Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Public Health 185 (2020) 261–263

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Short Communication

Coronavirus disease 2019 mortality: a multivariate ecological analysis in relation to ethnicity, population density, obesity, deprivation and pollution

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ARTICLE INFO

Article history:
Received 6 May 2020
Received in revised form
22 June 2020
Accepted 28 June 2020
Available online 7 July 2020

Keywords:
COVID-19
Deprivation
Ethnicity
Pollution
Overweight
Obesity
Population density

ABSTRACT

Background: There is emerging evidence about characteristics that may increase the risk of coronavirus disease 2019 (COVID-19) mortality, but they are highly correlated.
Methods: An ecological analysis was used to estimate associations between these variables and age-standardised COVID-19 mortality rates at the local authority level.
Results: Ethnicity, population density and overweight/obesity were all found to have strong independent associations with COVID-19 mortality, at the local authority level.
Discussion: This analysis provides some preliminary evidence about which variables are independently associated with COVID-19 mortality and suggests that others (deprivation and pollution) are not directly linked. It highlights the importance of multivariate analyses to understand the factors that increase vulnerability to COVID-19.

There is emerging evidence that certain groups are more susceptible to complications from Coronavirus disease 2019 (COVID-19) (for example, people who are obese[1] and people from ethnic minorities[2,3,4]) and that neighbourhood characteristics, such as population density[5] and pollution,[6] might also play a role. Estimating the importance of the various risk factors is complicated by the fact that they are highly correlated, so it is difficult to work out the relative contribution of each or if some are simply confounders. However, these factors are all positively associated with deprivation. Research on health inequalities, from the Black Report[7] to the Marmot review,[8] has emphasised the importance of material and social inequality as causes of health inequality, and age-standardised rates of deaths involving COVID-19 in the most deprived areas of England are more than double those in the more affluent areas.[9] We hypothesize that deprivation is an important underlying risk factor for COVID-19. Although several sociodemographic factors have been considered in isolation, there is no analysis to date which simultaneously includes and adjusts for all these variables. This is because the data are not yet available to do so. However, these variables are available at a local authority level, allowing an ecological approach to be taken. The aim of this study is to estimate the effect of deprivation on COVID-19 mortality rates, while taking into account the effects of other known risk factors.

Age-standardised rates of deaths involving COVID-19 for the period 1st March 2020 to 17th April 2020 were published by the Office for National Statistics (ONS) on 1st May 2020, for each local authority in England and Wales.[9] We have conducted an ecological analysis to assess possible associations with a range of sociodemographic variables using routinely available data for local authorities – ethnicity, overweight and obesity, population density, deprivation and pollution. These variables were calculated as follows: percentage of the population who are white (2011 census), percentage of the population who are overweight or obese (2013–15), people per square kilometre (based on mid-2018 estimates), median Index of Multiple Deprivation (IMD) for 2019 and annual mean concentration of particulate matter (PM2.5 $\mu g\ m^{-3}$) for 2018.

Data on all of these variables were available for 310 of 317 English local authorities for which the COVID-19 mortality rates have been published.[9] Although it is widely reported that older people and men are at increased risk, these variables are not included in

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https://doi.org/10.1016/j.puhe.2020.06.056
0033-3506/

Table 1
Bivariate Spearman correlation coefficients for all variables.

	Coronavirus disease 2019 (COVID-19) mortality rate	Percentage white	Percentage overweight or obese	Population density	Median IMD	PM2.5
COVID-19 mortality rate[c]	1.00					
Percentage white[d]	−0.607[a]	1.00				
Percentage overweight or obese[e]	−0.198[a]	0.450[a]	1.00			
Population density[f]	0.615[a]	−0.760[a]	−0.251[a]	1.00		
Median IMD[g]	0.243[a]	−0.183[a]	0.382[a]	0.459[a]	1.00	
PM2.5[h]	0.405[a]	−0.671[a]	−0.410[a]	0.531[a]	−0.143[b]	1.00

IMD, Index of Multiple Deprivation; PM2.5, annual mean concentration of particulate matter.
[a] p<0.01.
[b] p<0.05.
[c] https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/datasets/deathsinvolvingcovid19bylocalareaanddeprivation.
[d] https://www.ethnicity-facts-figures.service.gov.uk/uk-population-by-ethnicity/national-and-regional-populations/regional-ethnic-diversity/latest#ethnic-diversity-by-area.
[e] Public Health England, Prevalence of underweight, healthy weight, overweight, obesity, and excess weight among adults at local authority level for England, available from Knowledge Hub, available from https://khub.net/group/guest.
[f] Office for National Statistics, Population Estimates for UK, England and Wales, Scotland and Northern Ireland: mid-2018, using pre-April 2019 local authority district geography, available from https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationestimatesforukenglandandwalesscotlandandnorthernireland.
[g] https://www.gov.uk/government/statistics/english-indices-of-deprivation-2019.
[h] https://uk-air.defra.gov.uk/data/pcm-data#population_weighted_annual_mean_pm25_data.

this analysis (because the mortality rates are age standardised and because we would not expect to see sufficient variation in the percentage of local authority populations who are men).

Scatter plots and correlations between the outcome of interest and all potential predictors were assessed. Spearman rank correlation coefficients are given in Table 1. These exploratory analyses confirm that each of the variables considered is strongly associated with COVID-19 mortality and that there exist significant correlations between these potential predictors of COVID-19 mortality. The highest correlations with mortality rates were a positive association with population density ($r = 0.6$) and a negative association with the proportion of the population who are white ($r = -0.6$). There was a moderate positive association with PM2.5 ($r = 0.4$) and a weaker positive association with the median IMD score ($r = 0.2$). Finally, there was a weak but unexpected negative correlation with the percentage of the population who are overweight or obese ($r = -0.2$). These correlation coefficients suggest that each of these variables, taken in isolation, appears to predict the rate of deaths involving COVID-19.

Univariate linear regression models were fitted, along with a multiple linear regression model which estimates independent effects of the variables of interest on COVID-19 mortality rates adjusted for the other variables in the model (Table 2). In line with our hypothesis that deprivation underlies other risk factors, a univariate model predicts an increase in mortality rate of 0.9 per 100,000 for each unit increase in the median IMD score. However, the multivariate model suggests that this effect is mediated by other variables. When ethnicity, overweight/obesity, population density and PM2.5 are included in the model, then the relationship between deprivation and COVID-19 mortality rate is no longer significant. The multivariate model suggests strong positive associations between both population density and overweight/obesity and mortality rate. Interestingly, adjusting for the other variables in the model has reversed the direction of the relationship for overweight/obesity in the univariate analyses, and the multivariate model predicts a 0.7 per 100,000 increase in mortality rate for each percentage point increase in overweight/obesity. There is also a strong association between ethnicity and the rate of deaths involving COVID-19 – the model predicts a decrease of 1.2 per 100,000 for every percentage point increase in the proportion of the population who are white. This model provided strong evidence that ethnicity and population density are associated with the rate of deaths involving COVID-19 at the local authority level and also suggests that areas with higher rates of overweight/obesity have a higher rate of deaths involving COVID-19.

Table 2
Univariate and multivariate linear regression models for mortality rates of deaths involving Coronavirus disease 2019 (per 100,000) by local authority.

Explanatory variable	Univariate		Multivariate	
	Coefficient	*P*-value	Coefficient	*P*-value
Percentage white	−1.548	0.000	−1.172	0.000
Percentage overweight/obese	−0.1662	0.000	0.739	0.003
Population density	0.007	0.000	0.003	0.000
Median IMD score	0.885	0.000	−0.139	0.343
PM2.5	7.707	0.000	0.047	0.946

IMD, Index of Multiple Deprivation; PM2.5, annual mean concentration of particulate matter.

Of the variables considered, we found that the strongest predictors of the rate of deaths involving COVID-19 at the local authority level were population density and ethnicity. While the spread of the infection in more densely populated areas is unsurprising, it is less clear why people from ethnic minorities appear to be at increased risk, and this is the topic of urgent research.[4] It has been suggested that it may be because they are more exposed to COVID-19 by their over-representation in the caring professions and other 'public-facing' employment, or in urban populations where COVID-19 is more prevalent, or that it is due to other factors including deprivation. It is clear that ethnic minorities are over-represented in the National Health Service (NHS), where white people make up 79% of the workforce, compared with 86% of the entire working age population.[10] Although we have not been able to take occupation into account, we have controlled for deprivation and population density in this ecological analysis and found that the effect of ethnicity persisted.

Similarly, the previously reported effect of obesity on COVID-19 complications was supported by the multivariate analysis and does not appear to be due to confounding by deprivation. Data on comorbidities such as diabetes would be useful to determine whether they explain this relationship. While we confirmed a positive association between PM2.5 and COVID-19 mortality in univariate analyses (in agreement with a similar analysis of case fatality rates in London boroughs[6]), there was no evidence of a significant association after controlling for other variables in the

model. There are several possible reasons for this. Firstly, the outcomes considered in the earlier analysis were the number of reported cases per borough and case fatality rate per borough.[6] Secondly, the analysis of air pollution and COVID-19 mortality in London boroughs did not control for any other variables and may therefore be confounded (an analysis of pollution levels in England found that concentrations were higher in areas with more non-white residents[11]). Finally, previous research on neighbourhood pollution levels has concluded that air pollution inequalities are mainly an urban problem;[11] it is therefore possible that the association reported within London is diluted when studying local authorities across England.

Despite our initial hypothesis, our findings suggest that individual factors, such as ethnicity, and structural factors, such as population density, are stronger predictors of COVID-19 mortality than deprivation. However, an important limitation of this analysis is that it is conducted at the local authority level, and the associations observed do not necessarily hold at the individual level. We note that data on risk factors were not available for seven local authorities. Another important limitation relates to the measures included in the analysis. We used a very crude measure of ethnicity, so we did not estimate the risks for different non-white ethnicities; this estimate was based on 2011 census data which is likely to underestimate the proportion of non-white ethnicities; the use of median IMD masks inequalities within local Authorities; and of the two pollutants identified as being linked to COVID-19,[6] we used only one of these that was readily available for each local authority.

Nevertheless, our analysis provides some useful insights while detailed analyses of individual-level epidemiological data are conducted to provide more reliable evidence. The contribution of working in keyworker roles such as on public transport, or in health and social care, to COVID-19 complications and mortality rates amongst ethnic minority staff should be investigated further. We support the call for mixed methods research to explore the complex interplay between the various biological, social and cultural factors underlying the observed increase in risk for ethnic minorities.[2]

Given the apparent importance of population density in our analysis, we recommend that future research should include individual-level data on residential arrangements, such as multi-occupancy dwellings and multigenerational households, as well as neighbourhood-level data on population density. As alluded to the earlier fact with respect to pollution, we note that associations between each of these risk factors and COVID-19 are likely to differ between urban and rural areas, and subanalyses may reveal different patterns according to geography.

Our findings highlight the importance of multivariate analyses to understand the factors that increase risk of COVID-19 mortality. Amidst concerns that it is the most vulnerable who are most at risk during the current pandemic, it is crucial to understand the complex causal pathways between different vulnerabilities, including socio-economic disadvantage, and COVID-19 infection, complications and mortality to tackle these inequalities.

Author statements

Funding

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Competing interests

Nothing to declare.

Data statement

Data are available for sharing.

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