


BMJ Open Risk factors associated with COVID-19 severity among patients on maintenance haemodialysis: a retrospective multicentre cross-sectional study in the UK

Haresh Selvaskandan ^{1,2}, Katherine L Hull,^{1,2} Sherna Adenwalla,^{1,2} Safa Ahmed,³ Maria-Cristina Cusu,⁴ Matthew Graham-Brown ^{1,2}, Laura Gray,⁵ Matt Hall,⁶ Rizwan Hamer,³ Ammar Kanbar,⁷ Hemali Kanji,³ Mark Lambie,⁸ Han Sean Lee,⁶ Khalid Mahdi,⁹ Rupert Major,^{1,10} James F Medcalf,^{1,2} Sushiladevi Natarajan,¹ Boavojuvie Oseya,⁴ Stephanie Stringer,¹¹ Matthew Tabinor,¹¹ James Burton ^{1,2}

To cite: Selvaskandan H, Hull KL, Adenwalla S, *et al.* Risk factors associated with COVID-19 severity among patients on maintenance haemodialysis: a retrospective multicentre cross-sectional study in the UK. *BMJ Open* 2022;**12**:e054869. doi:10.1136/bmjopen-2021-054869

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (<http://dx.doi.org/10.1136/bmjopen-2021-054869>).

HS and KLH are joint first authors.

Received 25 June 2021
Accepted 28 April 2022



© Author(s) (or their employer(s)) 2022. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

For numbered affiliations see end of article.

Correspondence to

Dr Haresh Selvaskandan;
haresh.selvaskandan@nhs.net

ABSTRACT

Objectives To assess the applicability of risk factors for severe COVID-19 defined in the general population for patients on haemodialysis.

Setting A retrospective cross-sectional study performed across thirty four haemodialysis units in midlands of the UK.

Participants All 274 patients on maintenance haemodialysis who tested positive for SARS-CoV-2 on PCR testing between March and August 2020, in participating haemodialysis centres.

Exposure The utility of obesity, diabetes status, ethnicity, Charlson Comorbidity Index (CCI) and socioeconomic deprivation scores were investigated as risk factors for severe COVID-19.

Main outcomes and measures Severe COVID-19, defined as requiring supplemental oxygen or respiratory support, or a C reactive protein of ≥ 75 mg/dL (RECOVERY trial definitions), and its association with obesity, diabetes status, ethnicity, CCI, and socioeconomic deprivation.

Results 63.5% (174/274 patients) developed severe disease. Socioeconomic deprivation associated with severity, being most pronounced between the most and least deprived quartiles (OR 2.81, 95% CI 1.22 to 6.47, $p=0.015$), after adjusting for age, sex and ethnicity. There was no association between obesity, diabetes status, ethnicity or CCI with COVID-19 severity. We found no evidence of temporal evolution of cases ($p=0.209$) or clustering that would impact our findings.

Conclusion The incidence of severe COVID-19 is high among patients on haemodialysis; this cohort should be considered high risk. There was strong evidence of an association between socioeconomic deprivation and COVID-19 severity. Other risk factors that apply to the general population may not apply to this cohort.

INTRODUCTION

COVID-19 continues to exert a significant strain on healthcare systems worldwide.¹ It presents as a clinical spectrum, with severe disease often manifesting as respiratory

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ A multicentre study of thirty four haemodialysis units representative of urban and rural units.
- ⇒ Largest study to date looking at risk factors for COVID-19 severity among patients on haemodialysis.
- ⇒ Data collection was retrospective.
- ⇒ Sample size was limited by the number of COVID-19 cases, and the absence of protocolised testing of asymptomatic patients in the given time frame.

compromise leading to significant morbidity and mortality.^{2–4} Patients on haemodialysis are particularly at risk.^{5–10} Traditional public health measures do not apply due to their obligation to travel to and from enclosed units for regular treatment, often on public or shared transport. While the long-term impacts of COVID-19 are still being characterised in this group, the risk of morbidity and mortality afforded by acute COVID-19 is clear.^{5–10}

The widespread dissemination of COVID-19 vaccinations has therefore been welcome among those receiving haemodialysis. Despite the successful roll out of vaccines globally, access is yet to become universal and vaccine hesitancy remains an issue even where they are readily available.^{11 12} Understanding which patients on haemodialysis are most at risk of severe disease is thus an issue of continued importance; it would facilitate patient counselling, public health measures in the event of further outbreaks, and would inform the development of disease modelling and risk scores which are becoming increasingly important clinical decision aids.¹³

Most studies that have investigated COVID-19 among those receiving

haemodialysis examined risk of mortality, mostly reporting age, frailty and comorbidity burden as important predictors.^{14–19} Severe disease represents a different but important clinical outcome, conferring significant mental and physical morbidity, and may have different risk factors that associate with it.^{20–23} Associations with this outcome have not been investigated in detail among patients receiving haemodialysis. Large studies that have investigated this among those receiving haemodialysis used hospitalisation as a proxy for disease severity^{24 25} — this may not always translate to severe disease. Especially early in the pandemic, admission was also prompted for logistical reasons, such being unable to dialyse a symptomatic patient with confirmed or suspected COVID-19.²⁶

In this study, we chose to explore disease severity defined by the pragmatic and objective clinicopathological criteria set out by the RECOVERY trial (new oxygen requirement and/or a C reactive protein level ≥ 75 mg/L).²⁷ We report the incidence of severe COVID-19 in patients on haemodialysis from 34 dialysis units, managed by 5 tertiary centres in the UK, and investigate the applicability of accepted risk factors for severe COVID-19 in the general population for patients on maintenance haemodialysis.

METHODS

Study design and participants

Data were collected retrospectively from 34 haemodialysis units across the UK, from 1 March 2020 to 1 August 2020. Participants included adults (≥ 18 years) with end-stage kidney disease (ESKD) of any aetiology receiving maintenance haemodialysis at the time of data collection, with the SARS-CoV-2 virus confirmed on PCR swab testing. The swabs were taken either in hospital, at dialysis units or from community testing, and for indications, including: development of symptoms suggestive of COVID-19; exposure to an individual with COVID-19; hospital admission screening (emergency and elective) or: routine clinical testing during inpatient hospital stay.

Following a recent directive from the UK Government Department of Health and Social Care on the Control of Patient Information in response to COVID-19,²⁸ patient consent was not required. However, principles of the declaration of Helsinki, and the International Conference on Harmonisation Good Clinical Practice Guideline were followed. The lead centre for this work was University Hospitals of Leicester National Health Service (NHS) Trust (UHL) (registered project number 10802). Collection and sharing of anonymised patient data were approved with each participating renal network (online supplemental appendix 1). Subject data were deidentified within their local centres and data anonymity was maintained throughout.

Patient and public involvement

No formal patient and public involvement was undertaken for this study.

Outcomes of interest

The primary outcome of interest was the development of severe COVID-19 infection, defined as new oxygen requirement and/or a C reactive protein level ≥ 75 mg/L.²⁹ Admission to hospital during time of a positive SARS-CoV-2 PCR test, and 30-day mortality from date of a positive SARS-CoV-2 PCR test were also collected.

The primary exposures of interest were diabetes status (inclusive of all subtypes), body mass index (BMI), ethnicity, Charlson Comorbidity Index (CCI) and socioeconomic deprivation. Socioeconomic deprivation was identified through the UK government 'English indices of deprivation 2019' tool and was collected as deprivation ranks.³⁰

Secondary exposures of interest included: blood pressure, haemoglobin, history of renal transplantation, immunosuppressant use, medical blockade of the renin-angiotensin-aldosterone system (RAAS) and vitamin D supplementation. Additional characteristics collected included: age, sex, date of progression to ESKD, dialysis vintage, dialysis access and location of dialysis.

Data collection

All data were collected from electronic hospital clinical records (laboratory results and observation charts). Medical records were requested to clarify any events that were uncertain from electronic documentation. Patient identifiers were removed from the data collection tool prior to transfer to UHL NHS Trust for analysis.

Statistical analysis

Data were locked prior to analysis using SPSS V.26 for Windows IBM Corp. as per the prespecified statistical analysis plan (online supplemental appendix 2). Categorical data are presented as frequencies with percentages. Ethnicity was classified as Caucasian (includes British, Irish, Northern Irish, English, Scottish, Welsh, Cornish, white European and any other white background) and non-Caucasian (all other ethnicity groups) for analysis. The CCI and socioeconomic deprivation rank were divided into quartiles. For socioeconomic deprivation rank, the first quartile represents the most deprived and the fourth quartile represents the least deprived. Distribution of continuous data were assessed visually using Shapiro-Wilk tests and Q-Q plots, and are presented as either mean with SD, or median with IQR, as appropriate. Univariate analyses comparing categorical risk factors by COVID-19 severity were completed using χ^2 tests. Continuous risk factors were compared using independent t-tests or Mann-Whitney tests dependent on data distribution.

Unadjusted ORs were calculated for risk factors associated with severe COVID-19 infection. For social deprivation ranks, the ORs were calculated by comparing non-severe and severe COVID-19 infection for the first to third quartiles, to the fourth quartile. Logistic regression analysis with adjustments for age, sex and ethnicity (Caucasian and non-Caucasian) were planned for any primary exposure found to have statistically significant

Table 1 Demonstrates the number of haemodialysis units for each participating dialysis network, with the proportion of positive SARS-CoV-2 nasopharyngeal swabs, and the proportion of non-severe and severe COVID-19 outcomes

Dialysis network	Included dialysis units, n=34 (%)	Prevalent dialysis patients, n=2899 (%)	+ve SARS-CoV-2 swabs, n=274 (%)	Non-severe COVID-19, n=77 (%)	Severe COVID-19, n=174 (%)
Leicester	9 (26.5)	762 (26.3)	74 (27.0)	17 (22.1)	42 (24.4)
Birmingham	1 (2.95)	1031 (35.6)	105 (38.3)	33 (42.9)	67 (38.5)
Nottingham	5 (14.7)	454 (15.7)	31 (11.3)	10 (13.0)	20 (11.5)
Stoke	3 (8.82)	271 (9.35)	22 (8.0)	6 (7.79)	15 (8.62)
Coventry	6 (17.7)	381 (13.1)	42 (15.3)	11 (14.3)	30 (17.2)

relationship with COVID-19 severity. Data are rounded to three significant figures where appropriate. Patients with missing data were omitted from the analysis of that variable.

The influence of time on the incidence of severe and non-severe cases was explored, using the date of the first case of COVID-19 disease in our cohort as the reference. The median time in days from the first reported case was calculated for each new severe disease and non-severe disease case and were compared using a Mann-Whitney U test. Cumulative incidence of severe and non-severe cases over time was calculated as a percentage of total number of cases and explored.

Case cluster associations with disease severity were explored visually by plotting incident cases against time, for each dialysis unit, grouped by dialysis slots (Monday, Wednesday, Friday slots, or Tuesday, Thursday, Saturday slots), with overlapping shifts presented together, where these data were available.

RESULTS

Five dialysis networks contributed to data collection, gathered from thirty four haemodialysis units, as outlined in table 1. The total prevalent haemodialysis population was 2899 patients; 274 had a positive SARS-CoV-2 viral PCR swab result during the 5-month data collection period, representing an overall incidence of infection of 9.45%. The 30-day mortality for the 274 patients with a positive SARS-CoV-2 viral PCR was 73 patients (26.6%).

Patients diagnosed with COVID-19 were categorised into groups of 'non-severe' (n=77, 28.1%) or 'severe' (n=174, 63.5%) COVID-19 infection. Severe cases thus represented 6% of the overall population at the time of data collection. Incomplete severity data were recorded for 23 patients who were excluded from further analysis. From the 251 patients included in the analysis, 67 (26.7%) died within 30 days of their positive SARS-CoV-2 swab result.

Baseline characteristics

Table 2 demonstrates the key demographic features. The outcome groups (non-severe COVID-19 and severe COVID-19) were well matched with regard to age, sex, length of time with ESKD, dialysis vintage, dialysis access

and location of routine haemodialysis. There were significant differences between the outcome groups for admission to hospital ($X^2(1, N=251)=86.8, p<0.001$] and 30-day mortality ($X^2(1, N=244)=18.2, p<0.001$) (table 2).

Primary exposures of interest

On univariate analysis, there was no evidence of an association between diabetes status, ethnicity (Caucasian vs non-Caucasian), BMI or CCI with severe COVID-19. These exposures were well matched between the two outcome groups (table 3).

There was strong evidence of an association between socioeconomic deprivation and severe COVID-19. More patients living in the most deprived areas developed severe COVID-19 compared with those living in the least deprived areas. On unadjusted analysis by logistic regression, there was a greater risk of severe COVID-19 among the first quartile (OR 2.37, 95% CI 1.12 to 5.03, $p=0.025$), second quartile (OR 2.42, 95% CI 1.14 to 5.13, $p=0.021$) and third quartile (OR 2.57, 95% CI 1.18 to 5.57, $p=0.017$) of socioeconomic deprivation, compared with the fourth quartile (the least deprived). On adjusted analysis (figure 1), the evidence for an association persisted: first quartile (OR 2.81, 95% CI 1.22 to 6.47, $p=0.015$), second quartile (OR 2.63, 95% CI 1.19 to 5.79, $p=0.017$) and the third quartile (OR 2.74, 95% CI 1.24 to 6.05, $p=0.012$).

Secondary exposures of interest

Most secondary exposures of interest were not significantly different between the outcome groups: previous renal transplantation, immunosuppressant therapy, RAAS blockade and systolic blood pressure (table 3). There was strong evidence of an association between vitamin D supplementation for mineral bone disease treatment (OR 2.43, 95% CI 1.35 to 4.38, $p=0.03$) and severe COVID-19. There was also strong evidence of an association between haemoglobin level and severe COVID-19 ($t(249)=2.19, p=0.029$), with a mean haemoglobin level of 108 g/L in the non-severe group, and 103 g/L in the severe group (OR 0.981, 95% CI 0.964 to 0.998, $p=0.031$).

Time dependency and clustering

There was no difference in the timing of severe and non-severe case presentations to imply a time dependent effect of our findings (figure 2). The median time to a

Table 2 Baseline characteristics for the two outcome groups

Characteristic	Non-severe COVID-19 (n=77)	Severe COVID-19 (n=174)	Missing data, n (%)
Age, years, median (IQR)	70 (57–80)	68 (60–78)	0
Sex, female, n (%)	34 (44.2)	67 (39.4)	0
Ethnicity			0
Mixed British, n (%)	43 (55.8)	94 (54.0)	
Any other white background, n (%)	1 (1.30)	3 (1.91)	
Indian or British Indian, n (%)	11 (14.3)	21 (12.1)	
Pakistani or British Pakistani, n (%)	7 (9.10)	18 (10.3)	
Bangladeshi or British Bangladeshi, n (%)	3 (3.90)	3 (1.70)	
Any other Asian background, n (%)	2 (2.60)	6 (3.45)	
Caribbean, n (%)	1 (1.30)	4 (2.30)	
African, n (%)	0	1 (0.60)	
Mixed Black, n (%)	0	2 (1.10)	
Black British, n (%)	1 (1.30)	1 (0.60)	
Any other Black background, n (%)	5 (6.50)	14 (8.00)	
Chinese, n (%)	0	1 (0.60)	
Any other ethnic group, n (%)	2 (2.60)	0	
Not stated, n (%)	1 (1.30)	6 (3.40)	
Years since developing ESKD, median (IQR)	4 (2–7)	4 (2–8)	6 (2.39)
Dialysis vintage, years, median (IQR)	3 (2–7)	4 (2–7)	24 (9.56)
Hospital-based unit, n (%)	20 (26.0)	45 (25.9)	
Satellite unit, n (%)	55 (71.4)	125 (71.8)	1 (0.398)
Home haemodialysis, n (%)	2 (2.60)	3 (1.70)	
Arteriovenous fistula or graft, n (%)	54 (70.1)	135 (77.6)	1 (0.398)
Haemodialysis catheter, n (%)	23 (29.9)	38 (21.8)	
ESKD diagnosis			0
Diabetes, n (%)	28 (36.4)	66 (37.9)	
Glomerulonephritis, n (%)	12 (15.6)	26 (14.9)	
Hypertension, n (%)	3 (3.90)	11 (6.30)	
Polycystic kidney disease, n (%)	2 (2.60)	9 (5.20)	
Pyelonephritis, n (%)	1 (1.30)	3 (1.70)	
Renal vascular disease, n (%)	2 (2.60)	6 (3.40)	
Other, n (%)	18 (23.4)	26 (14.9)	
Uncertain aetiology, n (%)	11 (14.3)	27 (15.5)	
Admitted to hospital, n (%)*	25 (32.5)	156 (89.7)	0
Death, n (%)*	6 (7.80)	61 (35.1)	7 (2.79)

*P<0.05. Determined by unadjusted analysis.
ESKD, end-stage kidney disease.

diagnostic PCR test for each new severe and non-severe case was 32 and 33 days, respectively, with respect to the first recorded positive test in our data set (Mann-Whitney U test $p=0.209$) (figure 2).

Clustering was investigated in 15 of the 34 units due to data availability (online supplemental figure 1). While episodes of clustering seemed possible, this appeared to have no pattern of influence on disease severity. Given the small number of cases in each unit and dialysis slot

that could have clustered, it was not possible to perform any statistical analysis to investigate this further (online supplemental figure 1).

DISCUSSION

In this multicentre, retrospective, cross-sectional study, we investigated risk factors that associate with severe COVID-19 among haemodialysis patients. This study

Table 3 Summary of the results for the primary and secondary exposures of interest

Characteristic	Non-severe COVID-19 (n=71)	Severe COVID-19 (n=170)	P value	Missing data, n (%)
Primary exposures				
Caucasian, n (%)	44 (57.1)	97 (55.7)	0.891	0
Non-caucasian, n (%)	33 (42.9)	77 (44.3)		
Diabetes mellitus, n (%)	44 (57.1)	103 (59.2)	0.781	2 (0.797)
CCI first quartile (1–4), n (%)	11 (14.3)	26 (14.9)	0.580	0
CCI second quartile (5,6), n (%)	25 (32.5)	44 (25.3)		
CCI third quartile (7), n (%)	13 (16.9)	40 (23.0)		
CCI fourth quartile (≥8), n (%)	28 (36.4)	64 (36.8)		
BMI, kg/m ² , median (IQR)	27.7 (23.6–31.4)	28.5 (24.2–34.5)	0.148	24 (9.56)
Deprivation rank first quartile, n (%)	17 (22.1)	46 (26.4)	0.033*	5 (1.99)
Deprivation rank second quartile, n (%)	17 (22.1)	47 (27.0)		
Deprivation rank third quartile, n (%)	15 (19.5)	44 (25.3)		
Deprivation rank fourth quartile, n (%)	28 (36.4)	32 (18.4)		
Secondary exposures				
Previous renal transplant, n (%)	6 (7.80)	23 (13.2)	0.285	2 (0.797)
Immunosuppressant therapy, n (%)	5 (6.50)	20 (11.5)	0.246	83 (33.1)
Vitamin D supplementation, n (%)	46 (59.7)	134 (77.0)	0.005*	5 (1.99)
RAAS blockade	7 (9.10)	22 (12.6)	0.523	0
Haemoglobin, g/L, mean (SD)	108 (±15)	103 (±16)	0.029*	2 (0.797)
Systolic blood pressure, mm/Hg, mean (SD)	142 (±25)	136 (±28)	0.074	6 (2.39)

*Denotes statistical significance (p<0.05), determined by unadjusted analysis.

BMI, body mass index; CCI, Charlson Comorbidity Index; RAAS, renin-angiotensin aldosterone system.

produced three key findings. We found strong evidence that socioeconomic deprivation associates with severe COVID-19 (defined as new oxygen requirement and/or a C reactive protein level ≥75 mg/L) after adjusting for age, sex and ethnicity, while other risk factors reported

in the general population may not apply to haemodialysis patients. This study also highlights the high incidence of severe COVID-19 and subsequent 30-day mortality among patients on haemodialysis.

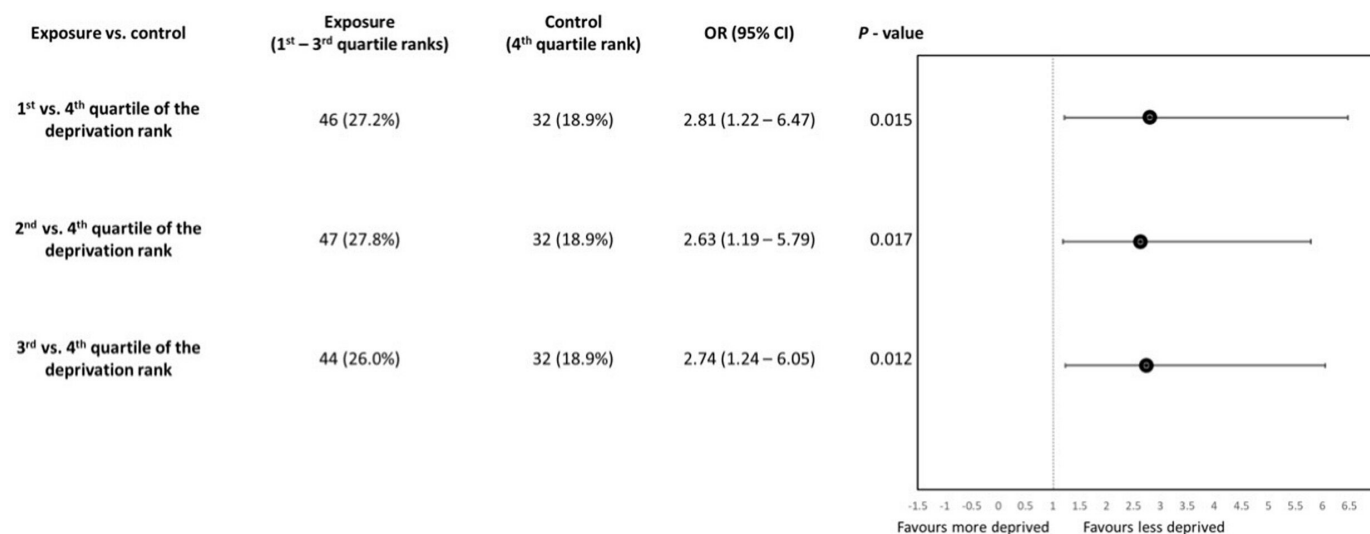


Figure 1 Forest plot demonstrating the ORs on adjusted analysis when comparing the risk of developing severe COVID-19 between the most socially deprived (first to third deprivation ranks quartiles) and the least socially deprived areas (fourth deprivation rank quartiles).

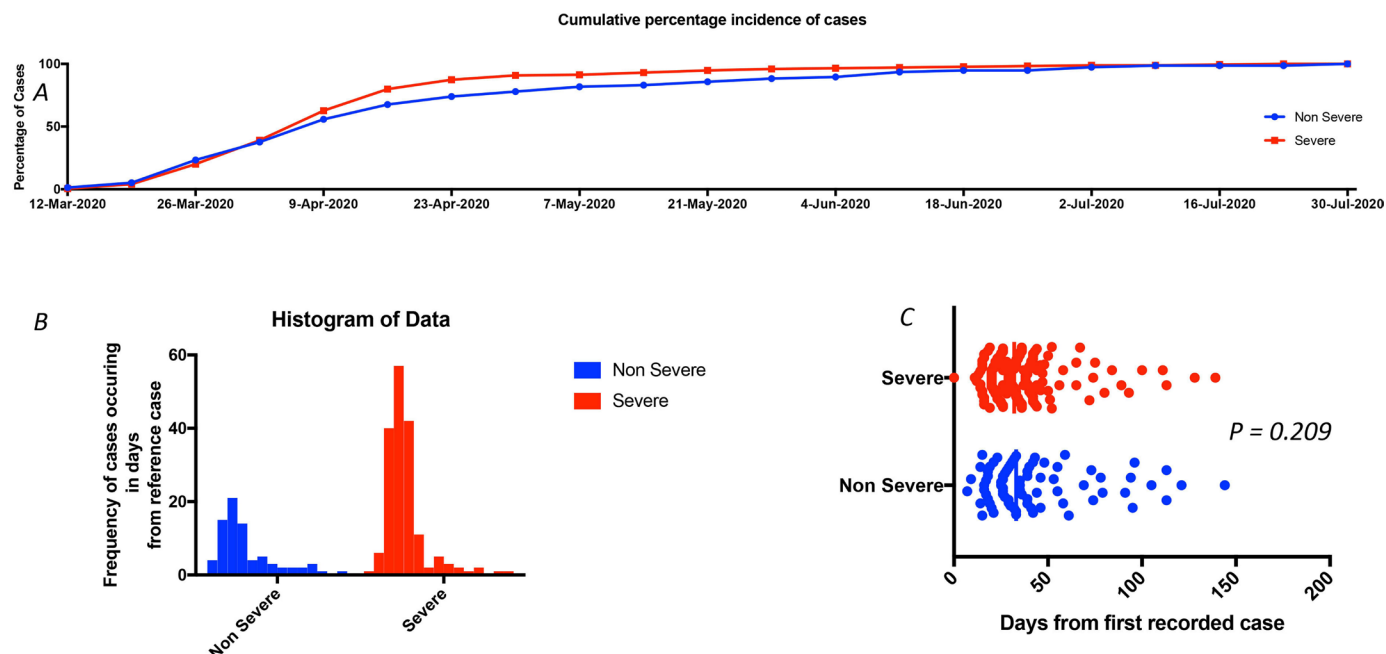


Figure 2 The incidence of severe and non-severe cases over time. (A) The cumulative percentage of cases over time for severe (n=174, 100%) an non-severe cases (n=77, 100%) was similar. (B) Histogram showing frequency of cases in days relative to the reference case, defined as the first positive case in our study cohort. The data are not normally distributed, and as such was explored with non-parametric methods. (C) The median number of days from the reference case for the presentation of severe and non severe cases was 32 and 33, respectively. A Mann-Whitney U test found this difference to be insignificant. Taken together, these data suggest that time dependency was unlikely to influence associations reported with disease severity.

The incidence of COVID-19 in our population matches national statistics for the period of data collection.³¹ Severe disease developed in 63.5% of those with COVID-19, considerably higher than in the general population, where it is estimated to be closer to 20%.³²⁻³³ This finding corroborates previously published data arising from smaller cohorts across the world, despite variable definitions for disease severity.²⁴⁻³⁴⁻³⁹ This finding also adds credence to the notion that all haemodialysis patients should be managed as being at risk for severe disease. With COVID-19 vaccinations becoming readily available, these results should be used to encourage immunisations among this patient group, and prioritise vaccines for those receiving haemodialysis in areas where vaccine availability is yet to become universal. In the event of future COVID-19 outbreaks, further measures should include reinforcing social distancing, isolated dialysis when appropriate and rigorous infection prevention measures at all dialysis units.

The high incidence observed is likely to be multifactorial. The generalised immunosuppressed state of haemodialysis patients has been well documented and is further evidenced by their increased susceptibility to infections and muted responses to immunisations.⁴⁰⁻⁴¹ Dialysis patients are also obliged to spend prolonged periods of time in enclosed, populated spaces to receive their treatment; this may increase their exposure to SARS-CoV-2 viral particles and subsequent viral load,⁴² particularly if other asymptomatic patients yet to be tested are dialysing out of isolation within the same unit, as may have occurred early

in the pandemic.⁴³⁻⁴⁵ Indeed, this has been observed in the context of other communicable diseases which propagate through droplet transmission.⁴⁶⁻⁴⁸ As viral load correlates with disease severity,⁴⁹ these factors together may predispose the entire haemodialysis cohort to severe COVID-19.

Despite the high rate of severe COVID-19 among haemodialysis patients, a proportion did not develop severe disease. We subsequently interrogated our data to determine if risk factors that associate with severe COVID-19 in the general population could be applicable to our cohort. Our key finding was strong evidence of an association between socioeconomic deprivation and COVID-19 severity among patients on haemodialysis. Socioeconomic deprivation has long been established as a predictor of poor health outcomes, and this has been demonstrated in the context of COVID-19.⁵⁻⁵⁰⁻⁵³ We used the English Index of Multiple Deprivation (IMD) as a marker of social deprivation. The IMD is a weighted composite of seven domains (income, employment, education, health, crime, barriers to housing, and living environments) which assigns a rank to 32844 areas in England, with a rank of one considered the most deprived on the index.³⁰ We present strong evidence that the IMD associated with a greater risk of severe COVID-19, being most pronounced between the least and most deprived quartiles. This finding persisted after adjusting for age, sex and ethnicity (OR 2.81, 95% CI 1.22 to 6.47, p=0.015). The Scottish Renal Registry recently demonstrated patients living in more deprived areas were more

susceptible to contracting COVID-19,⁵⁴ and residence in a congregate setting conferred a 17-fold risk for developing COVID-19 in the USA,¹⁷ but to the best of our knowledge, this is the first study demonstrating a link between socioeconomic deprivation and COVID-19 severity in the haemodialysis population.

Determining the precise factors that account for the relationship between the IMD and COVID-19 severity among haemodialysis patients is beyond the scope of this study, however, there are a number of potential contributors that could warrant further investigation. Household overcrowding is incorporated into the IMD as a contributing factor of social deprivation.³⁰ As with dialysis units, it is possible that this contributes to a greater exposure to viral load, should another member of the household be COVID-19 positive.^{49–51} Additionally, we were unable to collect data on patient smoking status, which may confound this association. Indeed, smoking is a possible a risk factor for severe COVID-19, and smoking habits are four times as more likely in areas ranked as most deprived by the IMD.^{55–56} Other factors that may explain this association are likely to be less COVID-19 specific; dialysis patients living in areas considered to be deprived have poorer survival rates,^{57–58} and this may be reflective of the physiological stressors associated with socioeconomic deprivation. Exposure to noise pollution, crowding, threat of crime, poor nutrition and other life pressures, including job and housing insecurity, can contribute to a state of chronic stress.⁵⁹ This exerts negative impacts on immunity^{60–61} and can promote proinflammatory states which predispose to cardiovascular frailty,^{62–63} perhaps accounting for the poor outcomes noted in this population.

Obesity, ethnicity and diabetes status predict severity in the general population,^{22–23–32–64–68} however, we found no evidence of these factors associating with COVID-19 severity in haemodialysis patients. This finding is in keeping with results of smaller French (122 patients) and Chinese (154) studies.^{7–16} We also investigated the CCI, a weighted index that predicts ten-year survival in patients with multiple comorbidities,⁶⁹ as a risk factor for COVID-19 severity. The CCI has shown value in predicting severe COVID-19 in the general population,^{70–73} but again, we found no evidence of an association with severe COVID-19 among patients on haemodialysis. This finding contrasts with those reported by Stefan *et al* who found a positive correlation between CCI and COVID-19 severity in a cohort of 37 Romanian dialysis patients.³⁴ However, the definition of severity used was different and a proportion of the patients in this study received treatments that included glucocorticoids, hydroxychloroquine, lopinavir-ritonavir and tocilizumab, which may have altered disease progression, confounding results. Other risk factors reported to be significant in the general population, including sex, cardiovascular disease and blood pressure were evenly matched in our severe and non-severe COVID-19 groups. These findings further corroborate the results of smaller previously published studies.^{7–16} It

is possible that the risk conferred by haemodialysis for severe COVID-19 far outweighs that of the established risk factors defined for the general population, minimising their effect sizes in this select cohort of patients.

We also noted strong evidence of an association between prescribed vitamin D supplementation and severe COVID-19 (OR 2.43, 95% CI 1.35 to 4.38, $p=0.03$). Vitamin D prescription in the dialysis population is principally in its activated form, used for the management for chronic kidney disease-related mineral bone disease, and not for routine supplementation.⁷⁴ Those supplemented with vitamin D are therefore at higher risk of hyperphosphataemia, secondary hyperparathyroidism and ultimately vascular calcification, all of which associate with poor outcomes.⁷⁵ Rather than suggesting these data infer any causal relationship between vitamin D supplementation and development of a severe manifestation of COVID-19, it is more likely that this 'relationship' is driven by residual confounding of the indications for vitamin D supplementations and related comorbidity. A difference was also noted in the haemoglobin levels between those with severe disease and non-severe disease (103 g/L vs 108 g/L, $p=0.029$). Although both groups showed evidence of chronic kidney disease-related anaemia, they also appeared to be adequately treated and within the limits recommended by international guidelines.⁷⁶ As with socioeconomic deprivation, establishing if these links are causal are beyond the scope of this study, but are hypothesis generating, nevertheless.

We opted to investigate severity over the commonly reported metrics of total incidence and mortality, as we found it to be more representative of the burden placed on healthcare resources by COVID-19, and an important clinical outcome with regards to the physical and mental morbidity. Mortality among those with COVID-19 on haemodialysis has been widely reported on, with age, frailty and co-morbidity burden featuring as strong predictors.^{14–16–17} However, mortality is commonly reported as a death occurring within 28 or 30 days of a positive PCR test^{77–81} and could therefore include mortalities not strictly attributable to COVID-19, particularly given the characteristics of those most at risk. Furthermore, risk factors for mortality may not be COVID-19 specific; this can be challenging to differentiate between and therefore act on from a public health perspective. Incidence is increasingly being accounted for by asymptomatic patients who place little strain on healthcare services beyond the need to dialyse in isolation.^{43–44} We found that COVID-19 severity as defined by the RECOVERY trial, associated with admission rates and mortality ($p<0.001$), and was therefore an adequate, relevant and generalisable marker for severity with regards to the objectives of this study. We opted to use the RECOVERY trial's definition for COVID-19 severity as it provided a pragmatic and clinically relevant definition. Larger studies have investigated disease severity using hospital admission as a proxy.^{25–26} We opted to explore a different definition of severity; early in the pandemic admissions occurred

to facilitate the logistics of isolated dialysis for COVID-19 patients who were otherwise well, and therefore an admission per se may not be truly reflective of disease severity.

The limitations of our study lie in our sampling methods, sample size and cross-sectional design. The issue of collider (sampling) bias has been highlighted in studies related to COVID-19.⁸² This arises from a risk of failing to appropriately identify COVID-19 cases. This may occur because: (1) certain symptomatic groups are systematically less likely to get tested for COVID-19 and (2) the prevalence of asymptomatic patients identifiable only through protocolised or opportunistic testing. The first issue could be considered mitigated in our study by virtue of our patients all being dialysis dependent. Every patient included would have presented to either a hospital or a dialysis unit for dialysis, where they would have been screened for COVID-19 symptoms as a matter of protocol. Thus unlike in the general population, all symptomatic patients would have been tested for COVID-19, reducing this risk of a sampling bias. There is a risk that the PCR tests performed returned a false negative. Again, the cohort of patients we report on would have been subject to repeat testing on each visit if symptoms persisted, reducing the risk of false negatives contributing to collider bias.⁸³

Our study did exclude asymptomatic patients who would not have been tested for COVID-19 at all. This is a reflection of testing availability and protocols that were being followed early in the pandemic. While the exclusion of this patient group could influence our findings, we believe this impact to be minimal; the burden of asymptomatic disease among haemodialysis patients in Midlands of the UK, where most participating units were based, was likely to have been low. We note a study from Oxford that was performed over a similar time period as our study found a prevalence of 1.8% of asymptomatic disease.⁸⁴ A study from Canada, which had a case:population ratio similar to that of the UK over the same period reported even lower rates.⁸⁵ We also note a study from London which quoted a prevalence of 12% of asymptomatic patients, but are aware the case burden of COVID-19 early in the pandemic was much higher in the capital than it was in the Midlands.^{86 87}

This work, therefore, included all haemodialysis patients for whom data was available, who tested positive for the SARS-CoV-2 virus on a PCR test during the first wave of the UK's COVID-19 pandemic. Although this is one of the larger studies investigating severity among of COVID-19 among haemodialysis patients, the relatively small sample size available limited its ability to identify smaller effect sizes that may have been exerted by the investigated exposures. It also prevented us from providing further granularity with regards to both ethnicity and socioeconomic deprivation and their associations with severe COVID-19, prompting a restriction in our analysis to Caucasian versus non-Caucasian and quartiles of socioeconomic deprivation, respectively. Given this was a cross-sectional observational study, causality cannot be inferred, and indeed

it is likely that social deprivation associates with other key determinants of COVID-19 severity that was beyond the scope of this study.

CONCLUSION

We confirmed a high incidence of severe COVID-19 among patients on haemodialysis and found that risk factors that apply to the general population may not be applicable in the same way for patients on haemodialysis. For patients on haemodialysis socioeconomic deprivation appears to be more closely associated with COVID-19 severity, but further work is needed to establish whether there is because of a causal link, or whether there are confounding factors that account for this finding.

Author affiliations

¹John Walls Renal Unit, University Hospitals of Leicester NHS Trust, Leicester, UK

²Department of Cardiovascular Sciences, University of Leicester, Leicester, UK

³Department of Renal Transplantation and Nephrology, University Hospitals Coventry and Warwickshire NHS Trust, Coventry, UK

⁴Department of Renal Medicine, Northampton General Hospital NHS Trust, Northampton, UK

⁵Department of Health Sciences, University of Leicester, Leicester, UK

⁶Nottingham Renal and Transplant Unit, Nottingham University Hospitals NHS Trust, Nottingham, UK

⁷Department of Renal Medicine, Royal Stoke University Hospital, Stoke-on-Trent, UK

⁸School of Medicine, Keele University, Keele, UK

⁹Department of Renal Medicine, Lincoln County Hospital, Lincoln, UK

¹⁰Department of Health Sciences, University Hospital of Leicester, Leicester, UK

¹¹Department of Renal Medicine, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK

Twitter Haresh Selvaskandan @haresh11, Sherna Adenwalla @SAdenwalla and James Burton @drjamesburton

Contributors HS, KLH and JB designed the study. HS, KLH, SAd, SAh, M-CC, MH, RH, AK, HK, ML, HSL, KM, SN, BO, SS and MT collected data. HS and KLH coordinated data collection. KLH performed the statistical analysis supervised by LG. HS, KLH and JB interpreted the data. HS and KLH wrote the manuscript supervised by JB. SAd, MG-B, MH, ML, JFM and SN critically revised the manuscript. All authors edited and approved the final manuscript. JB guarantors this study. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

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.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available on reasonable request.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is

properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

ORCID iDs

Haresh Selvaskandan <http://orcid.org/0000-0002-2874-7005>

Matthew Graham-Brown <http://orcid.org/0000-0002-6197-180X>

James Burton <http://orcid.org/0000-0003-1176-7592>

REFERENCES

- Dong E, Du H, Gardner L. An interactive web-based dashboard to track COVID-19 in real time. *Lancet Infect Dis* 2020;20:533–4.
- Rahim F, Amin S, Noor M, et al. Mortality of patients with severe COVID-19 in the intensive care unit: an observational study from a major COVID-19 receiving Hospital. *Cureus* 2020;12:e10906.
- Weiss P, Murdoch DR. Clinical course and mortality risk of severe COVID-19. *Lancet* 2020;395:1014–5.
- Rothan HA, Byrareddy SN. The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak. *J Autoimmun* 2020;109:102433.
- Williamson EJ, Walker AJ, Bhaskaran K, et al. Factors associated with COVID-19-related death using OpenSAFELY. *Nature* 2020;584:430–6.
- Andhika R, Huang I, Wijaya I. Severity of COVID-19 in end-stage kidney disease patients on chronic dialysis. *Ther Apher Dial* 2021;25:706–9.
- Xiong F, Tang H, Liu L, et al. Clinical characteristics of and medical interventions for COVID-19 in hemodialysis patients in Wuhan, China. *J Am Soc Nephrol* 2020;31:1387–97.
- Alberici F, Delbarba E, Manenti C, et al. A report from the Brescia Renal COVID Task Force on the clinical characteristics and short-term outcome of hemodialysis patients with SARS-CoV-2 infection. *Kidney Int* 2020;98:20–6.
- Valeri AM, Robbins-Juarez SY, Stevens JS, et al. Presentation and outcomes of patients with ESKD and COVID-19. *J Am Soc Nephrol* 2020;31:1409–15.
- Sim JJ, Huang C-W, Selevan DC, et al. COVID-19 and survival in maintenance dialysis. *Kidney Med* 2021;3:132–5.
- Peacocke EF, Heupink LF, Frønsdal K, et al. Global access to COVID-19 vaccines: a scoping review of factors that may influence equitable access for low and middle-income countries. *BMJ Open* 2021;11:e049505.
- Bazan IS, Akgün KM. COVID-19 healthcare inequity: lessons learned from annual influenza vaccination rates to mitigate COVID-19 vaccine disparities. *Yale J Biol Med* 2021;94:509–15.
- Monaghan CK, Larkin JW, Chaudhuri S, et al. Machine learning for prediction of patients on hemodialysis with an undetected SARS-CoV-2 infection. *Kidney360* 2021;2:456–68.
- Chaudhuri S, Lasky R, Jiao Y. Trajectories of clinical and laboratory characteristics associated with COVID-19 in hemodialysis patients by survival. 2021.
- Goffin E, Candellier A, Vart P, et al. COVID-19-related mortality in kidney transplant and haemodialysis patients: a comparative, prospective registry-based study. *Nephrol Dial Transplant* 2021;36:2094–2105.
- Lano G, Braconnier A, Bataille S, et al. Risk factors for severity of COVID-19 in chronic dialysis patients from a multicentre French cohort. *Clin Kidney J* 2020;13:878–88.
- Hsu CM, Weiner DE, Aweh G, et al. COVID-19 among US dialysis patients: risk factors and outcomes from a national dialysis provider. *Am J Kidney Dis* 2021;77:748–56.
- Medjeral-Thomas NR, Thomson T, Ashby D, et al. Cohort study of outpatient hemodialysis management strategies for COVID-19 in north-west London. *Kidney Int Rep* 2020;5:2055–65.
- Weiss S, Bhat P, Del Pilar Fernandez M, et al. COVID-19 infection in ESKD: findings from a prospective disease surveillance program at dialysis facilities in New York City and long island. *J Am Soc Nephrol* 2020;31:2517–21.
- Tu Y, Zhang Y, Li Y. Post-traumatic stress symptoms in COVID-19 survivors: a self-report and brain imaging follow-up study. *Mol Psychiatry* 2021;1–6.
- Maes M, Higginson E, Pereira-Dias J, et al. Ventilator-associated pneumonia in critically ill patients with COVID-19. *Crit Care* 2021;25:25.
- Grasselli G, Zangrillo A, Zanella A, et al. Baseline characteristics and outcomes of 1591 patients infected with SARS-CoV-2 admitted to ICUs of the lombardy region, Italy. *JAMA* 2020;323:1574–81.
- Huang C, Wang Y, Li X, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet* 2020;395:497–506.
- Medjeral-Thomas NR, Thomson T, Ashby D, et al. Cohort study of outpatient hemodialysis management strategies for COVID-19 in North-West London. *Kidney Int Rep* 2020;5:2055–65.
- Caplin B, Ashby D, McCafferty K, et al. Risk of COVID-19 disease, dialysis unit attributes, and infection control strategy among London In-Center hemodialysis patients. *Clin J Am Soc Nephrol* 2021;16:1237–46.
- Nithya G, Lamech TM, Arumugam V, et al. A clinical study on the changing dynamics of disease severity, management strategies and outcomes of COVID-19 in patients requiring haemodialysis. *J Nephrol* 2021;34:999–1006.
- Horby P, Juszczak E, Montgomery A. Dexamethasone in hospitalized patients with Covid-19 — preliminary report. *New Eng J Med* 2020;1–11.
- Department of Health and Social Care. Coronavirus (COVID-19): notice under regulation 3(4) of the health service (control of patient information) regulations 2002 — general 2020.
- Horby P, Lim WS, Emberson JR. Dexamethasone in hospitalized patients with Covid-19 - preliminary report. *N Engl J Med* 2020.
- The English indices of deprivation 2019. technical report. key non parliamentary papers local government 2019.
- UK Renal Registry. COVID-19 surveillance report for renal centres in the UK. A summary of the first wave of the pandemic — March to August 2020, 2020.
- Wu Z, McGoogan JM. Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: summary of a report of 72 314 cases from the Chinese center for disease control and prevention. *JAMA* 2020;323:1239–42.
- Richardson S, Hirsch JS, Narasimhan M, et al. Presenting characteristics, comorbidities, and outcomes among 5700 patients hospitalized with COVID-19 in the New York City Area. *JAMA* 2020;323:2052–9.
- Stefan G, Mehedinti AM, Andreiana I, et al. Clinical features and outcome of maintenance hemodialysis patients with COVID-19 from a tertiary nephrology care center in Romania. *Ren Fail* 2021;43:49–57.
- Fontana F, Giaroni F, Frisina M, et al. SARS-CoV-2 infection in dialysis patients in northern Italy: a single-centre experience. *Clin Kidney J* 2020;13:334–9.
- Zhang J, Cao F, Wu S-K, et al. Clinical characteristics of 31 hemodialysis patients with 2019 novel coronavirus: a retrospective study. *Ren Fail* 2020;42:726–32.
- Golcochea M, Sánchez Cámara LA, Macías N, et al. COVID-19: clinical course and outcomes of 36 hemodialysis patients in Spain. *Kidney Int* 2020;98:27–34.
- Tortonesi S, Scriabine I, Anjou L, et al. COVID-19 in patients on maintenance dialysis in the Paris region. *Kidney Int Rep* 2020;5:1535–44.
- Mazzoleni L, Ghafari C, Mestrez F, et al. COVID-19 outbreak in a hemodialysis center: a retrospective monocentric case series. *Can J Kidney Health Dis* 2020;7:205435812094429.
- Vaziri ND, Pahl MV, Crum A, et al. Effect of uremia on structure and function of immune system. *J Ren Nutr* 2012;22:149–56.
- Betjes MGH. Immune cell dysfunction and inflammation in end-stage renal disease. *Nat Rev Nephrol* 2013;9:255–65.
- Morawska L, Tang JW, Bahnfleth W, et al. How can airborne transmission of COVID-19 indoors be minimised? *Environ Int* 2020;142:105832.
- Albalade M, Arribas P, Torres E, et al. Alta prevalencia de COVID-19 asintomático en hemodiálisis. Aprendiendo día a día El primer mes de pandemia de COVID-19. *Nefrología* 2020;40:279–86.
- Yau K, Muller MP, Lin M, et al. COVID-19 outbreak in an urban hemodialysis unit. *Am J Kidney Dis* 2020;76:690–5.
- Rincón A, Moreso F, López-Herradón A, et al. The keys to control a COVID-19 outbreak in a haemodialysis unit. *Clin Kidney J* 2020;13:542–9.
- Lingquist JA, Rosaia CM, Riemer B, et al. Tuberculosis exposure of patients and staff in an outpatient hemodialysis unit. *Am J Infect Control* 2002;30:307–10.
- Centers for Disease Control and Prevention (CDC). Tuberculosis transmission in a renal dialysis center—Nevada, 2003. *MMWR Morb Mortal Wkly Rep* 2004;53:873–5.
- Ventura CG, Roque FL, Sousa IQde, et al. Influenza A (H1N1): outbreak management in a dialysis unit and clinical outcomes of infection in chronic hemodialysis patients. *J Bras Nefrol* 2020;42:182–90.
- Pujadas E, Chaudhry F, McBride R, et al. SARS-CoV-2 viral load predicts COVID-19 mortality. *Lancet Respir Med* 2020;8:e70.
- Raisi-Estabragh Z, McCracken C, Bethell MS, et al. Greater risk of severe COVID-19 in Black, Asian and Minority Ethnic populations is not explained by cardiometabolic, socioeconomic or behavioural

- factors, or by 25(OH)-vitamin D status: study of 1326 cases from the UK Biobank. *J Public Health* 2020;42:451–60.
- 51 Patel AP, Paranjpe MD, Kathiresan NP, *et al.* Race, socioeconomic deprivation, and hospitalization for COVID-19 in English participants of a national Biobank. *Int J Equity Health* 2020;19:114.
 - 52 K C M, Oral E, Straif-Bourgeois S, Rung AL, *et al.* The effect of area deprivation on COVID-19 risk in Louisiana. *PLoS One* 2020;15:e0243028.
 - 53 Foster HME, Celis-Morales CA, Nicholl BI, *et al.* The effect of socioeconomic deprivation on the association between an extended measurement of unhealthy lifestyle factors and health outcomes: a prospective analysis of the UK Biobank cohort. *Lancet Public Health* 2018;3:e576–85.
 - 54 Bell S, Campbell J, McDonald J, *et al.* COVID-19 in patients undergoing chronic kidney replacement therapy and kidney transplant recipients in Scotland: findings and experience from the Scottish renal registry. *BMC Nephrol* 2020;21:419.
 - 55 Karanasos A, Aznaouridis K, Latsios G, *et al.* Impact of smoking status on disease severity and mortality of hospitalized patients with COVID-19 infection: a systematic review and meta-analysis. *Nicotine Tob Res* 2020;22:1657–9.
 - 56 Office For National Statistics. *Likelihood of smoking four times higher in England's most deprived areas than least deprived* - Office for National Statistics. Office For National Statistics, 2016.
 - 57 Ward FL, O'Kelly P, Donohue F, *et al.* The influence of socioeconomic status on patient survival on chronic dialysis. *Hemodial Int* 2015;19:601–8.
 - 58 Caskey FJ. Renal replacement therapy: can we separate the effects of social deprivation and ethnicity? *Kidney Int Suppl* 2013;3:246–9.
 - 59 Baum A, Garofalo JP, Yali AM. Socioeconomic status and chronic stress. Does stress account for SES effects on health? *Ann N Y Acad Sci* 1999;896:131–44.
 - 60 Segerstrom SC, Miller GE. Psychological stress and the human immune system: a meta-analytic study of 30 years of inquiry. *Psychol Bull* 2004;130:601–30.
 - 61 Snyder-Mackler N, Sanz J, Kohn JN, *et al.* Social status alters immune regulation and response to infection in macaques. *Science* 2016;354:1041–5.
 - 62 Gouin J-P, Glaser R, Malarkey WB, *et al.* Chronic stress, daily stressors, and circulating inflammatory markers. *Health Psychol* 2012;31:264–8.
 - 63 Morey JN, Boggero IA, Scott AB, *et al.* Current directions in stress and human immune function. *Curr Opin Psychol* 2015;5:13–17.
 - 64 Lim S, Bae JH, Kwon H-S, *et al.* COVID-19 and diabetes mellitus: from pathophysiology to clinical management. *Nat Rev Endocrinol* 2021;17:11–30.
 - 65 Kalligeros M, Shehadeh F, Mylona EK, *et al.* Association of obesity with disease severity among patients with coronavirus disease 2019. *Obesity* 2020;28:1200–4.
 - 66 Jordan RE, Adab P, Cheng KK. Covid-19: risk factors for severe disease and death. *BMJ* 2020;368:m1198.
 - 67 Zheng Z, Peng F, Xu B, *et al.* Risk factors of critical & mortal COVID-19 cases: A systematic literature review and meta-analysis. *J Infect* 2020;81:e16–25.
 - 68 Khunti K, Singh AK, Pareek M, *et al.* Is ethnicity linked to incidence or outcomes of covid-19? *BMJ* 2020;369:m1548.
 - 69 Charlson ME, Pompei P, Ales KL, *et al.* A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *J Chronic Dis* 1987;40:373–83.
 - 70 Tuty Kuswardhani RA, Henrina J, Pranata R, *et al.* Charlson comorbidity index and a composite of poor outcomes in COVID-19 patients: a systematic review and meta-analysis. *Diabetes Metab Syndr* 2020;14:2103–9.
 - 71 Zhou W, Qin X, Hu X, *et al.* Prognosis models for severe and critical COVID-19 based on the Charlson and Elixhauser comorbidity indices. *Int J Med Sci* 2020;17:2257–63.
 - 72 Christensen DM, Strange JE, Gislason G, *et al.* Charlson comorbidity index score and risk of severe outcome and death in Danish COVID-19 patients. *J Gen Intern Med* 2020;35:2801–3.
 - 73 Ioannou GN, Locke E, Green P, *et al.* Risk factors for hospitalization, mechanical ventilation, or death among 10 131 US veterans with SARS-CoV-2 infection. *JAMA Netw Open* 2020;3:e2022310.
 - 74 KDIGO 2017 Clinical Practice Guideline Update for the Diagnosis, Evaluation, Prevention, and Treatment of Chronic Kidney Disease–Mineral and Bone Disorder (CKD-MBD). *Kidney international supplements* 2017;7:1–59.
 - 75 Eddington H, Kalra PA. The association of chronic kidney disease-mineral bone disorder and cardiovascular risk. *J Ren Care* 2010;36:61–7.
 - 76 KDIGO Clinical Practice Guideline for Anemia in Chronic Kidney Disease. *Kidney international supplements* 2012;2.
 - 77 Public Health England. Public health England data series on deaths in people with COVID-19 2020.
 - 78 Nersesjan V, Amir M, Christensen HK, *et al.* Thirty-day mortality and morbidity in COVID-19 positive vs. COVID-19 negative individuals and vs. individuals tested for influenza A/B: a population-based study. *Front Med* 2020;7:598272.
 - 79 King JT, Yoon JS, Rentsch CT, *et al.* Development and validation of a 30-day mortality index based on pre-existing medical administrative data from 13,323 COVID-19 patients: the Veterans health administration COVID-19 (VACO) index. *PLoS One* 2020;15:e0241825.
 - 80 Asch DA, Sheils NE, Islam MN, *et al.* Variation in US hospital mortality rates for patients admitted with COVID-19 during the first 6 months of the pandemic. *JAMA Intern Med* 2021;181:471–8.
 - 81 Jager KJ, Kramer A, Chesnaye NC, *et al.* Results from the ERA-EDTA registry indicate a high mortality due to COVID-19 in dialysis patients and kidney transplant recipients across Europe. *Kidney Int* 2020;98:1540–8.
 - 82 Griffith GJ, Morris TT, Tudball MJ, *et al.* Collider bias undermines our understanding of COVID-19 disease risk and severity. *Nat Commun* 2020;11:5749.
 - 83 Alizad-Rahvar AR, Vafadar S, Totonchi M, *et al.* False negative mitigation in group testing for COVID-19 screening. *Front Med* 2021;8:661277.
 - 84 Storey B, Bottomley M, Hammad S, *et al.* Regular RNA screening detects asymptomatic SARS-CoV-2 infection in haemodialysis patients. *Nephrol Dial Transplant* 2021;36:1130–2.
 - 85 Sniekers DC, Jung JKH, Blake PG, *et al.* Province-wide prevalence testing for SARS-CoV-2 of in-center hemodialysis patients and staff in Ontario, Canada: a cross-sectional study. *Can J Kidney Health Dis* 2021;8:20543581211036213.
 - 86 Clarke C, Prendecki M, Dhutia A, *et al.* High prevalence of asymptomatic COVID-19 infection in hemodialysis patients detected using serologic screening. *J Am Soc Nephrol* 2020;31:1969–75.
 - 87 Public Health England. Public health England: weekly coronavirus disease 2019 (COVID-19) surveillance report. summary of COVID-19 surveillance system.