oxygen saturations measured in the community by EMS and  
91 outcome. Patients who on assessment are severely hypoxic are clearly in need of emergency  
92 conveyance and hospital treatment, but by far the majority of patients with Covid-like symptoms  
93 seen and assessed by the EMS have relatively normal or near-normal oxygen saturations. These  
94 patients have generally not been conveyed and have been managed at home, but it has become  
95 apparent that even relatively minor derangements in oxygen saturations may be an early warning

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3 96 indicator for disease progression and the subsequent need for critical care. Use of oxygen saturation  
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5 97 as an indicator of disease severity may therefore underestimate the risk of leaving patients at home  
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7 98 after assessment by the EMS. National case fatality rates (CFR) (ratio of deaths to total cases) have  
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9 99 shown a strong inverse correlation between target oxygen saturation levels of 90-98% [6] suggesting  
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11 100 that even mild derangements in oxygen saturation untreated can be detrimental to outcome.

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13 101 Two small studies have suggested the utility of home oxygen monitoring for COVID-19 patients  
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15 102 discharged from hospital,[7, 8] but no studies to our knowledge have used out-of-hospital oxygen  
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17 103 saturation measurements as a trigger for initial hospital assessment. The purpose of this study  
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19 104 therefore is to understand the prognostic significance of oxygen saturation when first measured by  
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21 105 EMS clinicians. The understanding aims to inform escalation policies for safe and effective  
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23 106 community-based triage and self-monitoring at home by identify a threshold where the sensitivity  
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25 107 and specificity are of clinical value. It is hoped that the approach will contribute to hospital  
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27 108 admission avoidance, enable earlier recognition of deterioration in COVID-19 patients and  
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29 109 potentially improve outcome through early identification of those most at risk of disease  
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31 110 progression. Whilst using a pulse oximeter provides a way for patients to monitor disease  
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33 111 progression through a simple measurement procedure in contrast to the complexity of  
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35 112 measurements required to calculate a NEWS2 score.

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## 116 METHODS

### 117 Study Design

118 We undertook a retrospective review of clinically confirmed COVID-19 patients accessing a regional  
119 UK ambulance service who were conveyed to hospital and correlated their initial oxygen saturations  
120 measured at home with their in-hospital outcome. These were compared with the standard NEWS2  
121 patient score, as used by all UK ambulance services, to identify the deteriorating patient.[9]

122 The cohort included adult patients (aged 18 years of older) initially assessed and conveyed by  
123 personnel from South Central Ambulance Service (SCAS) to the Emergency Department at one of the  
124 two hospitals within north Hampshire; Basingstoke & North Hampshire Hospital, or the Royal  
125 Hampshire County Hospital (Winchester) at which the patients were subsequently admitted.

126 The standard care pathway included 1) Patients calling emergency (999) and urgent (111) where  
127 they are triaged using NHS Pathways telephone script (release 19), 2) Attendance, assessment and  
128 monitoring by ambulance staff at the patient's home, 3) Conveyance to hospital for patients  
129 considered at high risk of deterioration 4) Admission to hospital and escalation to ICU for patients  
130 requiring critical care.

131 We analysed EMS conveyances occurring between 1<sup>st</sup> March to 31<sup>st</sup> July 2020, to determine suspect  
132 COVID-19 among conveyances at initial time of contact by the call taker or EMS staff, each patient  
133 record was reviewed for inclusion of at least one of the following four identifiers:

- 134 1. Those in who the EMS call taker had classified the call as 'COVID- Respiratory Distress'
- 135 2. Those where the Patient Clinical Record (PCR) listed the 'Presenting complaint' as 'Suspected  
136 COVID-19'.
- 137 3. Those where the PCR free text for the 'Presenting complaint' contained the word 'COVID'
- 138 4. Those where the PCR narrative in the free text field summarising the symptoms and their  
139 details completed by the paramedic contained the word 'COVID'.

140 Conveyances from these suspect COVID-19 patients were then linked to their subsequent hospital  
141 attendance. Of suspect cases, we then identified confirmed COVID-19 cases by selecting only those  
142 with a confirmed diagnosis in their discharge summary (i.e., the presence of a U07.1 or U07.2 ICD10  
143 code). These confirmed COVID-19 cases made up our study cohort.

144 Seventeen patients did not have initial oxygen saturations recorded on air (but did have oxygen  
145 saturations recorded on oxygen) and were excluded from the data analysis. If this was because they  
146 were so obviously hypoxic clinically that EMS staff immediately administered oxygen without an

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3 147 initial reading on air (or were constantly on home oxygen treatment), the ability of oxygen  
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5 148 saturations to indicate risk of deterioration is likely to have been underestimated in this study.

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7 149 All patients in known palliative care pathways were excluded from data analysis because their care  
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9 150 did not follow standard care pathways.

### 11 151 **Study setting**

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13 152 SCAS is a provider of emergency care in the counties of Hampshire, Berkshire, Buckinghamshire and  
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15 153 Oxfordshire and covers a total of 3554 sq. miles (9205 km<sup>2</sup>). The service receives approximately  
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17 154 500,000 emergency and urgent calls annually. SCAS covers a residential population of approximately  
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19 155 4.0 million inhabitants in a mix of urban and rural areas. The north Hampshire region forms part of  
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21 156 the area covered by SCAS and comprises a residential population of approximately 306,000.[10]

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### 25 158 **Data collection**

26  
27 159 The initial oxygen saturation reading (SpO<sub>2</sub>) on air recorded by the attending EMS staff (prior to any  
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29 160 exercise or step test) and the NEWS2 score of patients fulfilling the inclusion criteria were collected  
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31 161 from the EMS PCR. (NEWS2 score is calculated using the following seven variables: systolic blood  
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33 162 pressure, heart rate, respiratory rate, temperature, oxygen saturation, supplemental oxygen  
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35 163 administration, and level of consciousness - [https://www.england.nhs.uk/ourwork/clinical-](https://www.england.nhs.uk/ourwork/clinical-policy/sepsis/nationalearlywarningscore)  
36  
37 164 [policy/sepsis/nationalearlywarningscore.](https://www.england.nhs.uk/ourwork/clinical-policy/sepsis/nationalearlywarningscore))

38 165 Patient outcome was obtained by linking the SCAS and hospital clinical records by their NHS number.  
39  
40 166 The primary outcome of our study was ICU admission within 30-days of conveyance and the  
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42 167 secondary outcomes was mortality and a combined outcome (ICU admission and/or mortality)  
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44 168 within 30-days of conveyance.

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### 48 170 **Data analysis**

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50 171 Analysis was performed in Python 3.7.2 [10], primarily making use of the statsmodels library [11].  
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52 172 Confidence intervals on observed mortality rates were estimated using the Wilson score interval.  
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54 173 Where relevant, significance of the difference between two observed adverse outcome rates were  
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56 174 tested using a two-population proportions z-test with the null hypothesis that the two-population  
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58 175 proportions are equal.

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3 176 To evaluate how predictive individual variables (e.g., oxygen saturation) and combinations of  
4 variables (e.g., oxygen saturation with age) were of 30-day adverse outcomes, we performed  
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6 178 Receiving Operator Characteristics curve analysis. In the univariate analysis, we performed a  
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8 179 complete case analysis (removing any patient with an incomplete record of vital signs) and assume a  
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10 180 patient's adverse outcome risk is a linear function of the respective variable (where negative or  
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12 181 positive correlation with outcome is assessed by clinical judgement) and calculated the ROC curve  
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14 182 corresponding to if this variable alone was used to predict a patient's risk of an adverse outcome.  
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16 183 We present both the sensitivity and specificity or the Area Under the Receiving Operator  
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18 184 Characteristic curve (AUROC). The AUROC provides an estimate of the degree to which the predictor  
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20 185 can discern between whether a patient has an adverse outcome within 30 days of conveyance or  
21  
22 186 not, it can take values between 0.5 and 1.0. An AUROC of 0.5 corresponds to randomly guessing  
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24 187 which patient have an adverse outcome within 30 days and an AUROC of 1.0 corresponds to a  
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26 188 perfect classifier - it can predict, without error, who will have an adverse outcome within 30-days of  
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28 189 conveyance. Confidence intervals were estimated by performing 1000 bootstrapping (sampling with  
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30 190 replacement) iterations on the available data, calculating the AUROC on each of the samples and  
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32 191 then calculating the relevant percentiles.

### 192 **Patient and Public Involvement**

33 193 This research was done without patient involvement. Patients were not invited to comment on the  
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35 194 study design and were not consulted to develop patient-relevant outcomes or interpret the results.  
36  
37 195 Patients were not invited to contribute to the writing or editing of this document for readability or  
38  
39 196 accuracy.

### 40 197 **Governance and ethics approval**

42  
43 198 Regulatory and ethical approval for the study were provided by the Health Research Authority (REC  
44  
45 199 reference 20/HRA/5445) and by the University of Southampton Ethics Committee (REF  
46  
47 200 ERGO/61242). NHS England and NHS Improvement have been given legal notice by the Secretary of  
48  
49 201 State for Health and Social Care to support the processing and sharing of information to help the  
50  
51 202 COVID-19 response under Health Service Control of Patient Information Regulations 2002  
52  
53 203 (COPI). This is to ensure that confidential patient information can be used and shared appropriately  
54  
55 204 and lawfully for purposes related to the COVID-19 response. Data were extracted from medical  
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57 205 records by clinicians providing care for the patients and an anonymised extract of the data were  
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59 206 provided to the team at the University of Southampton.

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**RESULTS**

A total of 19,868 patients were assessed at home and subsequently conveyed by EMS to North Hampshire Hospitals during the study period. The details of cohort selection are shown in Figure 1. The call handler or EMS staff identified 2,257 suspect COVID-19 cases and of these we identified 1,209 adults as having a confirmed diagnosis of COVID-19 (U07.1 or U07.2 coded in the patients discharge summary). Of the 1,209 confirmed cases we removed persons under palliative care (112 patients) and those with no initial oxygen saturation measurement on air recorded (17 patients). Overall, this left us with 1,080 confirmed COVID-19 patient records all of whom had initial oxygen saturation measurements on air. Of these 1,080, the complete records of vital signs were recorded at home by paramedics for 892 of the patients. The summary of the final patient cohort, with respect to demographics, comorbidities, and presence of vital sign measurements is given in Table 1. In our following discussions, we make use of all 1,080 patients, with the exception for our univariate analyses where we perform a complete case analysis and only use the 892 complete records.

Oxygen saturation was found to correlate with adverse outcome (Figure 2A), with lower initial oxygen saturation readings being associated with a higher mortality rate. In Figure 2A we display the correlation between the observed 30-day adverse outcome rates and initial oxygen saturation in detail, which displays correlation to all outcomes. In Table 2 we display the breakdown of our retrospective ROC analysis for using measured oxygen saturation as a binary triage tool (i.e., hospitalize or not) for different cut-offs (rows in Table 2). While the sensitivity vs specificity trade-off needs to be determined by the clinical context, this demonstrates that oxygen saturation is moderately discriminative for several cut-offs. For example, for a cut-off of 94 % or below, the sensitivity is 0.742 (95 % CI: 0.642-0.734) and the specificity is 0.706 (95 % CI: 0.678-0.734). Finally, we present comparisons of the results of ROC analysis for different variables measured in the community by EMS (Table 3). Across the three presented outcomes (30-day ICU admission, mortality, and combined outcome) correlations between variables and outcomes are broadly similar, with measured oxygen saturations and the NEWS2 score being the two most predictive of outcome. The notable differences are for the measured temperature which is moderately predictive of ICU admission (AUROC: 0.720 (95 % CI: 0.640-0.793)) but only weakly predictive of mortality (AUROC: 0.597 (95 % CI: 0.523-0.678)) and for patient age which is strongly positively correlated to mortality but displays a negative correlation to ICU admission (Figure 2B).

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Variable	Outcome Category		
Outcome	No adverse event(n=955)	30-day ICU admission (n=58)	30-day mortality (n=78)
<b>Age</b>			
18-49	159 (16.6%)	11 (19.0%)	1 (1.3%)
50-59	132 (13.8%)	16 (27.6%)	2 (2.6%)
60-69	119 (12.5%)	17 (29.3%)	9 (11.5%)
70-79	209 (21.9%)	9 (15.5%)	16 (20.5%)
80+	336 (35.2%)	5 (8.6%)	50 (64.1%)
<b>Comorbidities</b>			
Chronic Obstructive Pulmonary Disorder	33 (3.5%)	0 (0.0%)	6 (7.7%)
Dementia	90 (9.4%)	1 (1.7%)	18 (23.1%)
Diabetes	216 (22.6%)	14 (24.1%)	14 (17.9%)
Kidney disease	7 (0.7%)	1 (1.7%)	3 (3.8%)
Chronic pain	37 (3.9%)	3 (5.2%)	1 (1.3%)
<b>Vital signs</b>			
Heart rate present	946 (99.1%)	58 (100.0%)	77 (98.7%)
Systolic blood pressure present	869 (91.0%)	51 (87.9%)	71 (91.0%)
Respiratory rate present	852 (89.2%)	49 (84.5%)	70 (89.7%)
Oxygen saturation (on air) present	955 (100.0%)	58 (100.0%)	78 (100.0%)
Temperature present	825 (86.4%)	49 (84.5%)	67 (85.9%)
ACVPU present	849 (88.9%)	50 (86.2%)	67 (85.9%)

**Table 1: Characteristics of COVID-19 positive patients stratified by outcome. Note that n=11 patients experienced both ICU admission and mortality within 30 days.** We only report on comorbidities which were present in the dataset as provided by the EMS. Comorbidity presence was recorded for every patient in the study. ACVPU = alert, confused, responding to voice, responding to pain, unresponsive. Oxygen saturations were not missing for any patients as those with missing values had been excluded (n=17). Overall, vital signs records were complete for 83% of cases.



		Sensitivity (95 % CI)	Specificity (95 % CI)	Number of observations	Cumulative sum of number of observations
Oxygen Saturation (on air) threshold (%)	85	0.294 (0.200-0.400)	0.947 (0.933-0.962)	8	76
	86	0.316 (0.216-0.421)	0.941 (0.927-0.955)	8	84
	87	0.320 (0.216-0.432)	0.935 (0.920-0.950)	6	90
	88	0.370 (0.261-0.476)	0.916 (0.899-0.933)	23	113
	89	0.413 (0.304-0.523)	0.894 (0.874-0.913)	25	138
	90	0.512 (0.411-0.615)	0.870 (0.849-0.890)	32	170
	91	0.590 (0.477-0.699)	0.841 (0.823-0.867)	31	201
	92	0.655 (0.544-0.761)	0.817 (0.796-0.841)	33	234
	93	0.706 (0.593-0.803)	0.776 (0.751-0.801)	45	279
	94	0.742 (0.642-0.840)	0.706 (0.678-0.734)	74	353
	95	0.808 (0.718-0.892)	0.634 (0.605-0.662)	76	429
	96	0.848 (0.767-0.921)	0.508 (0.477-0.538)	129	558
	97	0.898 (0.822-0.963)	0.357 (0.330-0.386)	156	714
	98	0.911 (0.841-0.973)	0.226 (0.201-0.254)	132	846
99	0.961 (0.913-1.0)	0.091 (0.075-0.109)	139	985	
100	1	0	95	1080	

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252 **Table 2: Evaluation of initial oxygen saturation measured by paramedics in COVID-19 patients in**  
 253 **the community used as a binary classifier for predicting 30-day ICU admission within 30 days of**  
 254 **conveyance.** Each row denotes a different threshold for determining those at risk of an adverse  
 255 outcome. We display the sensitivity and specificity for each threshold, equivalent to all possible  
 256 intersections of the receiving operator curve using thresholds between 85 % and 100 %. In total 68  
 257 patients had an oxygen saturation of 84 % or less (not shown). The column on the far right denotes  
 258 the cumulative sum of the number of observations of the given oxygen saturation (row) or below.  
 259 For example, 76 patients had an oxygen saturation of 85 % or less recorded (top row) and 429  
 260 patients had an oxygen saturation of 95 % or less recorded. Confidence intervals are estimated by  
 261 bootstrapping.

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Variable	AUROC (95 % CI)		
	ICU admission	Mortality	Combined
<b>Oxygen Saturation (on air)</b>	0.753 (0.668-0.826)	0.778 (0.704-0.843)	0.775 (0.727-0.829)
<b>NEWS2</b>	0.731 (0.655-0.800)	0.768 (0.709-0.823)	0.760 (0.708-0.807)
<b>Respiration rate</b>	0.672 (0.586-0.756)	0.668 (0.599-0.736)	0.677 (0.618-0.738)
<b>Temperature</b>	0.720 (0.640-0.793)	0.597 (0.523-0.678)	0.636 (0.69-0.700)
<b>Systolic blood pressure</b>	0.634 (0.560-0.706)	0.604 (0.529-0.680)	0.626 (0.568-0.684)
<b>Heart rate</b>	0.590 (0.506-0.672)	0.558 (0.486-0.631)	0.574 (0.514-0.633)
<b>Age band</b>	0.670 (0.611-0.734)	0.685 (0.626-0.738)	0.557 (0.495-0.615)

25 268 **Table 3: Ranked Area Under Receiver Operator Curves (AUROC) calculated for isolated**  
 26 **physiological variables and the composite NEWS2 score with each outcome.** AUROCS were  
 27 269 calculated using a complete case analysis with 892 patients in total. Confidence intervals are  
 28 270 calculated using a complete case analysis with 892 patients in total. Confidence intervals are  
 29 271 estimated by bootstrapping, with 95 % confidence intervals presented alongside the mean validation  
 30 272 AUROC across samples.  
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**DISCUSSION**

Community assessment of patients with COVID-19 symptoms using a single initial oxygen saturation on air measurement correlates with 30-day clinical outcomes. Qualitatively, the observed 30-day adverse outcome rate is approximately constant between oxygen saturations of 100 - 96 % and then increase with decreasing oxygen saturation from 95 % to 90 %. Below 90 %, the mortality risk remains high. Although the therapeutic target range for oxygen saturations in the UK is 94-98%,<sup>[11]</sup> and in the USA is 92-96%,<sup>[12]</sup> this study suggests that patients at the lower end of this range are still at risk of deterioration in the context of COVID-like symptoms. For example, for patients in our cohort with presenting oxygen saturations in the range of 92-94 %, values often regarded as within this normal range, had a significantly ( $p=0.025$ ) higher risk of ICU admission within 30 days (5.9 %) compared to those presenting with oxygen saturations greater than 95 % (ICU admission rate 2.5 %). Outside this 'normal' range, our analysis suggests even relatively small decreases in oxygen saturation are markers of increased risk of death or ICU admission and suggest that a lower threshold for hospital conveyance may be necessary for patients who traditionally would be considered to have only minor physiological derangement and otherwise have been left at home. The sensitivity of home oxygen saturation measurements reflects the percentage of people correctly identified with adverse outcomes. The sensitivity of this parameter for adverse outcome decreased as oxygen saturation fell (Table 2). An oxygen saturation  $\leq 90\%$  was associated with a relatively low sensitivity of  $< 0.5$ . Specificity of identifying an adverse outcome, an indirect measure of unnecessary conveyance to hospital (but also including patients who survived and did not need ICU admissions), increased as oxygen saturations fell. However, it is important to ensure that patients at risk of deterioration are not missed and a degree of over-triage would be necessary to ensure that this was not the case. However, even oxygen saturations at the lower end of the normal range are associated with a risk of deterioration (sensitivity of 94% saturations = 0.713) and it therefore appears that oxygen saturation alone has significant limitations when it is within a normal range.

Although oxygen saturations as a risk factor for COVID-19 patients on presentation to the Emergency Department are widely reported,<sup>[13, 14]</sup> the ability of oxygen saturations measured in the community to indicate disease severity and the need for hospital conveyance has not been widely reported, presumably because of the challenges in equipping patients with pulse oximeters prior to the onset of any illness. Several studies have used oxygen levels in patients presenting in the ED as an indicator of the need for hospital admission and others have used the opportunity to send ED patients not requiring admission home with a pulse oximeter for self-monitoring. Oxygen saturations on presentation to the ED have also been shown to be strongly associated with outcome. The

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3 312 strongest critical illness risk has been shown to be admission oxygen saturation < 88% (OR 6.99).[14]  
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5 313 Other studies have shown that even a relatively mildly deranged oxygen saturation of <92% is  
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7 314 strongly associated with an increased risk of in-hospital mortality.[15] Conversely, an ED resting SpO<sub>2</sub>  
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9 315 ≥ 92% as part of discharge criteria can achieve hospital readmission rates as low as 4.6%, [16]  
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11 316 suggesting that it may be a safe threshold for discharge in symptomatic patients with mild disease  
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13 317 after diagnostic workup .

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15 318 Home oxygen saturation monitoring has been used for patients discharged from hospital, either  
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17 319 from the ED because their disease was not severe, or from intensive care for convalescence. A small  
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19 320 study of patients with COVID-19 discharged from an ED, reported similar results to ours using  
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21 321 subsequent home oxygen saturation monitoring. In these patients, resting home SpO<sub>2</sub> < 92% was  
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23 322 associated with an increased likelihood of re-hospitalization compared to SpO<sub>2</sub> ≥ 92% (relative risk =  
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25 323 7.0, 95% CI 3.4 to 14.5, p < 0.0001). Home SpO<sub>2</sub> < 92% was also associated with increased risk of  
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27 324 intensive care unit admission.[8]  
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31 326 Oxygen saturation is an integral variable in most critical illness tools. The association of prehospital  
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33 327 oxygen saturation has been shown to be predictive of 2-day mortality [17]and has been used to  
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35 328 identify COVID-19 patients requiring hospital admission.[18] NHS England has encouraged the use of  
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37 329 the NEWS2 scoring system to identify patients at risk of deterioration. This uses weighted  
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39 330 physiological variables of heart rate, systolic blood pressure, oxygen saturation (on air), respiratory  
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41 331 rate, temperature and level of consciousness to produce a score that is correlated with risk of  
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43 332 deterioration, not only as a general illness score, but specifically in patients with known COVID-  
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45 333 19.[19] NEWS2 has been compared with a quick COVID Sensitivity Index (qCSI), a test that includes  
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47 334 SpO<sub>2</sub>, respiratory rate and O<sub>2</sub> flow rate to calculate a score between 1 and 12, and risk level. The  
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49 335 study concludes NEWS2 is significantly better than qCSI, with AUC of 0.779 and 0.750 respectively  
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51 336 [20]. Furthermore, qCSI does not consider severity score for readings of 93% and above, whilst qCSI  
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53 337 pulse oximetry readings are the lowest reading recorded during the first 4 hours of patient  
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55 338 encounter at the hospital, rather than being prior to admission. In our study, we were concerned  
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57 339 with the ability of isolated oxygen saturations measured by EMS on attendance in comparison with  
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59 340 NEWS2 in our cohort to identify patients at risk of ICU admission (and mortality) within 30 days.  
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341 Using ROC analysis, the AUROC for oxygen saturations at predicting ICU admission alone was 0.753  
342 (95% CI 0.668-0.826) and for NEWS2 was 0.731 (95% CI 0.655-0.800). These results are consistent  
343 with a previous study using NEWS2 scores on hospital admission which has shown an AUROC of  
344 0.822 (95% CI 0.690-0.953) to predict risk of severe disease.[19] The lower observed AUROC of  
345 NEWS2 compared to oxygen saturations may be the result of the NEWS2 score incorporating

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3 346 physiological variables less predictive of COVID-19 outcomes than oxygen saturations, thereby  
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5 347 reducing the discriminative ability of the score, or because it uses discretized oxygen saturations  
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7 348 which amounts to information loss. Additionally, we have not assessed the reporting compliance of  
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9 349 the NEWS2 scores and this may have impacted the observed AUROCs. Interestingly, a recent review  
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11 350 of 22 prognostic models showed that oxygen saturation on room air and patient age were strong  
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13 351 predictors of deterioration and mortality among hospitalised adults with COVID-19 respectively, but  
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15 352 no other variables added incremental value to these predictors.[18] We have shown the same for  
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17 353 oxygen saturation as a univariate predictor in the pre-hospital setting, and that predictive value does  
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19 354 not increase by the addition of other physiological variables. The PRIEST study using NEWS2, age,  
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21 355 sex, and performance status of patients in the ED predicted adverse outcome with good  
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23 356 discrimination in adults with suspected COVID-19 [20]. The discriminatory ability of this more  
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25 357 complex scoring system was similar to that demonstrated by simply measuring the oxygen  
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27 358 saturations in the community and further reinforces the utility of home oxygen saturations as a  
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29 359 simple marker, not only for use by the EMS, but by members of the public equipped with home  
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31 360 oximetry.

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33 362 A number of remote home monitoring models for patients with suspected COVID-19 have been  
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35 363 proposed, all of which aim to achieve early identification of deterioration for patients self-managing  
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37 364 COVID-19 symptoms at home.[21] It would be expected that the utility of home monitoring would  
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39 365 be improved by the ability to measure oxygen saturations, although not all models currently  
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41 366 integrate this into their protocols. Our results show that resting oxygen saturations measured in  
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43 367 patients with confirmed COVID-19 perform on a par with the same measurements taken in the ED.  
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45 368 They therefore suggest that the predictive value of oxygen saturations may be able to be effectively  
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47 369 moved to an earlier stage in the disease process and measured while the patient is still at home.  
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49 370 Although initial home SpO<sub>2</sub> may provide a useful marker of disease severity and the need for  
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51 371 hospital conveyance, it is clear that it has limited sensitivity and may need to be interpreted as part  
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53 372 of an overall assessment of the patient. Some authors have argued that pulse oximetry identified the  
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55 373 need for hospitalisation when using a cut- off of 92%,[8] but based on our data (Table 2),  
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57 374 approximately one-third of patients with an adverse outcome would be missed using this threshold.  
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59 375 We have demonstrated that even patients presenting with oxygen saturations of 92-94 %, which are  
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376 values often regarded as within a normal range, have a higher mortality than those with oxygen  
377 saturations higher than 95 %. Even when measured in the ED, baseline median SpO<sub>2</sub> was as high as  
378 95.0 % in those with an adverse outcome, compared to 97.0% in those without.[22] It is clear that

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3 379 the relatively low sensitivity of oxygen saturation in those with mildly deranged values limits the  
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5 380 utility of this parameter alone in assessing risk of adverse outcome.  
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7 381 This is a relatively small retrospective cohort study with concomitant limitations of sample size. The  
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9 382 subjective nature of paramedic classification of symptoms consistent with COVID-19 may have  
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11 383 introduced some degree of bias into patients included in the study, as may have the presence of  
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13 384 known co-morbidities. Our dataset did not include patients who were reviewed by EMS but not  
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15 385 conveyed to hospital and this is arguably the most significant source of bias in our study. It is  
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17 386 reasonable that for patients where a decision was made not to convey them, they were less likely to  
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19 387 deteriorate and more likely to have normal vital signs. If this is the case, this would result in a  
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21 388 reduction of the discriminative ability of recorded oxygen saturations. We did not specifically  
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23 389 compare the outcome data of COVID and Non-COVID patients with mildly deranged oxygen  
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25 390 saturations. However, our data suggests that mild derangement in COVID patients is a significant risk  
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27 391 factor for deterioration and this does not match the clinical progression witnessed in non-COVID  
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29 392 patients. We acknowledge that for very low SpO<sub>2</sub> levels our results show poor clinical value and we  
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31 393 believe this is due to other factors influencing escalation decisions that are not included in our  
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33 394 dataset. Patients on palliative care pathways were also removed from the study cohort, but are  
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35 395 likely to be more susceptible to deterioration from COVID, irrespective of any alternative care  
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37 396 pathway.  
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43 398 With waves of COVID-19 regularly overwhelming EMS and hospital services, there is an urgent need  
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45 399 to optimise the identification of patients at risk of deterioration. We undertook this research to  
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47 400 ascertain the role simple physiological measures might have to inform clinical decision making.  
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49 401 While the results are hypothesis-forming (i.e., it shows oxygen saturations are predictive of clinical  
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51 402 outcomes within the care pathway studied in this manuscript), it has clinical utility as it helps inform  
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53 403 decisions made by clinicians at the point of conveyance. This will enable more patients to be safely  
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55 404 managed in the community and only referred to hospital once their clinical symptoms and  
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57 405 physiological signs suggest a risk of deterioration and the need for hospital care. This is particularly  
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59 406 needed for the majority of patients who have mild to moderate symptoms where it is not clear if  
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407 community or hospital management is appropriate. Home pulse oximetry is becoming relatively  
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409 cheap and easily accessible for the public and may be a relatively cost-effective tool in the safe  
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411 community management of these patients, perhaps focussed on those with significant co-  
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413 morbidities who are at higher risk. The utility of remote monitoring systems (or the COVID virtual  
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415 ward) has been an increasingly studied subject, and there is growing evidence that remote

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3 412 monitoring can facilitate more streamlined approaches to the delivery of patient care, especially in  
4 413 pulmonary disease.[7] The use of ICU admission as an endpoint identifies patients seen at home who  
5 414 go on to deteriorate and the correlation of home oxygen saturation with a risk of severe  
6 415 deterioration assists ambulance crews in identifying both those who should be conveyed to hospital  
7 416 as well as those who can, with a reasonable degree of certainty, be safely left at home. Further  
8 417 prospective studies are required to understand the utility of home pulse oximetry, but this study  
9 418 suggests that it may have the potential to significantly contribute to the safe and appropriate  
10 419 management of these patients in the community with timely referral to hospital when indicated.  
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### 421 **Conclusions**

422 We have demonstrated that even relatively minor derangements in peripheral oxygen saturation are  
423 an early warning of potential deterioration in confirmed COVID-19 patients conveyed by EMS to  
424 hospital and oxygen saturation would appear to have potential to be a key physiological variable  
425 that together with other clinical signs and clinical risk factors may be able to identify patients at risk  
426 of deterioration.

427

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### 436 **Author contributions**

437 MI-K, MJB, JJM Black, CDD led and conceptualized the study. MI-K led at HHFT, MJB led at UoS, CDD  
438 led at SCAS. FPC and DKB performed the data analysis with support and guidance from all authors.  
439 MI-K, HP and JJM Black performed the data extraction. MJB led the data governance. CDD and HP  
440 provided clinical insight. MI-K, CDD, HP and FPC wrote the first draft of the manuscript. All authors  
441 discussed the results. All others contributed to subsequent drafts of the manuscript. DKB prepared  
442 the final manuscript for submission.



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3 443 **Competing interests**  
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5 444 M. I-K. is National Clinical Lead Deterioration & National Specialist Advisor Sepsis, NHS England and  
6  
7 445 NHS Improvement. All other authors declare no competing interests.  
8

9 446 **Data accessibility**  
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11 447 Due to information governance concerns, the data will not be made public. However, it will be made  
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13 448 accessible via reasonable request to the corresponding author.  
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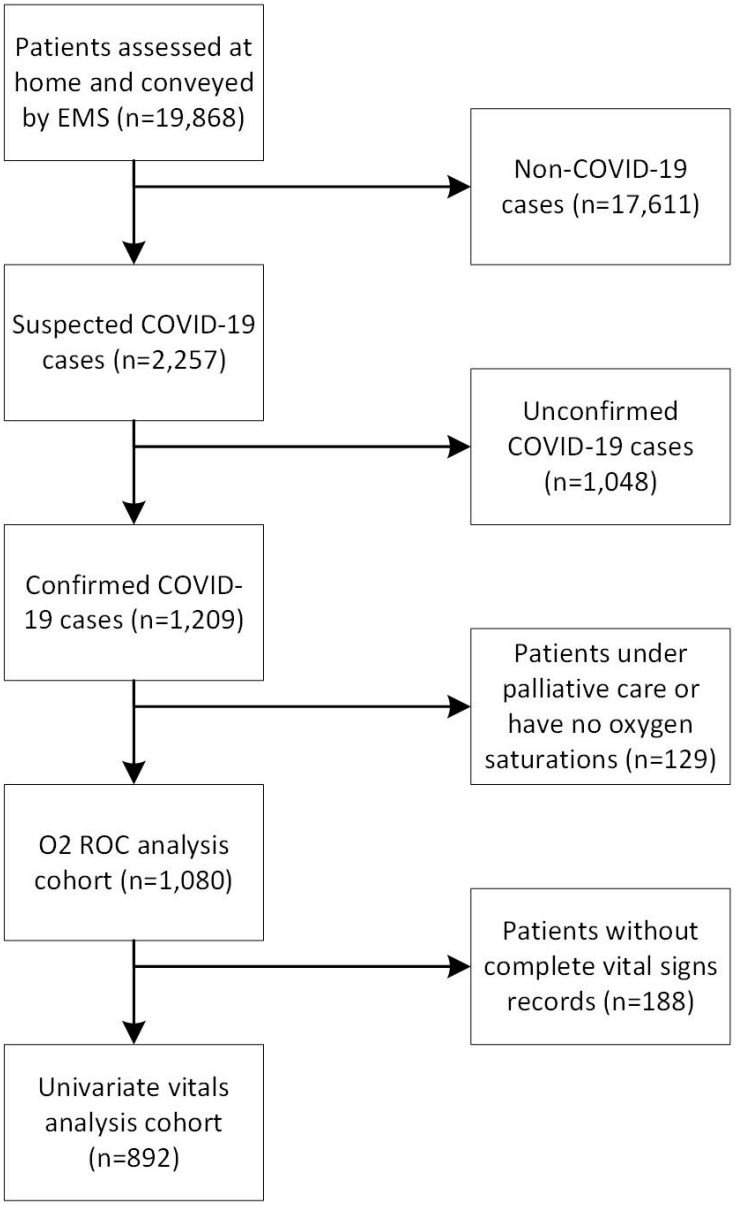
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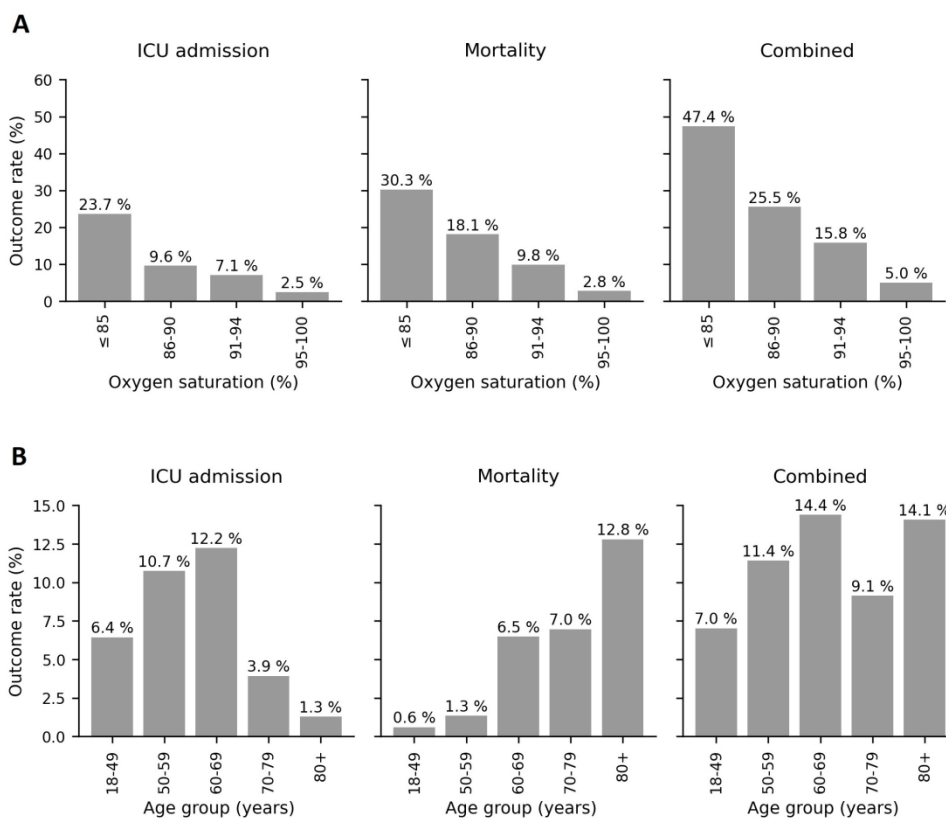
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The cohort selection of the EMS patients.

71x115mm (300 x 300 DPI)



A) The ICU admission, mortality, and combined outcome rates as a function of oxygen saturation %. B) The ICU admission, mortality, and combined outcome rates as a function of age group.

188x166mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of *cohort studies*

	Item No	Recommendation	Page No
<b>Title and abstract</b>	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	6
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7, 8
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up (b) For matched studies, give matching criteria and number of exposed and unexposed	7, 8
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8, 9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	8, 9
Bias	9	Describe any efforts to address potential sources of bias	16
Study size	10	Explain how the study size was arrived at	N/A
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8, 9
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) If applicable, explain how loss to follow-up was addressed (e) Describe any sensitivity analyses	8, 9, 10
<b>Results</b>			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage (c) Consider use of a flow diagram	7, 10
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders  (b) Indicate number of participants with missing data for each variable of interest  (c) Summarise follow-up time (eg, average and total amount)	Figures 1, 2, 3 Table 1  Pages 11, 12, 13

Outcome data	15*	Report numbers of outcome events or summary measures over time	10
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	10
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11, 12, 13
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	14, 15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16, 17
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	18
Generalisability	21	Discuss the generalisability (external validity) of the study results	16, 17
<b>Other information</b>			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	19

\*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at <http://www.strobe-statement.org>.



# BMJ Open

## Validation of oxygen saturations measured in the community by emergency medical services as a marker of clinical deterioration in patients with confirmed COVID-19 - a retrospective cohort study

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7 3 **Validation of oxygen saturations measured in the community by emergency medical**  
8 4 **services as a marker of clinical deterioration in patients with confirmed COVID-19 - a**  
9 5 **retrospective cohort study**  
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15 8 Matthew Inada-Kim<sup>[1]</sup>

16 9 Francis P. Chmiel<sup>[2]</sup>

17 10 Michael J. Boniface<sup>[2]</sup>

18 11 Daniel K. Burns<sup>[2]\*</sup>

19 12 Helen Pocock<sup>[3,4]</sup>

20 13 John J. M. Black<sup>[3,5]</sup>

21 14 Charles D. Deakin<sup>[3,6]</sup>

22 15  
23 16 [1] Acute Medical Unit, Department of Acute Medicine, Hampshire Hospitals NHS Foundation Trust, Winchester, United  
24 17 Kingdom.

25 18 [2] School of Electronics and Computer Science, University of Southampton, Southampton, SO17 1BJ, UK

26 19 [3] South Central Ambulance Service NHS Foundation Trust, Otterbourne, SO21 2RU, UK

27 20 [4] Warwick Clinical Trials Unit, University of Warwick, Coventry, CV4 7AL, UK

28 21 [5] Emergency Department, Oxford University Hospitals NHS Foundation Trust OX3 9DU.

29 22 [6] Southampton Respiratory Biomedical Research Unit, National Institute for Health Research, University Hospital  
30 23 Southampton, SO16 6YD  
31 24

32 25 \* Corresponding author: d.burns@soton.ac.uk  
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3 27 **ABSTRACT**  
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6 28  
7 29 **Objectives** To evaluate oxygen saturation and vital signs measured in the community by emergency  
8 30 medical services (EMS) as clinical markers of COVID-19-positive patient deterioration.  
9

10 31 **Design** A retrospective data analysis.  
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12

13 32 **Setting** Patients conveyed by EMS to two hospitals in Hampshire, UK between March 1<sup>st</sup> and July 31<sup>st</sup>  
14 33 2020.  
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17 34 **Participants** A total of 1,080 patients aged  $\geq$  18 years old with a COVID-19 diagnosis who were  
18 35 conveyed by EMS to hospital.  
19

20  
21 36 **Primary and secondary outcome measures** The primary study outcome was admission to ICU within  
22 37 30-days of conveyance with a secondary outcome representing mortality within 30-days of  
23 38 conveyance. ROC analysis was performed to evaluate, in a retrospective fashion, the efficacy of  
24 39 different variables in predicting patient outcomes.  
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27  
28 40 **Results** Vital signs measured by EMS staff at first point of contact in the community correlated with  
29 41 patient 30-day ICU admission and mortality. Oxygen saturation was comparably predictive of 30-day  
30 42 ICU admission (AUROC 0.753 (95 % CI: 0.668-0.826)) to the NEWS2 score (AUROC 0.731 (95 % CI:  
31 43 0.655-0.800)), followed by temperature (AUROC 0.720 (95 % CI: 0.640-0.793)), and respiration rate  
32 44 (AUROC 0.672 (95 % CI: 0.586-0.756)).  
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37 45 **Conclusions** Initial oxygen saturation measurements (on air) for confirmed COVID-19 patients  
38 46 conveyed by EMS correlated with short-term patient outcomes, demonstrating an AUROC of 0.753  
39 47 (95% CI: 0.668-0.826) in predicting 30-day ICU admission. We found that threshold of 93% SpO<sub>2</sub> is  
40 48 prognostic of adverse events and of value for clinician decision making with sensitivity (74.2 % CI  
41 49 0.642-0.840) and specificity (70.6 % CI 0.678-0.734).  
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3 52 **ARTICLE SUMMARY**  
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6 54 **Strengths and limitations of this study**  
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- 8 55 • We used baseline community oxygen saturation measurements (on air) for COVID-19  
9 56 patients conveyed by emergency medical services (EMS) to hospital to evaluate efficacy of  
10 57 these measurements as prognostic factors for short-term (30-day) ICU admission and/or  
11 58 mortality.  
12  
13 59 • We also assessed the prognostic value of NEWS2 and other vital signs measured by EMS to  
14 60 provide contrast with our oxygen saturation results.  
15 61 • The data is linked between EMS and hospital clinical records to enable our study.  
16  
17 62 • The data has limitations: only patients conveyed by emergency medical services were  
18 63 included, and the type of oxygen saturation measurement device for each patient was  
19 64 unknown.  
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## 66 INTRODUCTION

67 Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is a highly transmissible and  
68 pathogenic coronavirus that causes coronavirus disease 2019 (COVID-19) [1]. COVID-19 presents the  
69 biggest global healthcare challenge of our generation. As of February 2021, COVID-19 associated  
70 mortality stands at over 110,000 in the UK [2] COVID-19 presents a number of challenges in identifying  
71 optimal management pathways, not only in terms of the clinical care itself, but also identifying the  
72 stage at which hospital admission is necessary. Traditional management pathways involving  
73 paramedic assessment and conveyance to the Emergency Department (ED) for further review have  
74 proven impractical, not only because of the large numbers of patients involved, but because of the  
75 need to minimise contact of COVID-19 patients with others. Most patients who become symptomatic  
76 do so in a home environment where the majority will remain. In terms of optimising outcome, there  
77 is a need to understand which symptoms and signs in this environment are prognostic indicators of  
78 potential deterioration. The national recommendation for the implementation of COVID virtual wards  
79 recently announced by NHS England,[3] ushers in a novel approach of empowering patients through  
80 providing symptomatic, at risk patients a pulse oximeter and a toolkit for self-monitoring at home. It  
81 is hoped that this will enable the earlier recognition of deterioration in COVID-19 patients and  
82 potentially improved outcomes.

83 In most cases of bacterial and non-COVID pneumonia, breathlessness appears relatively early in the  
84 disease and ahead of any significant hypoxia. The challenge with assessing COVID-19 severity is that  
85 asymptomatic hypoxia often precedes breathlessness and by the time symptoms of breathlessness  
86 occur, patients have developed advanced disease and hypoxia may be significant.[4] The ability to  
87 detect this asymptomatic hypoxia before patients experience shortness of breath is critical for  
88 preventing respiratory involvement progressing to a life-threatening state. The key is to be able to  
89 detect this initial drop in oxygen saturation levels so that patients infected with COVID-19 who begin  
90 to suffer from pulmonary complications in the community can be detected early and conveyed to  
91 hospital for further treatment.[5] Although some studies have reported the relationship between  
92 oxygen saturation and outcome on presentation to the ED, we are not aware of any studies that have  
93 reported the relationship between oxygen saturations measured in the community by EMS and  
94 outcome. Patients who on assessment are severely hypoxic are clearly in need of emergency  
95 conveyance and hospital treatment, but by far the majority of patients with Covid-like symptoms seen  
96 and assessed by the EMS have relatively normal or near-normal oxygen saturations. These patients  
97 have generally not been conveyed and have been managed at home, but it has become apparent that  
98 even relatively minor derangements in oxygen saturations may be an early warning indicator for  
99 disease progression and the subsequent need for critical care. Use of oxygen saturation as an indicator

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3 100 of disease severity may therefore underestimate the risk of leaving patients at home after assessment  
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5 101 by the EMS. National case fatality rates (CFR) (ratio of deaths to total cases) have shown a strong  
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7 102 inverse correlation between target oxygen saturation levels of 90-98% [6] suggesting that even mild  
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9 103 derangements in oxygen saturation untreated can be detrimental to outcome.

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11 104 Two small studies have suggested the utility of home oxygen monitoring for COVID-19 patients  
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13 105 discharged from hospital,[7, 8] but no studies to our knowledge have used out-of-hospital oxygen  
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15 106 saturation measurements as a trigger for initial hospital assessment. The purpose of this study  
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17 107 therefore is to understand the prognostic significance of oxygen saturation when first measured by  
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19 108 EMS clinicians. The understanding aims to inform escalation policies for safe and effective community-  
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21 109 based triage and self-monitoring at home by identify a threshold where the sensitivity and specificity  
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23 110 are of clinical value. It is hoped that the approach will contribute to hospital admission avoidance,  
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25 111 enable earlier recognition of deterioration in COVID-19 patients and potentially improve outcome  
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27 112 through early identification of those most at risk of disease progression. Whilst using a pulse oximeter  
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29 113 provides a way for patients to monitor disease progression through a simple measurement procedure  
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31 114 in contrast to the complexity of measurements required to calculate a NEWS2 score.

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## 118 **METHODS**

### 119 **Study Design**

120 We undertook a retrospective review of clinically confirmed COVID-19 patients accessing a regional  
121 UK ambulance service who were conveyed to hospital and correlated their initial oxygen saturations  
122 measured at home with their in-hospital outcome. These were compared with the standard NEWS2  
123 patient score, as used by all UK ambulance services, to identify the deteriorating patient.[9]

124 The cohort included adult patients (aged 18 years of older) initially assessed and conveyed by  
125 personnel from South Central Ambulance Service (SCAS) to the Emergency Department at one of the  
126 two hospitals within north Hampshire; Basingstoke & North Hampshire Hospital, or the Royal  
127 Hampshire County Hospital (Winchester) at which the patients were subsequently admitted.

128 The standard care pathway included 1) Patients calling emergency (999) and urgent (111) where they  
129 are triaged using NHS Pathways telephone script (release 19), 2) Attendance, assessment and  
130 monitoring by ambulance staff at the patient's home, 3) Conveyance to hospital for patients  
131 considered at high risk of deterioration 4) Admission to hospital and escalation to ICU for patients  
132 requiring critical care.

133 We analysed EMS conveyances occurring between 1<sup>st</sup> March to 31<sup>st</sup> July 2020, to determine suspect  
134 COVID-19 among conveyances at initial time of contact by the call taker or EMS staff, each patient  
135 record was reviewed for inclusion of at least one of the following four identifiers:

- 136 1. Those in who the EMS call taker had classified the call as 'COVID- Respiratory Distress'
- 137 2. Those where the Patient Clinical Record (PCR) listed the 'Presenting complaint' as 'Suspected  
138 COVID-19'.
- 139 3. Those where the PCR free text for the 'Presenting complaint' contained the word 'COVID'
- 140 4. Those where the PCR narrative in the free text field summarising the symptoms and their  
141 details completed by the paramedic contained the word 'COVID'.

142 Conveyances from these suspect COVID-19 patients were then linked to their subsequent hospital  
143 attendance. Of suspect cases, we then identified confirmed COVID-19 cases by selecting only those  
144 with a confirmed diagnosis in their discharge summary (i.e., the presence of a U07.1 or U07.2 ICD10  
145 code). These confirmed COVID-19 cases made up our study cohort.

146 Seventeen patients did not have initial oxygen saturations recorded on air (but did have oxygen  
147 saturations recorded on oxygen) and were excluded from the data analysis. If this was because they  
148 were so obviously hypoxic clinically that EMS staff immediately administered oxygen without an initial



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3 149 reading on air (or were constantly on home oxygen treatment), the ability of oxygen saturations to  
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5 150 indicate risk of deterioration is likely to have been underestimated in this study.  
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7 151 All patients in known palliative care pathways were excluded from data analysis because their care  
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9 152 did not follow standard care pathways.  
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### 11 153 **Study setting**

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13 154 SCAS is a provider of emergency care in the counties of Hampshire, Berkshire, Buckinghamshire and  
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15 155 Oxfordshire and covers a total of 3554 sq. miles (9205 km<sup>2</sup>). The service receives approximately  
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17 156 500,000 emergency and urgent calls annually. SCAS covers a residential population of approximately  
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19 157 4.0 million inhabitants in a mix of urban and rural areas. The north Hampshire region forms part of the  
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21 158 area covered by SCAS and comprises a residential population of approximately 306,000.[10]  
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### 24 160 **Data collection**

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27 161 The initial oxygen saturation reading (SpO<sub>2</sub>) on air recorded by the attending EMS staff (prior to any  
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29 162 exercise or step test) and the NEWS2 score of patients fulfilling the inclusion criteria were collected  
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31 163 from the EMS PCR. (NEWS2 score is calculated using the following seven variables: systolic blood  
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33 164 pressure, heart rate, respiratory rate, temperature, oxygen saturation, supplemental oxygen  
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35 165 administration, and level of consciousness - [https://www.england.nhs.uk/ourwork/clinical-](https://www.england.nhs.uk/ourwork/clinical-policy/sepsis/nationalearlywarningscore)  
36 166 [policy/sepsis/nationalearlywarningscore.](https://www.england.nhs.uk/ourwork/clinical-policy/sepsis/nationalearlywarningscore))  
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38 167 Patient outcome was obtained by linking the SCAS and hospital clinical records by their NHS number.  
39  
40 168 The primary outcome of our study was ICU admission within 30-days of conveyance and the secondary  
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42 169 outcomes was mortality and a combined outcome (ICU admission and/or mortality) within 30-days of  
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44 170 conveyance.  
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### 47 172 **Data analysis**

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50 173 Analysis was performed in Python 3.7.2 [10], primarily making use of the statsmodels library [11].  
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52 174 Confidence intervals on observed mortality rates were estimated using the Wilson score interval.  
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54 175 Where relevant, significance of the difference between two observed adverse outcome rates were  
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56 176 tested using a two-population proportions z-test with the null hypothesis that the two-population  
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58 177 proportions are equal.  
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3 178 To evaluate how predictive individual variables (e.g., oxygen saturation) and combinations of variables  
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5 179 (e.g., oxygen saturation with age) were of 30-day adverse outcomes, we performed Receiving  
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7 180 Operator Characteristics curve analysis. In the univariate analysis, we performed a complete case  
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9 181 analysis (removing any patient with an incomplete record of vital signs) and assume a patient's  
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11 182 adverse outcome risk is a linear function of the respective variable (where negative or positive  
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13 183 correlation with outcome is assessed by clinical judgement) and calculated the ROC curve  
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15 184 corresponding to if this variable alone was used to predict a patient's risk of an adverse outcome. We  
16  
17 185 present both the sensitivity and specificity or the Area Under the Receiving Operator Characteristic  
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19 186 curve (AUROC). The AUROC provides an estimate of the degree to which the predictor can discern  
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21 187 between whether a patient has an adverse outcome within 30 days of conveyance or not, it can take  
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23 188 values between 0.5 and 1.0. An AUROC of 0.5 corresponds to randomly guessing which patient have  
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25 189 an adverse outcome within 30 days and an AUROC of 1.0 corresponds to a perfect classifier - it can  
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27 190 predict, without error, who will have an adverse outcome within 30-days of conveyance. Confidence  
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29 191 intervals were estimated by performing 1000 bootstrapping (sampling with replacement) iterations  
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31 192 on the available data, calculating the AUROC on each of the samples and then calculating the relevant  
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33 193 percentiles.

### 31 194 **Patient and Public Involvement**

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33 195 This research was done without patient involvement. Patients were not invited to comment on the  
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35 196 study design and were not consulted to develop patient-relevant outcomes or interpret the results.  
36  
37 197 Patients were not invited to contribute to the writing or editing of this document for readability or  
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39 198 accuracy.

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**RESULTS**

A total of 19,868 patients were assessed at home and subsequently conveyed by EMS to North Hampshire Hospitals during the study period. The details of cohort selection are shown in Figure 1. The call handler or EMS staff identified 2,257 suspect COVID-19 cases and of these we identified 1,209 adults as having a confirmed diagnosis of COVID-19 (U07.1 or U07.2 coded in the patients discharge summary). Of the 1,209 confirmed cases we removed persons under palliative care (112 patients) and those with no initial oxygen saturation measurement on air recorded (17 patients). Overall, this left us with 1,080 confirmed COVID-19 patient records all of whom had initial oxygen saturation measurements on air. Of these 1,080, the complete records of vital signs were recorded at home by paramedics for 892 of the patients. The summary of the final patient cohort, with respect to demographics, comorbidities, and presence of vital sign measurements is given in Table 1. In our following discussions, we make use of all 1,080 patients, with the exception for our univariate analyses where we perform a complete case analysis and only use the 892 complete records.

Oxygen saturation was found to correlate with adverse outcome (Figure 2A), with lower initial oxygen saturation readings being associated with a higher mortality rate. In Figure 2A we display the correlation between the observed 30-day adverse outcome rates and initial oxygen saturation in detail, which displays correlation to all outcomes. In Table 2 we display the breakdown of our retrospective ROC analysis for using measured oxygen saturation as a binary triage tool (i.e., hospitalize or not) for different cut-offs (rows in Table 2). While the sensitivity vs specificity trade-off needs to be determined by the clinical context, this demonstrates that oxygen saturation is moderately discriminative for several cut-offs. For example, for a cut-off of 94 % or below, the sensitivity is 0.742 (95 % CI: 0.642-0.734) and the specificity is 0.706 (95 % CI: 0.678-0.734). Finally, we present comparisons of the results of ROC analysis for different variables measured in the community by EMS (Table 3). Across the three presented outcomes (30-day ICU admission, mortality, and combined outcome) correlations between variables and outcomes are broadly similar, with measured oxygen saturations and the NEWS2 score being the two most predictive of outcome. The notable differences are for the measured temperature which is moderately predictive of ICU admission (AUROC: 0.720 (95 % CI: 0.640-0.793)) but only weakly predictive of mortality (AUROC: 0.597 (95 % CI: 0.523-0.678)) and for patient age which is strongly positively correlated to mortality but displays a negative correlation to ICU admission (Figure 2B).

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Variable	Outcome Category		
Outcome	No adverse event(n=955)	30-day ICU admission (n=58)	30-day mortality (n=78)
<b>Age</b>			
18-49	159 (16.6%)	11 (19.0%)	1 (1.3%)
50-59	132 (13.8%)	16 (27.6%)	2 (2.6%)
60-69	119 (12.5%)	17 (29.3%)	9 (11.5%)
70-79	209 (21.9%)	9 (15.5%)	16 (20.5%)
80+	336 (35.2%)	5 (8.6%)	50 (64.1%)
<b>Comorbidities</b>			
Chronic Obstructive Pulmonary Disorder	33 (3.5%)	0 (0.0%)	6 (7.7%)
Dementia	90 (9.4%)	1 (1.7%)	18 (23.1%)
Diabetes	216 (22.6%)	14 (24.1%)	14 (17.9%)
Kidney disease	7 (0.7%)	1 (1.7%)	3 (3.8%)
Chronic pain	37 (3.9%)	3 (5.2%)	1 (1.3%)
<b>Vital signs</b>			
Heart rate present	946 (99.1%)	58 (100.0%)	77 (98.7%)
Systolic blood pressure present	869 (91.0%)	51 (87.9%)	71 (91.0%)
Respiratory rate present	852 (89.2%)	49 (84.5%)	70 (89.7%)
Oxygen saturation (on air) present	955 (100.0%)	58 (100.0%)	78 (100.0%)
Temperature present	825 (86.4%)	49 (84.5%)	67 (85.9%)
ACVPU present	849 (88.9%)	50 (86.2%)	67 (85.9%)

**Table 1: Characteristics of COVID-19 positive patients stratified by outcome. Note that n=11 patients experienced both ICU admission and mortality within 30 days.** We only report on comorbidities which were present in the dataset as provided by the EMS. Comorbidity presence was recorded for every patient in the study. ACVPU = alert, confused, responding to voice, responding to pain, unresponsive. Oxygen saturations were not missing for any patients as those with missing values had been excluded (n=17). Overall, vital signs records were complete for 83% of cases.

		Sensitivity (95 % CI)	Specificity (95 % CI)	Number of observations	Cumulative sum of number of observations
Oxygen Saturation (on air) threshold (%)	85	0.294 (0.200-0.400)	0.947 (0.933-0.962)	8	76
	86	0.316 (0.216-0.421)	0.941 (0.927-0.955)	8	84
	87	0.320 (0.216-0.432)	0.935 (0.920-0.950)	6	90
	88	0.370 (0.261-0.476)	0.916 (0.899-0.933)	23	113
	89	0.413 (0.304-0.523)	0.894 (0.874-0.913)	25	138
	90	0.512 (0.411-0.615)	0.870 (0.849-0.890)	32	170
	91	0.590 (0.477-0.699)	0.841 (0.823-0.867)	31	201
	92	0.655 (0.544-0.761)	0.817 (0.796-0.841)	33	234
	93	0.706 (0.593-0.803)	0.776 (0.751-0.801)	45	279
	94	0.742 (0.642-0.840)	0.706 (0.678-0.734)	74	353
	95	0.808 (0.718-0.892)	0.634 (0.605-0.662)	76	429
	96	0.848 (0.767-0.921)	0.508 (0.477-0.538)	129	558
	97	0.898 (0.822-0.963)	0.357 (0.330-0.386)	156	714
	98	0.911 (0.841-0.973)	0.226 (0.201-0.254)	132	846
99	0.961 (0.913-1.0)	0.091 (0.075-0.109)	139	985	
100	1	0	95	1080	

**Table 2: Evaluation of initial oxygen saturation measured by paramedics in COVID-19 patients in the community used as a binary classifier for predicting 30-day ICU admission within 30 days of conveyance.** Each row denotes a different threshold for determining those at risk of an adverse outcome. We display the sensitivity and specificity for each threshold, equivalent to all possible intersections of the receiving operator curve using thresholds between 85 % and 100 %. In total 68 patients had an oxygen saturation of 84 % or less (not shown). The column on the far right denotes the cumulative sum of the number of observations of the given oxygen saturation (row) or below. For example, 76 patients had an oxygen saturation of 85 % or less recorded (top row) and 429 patients had an oxygen saturation of 95 % or less recorded. Confidence intervals are estimated by bootstrapping.

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Variable	AUROC (95 % CI)		
	ICU admission	Mortality	Combined
<b>Oxygen Saturation (on air)</b>	0.753 (0.668-0.826)	0.778 (0.704-0.843)	0.775 (0.727-0.829)
<b>NEWS2</b>	0.731 (0.655-0.800)	0.768 (0.709-0.823)	0.760 (0.708-0.807)
<b>Respiration rate</b>	0.672 (0.586-0.756)	0.668 (0.599-0.736)	0.677 (0.618-0.738)
<b>Temperature</b>	0.720 (0.640-0.793)	0.597 (0.523-0.678)	0.636 (0.69-0.700)
<b>Systolic blood pressure</b>	0.634 (0.560-0.706)	0.604 (0.529-0.680)	0.626 (0.568-0.684)
<b>Heart rate</b>	0.590 (0.506-0.672)	0.558 (0.486-0.631)	0.574 (0.514-0.633)
<b>Age band</b>	0.670 (0.611-0.734)	0.685 (0.626-0.738)	0.557 (0.495-0.615)

260 **Table 3: Ranked Area Under Receiver Operator Curves (AUROC) calculated for isolated physiological**  
 261 **variables and the composite NEWS2 score with each outcome.** AUROCS were calculated using a  
 262 complete case analysis with 892 patients in total. Confidence intervals are estimated by bootstrapping,  
 263 with 95 % confidence intervals presented alongside the mean validation AUROC across samples.

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**DISCUSSION**

Community assessment of patients with COVID-19 symptoms using a single initial oxygen saturation on air measurement correlates with 30-day clinical outcomes. Qualitatively, the observed 30-day adverse outcome rate is approximately constant between oxygen saturations of 100 - 96 % and then increase with decreasing oxygen saturation from 95 % to 90 %. Below 90 %, the mortality risk remains high. Although the therapeutic target range for oxygen saturations in the UK is 94-98%,<sup>[11]</sup> and in the USA is 92-96%,<sup>[12]</sup> this study suggests that patients at the lower end of this range are still at risk of deterioration in the context of COVID-like symptoms. For example, for patients in our cohort with presenting oxygen saturations in the range of 92-94 %, values often regarded as within this normal range, had a significantly ( $p=0.025$ ) higher risk of ICU admission within 30 days (5.9 %) compared to those presenting with oxygen saturations greater than 95 % (ICU admission rate 2.5 %). Outside this 'normal' range, our analysis suggests even relatively small decreases in oxygen saturation are markers of increased risk of death or ICU admission and suggest that a lower threshold for hospital conveyance may be necessary for patients who traditionally would be considered to have only minor physiological derangement and otherwise have been left at home.

The sensitivity of home oxygen saturation measurements reflects the percentage of people correctly identified with adverse outcomes. The sensitivity of this parameter for adverse outcome decreased as oxygen saturation fell (Table 2). An oxygen saturation  $\leq 90\%$  was associated with a relatively low sensitivity of  $< 0.5$ . Specificity of identifying an adverse outcome, an indirect measure of unnecessary conveyance to hospital (but also including patients who survived and did not need ICU admissions), increased as oxygen saturations fell. However, it is important to ensure that patients at risk of deterioration are not missed and a degree of over-triage would be necessary to ensure that this was not the case. However, even oxygen saturations at the lower end of the normal range are associated with a risk of deterioration (sensitivity of 94% saturations = 0.713) and it therefore appears that oxygen saturation alone has significant limitations when it is within a normal range.

Although oxygen saturations as a risk factor for COVID-19 patients on presentation to the Emergency Department are widely reported,<sup>[13, 14]</sup> the ability of oxygen saturations measured in the community to indicate disease severity and the need for hospital conveyance has not been widely reported, presumably because of the challenges in equipping patients with pulse oximeters prior to the onset of any illness. Several studies have used oxygen levels in patients presenting in the ED as an indicator of the need for hospital admission and others have used the opportunity to send ED patients not requiring admission home with a pulse oximeter for self-monitoring. Oxygen saturations on presentation to the ED have also been shown to be strongly associated with outcome. The strongest



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3 303 critical illness risk has been shown to be admission oxygen saturation < 88% (OR 6.99).[14] Other  
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5 304 studies have shown that even a relatively mildly deranged oxygen saturation of <92% is strongly  
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7 305 associated with an increased risk of in-hospital mortality.[15] Conversely, an ED resting SpO<sub>2</sub> ≥ 92% as  
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9 306 part of discharge criteria can achieve hospital readmission rates as low as 4.6%, [16] suggesting that it  
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11 307 may be a safe threshold for discharge in symptomatic patients with mild disease after diagnostic  
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13 308 workup .

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15 309 Home oxygen saturation monitoring has been used for patients discharged from hospital, either from  
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17 310 the ED because their disease was not severe, or from intensive care for convalescence. A small study  
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19 311 of patients with COVID-19 discharged from an ED, reported similar results to ours using subsequent  
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21 312 home oxygen saturation monitoring. In these patients, resting home SpO<sub>2</sub> < 92% was associated with  
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23 313 an increased likelihood of re-hospitalization compared to SpO<sub>2</sub> ≥ 92% (relative risk = 7.0, 95% CI 3.4 to  
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25 314 14.5, p < 0.0001). Home SpO<sub>2</sub> < 92% was also associated with increased risk of intensive care unit  
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27 315 admission.[8]  
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31 317 Oxygen saturation is an integral variable in most critical illness tools. The association of prehospital  
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33 318 oxygen saturation has been shown to be predictive of 2-day mortality [17]and has been used to  
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35 319 identify COVID-19 patients requiring hospital admission.[18] NHS England has encouraged the use of  
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37 320 the NEWS2 scoring system to identify patients at risk of deterioration. This uses weighted physiological  
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39 321 variables of heart rate, systolic blood pressure, oxygen saturation (on air), respiratory rate,  
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41 322 temperature and level of consciousness to produce a score that is correlated with risk of deterioration,  
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43 323 not only as a general illness score, but specifically in patients with known COVID-19.[19] NEWS2 has  
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45 324 been compared with a quick COVID Sensitivity Index (qCSI), a test that includes SpO<sub>2</sub>, respiratory rate  
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47 325 and O<sub>2</sub> flow rate to calculate a score between 1 and 12, and risk level. The study concludes NEWS2 is  
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49 326 significantly better than qCSI, with AUC of 0.779 and 0.750 respectively [20]. Furthermore, qCSI does  
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51 327 not consider severity score for readings of 93% and above, whilst qCSI pulse oximetry readings are the  
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53 328 lowest reading recorded during the first 4 hours of patient encounter at the hospital, rather than being  
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55 329 prior to admission. In our study, we were concerned with the ability of isolated oxygen saturations  
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57 330 measured by EMS on attendance in comparison with NEWS2 in our cohort to identify patients at risk  
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59 331 of ICU admission (and mortality) within 30 days. Using ROC analysis, the AUROC for oxygen saturations  
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332 at predicting ICU admission alone was 0.753 (95% CI 0.668-0.826) and for NEWS2 was 0.731 (95% CI  
333 0.655-0.800). These results are consistent with a previous study using NEWS2 scores on hospital  
334 admission which has shown an AUROC of 0.822 (95% CI 0.690-0.953) to predict risk of severe  
335 disease.[19] The lower observed AUROC of NEWS2 compared to oxygen saturations may be the result  
336 of the NEWS2 score incorporating physiological variables less predictive of COVID-19 outcomes than

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3 337 oxygen saturations, thereby reducing the discriminative ability of the score, or because it uses  
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5 338 discretized oxygen saturations which amounts to information loss. Additionally, we have not assessed  
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7 339 the reporting compliance of the NEWS2 scores and this may have impacted the observed AUROCs.  
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9 340 Interestingly, a recent review of 22 prognostic models showed that oxygen saturation on room air and  
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11 341 patient age were strong predictors of deterioration and mortality among hospitalised adults with  
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13 342 COVID-19 respectively, but no other variables added incremental value to these predictors.[18] We  
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15 343 have shown the same for oxygen saturation as a univariate predictor in the pre-hospital setting, and  
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17 344 that predictive value does not increase by the addition of other physiological variables. The PRIEST  
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19 345 study using NEWS2, age, sex, and performance status of patients in the ED predicted adverse outcome  
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21 346 with good discrimination in adults with suspected COVID-19 [20]. The discriminatory ability of this  
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23 347 more complex scoring system was similar to that demonstrated by simply measuring the oxygen  
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25 348 saturations in the community and further reinforces the utility of home oxygen saturations as a simple  
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27 349 marker, not only for use by the EMS, but by members of the public equipped with home oximetry.

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28 351 A number of remote home monitoring models for patients with suspected COVID-19 have been  
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30 352 proposed, all of which aim to achieve early identification of deterioration for patients self-managing  
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32 353 COVID-19 symptoms at home.[21] It would be expected that the utility of home monitoring would be  
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34 354 improved by the ability to measure oxygen saturations, although not all models currently integrate  
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36 355 this into their protocols. Our results show that resting oxygen saturations measured in patients with  
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38 356 confirmed COVID-19 perform on a par with the same measurements taken in the ED. They therefore  
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40 357 suggest that the predictive value of oxygen saturations may be able to be effectively moved to an  
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42 358 earlier stage in the disease process and measured while the patient is still at home. Although initial  
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44 359 home SpO<sub>2</sub> may provide a useful marker of disease severity and the need for hospital conveyance, it  
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46 360 is clear that it has limited sensitivity and may need to be interpreted as part of an overall assessment  
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48 361 of the patient. Some authors have argued that pulse oximetry identified the need for hospitalisation  
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50 362 when using a cut- off of 92%, [8] but based on our data (Table 2), approximately one-third of patients  
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52 363 with an adverse outcome would be missed using this threshold. We have demonstrated that even  
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54 364 patients presenting with oxygen saturations of 92-94 %, which are values often regarded as within a  
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56 365 normal range, have a higher mortality than those with oxygen saturations higher than 95 %. Even  
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58 366 when measured in the ED, baseline median SpO<sub>2</sub> was as high as 95.0 % in those with an adverse  
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60 367 outcome, compared to 97.0% in those without.[22] It is clear that the relatively low sensitivity of  
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369 oxygen saturation in those with mildly deranged values limits the utility of this parameter alone in  
assessing risk of adverse outcome.

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3 370 This is a relatively small retrospective cohort study with concomitant limitations of sample size. The  
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5 371 subjective nature of paramedic classification of symptoms consistent with COVID-19 may have  
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7 372 introduced some degree of bias into patients included in the study, as may have the presence of  
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9 373 known co-morbidities. Our dataset did not include patients who were reviewed by EMS but not  
10 374 conveyed to hospital and this is arguably the most significant source of bias in our study. It is  
11 375 reasonable that for patients where a decision was made not to convey them, they were less likely to  
12 376 deteriorate and more likely to have normal vital signs. If this is the case, this would result in a reduction  
13 377 of the discriminative ability of recorded oxygen saturations. We did not specifically compare the  
14 378 outcome data of COVID and Non-COVID patients with mildly deranged oxygen saturations. However,  
15 379 our data suggests that mild derangement in COVID patients is a significant risk factor for deterioration  
16 380 and this does not match the clinical progression witnessed in non-COVID patients. We acknowledge  
17 381 that for very low SpO<sub>2</sub> levels our results show poor clinical value and we believe this is due to other  
18 382 factors influencing escalation decisions that are not included in our dataset. Patients on palliative  
19 383 care pathways were also removed from the study cohort, but are likely to be more susceptible to  
20 384 deterioration from COVID, irrespective of any alternative care pathway.  
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32 386 With waves of COVID-19 regularly overwhelming EMS and hospital services, there is an urgent need  
33 387 to optimise the identification of patients at risk of deterioration. We undertook this research to  
34 388 ascertain the role simple physiological measures might have to inform clinical decision making. While  
35 389 the results are hypothesis-forming (i.e., it shows oxygen saturations are predictive of clinical outcomes  
36 390 within the care pathway studied in this manuscript), it has clinical utility as it helps inform decisions  
37 391 made by clinicians at the point of conveyance. This will enable more patients to be safely managed in  
38 392 the community and only referred to hospital once their clinical symptoms and physiological signs  
39 393 suggest a risk of deterioration and the need for hospital care. This is particularly needed for the  
40 394 majority of patients who have mild to moderate symptoms where it is not clear if community or  
41 395 hospital management is appropriate. Home pulse oximetry is becoming relatively cheap and easily  
42 396 accessible for the public and may be a relatively cost-effective tool in the safe community  
43 397 management of these patients, perhaps focussed on those with significant co-morbidities who are at  
44 398 higher risk. The utility of remote monitoring systems (or the COVID virtual ward) has been an  
45 399 increasingly studied subject, and there is growing evidence that remote monitoring can facilitate more  
46 400 streamlined approaches to the delivery of patient care, especially in pulmonary disease.[7] The use of  
47 401 ICU admission as an endpoint identifies patients seen at home who go on to deteriorate and the  
48 402 correlation of home oxygen saturation with a risk of severe deterioration assists ambulance crews in  
49 403 identifying both those who should be conveyed to hospital as well as those who can, with a reasonable  
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3 404 degree of certainty, be safely left at home. Further prospective studies are required to understand the  
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5 405 utility of home pulse oximetry, but this study suggests that it may have the potential to significantly  
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7 406 contribute to the safe and appropriate management of these patients in the community with timely  
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9 407 referral to hospital when indicated.

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## 11 12 409 **Conclusions**

13  
14 410 We have demonstrated that even relatively minor derangements in peripheral oxygen saturation are  
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16 411 an early warning of potential deterioration in confirmed COVID-19 patients conveyed by EMS to  
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18 412 hospital and oxygen saturation would appear to have potential to be a key physiological variable  
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20 413 that together with other clinical signs and clinical risk factors may be able to identify patients at risk  
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22 414 of deterioration.

23 415

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26  
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35  
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37  
38 422 author(s) and not necessarily those of the National Institute for Health Research or the Department  
39  
40 423 of Health and Social Care.

## 41 42 424 **Governance and ethics approval** statement

43  
44 425 Regulatory and ethical approval for the study were provided by the Health Research Authority (REC  
45  
46 426 reference 20/HRA/5445) and by the University of Southampton Ethics Committee (REF ERGO/61242).  
47  
48 427 NHS England and NHS Improvement have been given legal notice by the Secretary of State for Health  
49  
50 428 and Social Care to support the processing and sharing of information to help the COVID-19 response  
51  
52 429 under Health Service Control of Patient Information Regulations 2002 (COPI). This is to ensure that  
53  
54 430 confidential patient information can be used and shared appropriately and lawfully for purposes  
55  
56 431 related to the COVID-19 response. Data were extracted from medical records by clinicians providing  
57  
58 432 care for the patients and an anonymised extract of the data were provided to the team at the  
59  
60 433 University of Southampton.

## 61 62 434 **Author contributions**

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3 435 MI-K, MJB, JJM Black, CDD led and conceptualized the study. MI-K led at HHFT, MJB led at UoS, CDD  
4  
5 436 led at SCAS. FPC and DKB performed the data analysis with support and guidance from all authors.  
6  
7 437 MI-K, HP and JJM Black performed the data extraction. MJB led the data governance. CDD and HP  
8  
9 438 provided clinical insight. MI-K, CDD, HP and FPC wrote the first draft of the manuscript. All authors  
10  
11 439 discussed the results. All others contributed to subsequent drafts of the manuscript. DKB prepared  
12  
13 440 the final manuscript for submission.

#### 14 441 **Competing interests**

15  
16 442 M. I-K. is National Clinical Lead Deterioration & National Specialist Advisor Sepsis, NHS England and  
17  
18 443 NHS Improvement. All other authors declare no competing interests.

#### 19 444 **Data accessibility**

20  
21 445 Due to information governance concerns, the data will not be made public. However, it will be made  
22  
23 446 accessible via reasonable request to the corresponding author.

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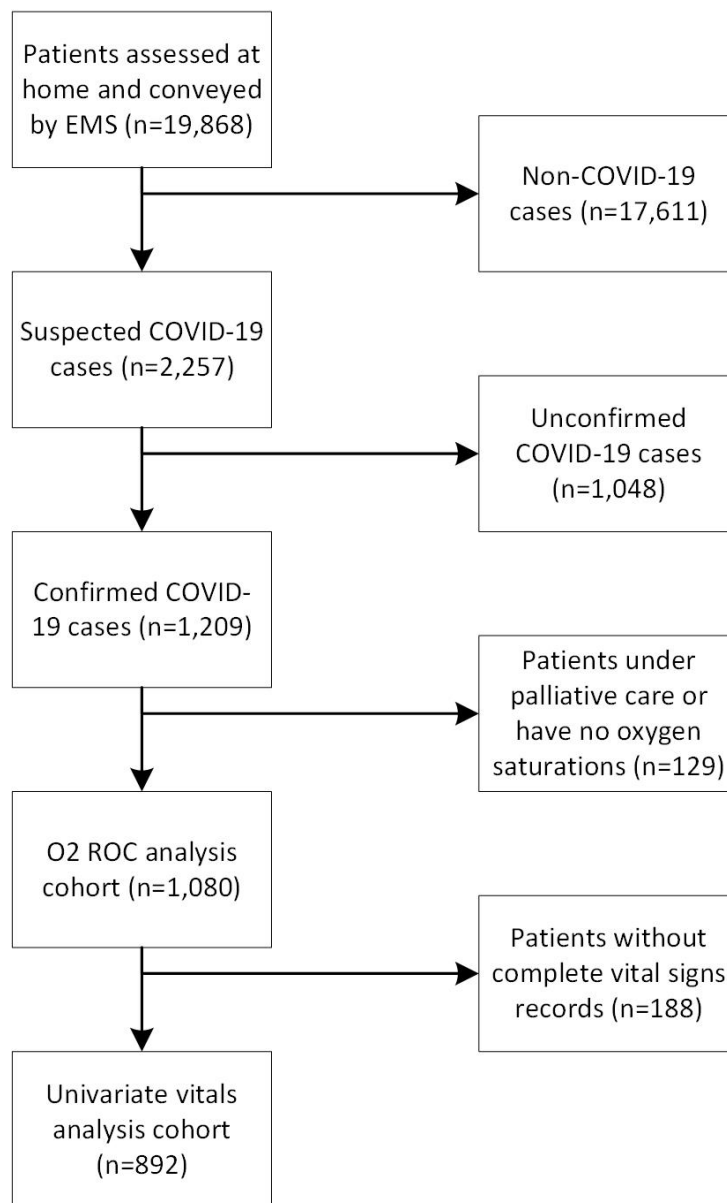
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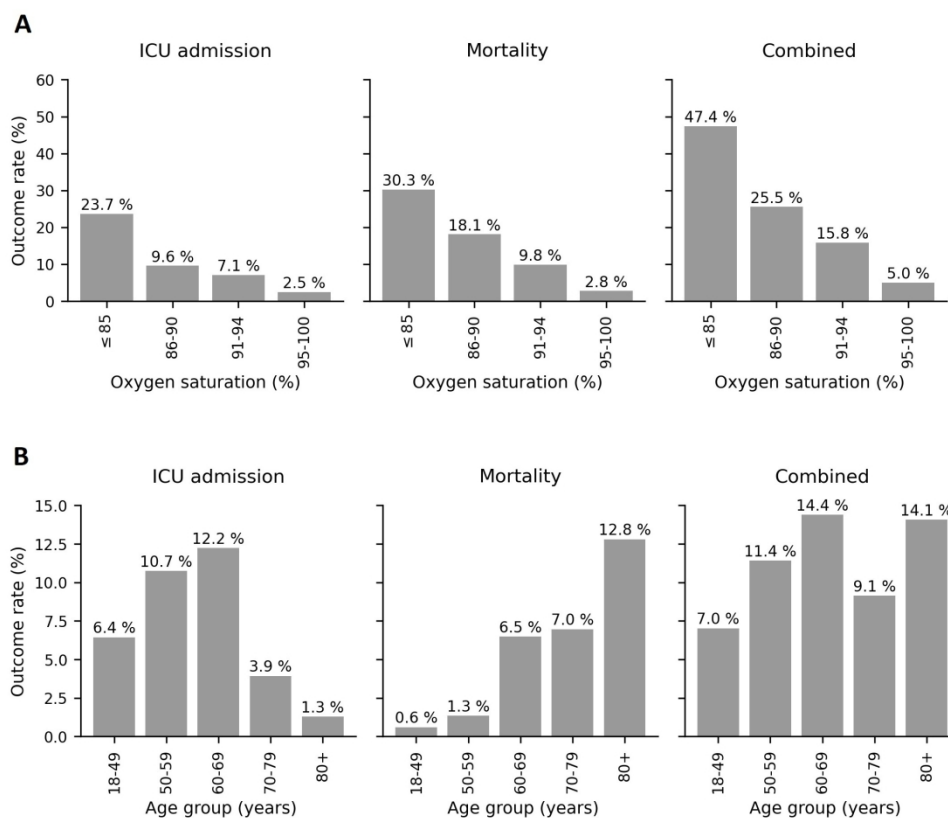
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The cohort selection of the EMS patients.

71x115mm (300 x 300 DPI)



A) The ICU admission, mortality, and combined outcome rates as a function of oxygen saturation %. B) The ICU admission, mortality, and combined outcome rates as a function of age group.

188x166mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of *cohort studies*

	Item No	Recommendation	Page No
<b>Title and abstract</b>	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	6
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up (b) For matched studies, give matching criteria and number of exposed and unexposed	7, 8
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8, 9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	8, 9
Bias	9	Describe any efforts to address potential sources of bias	16
Study size	10	Explain how the study size was arrived at	N/A
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8, 9
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) If applicable, explain how loss to follow-up was addressed (e) Describe any sensitivity analyses	8, 9
<b>Results</b>			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage (c) Consider use of a flow diagram	7, 10
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders  (b) Indicate number of participants with missing data for each variable of interest  (c) Summarise follow-up time (eg, average and total amount)	Figures 1, 2 Table 1  Pages 11, 12, 13

1	Outcome data	15*	Report numbers of outcome events or summary measures over time	10
2				
3				
4	Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10
5			(b) Report category boundaries when continuous variables were categorized	
6			(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
7				
8	Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11, 12
9				
10				
11				
12				
13				
14	<b>Discussion</b>			
15	Key results	18	Summarise key results with reference to study objectives	14, 15
16				
17	Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16, 17
18				
19	Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	17, 18
20				
21	Generalisability	21	Discuss the generalisability (external validity) of the study results	16, 17
22				
23				
24				
25	<b>Other information</b>			
26	Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	19
27				
28				

29 \*Give information separately for exposed and unexposed groups.

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31  
32 **Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at <http://www.strobe-statement.org>.