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Factors associated with, and variations in, COVID-19 hospital death rates in England's first two waves: observational study

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ABSTRACT

Objectives To assess patient-level and hospital-level predictors of death and variation in death rates following admission for COVID-19 in England's first two waves after accounting for random variation. To quantify the correlation between hospitals' first and second wave death rates.

Design Observational study using administrative data.

Setting Acute non-specialist hospitals in England.

Participants All patients admitted with a primary diagnosis of COVID-19.

Primary and secondary outcomes In-hospital death.

Results Hospital Episode Statistics (HES) data were extracted for all acute hospitals in England for COVID-19 admissions from March 2020 to March 2021. In wave 1 (March to July 2020), there were 74 484 admissions and 21 883 deaths (crude rate 29.4%); in wave 2 (August 2020 to March 2021), there were 165 642 admissions and 36 040 deaths (21.8%). Wave 2 patients were younger, with more hypertension and obesity but lower rates of other comorbidities. Mortality improved for all ages; in wave 2, it peaked in December 2020 at 24.2% (lower than wave 1's peak) but halved by March 2021. In multiple multilevel modelling combining HES with hospital-level data from Situational Reports, wave 2 and wave 1 variables significantly associated with death were mostly the same. The median odds ratio for wave 1 was just 1.05 and for wave 2 was 1.07. At 99.8% control limits, 3% of hospitals were high and 7% were low funnel plot outliers in wave 1; these figures were 9% and 12% for wave 2. Four hospitals were (low) outliers in both waves. The correlation between hospitals' adjusted mortality rates between waves was 0.45 ($p<0.0001$). Length of stay was similar in each wave.

Conclusions England's first two COVID-19 waves were similar regarding predictors and moderate interhospital variation. Despite the challenges, variation in death rates and length of stay between hospitals was modest and might be accounted for by unobserved patient factors.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This study benefitted from national data and multilevel modelling to account for both clustering of patients within hospitals and for random variation in death rates.
⇒ The administrative data lacked physiological information such as oxygen saturation and disease severity, leading to incomplete risk adjustment.
⇒ We did not have information on decision-making regarding transfers or selection of patients for limited intensive care beds

INTRODUCTION

Much is now known on which patient factors are associated with COVID-19 infection and poor COVID-19 outcomes.[1 2] These include older age, ethnicity, comorbidities and small-area ones like deprivation and geography, and in Africa, they additionally include population density, limited access to healthcare, HIV, tuberculosis and anaemia.[3] A pan-European analysis of country-level data found the case fatality rate to be positively associated with death rate due to smoking among people aged over 70 years, gross domestic product and level of democracy and negatively associated with hospital bed numbers.[4] However, studies on variations in COVID-19 outcomes between hospitals for the first wave in 2020 are still emerging. US studies on 65 intensive therapy units (ITUs),[5] 955 hospitals[6] and 117 hospitals[7] all showed notable variation between units, and there have been differences in how hospitals have responded to the pandemic in terms of increasing capacity and treatment options.[8] In the US Veterans Health Administration, differences in patient characteristics accounted for the majority of explained variation in mortality across the 160 facilities nationwide.[9] Modest variation in mortality after good risk adjustment has also been found between ITUs, with 80% of the variation across 70 facilities attributable to patient-level factors and area-level socioeconomic deprivation.[10] As populations and health systems differ, it is important to obtain evidence from around the world.

Before the arrival of the omicron variant in late 2021, the UK had three waves, roughly beginning in March 2020, September 2020 and May 2021. We found only modest

variation between hospitals in their risk-adjusted all-cause death rates across England during the first wave,[11] with large falls for all ages and hospital mortality quartiles; another Hospital Episode Statistics (HES)-based study found similar modest interhospital variation for deaths recorded as due to COVID-19.[12] Despite the consistent mortality falls, we found no correlation between early-wave and late-wave mortality. In this current analysis, we asked what has changed from the first wave. We compared first-wave and second-wave patient characteristics, factors associated with mortality and mortality rates. We then hypothesised that the hospitals with lower mortality during the first wave—potentially those that were better able to learn and implement new COVID-19 treatments and practices—would go on to have better mortality rates during the second wave. These were our research questions:

1. Were wave 2 patient-level and hospital-level covariates and patterns of mortality similar to those for wave 1?
2. After risk adjustment, did hospitals' wave 2 mortality correlate with their wave 1 mortality?

METHODS

Data

Hospital Episodes Statistics, HES, covers all NHS (public) patients treated in either NHS or private hospitals and also private patients treated in NHS hospitals in England. Information includes dates of admission and discharge, demographics, procedures, one primary diagnosis (main problem treated) and up to 19 secondary diagnosis fields (comorbidities and complications) with ICD-10 coding, and in-hospital outcomes such as length of stay (LOS) and death. For each patient, we linked records into admissions ('superspells') to take account of transfers between hospital consultants and between hospitals. The first receiving hospital with COVID-19 recorded was used in each superspell. We searched for either ICD-10 code U071[13] and U072[13 14] in the primary diagnosis field. Comorbidities were taken from any secondary diagnosis field in the index admission (see online supplemental appendix for ICD-10 codes). Small-area level deprivation was derived by linking the patient record to the 2019 Index of Multiple Deprivation scores, which were weighted by population and put into fifths so that areas in each deprivation fifth contained 20% of England's population.

As in our previous analysis,[11] we augmented the HES records with several hospital-level variables. One was simply its daily number of COVID-19 admissions. In addition, COVID-19 Situation Reports published by NHS England[15] were used to calculate the mean weekly number of occupied beds, occupied number of beds by confirmed patients with COVID-19, occupied number of mechanical ventilation (MV) beds occupied by confirmed patients with COVID-19, and number of COVID-19-related staff absences, either through sickness or self-isolation. Situation Report data were not available for March 2020; we imputed values using those for the first week of April 2020. The hospitals identified within the reports were matched against the hospitals within HES: we were able to match 122 out of a possible 126 acute, non-specialist hospitals. Two merged after the first wave but did not submit records using their new code. All analyses are based on the 122 hospitals.

HES data are, with a lag, linked to the national death register. This enabled the calculation of 30-day total mortality (ie, including in-of and out-of-hospital deaths), with day 0 being the day of admission. We report 30-day crude total mortality rates for context but focus on in-hospital death as the primary outcome.

Statistical analyses

In England's NHS, hospital trusts are organisational units providing acute services and can comprise multiple hospital sites. Our analyses used hospital trusts, but for brevity we refer to them as 'hospitals' throughout. We calculated crude death rates by hospital (trust) and then applied two-level logistic regression, with random intercepts for hospitals. These had the following patient (level-one) independent variables: age (see online supplemental appendix, figure A1), gender, diabetes, hypertension, coronary heart disease, COPD, obesity, cancer, renal disease, dementia, area-level Carstairs socioeconomic deprivation (as population-weighted quintiles), emergency versus planned admission (based on HES field 'ADMIMETH'), source of admission (from own home, transferred from another provider, based on HES field 'ADMISORC'), ethnic group, number of emergency admissions for any reason in the previous 12 months and month of admission. Hospital-level total bed occupancies confirmed COVID-19 bed occupancies, MV bed occupancies for confirmed COVID-19 cases, staff absences related to COVID-19 and COVID-19 admissions were also included as hospital-level (level 2) variables in the full model, each of them as one-knot splines or linear terms depending on fit (see online supplemental appendix figures A2 to A6). Patient comorbidity was also described using the Charlson comorbidity score calibrated to the NHS.[16] Independent variables were entered in two blocks separately before combining into the full model: patient-level variables and hospital-level variables. Coefficients for each variable were compared between the single-block model and the full model. This was done to determine whether any of the patient-level variables were confounded by hospital-level ones and vice versa. As only 4% of patients were admitted for COVID-19, at least two times over the entire study period, we did not try to adjust for such repeated observations by patient.

To derive adjusted mortality ratios and rates by hospital, predicted probabilities per patient were calculated from the fixed effects part of the fully adjusted model, that is, excluding the random hospital effects[17] and summed to give total expected deaths by hospital; the observed deaths were divided by these expected totals, giving a standardised mortality ratio, SMR. To convert this into

risk-adjusted rates, it was multiplied by the national crude rate. This was done for each wave separately.

To estimate the variation in mortality between hospitals, we first inspected the covariance estimate of the random effects and intraclass correlation coefficient (ICC), which indicates how much of the total variation in patient mortality is accounted for by the hospitals.[18] Median odds ratios (ORs) were calculated for each wave. These are based on the ICC and estimate the median value of the OR between the hospital with the highest death rate and the hospital with the lowest death rate when randomly choosing two hospitals. SMRs were plotted on funnel plots and the numbers of mortality outliers at 95% and 99.8% control limits based on the Poisson distribution noted.

To assess whether hospitals changed their mortality between the waves, the two sets of SMRs were first compared with Pearson's correlation coefficient. In each period, hospitals were then put into quartiles based on their SMRs. The weighted kappa statistic was calculated from the resulting 4×4 table.

Sensitivity analyses included (1) restricting the admissions to only confirmed cases (U071) as the primary diagnosis in either first or second episode and (2) expanding the admissions to cover COVID-19 codes in any diagnosis position during the admission.

Patient and public involvement

Patients were not actively involved in this study.

RESULTS

Of 165 hospital had one or more COVID-19 admissions, but we limited this to 122 acute, non-specialist hospitals that also had hospital-level published figures, thereby excluding 3501 COVID-19 cases and 829 deaths.

Wave 2 patients were slightly younger than those in wave 1 and had had fewer previous emergency admissions (table 1). They had lower rates of dementia but higher rates of hypertension and obesity. In the 165 642 wave 2 admissions with COVID-19 as the primary diagnosis, there were 36 040 in-hospital deaths (a rate of 21.8%; the 30-day total rate was 20.8%): this rate increased each month from 15.2% in August 2020 to peak at 24.2% in December before falling to 11.2% in March 2021 (online supplemental appendix, figure A7). Wave 1 mortality was 29.4%. The crude OR of death for wave 2 relative to wave 1 was 0.67 (95% CI 0.66 to 0.68, p<0.001). Mortality was lower in most age groups in wave 2 (table 1).

How did first wave (March to July 2020) and second wave (August 2020 to March 2021) mortality and factors associated with mortality compare?

Table 2 gives the logistic regression results for each wave for the full model (ie, with both blocks of variables). The ORs for the hospital-level variables are expressed as increases per unit, per 10 units and per one SD, with SDs measured at hospital level.

In the full multiple logistic regression model, covariates with statistically significant associations with in-hospital mortality for both waves were age, gender, ethnicity, deprivation, method of admission, source of admission, emergency admissions in the previous 12 months, month of admission, diabetes, hypertension (although the direction of the relation reversed), coronary heart disease, chronic obstructive pulmonary disease, obesity, cancer, renal disease and dementia (online supplemental appendix, table A1). Statistically significant covariates for the second wave only were COVID-19 daily admissions (3% higher odds per 10 extra occupied beds), COVID-19 bed occupancies (though only a tiny effect, even for one SD) and COVID-19 MV bed occupancies (4% lower odds per 10 extra occupied beds). Bed occupancies and COVID-19-related staff absences were not statistically significant covariates for either wave (table 2).

The coefficients for the variables in either block, particularly the patient-level ones, were little affected by the addition of the other block. The main change was in wave one for COVID-19 daily admissions (<4), where the adjusted OR fell from 1.10 (1.07 to 1.13, p<0.0001) to 1.02 (0.99 to 1.05, p=0.25) after adding the block of patient-level covariates.

Model discrimination was fair, with a c statistic of 0.74 and 0.77 for the first and second wave, respectively; calibration was reasonable as assessed by the Hosmer-Lemeshow plot (online supplemental appendix, figures A8 to A9).

How did each hospital's first wave mortality compare with their second wave mortality?

The Pearson correlation coefficient between first and second wave SMRs was 0.45 (p<0.0001). Figure 1 shows the scatterplot between hospital-level SMRs with local smoothers for the first and second waves.

The majority of hospitals moved between quartiles from first to second wave (table 3). No hospitals moved from the lowest to the highest quartile, though three (2.5%) moved from the highest to the lowest quartile. The weighted kappa coefficient was 0.35 (CI 0.22 to 0.48), indicating 'fair' agreement.

Online supplemental table A2 gives the average crude death rates by age group for quartile 1 and quartile 4 hospitals in the first and second waves. The age gradient was bigger for wave 2 in both quartiles even though the crude mortality was lower in wave 2 for both quartiles and all ages.

How much non-random variation existed between hospitals?

Crude death rates for acute, non-specialist hospitals varied from 14.4% to 42.7% in the first wave (online supplemental appendix, figure A10) and 9.3% and 34.8% in the second wave (online supplemental appendix, figure A11). Among the hospitals, there were 53 (43.4%) and 69 (56.6%) outliers at 95% control limits for first and second waves, respectively. For 99.8% control limits, there were 32 (26.2%) and 50 (41.0%) outliers for the first and

Table 1 Patient characteristics, counts and proportions of in-hospital deaths among 122 English hospital admissions for COVID-19 by wave

Wave		March 2020 to July 2020 (N=74 484)		August 2020 to March 2021 (N=1 65 642)	
Feature	**Value**	**N (%)**	**In-hospital deaths (crude rate as %)**	**N (%)**	**In-hospital deaths (crude rate as %)**
Age (years)	Mean (SD)	67.8 (18.6)	–	65.1 (18.6)	–
	0–9	708 (1.0)	Suppr.* (<5)	1452 (0.9)	Suppr.* (<5)
	10–19	389 (0.5)	10 (2.6)	929 (0.6)	8 (0.9)
	20–29	1518 (2.0)	33 (2.2)	4006 (2.4)	57 (1.4)
	30–39	3382 (4.5)	125 (3.7)	9603 (5.8)	200 (2.1)
	40–49	6209 (8.3)	398 (6.4)	16 443 (9.9)	691 (4.2)
	50–59	10 634 (14.3)	1432 (13.5)	27 786 (16.8)	2308 (8.3)
	60–69	11 775 (15.8)	2920 (24.8)	29 445 (17.8)	5330 (18.1)
	70–79	15 500 (20.8)	5674 (36.6)	33 396 (20.2)	9713 (29.1)
	80–89	17 995 (24.2)	8101 (45.0)	31 621 (19.1)	12 549 (39.7)
	90+	6374 (8.6)	3189 (50.0)	10 961 (6.6)	5184 (47.3)
Gender	Male	42 636 (57.2)	13 475 (31.6)	92 219 (55.7)	21 462 (23.3)
	Female	31 848 (42.8)	8408 (26.4)	73 423 (44.3)	14 578 (19.9)
Ethnic group	Black or Black British	4106 (5.5)	1053 (25.6)	6368 (3.8)	977 (15.3)
	Asian or Asian British	6761 (9.1)	1598 (23.6)	18 693 (11.3)	3445 (18.4)
	White	51 581 (69.3)	16 258 (31.5)	113 513 (68.5)	27 259 (24.0)
	Other inc Mixed	3595 (4.8)	751 (20.9)	7656 (4.6)	961 (12.6)
	Unknown	8441 (11.3)	2223 (26.3)	19 412 (11.7)	3398 (17.5)
Deprivation quintile	1 (least deprived)	11 212 (15.1)	3397 (30.3)	23 423 (14.1)	5350 (22.8)
	2	12 480 (16.8)	3815 (30.6)	27 600 (16.7)	6537 (23.7)
	3	14 005 (18.8)	4351 (31.1)	31 082 (18.8)	7193 (23.1)
	4	15 582 (20.9)	4554 (29.2)	35 671 (21.5)	7759 (21.8)
	5	20 846 (28.0)	5708 (27.4)	47 254 (28.5)	9122 (19.3)
	6 (unknown)	359 (0.5)	58 (16.2)	612 (0.4)	79 (12.9)
Method of admission	Emergency	73 277 (98.4)	21 645 (29.5)	163 622 (98.8)	35 772 (21.9)
	Non-emergency	1207 (1.6)	238 (19.7)	2020 (1.2)	268 (13.3)
Admission source	Home	66 579 (89.4)	19 302 (29.0)	152 588 (92.1)	32 632 (21.4)
	Transfer from acute hospital	513 (0.7)	165 (32.2)	599 (0.4)	202 (33.7)
	Transfer from non-acute hospital	116 (0.2)	53 (45.7)	354 (0.2)	189 (53.4)
	Transfer from unknown hospital	4675 (6.3)	1279 (27.4)	8605 (5.2)	1769 (20.6)
	Other/unknown	2601 (3.5)	1084 (41.7)	3496 (2.1)	1248 (35.7)
Emergency admissions in previous 12 months	0	42 371 (56.9)	10 364 (24.5)	108 959 (65.8)	18 789 (17.2)
	1	15 166 (20.4)	5265 (34.7)	30 858 (18.6)	8683 (28.1)
	2	7331 (9.8)	2744 (37.4)	12 642 (7.6)	4268 (33.8)
	3+	9616 (12.9)	3510 (36.5)	13 183 (8.0)	4300 (32.6)

Continued

Table 1 Continued

Wave		March 2020 to July 2020 (N=74 484)		August 2020 to March 2021 (N=1 65 642)	
Feature	**Value**	**N (%)**	**In-hospital deaths (crude rate as %)**	**N (%)**	**In-hospital deaths (crude rate as %)**
Admission month	March 2020	18 887 (25.4)	6205 (32.9)	–	–
	April	39 911 (53.6)	11 992 (30.0)	–	–
	May	10 860 (14.6)	2773 (25.5)	–	–
	June	3650 (4.9)	756 (20.7)	–	–
	July	1176 (1.6)	157 (13.4)	–	–
	August	–	–	1114 (0.7)	169 (15.2)
	September	–	–	4180 (2.5)	747 (17.9)
	October	–	–	15 611 (9.4)	3340 (21.4)
	November	–	–	23 523 (14.2)	5294 (22.5)
	December	–	–	31 738 (19.2)	7673 (24.2)
	January 2021	–	–	64 084 (38.7)	14 603 (22.8)
	February	–	–	20 588 (12.4)	3676 (17.9)
	March	–	–	4804 (2.9)	538 (11.2)
Charlson comorbidity score	Mean (SD)	9.3 (10.2)	–	7.7 (9.5)	–
Comorbidity	Diabetes	20 056 (26.9)	6949 (34.6)	43 743 (26.4)	11 452 (26.2)
	Hypertension	32 544 (43.7)	11 226 (34.5)	96 339 (58.2)	17 774 (18.4)
	Coronary heart disease	8974 (12.0)	4191 (46.7)	16 050 (9.7)	6981 (43.5)
	COPD	19 588 (26.3)	6211 (31.7)	43 955 (26.5)	11 415 (26.0)
	Obesity	6418 (8.6)	1663 (25.9)	20 496 (12.4)	3607 (17.6)
	Cancer	4644 (6.2)	1983 (42.7)	8192 (4.9)	3160 (38.6)
	Renal disease	12 333 (16.6)	5476 (44.4)	24 646 (14.9)	9776 (39.7)
	Dementia	6092 (8.2)	2968 (48.7)	9251 (5.6)	3963 (42.8)

*Data suppressed due to small numbers.
COPD, chronic obstructive pulmonary disease.

Table 2 Multilevel logistic regression results for in-hospital mortality for first and second wave COVID-19 admissions

Feature	Value	First wave (March 2020 to July 2020)		Second wave (August 20 to March 21)	
		OR (95% CI)	P value	OR (95% CI)	P value
Age: OR per year	<45 years	1.08 (1.07 to 1.10)	<0.0001	–	
	45+ years	1.05 (1.04 to 1.07)	<0.0001	–	
	Age	–		1.14 (1.13 to 1.15)	<0.0001
	Age squared	–		1.00 (1.00 to 1.00)	<0.0001
Gender	Male	1.44 (1.39 to 1.49)	<0.0001	1.42 (1.38 to 1.46)	<0.0001
	Female	1		1	
Ethnic group	Black or Black British	1.06 (0.97 to 1.16)	0.1845	0.99 (0.91 to 1.07)	0.7459
	Asian or Asian British	1.19 (1.11 to 1.28)	<0.0001	1.36 (1.29 to 1.42)	<0.0001
	White	1		1	
	Other inc Mixed	1.06 (0.97 to 1.17)	0.2198	0.96 (0.89 to 1.04)	0.3511
	Unknown	1.13 (1.07 to 1.20)	<0.0001	1.07 (1.02 to 1.12)	0.0029
Deprivation quintile	1 (least deprived)	1		1	
	2	1.05 (0.98 to 1.11)	0.1447	1.06 (1.02 to 1.11)	0.007
	3	1.10 (1.03 to 1.16)	0.0029	1.09 (1.04 to 1.14)	0.0001
	4	1.08 (1.02 to 1.15)	0.0088	1.12 (1.07 to 1.17)	<0.0001
	5	1.12 (1.06 to 1.19)	0.0002	1.13 (1.08 to 1.19)	<0.0001
	6 (unknown)	0.73 (0.53 to 0.99)	0.0433	0.88 (0.68 to 1.15)	0.3606
Method of admission	Emergency	1		1	
	Non-emergency	0.77 (0.65 to 0.92)	0.0035	0.79 (0.67 to 0.93)	0.0045
Admission source	Home	1		1	
	Transfer from acute hospital	1.78 (1.42 to 2.22)	<0.0001	1.97 (1.60 to 2.43)	<0.0001
	Transfer from non-acute hospital	1.25 (0.85 to 1.83)	0.2635	2.12 (1.70 to 2.65)	<0.0001
	Transfer from unknown hospital	0.97 (0.88 to 1.07)	0.5370	1.03 (0.95 to 1.12)	0.4238
	Other/unknown	1.17 (1.07 to 1.28)	0.0009	1.25 (1.15 to 1.35)	<0.0001
Emergency admissions in previous 12 months	0	1		1	
	1	1.13 (1.08 to 1.18)	<0.0001	1.16 (1.12 to 1.20)	<0.0001
	2	1.14 (1.07 to 1.21)	<0.0001	1.25 (1.20 to 1.31)	<0.0001
	3+	1.11 (1.05 to 1.17)	0.0003	1.19 (1.14 to 1.24)	<0.0001
Admission month	March 2020	1		–	
	April 2020	0.77 (0.73 to 0.80)	<0.0001	–	
	May 2020	0.57 (0.53 to 0.61)	<0.0001	–	
	June 2020	0.46 (0.41 to 0.51)	<0.0001	–	
	July 2020	0.32 (0.26 to 0.40)	<0.0001	–	
	August 2020	–		0.68 (0.57 to 0.82)	<0.0001
	September 2020			0.86 (0.77 to 0.95)	0.0023
	October 2020			0.87 (0.82 to 0.92)	<0.0001
	November 2020			0.85 (0.81 to 0.89)	<0.0001
	December 2020			1.04 (1.00 to 1.09)	0.0353
	January 2021			1	
	February 2021			0.81 (0.77 to 0.85)	<0.0001
	March 2021			0.62 (0.56 to 0.69)	<0.0001

Continued

Table 2 Continued

Feature	Value	First wave (March 2020 to July 2020) OR (95% CI)	P value	Second wave (August 20 to March 21) OR (95% CI)	P value
Comorbidity	Diabetes	1.15 (1.11 to 1.20)	<0.0001	1.10 (1.07 to 1.13)	<0.0001
	Hypertension	0.93 (0.90 to 0.96)	<0.0001	1.16 (1.13 to 1.19)	<0.0001
	Coronary heart disease	1.42 (1.35 to 1.49)	<0.0001	1.58 (1.52 to 1.64)	<0.0001
	COPD	1.05 (1.01 to 1.09)	0.0129	1.18 (1.15 to 1.22)	<0.0001
	Obesity	1.46 (1.37 to 1.56)	<0.0001	1.49 (1.43 to 1.56)	<0.0001
	Cancer	1.55 (1.45 to 1.65)	<0.0001	1.63 (1.55 to 1.72)	<0.0001
	Renal disease	1.30 (1.24 to 1.36)	<0.0001	1.41 (1.37 to 1.46)	<0.0001
	Dementia	1.38 (1.30 to 1.46)	<0.0001	1.34 (1.28 to 1.40)	<0.0001
COVID19 daily admissions: OR per admission	<4 admissions	1.02 (0.99 to 1.05)	0.2500	–	–
	4+admissions	1.01 (0.97 to 1.04)	0.4425	–	–
	Per 10 extra admissions	–	–	1.03 (1.01 to 1.05)	0.0047
	Per 1 SD extra (5.1)	–	–	1.01 (1.00 to 1.03)	
Bed occupancy	Per 10 extra occupancies	1.00 (0.998 to 1.00)	0.1849	1.00 (1.00 to 1.00)	0.1077
	Per 1 SD extra (29.2)	1.00 (1.00 to 1.00)		1.00 (1.00 to 1.00)	
COVID-19 bed occupancy	Per 10 extra occupancies	1.00 (0.999 to 1.01)	0.1507	1.01 (1.00 to 1.01)	<0.0001
	Per 1 SD extra (74.7)	1.00 (0.999 to 1.001)		1.05 (1.05 to 1.06)	
COVID-19 MV bed occupancy: OR per bed	<4 beds	1.01 (0.98 to 1.03) –	0.5867	–	<0.0001
	4+beds	1.00 (0.97 to 1.02)	0.4861	–	
	Per 10 extra occupancies	–	–	0.96 (0.94 to 0.97)	
	Per 1 SD extra (8.7)	–	–	0.96 (0.95 to 0.97)	
COVID-19-related staff absences	Per 10 extra absences	1.00 (1.00 to 1.00)	0.9398	1.00 (1.00 to 1.002)	0.6952
	Per 1 SD extra (66.5)	1.00 (1.00 to 1.00)		1.00 (1.00 to 1.00)	

SD: SD of admissions etc, calculated at hospital level.
COPD, chronic obstructive pulmonary disease; MV, mechanical ventilation.

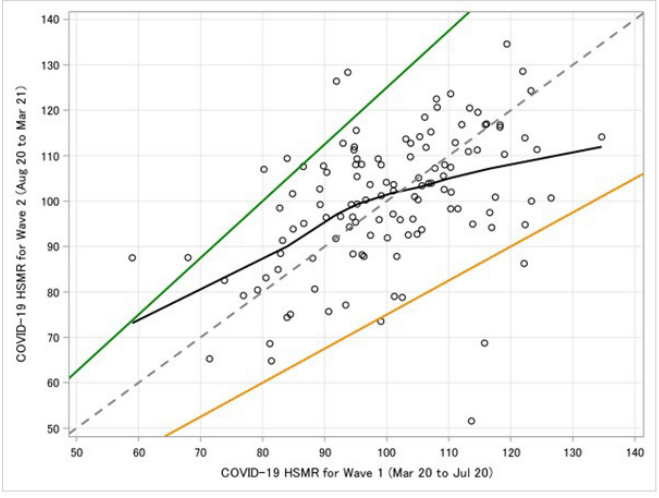

Figure 1 Scatterplot of COVID-19 hospital-level standardised mortality ratios for the first and second wave among 122 English hospitals with a local smoother (black curve) and lines of difference of±25% (green and orange lines).

second waves, with 16 (13.1%) and 29 (23.8%) hospitals as high outliers and 16 (13.1%) and 21 (17.2%) hospitals as low outliers for the first and second wave, respectively.

Following risk adjustment, SMRs varied from 60 to 135 and 52 to 135 between hospitals for the first (online supplemental appendix, figure A12) and second wave (figure 2) respectively, with 24 (19.7%) and 44 (36.1%) outliers at the 95% control limit (2 SD) and 12 (9.8%) and 26 (21.3%) at the 99.8% control limit. Wave two had more outliers than wave one, with 15 (12.3%) low and 11 (9.0%) high at 99.8% control limits compared with 9 (7.4%) and 3 (2.5%) in wave one.

Four hospitals were outliers at 99.8% in both waves, all low outliers.

The ICC from the multilevel model for first and second wave was 1.6% and 2.1%, respectively; the covariance parameters for the random effects were 0.055 for the first wave and 0.070 for the second wave, both p<0.0001, showing a statistically significant but small variation in mortality between hospitals for both periods after adjusting for available patient factors. These correspond

Table 3 Risk-adjusted mortality rates and number (% of total) of hospitals by hospital mortality quartile in the first and second wave

First wave	Second wave				
	Quartile 1 (risk-adj rate 1.7%)	Quartile 2 (risk-adj rate 2.1%)	Quartile 3 (risk-adj rate 2.3%)	Quartile 4 (risk-adj rate 2.6%)	Total
Quartile 1 (risk-adj rate 2.4%)	18 (14.8%)	5 (4.1%)	7 (5.7%)	0 (0.0%)	30
Quartile 2 (risk-adj rate 2.8%)	6 (4.9%)	10 (8.2%)	9 (7.4%)	6 (4.9%)	31
Quartile 3 (risk-adj rate 3.1%)	3 (2.5%)	7 (5.7%)	12 (9.8%)	9 (7.4%)	31
Quartile 4 (risk-adj rate 3.5%)	3 (2.5%)	9 (7.4%)	3 (2.5%)	15 (12.3%)	30
Total	30	31	31	30	122

to median ORs of just 1.05 for wave one and 1.07 for wave two.

Overall LOS for COVID-19 admissions ranged from 0 to 311 nights for the first wave and 0 to 228 nights for the second wave across hospitals, with a national overall median of six nights for both the first and second waves. First and second wave IQRs were 3 to 12. This was similar for survivors and deceased for the first wave (data not shown) but was longer among the deceased in the second wave where the median (IQR) was eight (4–15) among the deceased compared with six (3–11) among those who survived. The median hospital-level stay was six nights (IQR 6–7) for both waves.

We found that median LOS varied only modestly between hospitals in the first wave, with very limited correlation with mortality rates (data not shown). However, during the second wave, the Pearson correlation coefficient between the SMRs and median LOS was moderate (rho=0.33, p=0.0002).

Sensitivity analyses

COVID-19 occurred in a secondary position 35.7% of the time in wave 2. More hospitals were outliers than for COVID-19 as the primary diagnosis (see online supplemental appendix). Correlation between the two sets of SMRs was high at 0.87 (p<0.0001). When we restricted admissions to only confirmed cases (U071), the outlier rate was similar to the main analysis. Correlation with the SMRs derived from the main analysis was very high at 0.99 (p<0.0001).

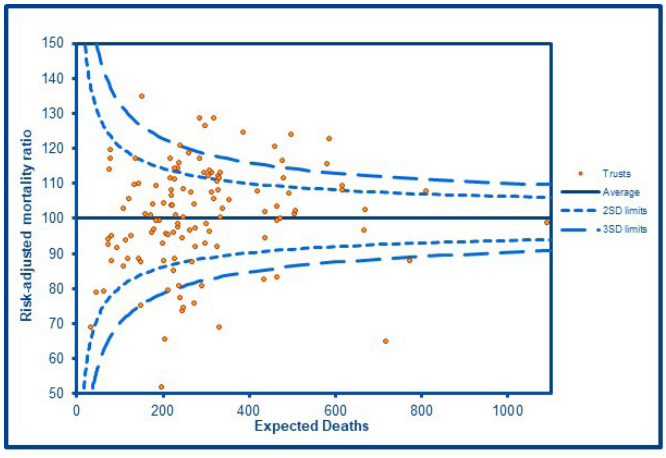

Figure 2 Funnel plot for adjusted COVID-19 standardised mortality ratio for the second wave (August 2020 to March 2021).

DISCUSSION

Summary of main findings

After the end of England's first COVID-19 wave, in-hospital mortality after admission for COVID-19 steadily rose, peaking in December 2020 before halving. Wave 2 patients were notably younger and less comorbid than wave 1 patients. Most factors significantly associated with mortality were the same, such as older age, male gender, Asian ethnic group and comorbidities, with fairly limited relation with hospital-level factors, though the number of COVID-19 admissions (positive association) and MV bed occupancy (negative association) were statistically significant and of non-negligible effect size.

As in wave 1, there was modest variation between hospitals in their mortality after adjusting for available patient risk factors and random variation. There were more high and low outliers in wave 2, but it had more than two times the statistical power to detect outliers. There was moderate correlation between hospitals' risk-adjusted mortality rates in the two waves.

Comparison with previous literature on changes in case-mix and mortality over time

Our finding that the case-mix of patients hospitalised for COVID-19 changed over time agrees with other studies. Unsurprisingly, another HES analysis, which split the period March to September 2020 into two, also found the later period was more likely to be male and Asian and with lower mortality rates.[19] Vaccination began in December 2020, with a 3-month gap between doses, so only the elderly and most vulnerable would have had at most one dose by the end of the second wave. Our patient factors associated with mortality agreed with those from another, more recent HES study.[20] In Sweden, the 60-day mortality for hospitalisations between 1 March and 30 September 2020 fell from 25% to 10%, with roughly a halving of the proportion admitted to ITU over the period.[21] Similarly, in Italy, between February 2020 and February 2021, the second wave, defined as August 2020 onwards, had lower mortality and ITU need.[22] Outside Europe, the

pattern has at least sometimes been different. In South Africa between March 2020 and March 2021, results from the national active surveillance system DATCOV (Daily Hospital Surveillance) showed that peak cases, admissions and deaths were greater in the second wave compared with the first, perhaps due to the beta mutation. Compared with in the first wave, second-wave patients were more likely to be aged 40–64, of mixed race and have comorbidities.[23] In Brazil, one of the most affected countries, between February 2020 and May 2021, the maximum number of weekly admitted patients requiring non-invasive ventilation, invasive MV or both increased by 192% in the second compared with the first wave. There was no change in proportion of patients receiving ITU care, around 37%, but the authors suggested that this was due to lack of access to critical care rather than changes in disease severity. Despite the younger average age of wave 2 admissions, the in-hospital mortality seems to have risen.[24]

Other viral respiratory illnesses such as influenza and pneumonia show regular seasonal variation in incidence and lethality. For example, weekly counts of death for respiratory disease in England and Wales from the Office for National Statistics for 2019[25] (ie, pre-COVID-19) showed huge seasonal differences, from a low in August of 854 to a high in mid-January of 2214; the last week in March 2019 saw 1486 respiratory deaths, a fall of 33% from the January peak. Five-year (2015 to 2019) average death counts from the same source but only for deaths involving influenza and pneumonia showed a 28% fall in the last week in March compared with the first week in January. Assuming that these falls in the counts of deaths are good estimates of the changes in rates of death, the difference in in-hospital mortality rate for COVID-19 is much greater at around a halving by March 2020 compared with its wave 2 peak. Some of the wave 2 peaks are likely to be due to factors beyond seasonal variation such as changes in hospital/ITU admission thresholds (sicker patients being admitted during the peak, with less-sick ones turned away) and general practitioner (GP) referral thresholds. Such admission threshold changes might also affect some of the ORs in table 2 in unpredictable ways.

Comparison with previous literature on variations between hospitals

We noted earlier that some studies have found that much of the between-hospital variations in death rates are due to differences in case-mix, but other studies have in addition identified management and supply differences that could contribute to the mortality variations. Real differences in ITU practice were reported between 1 February and 31 July 2020 by the Case Mix Programme national clinical audit, which covers England, Wales and Northern Ireland, such as falls in invasive ventilation and renal replacement therapy over time.[26] These changes may be partly due to the increasing severity of disease in patients admitted to the ITU and by earlier recognition and diagnosis of the disease during wave 1.

A national study in France looked at the relation between aggregate data on hospital mortality rates and various local-level supply factors such as ITU beds, doctors and specialists (all per 100 000 population).[27] They found significant associations for four variables: a higher prepandemic ITU capacity, a lower density of general practitioners, a lower fraction of activity from the for-profit private sector (though the effect was very small) and the ratio of people older than 75 years.

Mateen *et al*[28] concluded that 'throughout the first wave of the pandemic, an adequate supply of all bed types existed at a national level. However, due to an unequal distribution of bed utilisation, many (hospital) trusts spent a significant period operating above 'safe-occupancy' thresholds despite substantial capacity in geographically colocated trusts'. We found a positive association between COVID-19 admissions and mortality, which we did not see so strongly in our earlier study that split wave 1 into two parts.[11] We found a negative relation with MV bed occupancy, unlike another English study, this time of 89 ITUs between April and 1 December 2020, which found that the odds of death during high-occupancy periods was 23% (95% CI 8% to 39%) higher than in low-occupancy periods, although the authors noted other studies that did not find such an association.[29]

We have not found other studies comparing waves 1 and 2 in terms of hospital-level mortality. Our findings of moderate correlation between SMRs in each wave and a greater than expected number of funnel plot outliers points to some systematic differences between hospitals. These are likely to include residual confounding due to case-mix—as seen in the overdispersion (variation beyond what is expected purely by chance) in the funnel plot—but also differences in patient management, partly influenced by bed and staff availability and partly due to local practices.

Strengths and limitations

Our study benefits from national data in a public healthcare system with a negligible private sector for emergency care. We augmented this database with several published hospital-level variables. Limitations stem from it being for administrative purposes and thereby lacking physiological information such as blood pressure, heart rate, respiratory rate, oxygen saturation, creatinine and other laboratory results available in studies such as Churpek *et al*.[10] We compared our main analysis hospital admission counts against published Public Health England (PHE) figures.[30 31] We found that 152% of COVID-19 cases for August 2020, 147% for September, 114% for October, 102% for November, 101% for December, 90% for January 2021, 87% for February and 73% for March were accounted for in HES. There was a broadening of the laboratory testing included in PHE counts from mid-July 2020 onwards; the PHE definition for their daily COVID-19 patients

admitted to hospital in England are those 'admitted to hospital who tested positive for COVID-19 in the 14 days prior to admission, and those who tested positive in hospital after admission'. Our main analysis also included U072, diagnosed clinically without laboratory confirmation, which could explain why our HES counts were higher for some months. On the other hand, PHE counts would include people testing positive before hospitalisation and then admitted for some non-COVID-19 reason, which could explain why their counts were higher than ours. We could find no coding change regarding the use of ICD-10 U071 and U072 during the study period.

In our earlier wave 1 study,[11] we considered treatment choices as one explanation for differences in death rates between hospital. One element of this is the decision to admit to intensive care, which in turn is influenced by bed availability. The UK has among the lowest ITU bed rate per capita in Europe, which led to difficult decisions in some cases and transfers between hospitals in other cases. HES lacks data on such decisions and on treatments such as when dexamethasone was rolled out in 2020 and the early or unlicensed use of tocilizumab in 2021.

Collider bias could affect some of our observed associations. For collider bias to occur, the case-mix would need to differ between waves (we found some differences), and the patient characteristics would need to correlate with some unobserved characteristics that affected the risk of death in a way that differed between waves. We cannot prove this, but we do not think this likely to have had a large impact.

We observed only a modest relation between the number of COVID-19 admissions and mortality. This conceals different effects that are difficult to model. As cases rise, a hospital can become overwhelmed but may also be able to ramp up capacity and learn from the experience, leading to a fall in their death rate (other things being equal); we did not, however, observe an overall change in LOS. We were limited by the frequency of available data on bed and staff numbers to test this empirically. Another effect of experience is that in wave 1, there was little consensus on the use of non-invasive ventilation, and there were concerns over the risk of viral transmission to staff via the aerosol route. By wave 2, staff were more comfortable using it, partly because of the wide vaccination uptake by that time. However, ventilation methods appear underrecorded in HES.

CONCLUSION

Despite new treatments, patients with certain characteristics such as older age, male gender and some comorbidities remain at higher risk of death. Vaccination roll-out from December 2020 had little impact on the characteristics of those admitted. Despite the challenges, variation in death rates and LOS between hospitals was modest and might be accounted for by unobserved patient factors. Further investigation of the low outliers could be useful to identify successful strategies for the other hospitals. It will be also important to monitor the survivors, some of whom would later have 'long COVID-19' and will need further hospital admissions.

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Competing interests All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: AB, PF and PA had financial support from Dr Foster® for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval We had approval from the Secretary of State and the Health Research Authority under Regulation 5 of the Health Service (Control of Patient Information) Regulations 2002 to hold confidential data and analyse them for research purposes (CAG ref 15/CAG/0005). We have approval to use them for research and measuring quality of delivery of healthcare, from the London - South East Ethics Committee (REC ref 20/LO/0611).The need for patient consent was waived under Section 251 of the NHS Act.

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