

Supplementary document for:

Revisiting ethnic discrepancies in a Covid-19 hospitalised cohort: a correction for collider bias

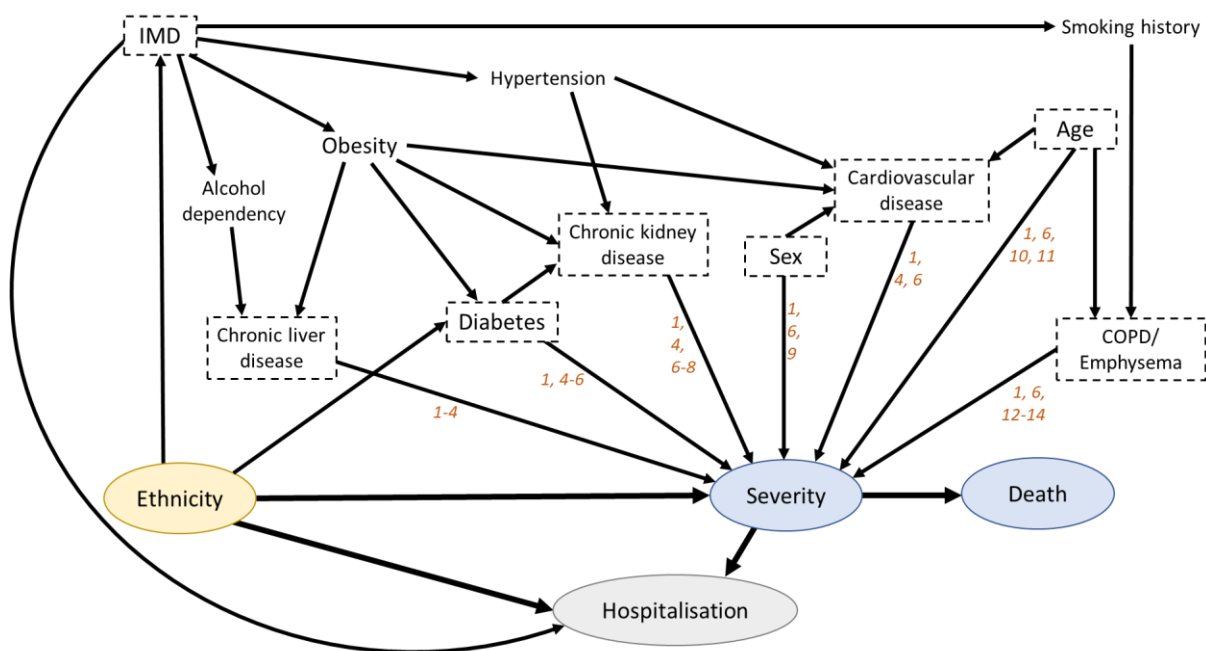
Anastazia E Learoyd¹, Jennifer Nicholas², Nicholas Hart^{3,4} and Abdel Douiri¹

¹ School of Life Course and Population Sciences, King College London, London, UK

² Department of Medical Statistics, London School of Hygiene and Tropical Medicine, London, UK

³ Lane Fox Clinical Respiratory Physiology Research Centre, Guy's & St Thomas' NHS Foundation Trust, London, UK

⁴ Centre for Human and Applied Physiological Sciences, King's College London, UK



Supplementary Figure 1: Directed acyclic graph demonstrating the relationships between ethnicity (key exposure, yellow), Covid-19 severity/death (outcomes, blue), hospitalisation due to Covid-19 (collider, grey), and other relevant comorbidities. Chronic liver disease¹⁻⁴, diabetes^{1,4-6}, chronic kidney disease^{1,4,6-8}, sex^{1,6,9}, cardiovascular disease^{1,4,6}, age^{1,6,10,11}, and respiratory disease in the form of COPD and emphysema^{1,6,12-14} were corrected for in adjusted analyses along with index of multiple deprivation^{1,15} (indicated by dashed borders). These confounders were chosen based on evidence of an independent relationship with Covid-19 severity. IMD=Index of Multiple Deprivation. COPD=Chronic Obstructive Pulmonary Disease.

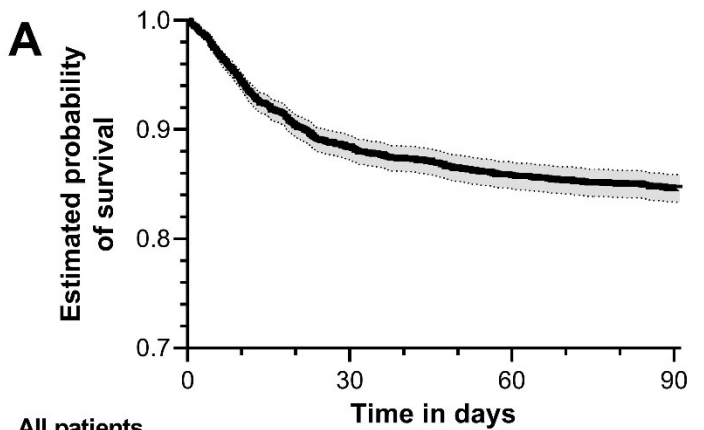
Additional results

Patient characteristics in Wave 1	All patients	Ethnicity groups					Comparison p-value
		White	Black	Asian	Mixed/Other	Unknown	
Num. (%) patients	1,010	415 (41.1%)	274 (27.1%)	87 (8.6%)	72 (7.1%)	162 (16.0%)	
Covariates							
Index of Multiple Deprivation (IMD)							
Rank [Median (IQR)]	9,412 (6,760-13,960)	9,939 (7,224-15,563)	8,087 (6,008-11,736)	10,176 (7,294-14,996)	8,581 (6,630-11,462)	9,907 (6,734-15,472)	<0.001
Quintile (%):							
1 (Most)	226 (22.4%)	77 (18.6%)	81 (29.6%)	14 (16.1%)	18 (25.0%)	36 (22.2%)	<0.001
2	508 (50.3%)	203 (48.9%)	145 (52.9%)	42 (48.3%)	43 (59.7%)	75 (46.3%)	
3	168 (16.6%)	81 (19.5%)	40 (14.6%)	20 (23.0%)	5 (6.9%)	22 (13.6%)	
4	69 (6.8%)	33 (8.0%)	8 (2.9%)	7 (8.0%)	5 (6.9%)	16 (9.9%)	
5 (Least)	39 (3.9%)	21 (5.1%)	0 (0.0%)	4 (4.6%)	1 (1.4%)	13 (8.0%)	
Age (Mean±SD)	62.19±18.54	65.30±18.73	60.94±17.87	60.15±17.09	53.81±19.51	61.19±18.03	<0.001
Male Sex (%)	584 (57.8%)	250 (60.2%)	138 (50.4%)	54 (62.1%)	47 (65.3%)	95 (58.6%)	0.048
DNARCPR applied							
Number (%)	303 (30.0%)	142 (34.2%)	68 (24.8%)	28 (32.2%)	14 (19.4%)	51 (31.5%)	0.024
Time to DNARCPR (days)	1.2 (0.2-0.8)	1.0 (0.2-11.5)	1.2 (0.2-5.7)	1.5 (0.1-6.7)	0.3 (0.2-3.7)	2.0 (0.2-9.2)	0.526
Cardiovascular conds (%)	659 (65.2%)	287 (69.2%)	192 (70.1%)	51 (58.6%)	37 (51.4%)	92 (56.8%)	0.001
COPD/Emphysema (%)	115 (11.4%)	78 (18.8%)	12 (4.4%)	5 (5.7%)	8 (11.1%)	12 (7.4%)	<0.001
Diabetes (%)	376 (37.2%)	141 (34.0%)	125 (45.6%)	35 (40.2%)	21 (29.2%)	54 (33.3%)	0.009
Kidney conditions (%)	362 (35.8%)	145 (34.9%)	124 (45.3%)	25 (28.7%)	16 (22.2%)	52 (32.1%)	0.001
Liver conditions (%)	40 (4.0%)	17 (4.1%)	14 (5.1%)	5 (5.7%)	2 (2.8%)	2 (1.2%)	0.274
Death during hospital stay							
Number (%)	176 (17.4%)	86 (20.7%)	34 (12.4%)	23 (26.4%)	10 (13.9%)	23 (14.2%)	0.006
Time to death (days)	9.8 (5.2-17.5)	10.4 (5.0-20.7)	9.5 (5.6-13.4)	8.4 (5.5-13.1)	8.2 (3.7-9.5)	10.7 (7.4-16.7)	0.560
Time to censor (days)	6.9 (2.1-17.5)	7.3 (2.3-21.0)	7.0 (2.2-19.0)	4.3 (1.9-9.0)	3.1 (0.9-9.8)	7.3 (3.0-17.7)	
ICU admission/Death within 30 days							
Total Number (%)	343 (34.0%)	142 (34.2%)	89 (32.5%)	33 (37.9%)	24 (33.3%)	55 (34.0%)	0.924
Contribution:							
ICU admission	163 (47.5%)	56 (39.4%)	52 (58.4%)	13 (39.4%)	12 (50.0%)	30 (54.6%)	0.146
Death	127 (37.0%)	62 (43.7%)	24 (27.0%)	15 (45.5%)	10 (41.7%)	16 (29.1%)	
Both	53 (15.5%)	24 (16.9%)	13 (14.6%)	5 (15.2%)	2 (8.3%)	9 (16.4%)	

Supplementary Table 1: Patient characteristics for patients admitted to GSTT in Wave 1 (Jan 2020-Aug 2020). Times are days reported as Median (IQR). Censored means patient discharged without experiencing event. P-values come from Kruskal-Wallis (continuous measures) or chi-squared tests (counts). IQR=Interquartile Range. DNARCPR= “do not attempt resuscitation” order. COPD=chronic obstructive pulmonary disease.

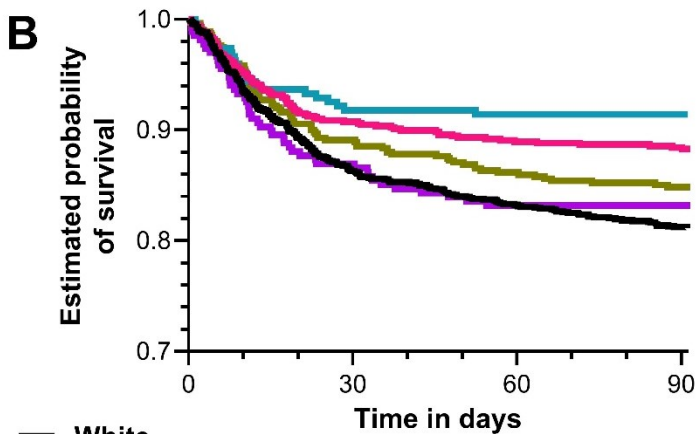
Patient characteristics in Wave 2	All patients	Ethnicity groups					Comparison p-value
		White	Black	Asian	Mixed/Other	Unknown	
Num. (%) patients	2,123	850 (40.0%)	505 (23.8%)	181 (8.5%)	196 (9.2%)	391 (18.4%)	
Covariates							
Index of Multiple Deprivation (IMD)							
Rank [Median (IQR)]	9,248 (6,537-13,839)	9,885 (7,024-14,645)	8,211 (6,016-11,322)	7,919 (5,652-11,039)	8,915 (6,796-13,839)	10,007 (6,581-15,958)	<0.001
Quintile (%):							
1 (Most)	549 (25.9%)	190 (22.4%)	155 (30.7%)	61 (33.7%)	46 (23.5%)	97 (24.8%)	<0.001
2	1,020 (48.0%)	414 (48.7%)	257 (50.9%)	86 (47.5%)	98 (50.0%)	165 (42.2%)	
3	330 (15.5%)	140 (16.5%)	71 (14.1%)	20 (11.0%)	33 (16.8%)	66 (16.9%)	
4	158 (7.4%)	67 (7.9%)	19 (3.8%)	12 (6.6%)	14 (7.1%)	46 (11.8%)	
5 (Least)	66 (3.1%)	39 (4.6%)	3 (0.6%)	2 (1.1%)	5 (2.6%)	17 (4.3%)	
Age (Mean±SD)	58.53±18.82	63.45±18.83	55.73±18.33	54.20±17.72	53.22±17.43	56.09±18.21	<0.001
Male Sex (%)	1,090 (51.3%)	441 (51.9%)	231 (45.7%)	99 (54.7%)	87 (44.4%)	232 (59.3%)	<0.001
DNARCPR applied							
Number (%)	390 (18.4%)	206 (24.2%)	71 (14.1%)	28 (15.5%)	18 (9.2%)	67 (17.1%)	<0.001
Time to DNARCPR (days)	1.6 (0.3-11.7)	1.1 (0.2-7.2)	1.7 (0.3-11.0)	2.6 (0.3-17.5)	1.7 (0.3-6.2)	4.1 (0.5-21.6)	0.296
Cardiovascular conds (%)	1,051 (49.5%)	489 (57.5%)	262 (51.9%)	85 (47.0%)	86 (43.9%)	129 (33.0%)	<0.001
COPD/Emphysema (%)	147 (6.9%)	98 (11.5%)	15 (3.0%)	4 (2.2%)	10 (5.1%)	20 (5.1%)	<0.001
Diabetes (%)	499 (23.5%)	185 (21.8%)	151 (29.9%)	61 (33.7%)	35 (17.9%)	67 (17.1%)	<0.001
Kidney conditions (%)	269 (12.7%)	118 (13.9%)	86 (17.0%)	28 (15.5%)	16 (8.2%)	21 (5.4%)	<0.001
Liver conditions (%)	42 (2.0%)	25 (2.9%)	6 (1.2%)	4 (2.2%)	2 (1.0%)	5 (1.3%)	0.105
Death during hospital stay							
Number (%)	180 (8.5%)	80 (9.4%)	38 (7.5%)	19 (10.5%)	6 (3.1%)	37 (9.5%)	0.034
Time to death (days)	12.9 (5.9-23.6)	12.6 (6.7-23.7)	16.1 (4.8-23.4)	17.4 (5.4-33.6)	5.6 (1.6-23.3)	12.8 (7.3-23.6)	0.649
Time to censor (days)	4.5 (1.1-10.9)	5.7 (1.6-13.1)	4.2 (1.1-10.2)	3.8 (0.9-8.3)	3.3 (0.8-10.1)	4.1 (1.1-9.3)	
ICU admission/Death within 30 days							
Total Number (%)	447 (21.1%)	191 (22.5%)	103 (20.4%)	42 (23.2%)	39 (19.9%)	72 (18.4%)	0.484
Contribution:							
ICU admission	265 (59.3%)	104 (54.5%)	68 (66.0%)	27 (64.3%)	29 (74.4%)	37 (51.4%)	0.025
Death	124 (27.7%)	58 (30.4%)	18 (17.5%)	12 (28.6%)	8 (20.5%)	28 (38.9%)	
Both	58 (13.0%)	29 (15.2%)	17 (16.5%)	3 (7.1%)	2 (5.1%)	7 (9.7%)	

Supplementary Table 2: Patient characteristics for patients admitted to GSTT in Wave 2 (Jan 2020-Aug 2020). Times are days reported as Median (IQR). Censored means patient discharged without experiencing event. P-values come from Kruskal-Wallis (continuous measures) or chi-squared tests (counts). IQR=Interquartile Range. DNARCPR= “do not attempt resuscitation” order. COPD=chronic obstructive pulmonary disease.



All patients

At risk	3,133	2,762	2,668	2,595
Censored	0	9	23	60
Events	0	362	442	478



— White				
At risk	1,265	1,092	1,047	1,006
Censored	0	0	6	22
Events	0	173	212	237
— Black				
At risk	779	705	690	677
Censored	0	2	3	12
Events	0	72	86	90
— Asian				
At risk	268	232	221	219
Censored	0	1	2	4
Events	0	35	45	45
— Mixed/Other				
At risk	268	246	242	238
Censored	0	0	3	7
Events	0	22	23	23
— Unknown				
At risk	553	487	468	455
Censored	0	6	9	15
Events	0	60	76	83

Figure 2: Kaplan Meier plots with associated risk tables for the probability of death over days from hospital admission (in all patients (A) and the following ethnic groups (B): White (black), Black (red), Asian (purple), Mixed/Other (turquoise) and Unknown (brown).

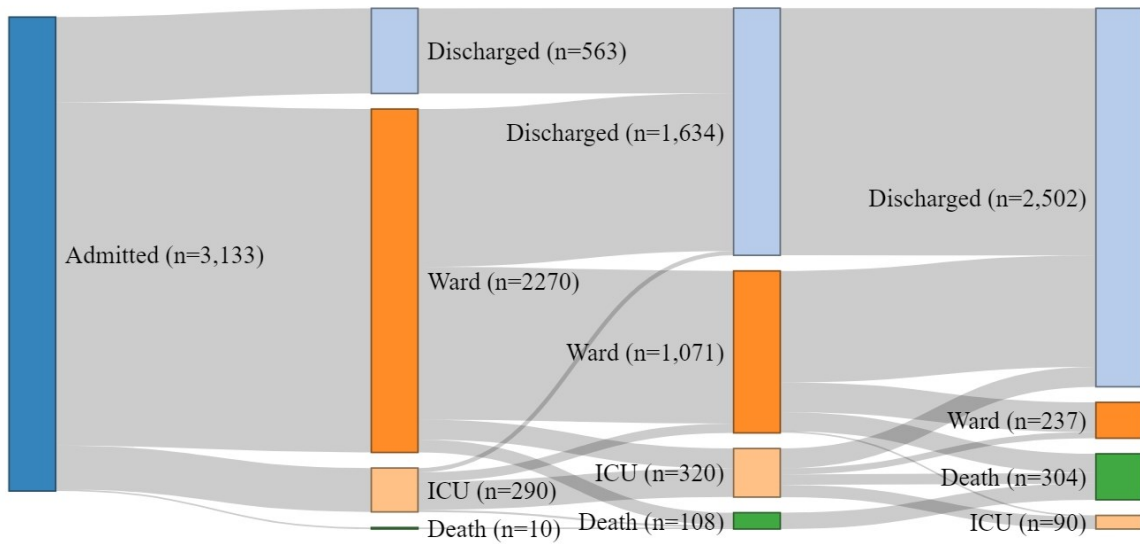


Figure 3: Sankey Diagram demonstrating patient movement between ward and ICU alongside with discharge status at 1 day, 1 week and 1 month (30 days) from the point of admission.

Death		Unadjusted estimates		Adjusted for:					
				Age, sex, and ethnicity		All covariates and ethnicity		All factors plus IPW	
		Hazard ratio (95% CI)	p-value	Hazard ratio (95% CI)	p-value	Hazard ratio (95% CI)	p-value	Hazard ratio (95% CI)	p-value
Both Waves (n=3,133)									
Age	[Centred at 59.7 years]	1.05 (1.05, 1.06) ¹	<0.001 ¹	1.06 (1.05, 1.06)	<0.001	1.01 (0.99, 1.02)	0.283	1.01 (0.99, 1.02)	0.379
Sex	Female (ref)	1	-	1	-	1	-	1	-
	Male	1.47 (1.18, 1.82) ²	<0.001 ²	1.51 (1.21, 1.88)	<0.001	1.48 (1.15, 1.87)	0.002	1.80 (1.33, 2.43)	<0.001
IMD	Quintile 1 (Most deprived)	1.09 (0.84, 1.40) ³	0.531 ³	-	-	0.95 (0.71, 1.26)	0.708	0.89 (0.62, 1.28)	0.531
	Quintile 2 (ref)	1	-	-	-	1	-	1	-
	Quintile 3 (Less deprived)	0.97 (0.71, 1.33) ³	0.872 ³	-	-	0.82 (0.58, 1.17)	0.279	0.66 (0.42, 1.05)	0.076
	Quintile 4 (Less deprived)	1.12 (0.74, 1.68) ³	0.592 ³	-	-	1.15 (0.73, 1.82)	0.555	1.30 (0.74, 2.27)	0.357
	Quintile 5 (Least deprived)	1.82 (1.16, 2.88) ³	0.010 ³	-	-	1.24 (0.71, 2.15)	0.452	1.46 (0.72, 2.93)	0.293
Wave 1 (n=1,010)									
Age	[Centred at 59.7 years]	1.04 (1.03, 1.05) ²	<0.001 ¹	1.04 (1.03, 1.05)	<0.001	1.00 (0.99, 1.01)	0.945	1.00 (0.98, 1.02)	0.976
Sex	Female (ref)	1	-	1	-	1	-	1	-
	Male	1.27 (0.93, 1.73) ²	0.129 ²	1.31 (0.96, 1.80)	0.087	1.23 (0.87, 1.73)	0.246	1.48 (0.95, 2.32)	0.085
IMD	Quintile 1 (Most deprived)	1.18 (0.82, 1.70) ³	0.366 ³	-	-	1.13 (0.75, 1.68)	0.559	1.01 (0.58, 1.76)	0.975
	Quintile 2 (ref)	1	-	-	-	1	-	1	-
	Quintile 3 (Less deprived)	0.92 (0.59, 1.43) ³	0.715 ³	-	-	1.06 (0.64, 1.75)	0.828	0.92 (0.46, 1.82)	0.811
	Quintile 4 (Less deprived)	0.86 (0.44, 1.66) ³	0.651 ³	-	-	0.99 (0.47, 2.11)	0.984	0.84 (0.34, 2.07)	0.705
	Quintile 5 (Least deprived)	1.21 (0.60, 2.44) ³	0.602 ³	-	-	1.04 (0.41, 2.65)	0.928	0.70 (0.20, 2.45)	0.578
Wave 2 (n=2,123)									
Age	[Centred at 59.7 years]	1.06 (1.05, 1.07) ¹	<0.001 ¹	1.06 (1.05, 1.08)	<0.001	1.01 (0.99, 1.03)	0.164	1.02 (1.00, 1.04)	0.127
Sex	Female (ref)	1	-	1	-	1	-	1	-
	Male	1.53 (1.13, 2.07) ²	0.006 ²	1.58 (1.16, 2.14)	0.003	1.58 (1.12, 2.24)	0.009	1.91 (1.25, 2.94)	0.003
IMD	Quintile 1 (Most deprived)	1.09 (0.76, 1.57) ³	0.632 ³	-	-	0.85 (0.56, 1.31)	0.470	0.89 (0.53, 1.48)	0.645
	Quintile 2 (ref)	1	-	-	-	1	-	1	-
	Quintile 3 (Less deprived)	1.03 (0.66, 1.61) ³	0.895 ³	-	-	0.65 (0.39, 1.08)	0.097	0.55 (0.29, 1.04)	0.064
	Quintile 4 (Less deprived)	1.43 (0.85, 2.43) ³	0.180 ³	-	-	1.41 (0.81, 2.48)	0.227	1.91 (0.94, 3.91)	0.076
	Quintile 5 (Least deprived)	2.49 (1.36, 4.54) ³	0.003 ³	-	-	1.29 (0.62, 2.65)	0.494	1.90 (0.72, 4.97)	0.193

Supplementary Table 3: Association of age, sex, or index of multiple deprivation with risk of death across time within a covid-associated hospital stay during time periods: Jan 2020-May 2021 (both waves), Jan 2020-Aug 2020 (Wave 1), and Sept 2020-May 2021 (Wave 2) both unadjusted and adjusted for different factors. Unadjusted models are separate models for each covariate (labelled 1, 2, 3). “All covariates” includes age, sex, medical history (cardiovascular, kidney and liver conditions, COPD/emphysema, diabetes, and DNAR CPR), and Index of Multiple Deprivation (IMD) quintile. P-values are derived from univariate Wald tests of the relevant hazard ratio. CI=Confidence Interval. IPW=Inverse probability weighting.

Secondary outcomes: Respiratory measures recorded within 24hrs of hospital admission

Respiratory measures were obtained from a single observed timepoint containing the most available data and closest to the point of hospital admission. Only patients with measures recorded within 24 hours of admission were included in these analyses. These exclusions meant that respiratory measures were examined in a sample of 2,471 patients (78.9% of the studied cohort) although a number of these patients had missing data in one or more individual measures.

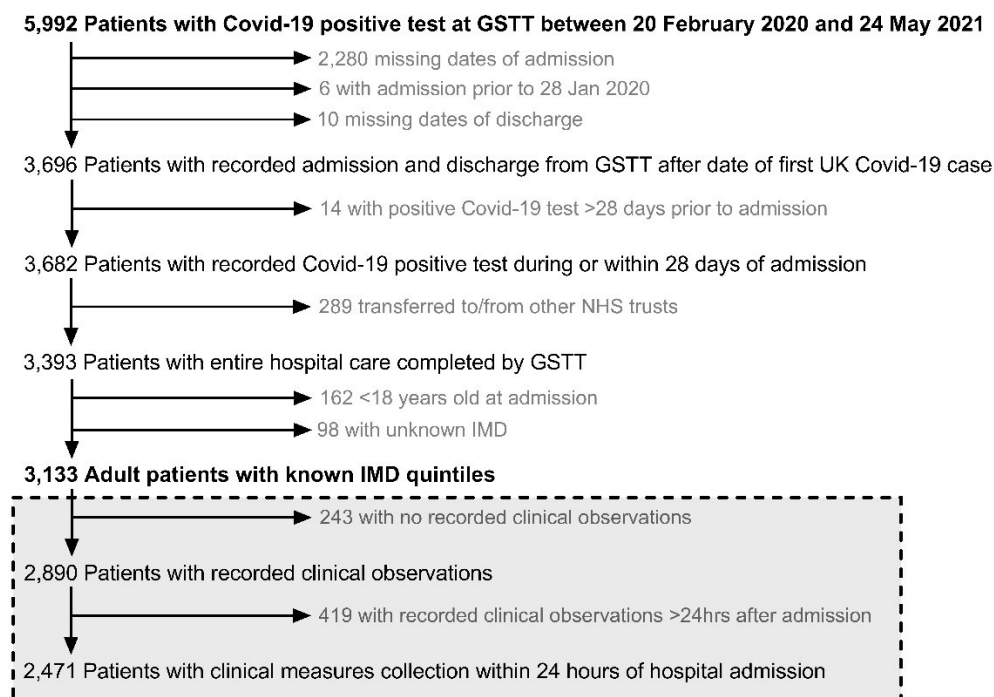


Figure 4: Study population with additional exclusions for analysis of respiratory measures (indicates with grey box). GSTT= Guy’s and St. Thomas’ NHS Foundation Trust. IMD= Index of Multiple Deprivation.

The respiratory measures assessed were respiratory rate, oxygen saturation, administration of oxygen therapy, fraction of inspired oxygen (FiO_2) and ROX index (as a predictor of need for intubation¹⁶ where a low score indicates intubation). The binary outcome ‘administration of oxygen support’ is a simplification of the described provided oxygen support which ranged from a nasal cannula to invasive ventilation. FiO_2 was determined using a conversion table from the provided oxygen support device and oxygen flow rate information. ROX Index was calculated from oxygen saturation, fraction of inspired oxygen and respiratory rate recorded at a single timepoint using the following equation:

$$ROX_i = \left(\frac{SP(O_2)_i}{Fi(O_2)_i} \times 100 \right) / Resp_i$$

$(SP(O_2)_i)$ is the oxygen saturation for individual i , $Fi(O_2)_i$ their fraction of inspired oxygen and $Resp_i$ their respiratory rate.

The following statistical models were applied to analyse each outcome: Administration of oxygen therapy within 24 hours of admission was analysed using logistic regression. Respiratory rate was analysed using Poisson regression with robust variance. Oxygen saturation, FiO_2 and ROX Index were analysed using Gamma model with a log link function. Robust standard errors were used for all models. Model assumptions including overall model fit, specification of the linear predictor, and the distribution of residuals were checked and verified to be appropriate using plots appropriate to the model type.

Concerns

Respiratory measures were provided for a single timepoint, commonly within 24hrs of admission. These measures were not present for all patients (Table 4) and patients with measures more than 24hrs post-admission (n=419, 13.4%) were excluded from these analyses in order to reduce selection bias towards patients with long hospital stays. As a result of these exclusions, outcome data is assumed to be missing at random. If the observation of these outcomes within 24hrs of admission is dependent on clinical need, then this data will be missing not at random. The estimated effect on ethnicity on these outcomes relies on this assumption of missing at random to be unbiased.

The single observation creates another issue. It is assumed that this measure is illustrative of severity upon admission. But clinical presentation may change quite quickly such that observations 9hrs post-admission (upper IQR limit) do not represent severity at admission. This would lead to misclassification bias, particular in the binary outcome administration of oxygen support. Another cause of misclassification bias is ethnic discrepancies in the collected clinical measures. In particular, accuracy of pulse oximeters is known to be poor in darker skinned individuals¹⁷. Studies in Covid-19 patients disagree about the impact of this issue^{18,19}, but it could minimise ethnic differences in severity measured by ROX Index and administration of oxygen therapy (due to delayed patient triage).

Secondary clinical outcomes descriptive statistics	All patients	Ethnicity Groups					Comparison p-value
		White	Black	Asian	Mixed/Other	Unknown	
Number (%) of patients	3,133	1,265 (40.4%)	779 (24.9%)	268 (8.6%)	268 (8.6%)	553 (17.7%)	
Collected Clinical Respiratory Observations							
Total Number (%)	2,890 (92.2%)	1,174 (92.8%)	718 (92.2%)	235 (87.7%)	245 (91.4%)	518 (93.7%)	0.038
Time to Observation (days)	0.2 (0.0-0.6)	0.2 (0.0-0.7)	0.2 (0.0-0.5)	0.2 (0.0-0.5)	0.2 (0.0-0.5)	0.2 (0.0-0.7)	<0.001
Number recorded <24 hrs (%)	2,471 (78.9%)	960 (75.9%)	646 (82.9%)	211 (78.7%)	219 (81.7%)	435 (78.7%)	0.003
Time to Observation (hrs)	4.4 (0.0-9.3)	4.4 (0.0-9.7)	4.5 (0.0-9.6)	4.3 (0.0-9.0)	4.1 (0.0-7.9)	4.4 (0.0-8.7)	0.383
Clinical Respiratory Outcomes collected within 24 hrs							
Respiratory Rate (breathes/min)	19 (18-22)	20 (18-22)	19 (17-22)	20 (18-24)	20 (18-22)	19 (18-22)	0.056
<i>Missing</i>	8	5	2	0	1	0	
Oxygen Saturation (units: %)	96 (94-97)	96 (94-97)	96 (95-98)	96 (94-97)	96 (95-97)	96 (94-97)	<0.001
<i>Missing</i>	79	50	14	1	10	4	
Oxygen Therapy administered (%)	1,033 (43.1%)	402 (43.1%)	258 (41.4%)	91 (44.8%)	87 (41.0%)	195 (46.0%)	0.595
<i>Missing</i>	76	27	23	8	7	11	
FiO ₂ (units: %)	21 (21-32)	21 (21-32)	21 (21-28)	21 (21-35)	21 (21-30)	21 (21-32)	0.507
Type of therapy (% out of those administered oxygen)							0.474
Nasal Cannula	620 (60.0%)	240 (59.7%)	151 (58.5%)	53 (58.2%)	56 (64.4%)	120 (61.5%)	
Face mask	239 (23.1%)	101 (25.1%)	57 (22.1%)	26 (28.6%)	13 (14.9%)	42 (21.5%)	
Ventilator	104 (10.1%)	34 (8.5%)	34 (13.2%)	8 (8.8%)	10 (11.5%)	18 (9.2%)	
Unknown	70 (6.8%)	27 (6.7%)	16 (6.2%)	4 (4.4%)	8 (9.2%)	15 (7.7%)	
ROX Index	20.8 (14.0-25.4)	21.0 (14.5-25.1)	21.6 (13.9-25.7)	19.4 (13.3-24.9)	21.8 (14.5-25.9)	20.3 (13.9-25.1)	0.225
<i>Missing</i>	163	80	41	10	17	15	

Supplementary Table 4: Secondary clinical outcomes (observed within 24hours of admission) by ethnic group. Times reported as Median (Interquartile Range) with indicated units. Respiratory rate, oxygen saturation, FiO₂ and ROX Index are reported as Median (Interquartile Range). FiO₂=Fraction of inspired oxygen.

Respiratory Rate	Unadjusted estimates		Age and sex		<i>Adjusted for:</i> All covariates		All covariates plus IPW for hospitalisation	
	Rate ratio (95% CI)	p-value	Rate ratio (95% CI)	p-value	Rate ratio (95% CI)	p-value	Rate ratio (95% CI)	p-value
Both Waves (n=2,463)								
White (ref)	1	-	1	-	1	-	1	-
Black	1.02 (0.99, 1.05)	0.157	1.03 (1.00, 1.05)	0.046	1.03 (1.00, 1.05)	0.058	1.02 (0.99, 1.05)	0.282
Asian	1.05 (1.01, 1.09)	0.013	1.06 (1.02, 1.10)	0.004	1.05 (1.02, 1.10)	0.005	1.01 (0.97, 1.06)	0.611
Mixed/Other	1.02 (0.98, 1.05)	0.406	1.03 (0.99, 1.07)	0.152	1.03 (0.99, 1.07)	0.169	1.03 (0.99, 1.07)	0.129
Unknown	1.00 (0.98, 1.03)	0.807	1.01 (0.98, 1.04)	0.429	1.02 (0.99, 1.04)	0.285	1.01 (0.98, 1.03)	0.726
Wave 1 (n=765)								
White (ref)	1	-	1	-	1	-	1	-
Black	0.99 (0.94, 1.04)	0.698	0.99 (0.94, 1.04)	0.744	0.99 (0.94, 1.04)	0.701	0.97 (0.91, 1.03)	0.331
Asian	1.03 (0.96, 1.11)	0.352	1.03 (0.96, 1.11)	0.343	1.03 (0.96, 1.11)	0.355	0.98 (0.92, 1.04)	0.504
Mixed/Other	1.00 (0.92, 1.09)	0.958	1.00 (0.92, 1.09)	0.997	0.99 (0.90, 1.08)	0.771	0.98 (0.89, 1.09)	0.777
Unknown	1.01 (0.95, 1.06)	0.848	1.01 (0.95, 1.06)	0.808	1.01 (0.95, 1.07)	0.788	0.98 (0.93, 1.04)	0.557
Wave 2 (n=1,698)								
White (ref)	1	-	1	-	1	-	1	-
Black	1.03 (1.00, 1.06)	0.032	1.04 (1.01, 1.08)	0.004	1.05 (1.01, 1.08)	0.004	1.03 (0.99, 1.06)	0.121
Asian	1.06 (1.01, 1.10)	0.015	1.07 (1.02, 1.11)	0.003	1.07 (1.02, 1.12)	0.003	1.02 (0.97, 1.08)	0.432
Mixed/Other	1.03 (0.99, 1.07)	0.214	1.04 (1.00, 1.08)	0.043	1.04 (1.00, 1.08)	0.044	1.04 (1.00, 1.08)	0.076
Unknown	1.01 (0.98, 1.04)	0.707	1.02 (0.99, 1.05)	0.299	1.02 (0.99, 1.05)	0.223	1.01 (0.98, 1.04)	0.562

Supplementary Table 5: Association of ethnicity with respiratory rate as measured during the most severe point of Covid-19 infection [within 24hrs of hospital admission] during time periods: Jan 2020-May 2021 (both waves), Jan 2020-Aug 2020 (Wave 1), and Sept 2020-May 2021 (Wave 2). Unadjusted analysis represents biased estimates restricted to hospitalised populations. Sequential adjustment allows for consideration of confounding and collider bias. “All covariates” includes age, sex, medical history (cardiovascular, kidney and liver conditions, COPD/emphysema, diabetes, and DNARCPR), and IMD quintile. P-values are derived from univariate Wald tests of the relevant hazard ratio. CI=Confidence Interval. IPW=Inverse probability weighting.

Oxygen Saturation	Unadjusted estimates		Age and sex		Adjusted for: All covariates		All covariates plus IPW for hospitalisation	
	Log difference in saturation (95% CI)	p-value	Log difference in saturation (95% CI)	p-value	Log difference in saturation (95% CI)	p-value	Log difference in saturation (95% CI)	p-value
Both Waves (n=2,392)								
White (ref)	0	-	0	-	0	-	0	-
Black	0.13 (0.07, 0.19)	<0.001	0.09 (0.03, 0.15)	0.001	0.08 (0.03, 0.14)	0.004	0.06 (-0.01, 0.12)	0.072
Asian	0.04 (-0.04, 0.12)	0.333	0.00 (-0.07, 0.08)	0.903	-0.01 (-0.08, 0.07)	0.885	0.00 (-0.10, 0.11)	0.969
Mixed/Other	0.09 (0.02, 0.16)	0.008	0.03 (-0.03, 0.10)	0.347	0.03 (-0.04, 0.09)	0.456	0.03 (-0.04, 0.10)	0.423
Unknown	0.08 (0.03, 0.14)	0.003	0.04 (-0.02, 0.09)	0.158	0.02 (-0.03, 0.08)	0.415	0.01 (-0.04, 0.07)	0.621
Wave 1 (n=726)								
White (ref)	0	-	0	-	0	-	0	-
Black	0.17 (0.08, 0.28)	0.001	0.15 (0.05, 0.25)	0.004	0.14 (0.04, 0.24)	0.004	0.10 (-0.01, 0.21)	0.076
Asian	-0.01 (-0.15, 0.13)	0.901	-0.02 (-0.15, 0.12)	0.797	-0.02 (-0.15, 0.10)	0.701	-0.03 (-0.14, 0.09)	0.631
Mixed/Other	0.07 (-0.08, 0.22)	0.361	0.01 (-0.13, 0.16)	0.869	0.02 (-0.13, 0.17)	0.782	0.15 (-0.13, 0.16)	0.846
Unknown	0.13 (0.01, 0.25)	0.036	0.10 (-0.02, 0.22)	0.093	0.09 (-0.03, 0.20)	0.136	0.04 (-0.08, 0.16)	0.488
Wave 2 (n=1,666)								
White (ref)	0	-	0	-	0	-	0	-
Black	0.11 (0.04, 0.17)	0.001	0.06 (-0.01, 0.12)	0.083	0.05 (-0.02, 0.12)	0.144	0.05 (-0.02, 0.12)	0.168
Asian	0.06 (0.03, 0.15)	0.206	0.01 (-0.08, 0.10)	0.789	0.00 (-0.09, 0.09)	0.979	0.00 (-0.12, 0.12)	0.959
Mixed/Other	0.10 (0.03, 0.18)	0.009	0.04 (-0.04, 0.11)	0.304	0.03 (-0.05, 0.10)	0.449	0.03 (-0.04, 0.11)	0.421
Unknown	0.07 (0.01, 0.13)	0.025	0.02 (-0.04, 0.08)	0.487	0.00 (-0.06, 0.06)	0.946	0.01 (-0.05, 0.07)	0.790

Supplementary Table 6: Association of ethnicity with oxygen saturation as measured during the most severe point of Covid-19 infection [within 24hrs of hospital admission] during time periods: Jan 2020-May 2021 (both waves), Jan 2020-Aug 2020 (Wave 1), and Sept 2020-May 2021 (Wave 2). Unadjusted analysis represents biased estimates restricted to hospitalised populations. Sequential adjustment allows for consideration of confounding and collider bias. “All covariates” includes age, sex, medical history (cardiovascular, kidney and liver conditions, COPD/emphysema, diabetes, and DNARCPR), and IMD quintile. P-values are derived from univariate Wald tests of the relevant hazard ratio. CI=Confidence Interval. IPW=Inverse probability weighting.

Oxygen Therapy	Unadjusted estimates		Age and sex		<i>Adjusted for:</i> All covariates		All covariates plus IPW for hospitalisation	
	Coefficient (95% CI)	p-value	Coefficient (95% CI)	p-value	Coefficient (95% CI)	p-value	Coefficient (95% CI)	p-value
Administered Oxygen Therapy (coefficient: Odds Ratio)								
<i>Both Waves (n=2,395)</i>								
White (ref)	1	-	1	-	1	-	1	-
Black	0.93 (0.76, 1.15)	0.513	1.12 (0.90, 1.39)	0.307	1.08 (0.86, 1.34)	0.518	0.94 (0.73, 1.20)	0.608
Asian	1.07 (0.79, 1.46)	0.650	1.28 (0.93, 1.75)	0.125	1.19 (0.86, 1.64)	0.300	1.15 (0.66, 2.01)	0.612
Mixed/Other	0.92 (0.68, 1.24)	0.586	1.20 (0.88, 1.65)	0.246	1.18 (0.86, 1.61)	0.310	1.22 (0.86, 1.72)	0.270
Unknown	1.12 (0.89, 1.42)	0.318	1.36 (1.07, 1.73)	0.011	1.34 (1.05, 1.70)	0.019	1.31 (1.00, 1.71)	0.047
<i>Wave 1 (n=733)</i>								
White (ref)	1	-	1	-	1	-	1	-
Black	1.27 (0.89, 1.81)	0.182	1.41 (0.98, 2.03)	0.063	1.33 (0.91, 1.95)	0.142	1.48 (0.95, 2.29)	0.080
Asian	1.37 (0.79, 2.37)	0.269	1.44 (0.81, 2.53)	0.210	1.36 (0.75, 2.46)	0.305	2.43 (1.13, 5.25)	0.024
Mixed/Other	0.93 (0.51, 1.68)	0.801	1.02 (0.55, 1.88)	0.949	0.92 (0.49, 1.73)	0.798	0.94 (0.45, 1.96)	0.870
Unknown	1.11 (0.56, 1.73)	0.659	1.22 (0.78, 1.90)	0.387	1.17 (0.74, 1.85)	0.494	1.17 (0.70, 1.93)	0.551
<i>Wave 2 (n=1,662)</i>								
White (ref)	1	-	1	-	1	-	1	-
Black	0.79 (0.62, 1.02)	0.076	1.00 (0.76, 1.30)	0.991	0.96 (0.73, 1.27)	0.786	0.86 (0.64, 1.15)	0.297
Asian	0.96 (0.67, 1.39)	0.847	1.23 (0.84, 1.80)	0.285	1.13 (0.77, 1.67)	0.527	1.07 (0.56, 2.03)	0.834
Mixed/Other	0.91 (0.64, 1.29)	0.595	1.27 (0.88, 1.84)	0.204	1.26 (0.87, 1.83)	0.229	1.22 (0.83, 1.81)	0.315
Unknown	1.12 (0.67, 1.47)	0.407	1.44 (1.08, 1.91)	0.013	1.40 (1.05, 1.87)	0.023	1.34 (0.99, 1.83)	0.059
Fraction of inspired oxygen (FiO₂, coefficient: Mean Ratio)								
<i>Both Waves (n=2,389)</i>								
White (ref)	1	-	1	-	1	-	1	-
Black	1.01 (0.95, 1.06)	0.763	1.04 (0.99, 1.10)	0.113	1.02 (0.97, 1.08)	0.451	1.00 (0.94, 1.06)	0.953
Asian	1.08 (0.99, 1.18)	0.076	1.11 (0.02, 1.20)	0.019	1.08 (0.99, 1.17)	0.078	1.12 (0.94, 1.33)	0.201
Mixed/Other	1.02 (0.93, 1.10)	0.721	1.06 (0.98, 1.15)	0.146	1.05 (0.98, 1.14)	0.183	1.09 (1.00, 1.19)	0.056
Unknown	1.03 (0.97, 1.09)	0.396	1.05 (0.99, 1.12)	0.079	1.06 (1.00, 1.12)	0.060	1.03 (0.97, 1.09)	0.311

Wave 1 (n=730)									
White (ref)	1	-	1	-	1	-	1	-	
Black	1.01 (0.92, 1.11)	0.808	1.05 (0.96, 1.15)	0.322	1.00 (0.91, 1.10)	0.969	1.00 (0.92, 1.10)	0.926	
Asian	1.07 (0.91, 1.25)	0.419	1.08 (0.92, 1.26)	0.334	1.05 (0.92, 1.20)	0.478	1.09 (0.97, 1.24)	0.149	
Mixed/Other	0.99 (0.85, 1.17)	0.949	1.02 (0.87, 1.19)	0.846	0.99 (0.85, 1.15)	0.904	1.02 (0.87, 1.19)	0.844	
Unknown	1.06 (0.93, 1.21)	0.368	1.09 (0.96, 1.23)	0.185	1.05 (0.94, 1.18)	0.364	1.04 (0.94, 1.15)	0.474	
Wave 2 (n=1,659)									
White (ref)	1	-	1	-	1	-	1	-	
Black	1.00 (0.94, 1.07)	0.890	1.04 (0.98, 1.11)	0.220	1.03 (0.96, 1.10)	0.404	1.00 (0.93, 1.07)	0.934	
Asian	1.09 (0.98, 1.21)	0.103	1.12 (1.01, 1.24)	0.027	1.09 (0.99, 1.21)	0.081	1.14 (0.94, 1.38)	0.195	
Mixed/Other	1.03 (0.93, 1.13)	0.576	1.08 (0.98, 1.19)	0.111	1.07 (0.98, 1.17)	0.132	1.09 (0.99, 1.20)	0.079	
Unknown	1.02 (0.95, 1.09)	0.570	1.05 (0.98, 1.12)	0.162	1.05 (0.98, 1.12)	0.146	1.02 (0.96, 1.09)	0.539	

Supplementary Table 7: Association of ethnicity with the need for oxygen therapy and the fraction of inspired oxygen as measured during the most severe point of Covid-19 infection [within 24hrs of hospital admission] during time periods: Jan 2020-May 2021 (both waves), Jan 2020-Aug 2020 (Wave 1), and Sept 2020-May 2021 (Wave 2). Unadjusted analysis represents biased estimates restricted to hospitalised populations. Sequential adjustment allows for consideration of confounding and collider bias. “All covariates” includes age, sex, medical history (cardiovascular, kidney and liver conditions, COPD/emphysema, diabetes, and DNARCPR), and IMD quintile. P-values are derived from univariate Wald tests of the relevant hazard ratio. CI=Confidence Interval. IPW=Inverse probability weighting.

ROX Index	Unadjusted estimates		Age and sex		<i>Adjusted for:</i> All covariates		All covariates plus IPW for hospitalisation	
	Mean ratio (95% CI)	p-value	Mean ratio (95% CI)	p-value	Mean ratio (95% CI)	p-value	Mean ratio (95% CI)	p-value
Both Waves (n=2,308)								
White (ref)	1	-	1	-	1	-	1	-
Black	1.01 (0.97, 1.05)	0.550	0.98 (0.94, 1.02)	0.343	0.99 (0.95, 1.03)	0.720	1.01 (0.97, 1.05)	0.737
Asian	0.94 (0.89, 1.00)	0.070	0.92 (0.86, 0.98)	0.007	0.93 (0.87, 0.99)	0.022	0.95 (0.86, 1.05)	0.301
Mixed/Other	1.01 (0.95, 1.07)	0.798	0.96 (0.91, 1.02)	0.153	0.96 (0.91, 1.02)	0.186	0.94 (0.89, 1.01)	0.073
Unknown	0.98 (0.94, 1.03)	0.430	0.95 (0.92, 1.00)	0.032	0.95 (0.91, 0.99)	0.018	0.96 (0.92, 1.00)	0.078
Wave 1 (n=689)								
White (ref)	1	-	1	-	1	-	1	-
Black	1.01 (0.95, 1.09)	0.680	1.00 (0.93, 1.07)	0.980	1.02 (0.95, 1.10)	0.538	1.04 (0.96, 1.12)	0.359
Asian	0.96 (0.85, 1.08)	0.457	0.95 (0.84, 1.07)	0.398	0.95 (0.84, 1.07)	0.381	0.93 (0.83, 1.04)	0.207
Mixed/Other	1.05 (0.94, 1.20)	0.401	1.04 (0.93, 1.16)	0.542	1.07 (0.95, 1.21)	0.259	1.05 (0.93, 1.19)	0.422
Unknown	0.97 (0.89, 1.06)	0.458	0.95 (0.87, 1.04)	0.265	0.96 (0.88, 1.05)	0.363	0.98 (0.91, 1.07)	0.701
Wave 2 (n=1,619)								
White (ref)	1	-	1	-	1	-	1	-
Black	1.01 (0.97, 1.06)	0.606	0.97 (0.93, 1.02)	0.244	0.98 (0.93, 1.03)	0.347	1.00 (0.96, 1.05)	0.948
Asian	0.94 (0.87, 1.01)	0.088	0.90 (0.84, 0.97)	0.006	0.91 (0.85, 0.98)	0.012	0.94 (0.84, 1.05)	0.291
Mixed/Other	0.99 (0.93, 1.06)	0.784	0.94 (0.88, 1.00)	0.046	0.94 (0.88, 1.00)	0.046	0.93 (0.87, 1.00)	0.060
Unknown	0.98 (0.94, 1.03)	0.532	0.95 (0.91, 1.00)	0.039	0.95 (0.90, 0.99)	0.025	0.96 (0.91, 1.01)	0.092

Supplementary Table 8: Association of ethnicity with ROX Index as measured during the most severe point of Covid-19 infection [within 24hrs of hospital admission] during time periods: Jan 2020-May 2021 (both waves), Jan 2020-Aug 2020 (Wave 1), and Sept 2020-May 2021 (Wave 2). Unadjusted analysis represents biased estimates restricted to hospitalised populations. Sequential adjustment allows for consideration of confounding and collider bias. “All covariates” includes age, sex, medical history (cardiovascular, kidney and liver conditions, COPD/emphysema, diabetes, and DNARCP), and IMD quintile. P-values are derived from univariate Wald tests of the relevant hazard ratio. CI=Confidence Interval. IPW=Inverse probability weighting.

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