Title: Income-based inequalities in hypertension and in undiagnosed hypertension: analysis of Health Survey for England data

Short title: Inequalities in undiagnosed hypertension

Shaun SCHOLES[a*], Anne CONOLLY[b], Jennifer S MINDELL[a]

[a] Research Department of Epidemiology and Public Health, UCL, 1-19 Torrington Place, London WC1E 7HB, UK.

[b] NatCen Social Research, London, 35 Northampton Square, London EC1V 0AX, UK.

*Corresponding author

Correspondence: Dr. Shaun Scholes; Research Department of Epidemiology and Public Health, UCL; 1-19 Torrington Place; London; WC1E 7HB, United Kingdom (email: s.scholes@ucl.ac.uk; phone: +44: 0207 679 1727)

Previous presentation: We presented part of the submitted work at the European Survey Research Association (ESRA) conference (Lisbon: 17-21 July 2017).

Funding: The Health Survey for England (HSE) 2011-16 was funded by NHS Digital. NHS Digital is the trading name of the Health and Social Care Information Centre. SCHOLES, CONOLLY and MINDELL are funded to conduct the annual HSE but this specific study was not funded.

Conflicts of interest: There are no conflicts of interest.

Full word count (including references, but not tables or legends): 6646 (including abstract)

Number of tables: 4

Number of figures: 4

Number of supplementary digital content files: 1

ABSTRACT

Objective: To quantify income-based inequalities in hypertension and in undiagnosed hypertension.

Methods: We used nationally representative data from 28,002 adults (aged 16 years and older) living in private households who participated in the cross-sectional Health Survey for England 2011 to 2016. Using bivariate probit regression modelling, we jointly modelled hypertension and self-reported previous diagnosis of hypertension by a doctor or nurse. We then used the model estimates to quantify inequalities in undiagnosed hypertension. Inequalities, using household income tertiles as an indicator of socioeconomic status, were quantified using average marginal effects (AMEs) after adjustment for confounding variables.

Results: Overall, 32% of men and 27% of women had survey-defined hypertension (measured blood pressure ≥140/90mmHg and/or currently using medicine to treat high blood pressure). Higher proportions (38% of men and 32% of women) either self-reported previous diagnosis or had survey-defined hypertension. Of these, 65% of men and 70% of women had diagnosed hypertension. Among all adults, participants in low- versus high-income households had a higher probability of being hypertensive (AMEs: men 2.1%; 95% CI: -0.2, 4.4%; women 3.7%; 95% CI: 1.8, 5.5%) and of being diagnosed as hypertensive (AMEs: men 2.0%; 95% CI: 0.4, 3.7%; women 2.5%; 95% CI: 1.1, 3.9%). Among those classed as hypertensive, men in low-income households had a marginally lower probability of being undiagnosed than men in high-income households (AME: -5.2%; 95% CI: -10.5, 0.1%) whereas no difference was found among women.

Conclusion: Our findings suggest that income-based inequalities in hypertension co-exist with equity in undiagnosed hypertension.

Keywords: hypertension; undiagnosed; inequalities; health examination surveys; England

INTRODUCTION

Hypertension is the leading modifiable cause of morbidity and mortality worldwide, being responsible for 7.6 million premature deaths per year (13.5% of all deaths worldwide) and 92 million disability-adjusted life-years [1]. Within health examination surveys, questions on hypertension combined with direct measurement of blood pressure (BP) enable surveillance of hypertension prevalence and indicators of its management overall and across population subgroups [2]. The prevalence of hypertension remains stubbornly high, with sub-optimal levels of management. A recent systematic review of population-based studies from 90 countries estimated a global hypertension prevalence of 31.1% among adults aged 20 years and older in 2010 [3]. Among those with hypertension, 46.5% were aware (i.e. self-reported diagnosed hypertension), 36.6% received treatment, and 13.8% had their BP controlled [3]. Among those who were treated, 37.1% had controlled hypertension [3]. This is worrisome, as successful control of BP is instrumental in reducing long-term risk of cardiovascular disease (CVD) events and premature death [4].

Compared with high-income countries, hypertension prevalence is higher in low- and middle-income countries whilst levels of awareness, treatment and control are lower [3,5]. Within countries, inequalities in the prevalence of hypertension persist [6], reflecting at least partly the social patterning in other CVD risk factors such as obesity, diabetes, physical inactivity and unhealthy diets (e.g. high in salt intake and low in fruit and vegetables) [7,8]. Inequalities in hypertension prevalence are potentially magnified by inequalities in diagnosis, treatment and control of hypertension, even in countries with universal health coverage [3], reflecting barriers related to the availability, accessibility and affordability of healthcare, including medication [5,9].

To date, most analyses of inequalities in diagnosed, treated and controlled hypertension using national health examination survey data have applied conventional techniques such as standard logistic regression models on the subset of participants classed as hypertensive [5]. However, such analyses fail to account for possible underlying, unobservable factors which jointly influence the propensity for having elevated BP, and the propensity for having ever been diagnosed as having high BP [10-12]. Accounting for these unmeasured characteristics through more complex methods (e.g. bivariate probit regression modelling) can lead to different conclusions about the direction and/or the magnitude of inequalities [10-13]. Using data collected among adults in the Health Survey for England, the objective of our study was to use bivariate probit regression modelling to: (1) quantify inequalities in the correlated joint outcomes of hypertension and self-reported diagnosed hypertension; and (2) use the estimated distributions of the two binary outcomes to quantify inequalities in undiagnosed hypertension. Our hypotheses were that adults living in the lowest-income households would be more likely than those in the highest-income households to be hypertensive; and that conditional on being classed as hypertensive, they would be more likely to have undiagnosed hypertension.

MATERIALS AND METHODS

Study population

We used data on adults (aged 16 years and older) from the Health Survey for England (HSE) 2011 to 2016. We pooled annual data to maximise the size of the analytical sample. The HSE is a cross-sectional, general population survey of individuals living in private households, with a new sample each year randomly selected by address [14]. Data collection occurs throughout the year. The first stage is a health-interview using computer-assisted personal interviewing, including questions about diagnosed conditions (e.g. hypertension and diabetes), self-rated health, behavioural risk factors, and measured height and weight. The second stage is a nurse-visit, including recording of prescribed medicines and measurement of BP. Both the interview and nurse-visit take place in participants' own homes. All adults in selected households for the HSE 2011-16 were eligible for interview (up to a maximum of ten), and all interviewed participants were eligible for the nurse-visit.

The percentage of eligible households taking part in the HSE ranged from 66% in 2011 to 59% in 2016. Participants gave verbal consent to be interviewed, visited by a nurse, and to have BP and anthropometric measurements taken. Research ethics approval was obtained from relevant committees. The analytical sample was limited to 28,002 non-pregnant participants with valid data on diagnosed hypertension and BP. This represented 56.2% of all adult participants; for our primary analysis based on complete cases we used a smaller analytical sample of 23,254 participants to examine income-based inequalities in hypertension due to missing income data (see Figure S1, Supplemental Digital Content 1, which sets out derivation of the analytical sample). Our study is based on existing data hence the sample size was fixed. An achieved adult interview sample of 8000 adults per survey year (assumed to comprise 3580 men and 4420 women) was implemented in order to balance the need for greater statistical precision with lower data collection costs. The HSE sample was designed to enable the detection of changes in key survey estimates over time. Based on the assumption that 60% of those interviewed would have valid BP data (~2150 men; ~2630 women), of which three in ten would have survey-defined hypertension (32% men; 29% women), the margin of error for estimates of hypertension prevalence would be approximately 2.0% and 1.7% for men and women respectively. With an achieved sample size of 8000 adults, 80% power, and 5% significance level, hypertension prevalence would have to rise or fall by 4.0 and 3.6 percentage points among men and women respectively to detect a significant change between two survey years.

Definitions of hypertension

Definitions of hypertension prevalence are of fundamental importance in assessing national goals for prevention and control [15]. In this study, we focused on three definitions: diagnosed, survey-defined and total hypertension.

Self-reported diagnosed hypertension

Participants were asked in the main interview "*Do you now have, or have you ever had, high blood pressure?*" Participants reporting ever having had high BP were asked: "*Were you told by a doctor or nurse that you had high blood pressure?*" Participants were classed as having self-reported diagnosed hypertension if they answered positively to both questions, apart from those who only had high blood pressure during pregnancy.

Survey-defined hypertension: measured high BP and/or current use of medicine to treat high BP

Trained, qualified nurses measured BP following a standardised protocol with an Omron digital monitor (Omron HEM-207): three BP readings were taken from each participant in a seated position at 1-minute intervals with use of an appropriately sized cuff on the right arm if possible, after a 5-minute rest. Our analyses excluded participants who had exercised, eaten, drunk alcohol, or smoked in the 30 minutes before the measurements. BP was summarised using the mean of the second and third readings. We classed participants as having survey-defined hypertension if they had systolic blood pressure (SBP) ≥140mmHg, or diastolic blood pressure (DBP) ≥90mmHg, and/or self-reported current use of medicine prescribed for high BP (hereafter referred to as BP medicine) [16]. Survey-defined hypertension therefore does not use information on self-reported previous diagnosis. The BP thresholds of ≥140/90mmHg used in our study was the target recommended in most hypertension guidelines at the time of data collection [17]. As in other studies [10,13], current use of BP medicine was included in the definition of survey-defined hypertension as these participants are presumed to have been prescribed BP medicine as a result of satisfying the clinical definition of hypertension [2].

Total prevalence: survey-defined or diagnosed hypertension

According to the total definition, we classed participants as hypertensive if they either had survey-defined hypertension or self-reported previous diagnosis by a doctor or nurse. Total prevalence therefore was the most comprehensive definition as it included both diagnosed and undiagnosed cases (defined below).

Undiagnosed hypertension

We classed participants as having undiagnosed hypertension if they did not report a previous diagnosis but had survey-defined hypertension. The level of undiagnosed hypertension represents therefore the fraction of total prevalence not reported as diagnosed [10].

Socioeconomic status, demographics and co-morbid conditions

We chose household income as our primary marker of socioeconomic status (SES). In the HSE series, the household reference person reports gross household income via a card showing banded incomes (31 bands in total ranging from ‘less than £520 annually’ to ‘£150,000 or more annually’). Household income is equivalised taking account of the number of adults, children and infants in the household (using the McClements [18] scoring system), and is grouped into tertiles (thirds). Educational status was used as a secondary SES measure; ascertained as the highest formal qualification attained. This was categorised as follows: degree or equivalent, 'A' levels/NVQ3 or other higher qualifications below degree level, 'O' level, other, and none. The address of each responding household was categorised as residing in an urban or rural area (town and fringe; village, hamlet and isolated dwellings) based on the Department for Environment, Food and Rural Affairs 2011 classification of Local Authorities [19].

We classed participants who reported that their doctor had diagnosed them with diabetes (except if only when pregnant) as having 'doctor-diagnosed diabetes'. Cigarette smoking categories were current, ex-regular and never. Trained interviewers took single measurements of height and weight. We computed Body Mass Index (BMI) as weight in kilogrammes (kg) divided by height in metres squared (m^2), classifying participants into four groups: underweight (<18.5kg/m^2), normal weight (18.5-24.9kg/m^2), overweight (25.0-29.9kg/m^2), or obese (≥30.0kg/m^2).

Statistical analysis

Missing data

Using descriptive analyses, we examined differences in the key variables between participants interviewed in the survey with and without data from the nurse-visit (33,286 and 16,531 respectively). Among the 28,002 adults with valid data on diagnosed hypertension and BP, we examined differences between those with and without income data (23,254 and 4748 respectively). To account for the complex survey design we used Rao-Scott chi-square tests for a two-way table to test for independence [20].

Descriptive characteristics

Differences in the key survey variables according to income group were evaluated using Rao-Scott tests. We decided, a priori, to conduct gender-specific analyses due to potential gender differences in the SES and hypertension associations as previously reported in the literature [6]. Among the 28,002 non-pregnant adults with valid data on diagnosed hypertension and BP, we estimated the prevalence of: (1) diagnosed hypertension, (2) survey-defined hypertension, and (3) total hypertension among all adults and by income group. Income-specific estimates were directly age-standardised within gender (using the pooled HSE data as the standard population). Among the 10,912 persons classed as hypertensive according to the total prevalence definition, levels of diagnosed, treated (currently taking BP medicine) and controlled (BP<140/90mmHg) hypertension were estimated overall and by income group. We also estimated levels of BP control among those treated. The income-specific estimates of diagnosed, treated and controlled hypertension were directly age-standardised using the subset of participants classed as hypertensive as the standard population [2]. Differences between income groups (middle- versus highest-income; lowest- versus highest-income) were tested for statistical significance using a linear combination of the coefficients [21].

Multivariate analysis: bivariate probit model

We performed multivariate analysis by using bivariate probit regression modelling. This is a model for jointly analysing two potentially correlated binary outcomes [22]. In a bivariate probit analysis, simultaneous estimation of two separate probit models is performed, with a non-zero correlation (ρ) allowed between the error terms of the two equations. Estimation of the correlation coefficient ρ accounts for the influence of unobserved factors that jointly determine the two outcomes. The outcomes were hypertension (coded as one for hypertensives according to the total prevalence definition), and self-reported diagnosed hypertension (coded as one for diagnosed cases).

For ease of interpretation, we report the average marginal effects (AMEs) from the fitted regression model. The AMEs for categorical variables represent the estimated average change in the probability that the outcome equalled one comparing one category with the reference, holding all other variables constant at specified reference values [22]. We quantified the magnitude of inequalities using two sets of AMEs. First, we calculated AMEs based on the marginal (i.e. unconditional) probabilities from each outcome to quantify the inequalities in hypertension and in diagnosed hypertension. Secondly, we calculated AMEs to quantify inequalities in the probability of having undiagnosed hypertension. The latter AMEs represent differences between income groups in a conditional probability: the probability of not self-reporting diagnosed hypertension among those participants classed as hypertensive. These AMEs correspond to a widely used 'standard' definition of undiagnosed disease in the public health literature: the probability an individual self-reports not having the disease given that they actually have the disease according to medical criteria [10].

As in similar studies [10,13], the estimates of inequalities were adjusted for potentially confounding variables. For our primary analysis these were as follows: age (entered into models as a continuous variable), age-squared (to account for non-linearity), marital status (married as reference), diagnosed diabetes (no diagnosed diabetes as reference), BMI status (normal weight as reference), and cigarette smoking status (never smokers as reference). Underweight participants were excluded from the statistical modelling due to small numbers (N=289). Age in single years was not released in the most recent HSE datasets and so we used the midpoint of the five-year age band. Other potential confounders such as unhealthy diets and physical inactivity were not included as information on these was not collected in at least one survey year between 2011 and 2016. Our primary multivariate analyses were run on complete-case data (men: 9403; women: 11,591), excluding participants with missing data on income (men: 2004; women: 2744) or any of the four confounding variables listed above (men: 908; women: 1,352).

Sensitivity analyses

We conducted four sensitivity analyses to examine the robustness of our findings. First, we fitted a standard probit model on the binary outcome of diagnosed hypertension estimated on the subset of participants classed as hypertensive (according to the total prevalence definition). Secondly, we repeated our primary analyses by accounting for the severity of hypertension by adding SBP as a continuous variable into the empirical model. Thirdly, we added urban/rural area of residence and educational status separately into the models to assess impact on the estimated differences in the outcomes between income groups. Fourthly, to examine the potential for bias in our findings due to item non-response, including income, we repeated our primary analysis with the missing values replaced by multiply imputed data [23].

All analyses accounted for the complex survey design, incorporating the nurse-visit weight which accounted for individual non-participation and preserved the national representativeness of the sample. Statistical significance was set at $p<0.05$ for two-tailed tests, with no adjustment for multiple comparisons. Dataset preparation and analysis was performed in SPSS V20.0 (SPSS IBM Inc., Chicago, Illinois, USA) and in Stata V15.0 (College Station, Texas, USA) respectively. HSE datasets are available via the UK Data Service (UKDS: http://www.ukdataservice.ac.uk) [24-29]; syntax to enable replication of our results (using the datasets deposited at the UKDS) is available on request from the corresponding author.

RESULTS

In HSE 2011-16, of the 49,817 adults who took part in the main interview, 33,286 (66.8%) had a nurse-visit. Compared with participants who had a nurse-visit, participants interviewed in the main survey but not taking part in the nurse-visit were more likely to be younger, male, be non-married, be non-White, live in low-income households, have no formal qualifications, reside in urban areas, currently smoke, and to report never being diagnosed as having high BP (see Table S1, Supplemental Digital Content 1, which shows all $p<0.001$ using the Rao-Scott chi-square test for two-way tables). Amongst the 28,002 adults with valid data on diagnosed hypertension and BP, participants aged 75+, female, of Black ethnicity, single, having no qualifications, living in urban areas, and having diagnosed diabetes were more likely to have missing income data (see Table S2, Supplemental Digital Content 1).

Socio-demographic characteristics and co-morbid conditions by income group

Table 1 shows sociodemographic characteristics and prevalence of co-morbid conditions according to income. Living in the lowest-income households was more common among participants who were aged 16-24 and 75+, non-White, not married, residing in urban areas, had no qualifications, were current smokers, obese, and ever had high BP or diagnosed diabetes (Table 1). More than one-third (36%) of participants in the lowest-income households had no formal qualifications compared with 6% of those in the highest-income households.

Table 1 here

Descriptive analysis: Inequalities in hypertension prevalence

Among men, 25%, 32% and 38% had diagnosed, survey-defined and total hypertension respectively; the equivalent figures for women were 22%, 27% and 32% (**Table 2**). **Table 3** and **Figure 1** show the directly age-standardised prevalence estimates by income group. Inequalities in hypertension were evident, regardless of whether hypertension was defined using self-report, objective data, or both. For men and women, levels of diagnosed and total hypertension were higher by five or more percentage points among participants in the lowest- versus highest-income households (p<0.01). Levels of survey-defined hypertension (BP≥140/90mmHg and/or current use of medicine to treat high BP) were also significantly higher in the lowest- versus highest-income households (p=0.032 and p<0.001 for men and women respectively).

Tables 2 and 3 here

Figure 1 here

Descriptive analysis: Inequalities in hypertension management

Among those classed as hypertensive according to the total prevalence definition, 65%, 44% and 43% of men were diagnosed, treated, and controlled, respectively; the equivalent figures for women were 70%, 51% and 46% (**Table 2**). As **Figure** 2 shows, levels of diagnosed hypertension among those with hypertension were higher for those in the lowest- versus highest-income households among men (68% versus 63% respectively; p=0.007) and women (73% versus 69% respectively; p=0.039) (Table 3). Levels of treatment and control were also significantly higher in the lowest- versus highest-income households for men and women. Differences in the levels of BP control among those currently treated according to income were not statistically significant.

Figure 2 here

Multivariate analysis: Inequalities in hypertension and diagnosed hypertension

Table 4 and Figure 3 show the estimates (marginal or unconditional probabilities: expressed as AMEs) of the fully adjusted bivariate probit model for the correlated binary outcomes of total hypertension (black circles) and self-reported diagnosed hypertension (grey diamonds). For men and women, older age, being overweight or obese, and having diagnosed diabetes increased the probability of being hypertensive. Among men but not among women, current- and ex-smokers, and those not married had a higher probability of being hypertensive. Compared with those in the highest-income households, participants in the lowest-income households had a higher probability of being hypertensive, with a more pronounced difference among women (AMEs: men 2.1%; 95% CI: -0.2, 4.4%; women 3.7%; 95% CI: 1.8, 5.5%). AMEs were lower in magnitude for diagnosed hypertension but the patterns were similar. Compared with those in the highest-income households, participants in the lowest-income households had a higher probability of being diagnosed as hypertensive (AMEs: men 2.0%; 95% CI: 0.4, 3.7%; women 2.5%; 95% CI: 1.1, 3.9%).

Table 4 here

Figure 3 here

Multivariate analysis: Inequalities in undiagnosed hypertension

Based on the estimated distributions of the binary outcomes (total hypertension and diagnosed hypertension), **Table 4** and **Figure 4** show the AMEs for the (conditional) probability of undiagnosed hypertension. Among hypertensive men, older age, being obese, and reporting diagnosed diabetes were associated with lower probability of undiagnosed hypertension (AMEs<0). Compared with their hypertensive counterparts in the highest-income households, men in the lowest-income households had a marginally lower probability of undiagnosed hypertension (AME: -5.2%; 95% CI: -10.5, 0.1%; *p*=0.056). In contrast, the probabilities of undiagnosed hypertension were similar across the income groups among women.

Figure 4 here

Sensitivity analyses

We ran four sensitivity analyses to examine the robustness of our primary findings. First, a fully adjusted standard probit model on the binary outcome of diagnosed hypertension estimated on the subset of participants classed as hypertensive (according to the total prevalence definition) produced similar findings as our descriptive analyses (see Table S3, Supplemental Digital Content 1, which shows estimates and accompanying 95% CIs). Compared with their hypertensive counterparts in the highest-income households, men in the lowest-income households had a significantly higher probability of diagnosed hypertension (AME: 5.2%; 95% CI: 0.8, 9.6%; *p*=0.022). Likewise, the AME was positive among women but the association was no longer statistically significant after confounder adjustment (AME: 3.4%; 95% CI: -1.0, 7.7%; *p*=0.128). Secondly, no significant differences between participants in the lowest- versus highest-income households in the probability of undiagnosed hypertension were found when we repeated our main analysis by adding SBP as a continuous variable into the empirical model to adjust for the severity of hypertension (AMEs: men 0.6%; 95% CI: -4.3, 5.5%; women 1.9%; 95% CI: -5.2, 9.1%) (data not shown). Thirdly, adding urban/rural area of residence into the empirical model had little effect (<0.5%) on the estimated income-based AMEs for undiagnosed hypertension. Adjustment for educational status attenuated the estimates for undiagnosed hypertension towards the null among men (AME for low-income: -4.3%; 95% CI: -10.4, 1.8%) but increased the estimate among women, although the AME remained statistically insignificant (AME for low-income: -2.8%; 95% CI: -9.7, 4.1%) (see Table S4, Supplemental Digital Content 1). Finally, accounting for missing data by using multiple imputation slightly increased the magnitude of the income-based AMEs for total, diagnosed and undiagnosed hypertension, with the latter attaining statistical significance among men (AME for low-income: -5.8%, 95% CI: -11.1, -0.5%; p=0.034) (see Table S5, Supplemental Digital Content 1).

Discussion

In this study, we quantified income-based inequalities in hypertension and in undiagnosed hypertension using data from adults living in private households in England. Our hypotheses were that adults in the lowest-income households would be more likely to be hypertensive and, among those hypertensive, to have undiagnosed hypertension. Our descriptive analysis produced two main findings. First, inequalities in hypertension were evident for both diagnosed- and survey-defined hypertension, with higher levels among adults in the lower income households. Secondly, among those with hypertension, levels of diagnosed hypertension were higher among adults in low-income households. Results from empirical models - which accounted for the unobserved characteristics that jointly determine being hypertensive and reporting previous diagnosis of high blood pressure by a doctor or nurse - showed that inequalities in hypertension were robust to adjustment for demographics and other co-morbid conditions, whilst undiagnosed hypertension showed no inequalities.

Inequalities in hypertension

Our findings of inequalities in hypertension prevalence agrees with a recent meta-analysis [6]. Individuals with elevated BP are more likely to have other CVD risk factors such as obesity, diabetes, smoking and dyslipidaemia [7,30]. Previous analyses of HSE data have confirmed inequalities in these other CVD risk factors [31-33]; these at least partially explain the inequalities in hypertension prevalence found in our study.

Inequalities in diagnosed hypertension

Two confounding factors may partially explain the higher (age-standardised) levels of diagnosed hypertension among adults in low-income households shown in our descriptive analyses (Table 3; Figure 2). First, such inequalities may arise through income-based differences in the severity of the disease. Adults in low-income households may have more severe chronic health conditions, and those with more severe conditions are more likely to have diagnosed disease [10]. Secondly, adults in low-income households may have been more likely to have received routine healthcare assessment and/or screening for high BP due to the increased risk of other conditions that are associated with high BP, such as obesity, or are indications for anti-hypertensive medication, such as diabetes. Evidence from the US suggests that the decline in the levels of untreated hypertension has been greatest among obese adults, indicating that these individuals are more likely to have been screened and tested for CVD risks [34]. Our empirical models provide some support for this explanation. After adjustment for income and demographic variables, adults at higher risk of hypertension (e.g. those obese and those reporting doctor-diagnosed diabetes) were substantially more likely to have diagnosed hypertension (Figure 3). This finding is in agreement with other studies [13,35].

Inequalities in undiagnosed hypertension

Based on our modelling, we found that hypertensive men in low-income households had a marginally lower probability of being undiagnosed than their hypertensive counterparts in high-income households (Figure 4). Adjusting for SBP to account for the severity of hypertension reduced the magnitude of the difference, thereby confirming the absence of income-based inequalities in undiagnosed hypertension. Adjustment for educational status in a sensitivity analysis had a similar but weaker effect. Our findings are supported by UK studies which found no evidence of systematic inequity in the utilisation of healthcare (namely use of medicines) adjusted for need [36]. For example, analyses of population-level record-linked cohort studies showed that the use of antihypertensive medication in individuals with high SBP but otherwise at low risk for coronary heart disease (CHD) was higher among adults living in the most-deprived areas in Wales [36]. The same research team found no significant evidence of inequalities in the persistence of recommended medication for primary and secondary prevention of CHD [37].

Furthermore, our finding of no income-based inequalities in undiagnosed hypertension agrees with a number of studies using similar analytical techniques. An analysis of the US National Health and Examination Survey (NHANES) found no educational inequalities in undiagnosed hypertension and a positive (though low in magnitude) association between income and undiagnosed hypertension (i.e. high-income individuals had a higher risk of being undiagnosed) [10]. Likewise, a similar analysis of data from South Africa's National Income Dynamics Survey (NIDS) found no educational- or income-inequalities in awareness [13]. An analysis of data from the Republic of Korea based on simpler methods produced similar findings [35]. Based on a univariate logit model, higher education was associated with higher awareness in low- but not in middle- or high-income countries in the Prospective Urban Rural

Epidemiology (PURE) study [5]. In contrast, an analysis of data from the Portuguese National Health Examination Survey (INSEF) showed income-based inequalities in diagnosed hypertension [38]. Using a three-step model on data spanning 18 years of the China Health and Nutrition Survey (CHNS), Gordon-Larsen and colleagues found lower hypertension prevalence among adults of higher versus lower attained education, but higher diagnosis (conditional on having elevated BP) [12].

A widely cited analysis of HSE data (1998 and 2003) by Johnston and colleagues (2009) found no evidence of an income gradient using self-reported hypertension (volunteered as a ‘long-standing illness, disability or infirmity’) but a sizeable income gradient using objectively-measured hypertension (BP≥140/90mmHg), with higher probability among those with lower incomes [11]. Our study used the most recent HSE data available, and it is plausible that income gradients in the BP≥140/90mmHg indicator (regardless of treatment) have narrowed since. In addition, any comparison is not like-for-like, as we were interested in quantifying inequalities in undiagnosed hypertension rather than assessing income gradients in the under-estimation of hypertension prevalence [11].

Although we interpret our results as confirming the absence of income-based inequalities in undiagnosed hypertension, the unexpected finding of higher levels of undiagnosed hypertension in high-income households (among both genders in descriptive analyses) and a marginally higher probability of undiagnosed hypertension (among men but not among women) in the statistical models may warrant concern and further investigation. As mentioned above, this finding may indicate disparities in levels of severity or in levels of healthcare assessment and/or screening for high BP (reflecting at least in part the social patterning of poor health outcomes) that we have not been able to fully adjust for.

Policy implications

Similar to the worldwide prevalence [3], about three in ten adults in England had survey-defined hypertension. Amongst those currently hypertensive (survey-defined or previous diagnosis), about two-thirds had diagnosed hypertension, but fewer than one-half were treated and fewer than one-half had their BP controlled. Over the past two decades, levels of survey-defined hypertension in England have been stable whilst levels of awareness, treatment, and control have improved significantly [16] but there is room for substantial further improvement. Worldwide, proposals to improve levels of BP control – thereby reducing disease and increase life expectancy – include the earlier initiation of BP-lowering treatment and the setting of more ambitious BP goals in the initial stages of hypertension [7]. In the UK, recent draft clinical guidelines published by the National Institute for Health and Care Excellence (NICE) include new recommendations for reducing the 10-year CVD risk threshold at which BP-lowering treatment should be considered from 20% to 10% [39,40]. In addition, Public Health England recently set targets of 80% for diagnosed hypertension and for treatment (as per NICE guidelines) by 2029 [41]. Improvements in the modifiable behavioural risk factors for hypertension such as higher levels of physical activity and fruit and vegetable consumption, and lower levels of overweight and obesity, dietary salt-intake and alcohol consumption could reduce the prevalence of survey-defined hypertension (by achieving BP <140/90mmHg among untreated adults) as well as reduce incidence [42]. Reductions in these socially patterned, other CVD risk factors could achieve sizeable reductions in socioeconomic inequalities in hypertension prevalence.

Strengths and limitations

Our study has a number of strengths. By including direct measurements of blood pressure, national health examination surveys such as the Health Survey for England allow the surveillance of hypertension prevalence according to current guidelines and the identification of participants with undiagnosed, untreated and uncontrolled hypertension [2,14]. Use of objective measures also avoids “diagnosis bias”: that is, estimates of inequalities in hypertension are incorrect when relying solely on self-reports of previous diagnosis by a doctor or nurse when inequalities exist in access to medical care [43]. Our analytical sample size was maximised by pooling six years of annual data with a standardised BP measurement protocol. Using bivariate probit regression modelling, we quantified inequalities in undiagnosed hypertension whilst accounting for the unmeasured factors which influence both having hypertension and the propensity for being diagnosed as hypertensive [10]. As in other studies, we assumed income to be exogenous [13], and we did not use any exclusion restrictions for identification (i.e. a variable that determines the probability of being hypertensive but does not directly influence the propensity for reporting diagnosed hypertension conditional on the variables included in the model) [13]. As explained by Chatterji et al (2009), it is not required to fit exclusion restrictions in bivariate probit regression modelling, and it is difficult to identify plausible candidates given the considerable overlap between the two outcomes [10]. Other modelling approaches may produce different conclusions. However, we examined the sensitivity of our results through robustness checks and found our main results were unchanged.

Our study has a number of limitations, which should be borne in mind when interpreting our findings. We cannot draw causal inferences, as this was a descriptive study based on cross-sectional data. As in most national health examination surveys, nurses collected BP at a single visit, in contrast to the multiple occasions recommended in clinical definitions [38], so raised BP is not necessarily persistent. However, conducting BP measurements on multiple occasions is impractical in large surveys; as a result, surveillance definitions of hypertension typically differ from clinical definitions [2]. Response rates to the HSE (as worldwide) are decreasing over time, and response to the nurse visit showed evidence of bias. We minimised the bias to some extent by using a survey non-response weight, which additionally adjusts for differences in response propensity between the interview and the nurse-visit. Although we pooled data collected over six years, our analyses (stratified by gender and conditional on being hypertensive in some cases) may have been statistically underpowered to some extent, requiring caution when interpreting our findings. Finally, although we adjusted for several confounding variables in the assessment of income inequalities there remains the possibility for unmeasured or residual confounding. For example, we were unable to adjust our modelled estimates for potentially useful variables such as diet, physical activity, use of health services or history of CVD status. Variables on use of health services and history of CVD status (captured by the CVD module) were available only in two years.

Conclusion

Our results have confirmed that income-based inequalities in the prevalence of hypertension co-exist with equity in undiagnosed hypertension. The sub-optimal levels of diagnosis across all income groups represent a missed opportunity for reducing the disease burden associated with hypertension.

Acknowledgements

The authors thank the interviewers and nurses, and the participants in the Health Survey for England series.

Legend for Figure 1

Prevalence of hypertension among adults aged 16 years and older by gender and income tertile. Three definitions of hypertension are presented: (1) ***diagnosed hypertension***: whether a doctor or a nurse had ever told the participant that they have high blood pressure (excluding pregnancy); (2) ***survey-defined hypertension***: BP ≥140/90mmHg or current use of medicine to treat hypertension; and (3) ***total hypertension***: diagnosed or survey-defined hypertension. Estimates were age-standardised by the direct method within gender to the pooled data using the age groups 16-44, 45-54, 55-64, 65-74, and 75+.

Legend for Figure 2

Prevalence of diagnosed, treated and controlled hypertension among hypertensive adults aged 16 years and older by gender and income tertile. Adults classed as hypertensive according to the total definition: i.e. those who reported diagnosed or survey-defined hypertension (BP ≥140/90mmHg and/or current use of medicine to treat hypertension). Three indicators of hypertension management are presented: (1) ***diagnosed hypertension***: whether a doctor or a nurse had ever told the participant that they have high blood pressure (excluding pregnancy); (2) ***treated hypertension***: current use of medicine to treat hypertension; and (3) ***controlled hypertension***: BP <140/90mmHg. Estimates were age-standardised by the direct method within gender using the subpopulation of participants who had hypertension according to the total definition (age groups: 16-44, 45-54, 55-64, 65-74, 75+).

Legend for Figure 3

Average Marginal Effects (AMEs) and 95% Confidence Intervals based on bivariate probit model among adults aged 16+ years by gender. The model contained two outcomes: (1) **total hypertension** (AMEs shown by black circles): reported diagnosed or survey-defined hypertension (BP ≥140/90mmHg or current use of medicine to treat hypertension); and (2) **self-reported diagnosed hypertension** (AMEs shown as grey diamonds): whether a doctor or a nurse had ever told the participant that they have high blood pressure (excluding pregnancy). The AME of a categorical variable can be interpreted as the average change in the predicted probability that the outcome = 1 compared with the reference category, holding all other variables constant at the specified reference values (mean age; highest-income tertile; never smoker; normal-weight; married; and no reported diabetes). For example, among men, the marginal (i.e. unconditional) probability of being hypertensive according to the total definition was 2.1 percentage points higher for those in the lowest-income households than for those in the highest income households (AME: 2.1%, 95% CI: -0.2, 4.4%) at the specified reference values of the other variables. Estimates and 95% CIs are shown in Table 4.

Legend for Figure 4

Average Marginal Effects (AMEs) and 95% Confidence Intervals based on bivariate probit model among adults aged 16+ years by gender. The model contained two outcomes: (1) **total hypertension**: reported diagnosed or survey-defined hypertension (BP ≥140/90mmHg or current use of medicine to treat hypertension); and (2) **self-reported diagnosed hypertension**: whether a doctor or a nurse had ever told the participant that they have high blood pressure (excluding pregnancy). Based on the model estimates, we used the marginal (total hypertension) and joint probabilities (total hypertension but no diagnosed hypertension) to calculate AMEs for undiagnosed hypertension. These represent differences in a conditional probability: the probability of not self-reporting diagnosed hypertension among those participants classed as hypertensive. The AME of a categorical variable can be interpreted as the average change in the predicted probability that the outcome = 1 (undiagnosed hypertension) compared with the reference category, holding all other variables constant at the specified reference values (mean age; highest-income tertile; never smoker; normal-weight; married; and no reported diabetes). For example, among men classed as hypertensive, the (conditional) probability of being undiagnosed was 5.2 percentage points lower for those in the lowest-income households than for those in the highest income households (AME: -5.2%, 95% CI: -10.5, 0.1%) at the specified reference values. Estimates and 95% CIs are shown in Table 4.

TABLE 1. Socio-demographic characteristics and co-morbid conditions by income tertile

Characteristics	Household income			
	Highest	**Middle**	**Lowest**	**P-value[a]**
N (%)	8430 (100)	8083 (100)	6741 (100)	-
Age in years, Mean (SD)	48.7 (15.4)	53.6 (18.4)	53.2 (19.7)	<0.001[b]
Age, N (%):				
16-24	419 (5)	543 (7)	691 (10)	<0.001
25-34	1282 (15)	964 (12)	749 (11)	
35-44	1718 (20)	1191 (15)	933 (14)	
45-54	1980 (24)	1268 (16)	1006 (15)	
55-64	1660 (20)	1367 (17)	1053 (16)	
65-74	938 (11)	1689 (21)	1223 (18)	
75+	433 (5)	1061 (13)	1086 (16)	
Ethnicity, N (%):				
White	7895 (94)	7512 (93)	5849 (87)	<0.001
Black	108 (1)	141 (2)	248 (4)	
Asian	318 (4)	299 (4)	491 (7)	
Mixed	78 (1)	84 (1)	82 (1)	
Marital status, N (%):				
Married	6359 (75)	5533 (68)	3732 (55)	<0.001
Single	1095 (13)	1105 (14)	1425 (21)	
Separated/divorced/widowed	975 (12)	1445 (18)	1583 (23)	
Educational status, N (%):				
Degree or equivalent	4015 (48)	1660 (21)	710 (11)	<0.001
A level	2348 (28)	2388 (30)	1556 (23)	
O level	1466 (17)	2194 (27)	1932 (29)	
No qualifications	539 (6)	1675 (21)	2410 (36)	
Other	58 (1)	160 (2)	125 (2)	
Type of area, N (%)				
Urban	5619 (67)	5612 (69)	5171 (77)	<0.001
Current smoking, N (%):				
Never regular	5304 (63)	4475 (55)	3347 (50)	<0.001
Ex-regular	2365 (28)	2510 (31)	2011 (30)	
Current	747 (9)	1086 (14)	1350 (20)	
BMI, N (%):				
Underweight	64 (1)	100 (1)	125 (2)	<0.001
Normal	2926 (37)	2357 (32)	1825 (30)	
Overweight	3119 (40)	2856 (39)	2148 (35)	
Obese	1758 (22)	2076 (28)	1989 (33)	
Ever had high BP, N (%)	1810 (22)	2484 (31)	2372 (35)	<0.001
Diagnosed diabetes, N (%)	336 (4)	571 (7)	681 (10)	<0.001

BMI: body mass index; SD: standard deviation. Sample sizes and estimates are unweighted; estimates shown as column percentages. [a] P-values computed using Rao-Scott chi-square tests of independence after exclusion of missing values. [b] P-value computed using adjusted Wald test. Missing categories and cell sizes below 30 not shown.

TABLE 2. Prevalence of hypertension and indicators of its management by gender

	Men	Women
Hypertension:		
N (*All adults*)	12,315	15,687
Outcome:		
Diagnosed % (95% CI)[a]	25 (24-26)	22 (22-23)
Survey-defined (95% CI)[b]	32 (32-33)	27 (26-28)
Total % (95% CI)[c]	38 (37-39)	32 (31-33)
Management:		
N (*Hypertensive by total definition*)	5392	5520
Outcome:		
Diagnosed % (95% CI)	65 (63-66)	70 (69-72)
Treated % (95% CI)[d]	44 (42-45)	51 (50-52)
Controlled % (95% CI)[e]	43 (41-44)	46 (45-48)
Treated:		
N (*Treated*)	2571	2853
Controlled % (95% CI)	64 (61-66)	62 (60-64)

Overall estimates include 4748 participants with missing data on income.

[a] **Diagnosed hypertension**: whether a doctor or nurse had ever told the participant that they have high blood pressure (BP), excluding pregnancy. [b] **Survey-defined hypertension**: BP ≥140/90mmHg or current use of medicine to treat hypertension. [c] **Total hypertension**: reported diagnosed or survey-defined hypertension. [d] **Treated hypertension**: current use of medicine to treat hypertension. [e] **Controlled hypertension**: (BP <140/90mmHg).

TABLE 3. Age-adjusted prevalence of hypertension and indicators of its management, by gender and income tertile

	Men			Women		
	Income			Income		
	Highest	**Middle**	**Lowest**	**Highest**	**Middle**	**Lowest**
Hypertension:						
N (*All adults*)	4032	3560	2719	4398	4523	4022
Outcome:						
Diagnosed % (95% CI)[a]	23 (21-24)	25 (23-26)*	28 (26-30)***	20 (18-21)	22 (21-24)**	26 (25-28)***
Survey-defined % (95% CI)[b]	31 (30-32)	33 (32-34)	34 (32-36)*	25 (23-26)	28 (26-29)**	30 (28-31)***
Total % (95% CI)[c]	36 (35-38)	38 (37-40)	41 (39-43)**	28 (27-30)	32 (31-34)***	36 (35-37)***
Management:						
N (*Hypertensive*)	1464	1639	1356	1100	1700	1638
Outcome:						
Diagnosed % (95% CI)	63 (60-66)	65 (62-67)	68 (65-71)**	69 (67-72)	70 (67-73)	73 (70-76)*
Treated % (95% CI)[d]	40 (38-43)	43 (42-45)	46 (43-48)**	48 (46-51)	51 (48-53)	53 (50-56)*
Controlled % (95% CI)[e]	40 (38-43)	40 (38-43)	46 (44-49)**	43 (40-47)	45 (43-48)	49 (46-52)*
Treated:						
N (*Treated*)	582	799	712	476	880	896
Controlled % (95% CI)	65 (60-70)	60 (56-65)	66 (61-70)	64 (59-70)	62 (57-66)	61 (58-65)

Hypertension prevalence estimates were age-adjusted by the direct method within gender to the pooled HSE data using the age-groups 16-44; 45-54; 55-64; 65-74; and ≥75. Estimates for diagnosed, treated and controlled hypertension were age-adjusted by the direct method within gender using the subpopulation of participants who had hypertension according to the total prevalence definition using the age-groups listed above. Difference in percentages between income groups (middle vs highest; lowest vs. highest) tested via linear combination of coefficients. ****p*<0.001; ***p*<0.01; **p*<0.05.

[a] **Diagnosed hypertension**: whether a doctor or nurse had ever told the participant that they have high blood pressure (BP), excluding pregnancy. [b] **Survey-defined hypertension**: BP ≥140/90mmHg or current use of medicine to treat hypertension. [c] **Total hypertension**: reported diagnosed or survey-defined hypertension. [d] **Treated hypertension**: current use of medicine to treat hypertension. [e] **Controlled hypertension**: (BP <140/90mmHg).

TABLE 4. Average marginal effects (AMEs) in the bivariate probit model for hypertension (total) and diagnosed hypertension

Variables	**Total hypertension[a]**		**Diagnosed hypertension[b]**		**Undiagnosed hypertension[c]**	
	AME % (95% CI)	**p-value**	**AME % (95% CI)**	**p-value**	**AME % (95% CI)**	**p-value**
			Men (N=9403)			
Age	**1.1 (0.9, 1.3)**	**<0.001**	**1.2 (1.0, 1.4)**	**<0.001**	**-1.6 (-1.9, -1.4)**	**<0.001**
Middle-income	1.5 (-0.6, 3.5)	0.151	1.2 (-0.2, 2.6)	0.096	-2.5 (-8.1, 3.0)	0.362
Lowest-income	2.1 (-0.2, 4.4)	0.074	**2.0 (0.4, 3.7)**	**0.017**	-5.2 (-10.5, 0.1)	0.056
Current smoker	**3.9 (1.6, 6.1)**	**0.001**	1.3 (-0.3, 3.0)	0.110	2.6 (-4.9, 10.1)	0.493
Ex-smoker	**2.7 (0.5, 4.8)**	**0.016**	**1.7 (0.6, 2.9)**	**0.004**	-2.3 (-6.6, 2.1)	0.300
Overweight	**10.7 (8.1, 13.3)**	**<0.001**	**5.4 (3.7, 7.0)**	**<0.001**	-0.5 (-6.0, 5.1)	0.865
Obese	**25.7 (23.5, 28.0)**	**<0.001**	**15.3 (13.3, 17.3)**	**<0.001**	**-6.3 (-11.1, -1.4)**	**0.013**
Diagnosed diabetes	**16.8 (13.7, 20.0)**	**<0.001**	**14.6 (11.1, 18.1)**	**<0.001**	**-18.6 (-25.0, -12.2)**	**<0.001**
Single	**5.8 (2.5, 9.0)**	**0.001**	1.8 (-0.4, 4.0)	0.108	4.5 (-2.0, 11.0)	0.171
Separated/divorced/widowed	**3.9 (2.0, 5.8)**	**<0.001**	1.1 (-0.3, 2.5)	0.112	3.8 (-1.9, 9.4)	0.184
			Women (N=11,591)			
Age	**0.8 (0.5, 1.1)**	**<0.001**	**0.5 (0.2, 0.7)**	**<0.001**	0.6 (-0.6, 1.8)	0.326
Middle-income	**1.9 (0.4, 3.5)**	**0.016**	**1.2 (0.0, 2.4)**	**0.043**	-0.1 (-5.6, 5.5)	0.982
Lowest-income	**3.7 (1.8, 5.5)**	**<0.001**	**2.5 (1.1, 3.9)**	**<0.001**	-1.2 (-7.3, 5.0)	0.698
Current smoker	1.4 (-0.6, 3.4)	0.179	0.6 (-0.9, 2.0)	0.446	2.1 (-4.7, 8.9)	0.540
Ex-smoker	0.1 (-1.2, 1.4)	0.833	0.0 (-0.9, 0.9)	0.956	0.9 (-4.2, 6.0)	0.736
Overweight	**8.3 (6.2, 10.4)**	**<0.001**	**5.5 (3.9, 7.2)**	**<0.001**	-1.8 (-6.8, 3.2)	0.470
Obese	**23.2 (20.4, 26.1)**	**<0.001**	**14.5 (12.1, 16.9)**	**<0.001**	-0.1 (-5.6, 5.3)	0.957
Diagnosed diabetes	**21.7 (15.7, 27.8)**	**<0.001**	**15.7 (11.2, 20.1)**	**<0.001**	-6.1 (-14.7, 2.4)	0.157
Single	1.6 (-0.5, 3.8)	0.133	1.7 (0.0, 3.5)	0.056	-4.9 (-13.3, 3.4)	0.238
Separated/divorced/widowed	0.1 (-1.9, 2.2)	0.886	0.8 (-0.6, 2.3)	0.247	-5.9 (-12.5, 0.8)	0.082

AME: Average marginal effect. The AME of a categorical variable can be interpreted as the average change in the predicted probability that the outcome is equal to one compared to the reference category, holding all other covariates at their observed values. For example, the probability of being hypertensive according to the total definition is 2.1 percentage points higher for men in the lowest-income households than for men in the highest-income households (95% CI: -0.2, 4.4%), holding all other covariates at their reference values. The outcomes showed perfect correlation between the error terms in two equations (ρ=1.0): reflecting that all persons who reported diagnosed hypertension were included in the total prevalence definition. The reference categories were as follows: mean age; income (highest-income), smoking status (never-smoker), BMI (normal-weight), diabetes (no diagnosed diabetes), and marital status (married).

[a]**Total hypertension**: diagnosed or survey-defined hypertension (≥140/90mmHg or current use of BP medicine). [b]**Diagnosed hypertension**: whether a doctor or nurse had ever told the participant that they have high blood pressure (excluding pregnancy). [c]**Undiagnosed hypertension**: did not self-report diagnosed hypertension but were hypertensive according to the total definition (i.e. had BP ≥140/90mmHg and/or reported current use of BP medicine).

Supplemental Digital Content 1: Scholes_hypertension_inequalities_sup_data.pdf

Reference List

1. Lawes CM, Vander Hoorn S, Rodgers A. Global burden of blood-pressure-related disease, 2001. Lancet 2008; **371**: 1513-1518.

2. Crim MT, Yoon SS, Ortiz E, Wall HK, Schober S, Gillespie C et al. National surveillance definitions for hypertension prevalence and control among adults. Circ Cardiovasc Qual Outcomes 2012; **5**: 343-351.

3. Mills KT, Bundy JD, Kelly TN, Reed JE, Kearney PM, Reynolds K et al. Global disparities of hypertension prevalence and control: a systematic analysis of population-based studies from 90 countries. Circulation 2016; **134**: 441-450.

4. Zhou D, Xi B, Zhao M, Wang L, Veeranki SP. Uncontrolled hypertension increases risk of all-cause and cardiovascular disease mortality in US adults: the NHANES III Linked Mortality Study. Sci Rep 2018; **8**: 9418.

5. Chow CK, Teo KK, Rangarajan S, Islam S, Gupta R, Avezum A et al. Prevalence, awareness, treatment, and control of hypertension in rural and urban communities in high-, middle-, and low-income countries. JAMA 2013; 310: 959-968.

6. Leng B, Jin Y, Li G, Chen L, Jin N: Socioeconomic status and hypertension: a meta-analysis. J Hypertens 2015; **33**: 221-229.

7. Blacher J, Levy BI, Mourad JJ, Safar ME, Bakris G. From epidemiological transition to modern cardiovascular epidemiology: hypertension in the 21st century. Lancet 2016; **388**: 530-532.

8. Adler AJ, Prabhakaran D, Bovet P, Kazi DS, Mancia G, Mungal-Singh V et al. Reducing cardiovascular mortality through prevention and management of raised blood pressure. Glob Heart 2015; **10**: 111-122.

9. Zhou B, Danaei G, Stevens GA, Bixby H, Taddei C, Carrillo-Larco RM et al. Long-term and recent trends in hypertension awareness, treatment, and control in 12 high-income countries: an analysis of 123 nationally representative surveys. Lancet 2019; **394**: 639-651.

10. Chatterji P, Joo H, Lahiri K. EXAMINING THE EDUCATION GRADIENT IN CHRONIC ILLNESS. Educ Econ 2015; **23**: 735-750.

11. Johnston DW, Propper C, Shields MA. Comparing subjective and objective measures of health: Evidence from hypertension for the income/health gradient. J Health Econ 2009; **28**: 540-552.

12. Gordon-Larsen P, Attard SM, Howard AG, Popkin BM, Zhang B, Du S et al. Accounting for selectivity bias and correlation across the sequence from

elevated blood pressure to hypertension diagnosis and treatment. Am J Hypertens 2017; **31**: 63-71.

13. Thomas R, Burger R, Hauck K. Richer, wiser and in better health? The socioeconomic gradient in hypertension prevalence, unawareness and control in South Africa. Soc Sci Med 2018; **217**: 18-30.

14. Mindell J, Biddulph JP, Hirani V, Stamatakis E, Craig R, Nunn S et al. Cohort profile: the health survey for England. Int J Epidemiol 2012; **41**: 1585-1593.

15. Egan BM, Zhao Y. Different definitions of prevalent hypertension impact: the clinical epidemiology of hypertension and attainment of Healthy People goals. J Clin Hypertens (Greenwich) 2013; **15**: 154-161.

16. Falaschetti E, Mindell J, Knott C, Poulter N. Hypertension management in England: a serial cross-sectional study from 1994 to 2011. Lancet 2014; **383**: 1912-1919.

17. National Institute for Health and Clinical Excellence (NICE). *Hypertension: clinical management of primary hypertension in adults (update). (Clinical guideline 127).* NICE; 2011.

18. McClements LD. Equivalence scales for children. J Public Econ 1977; **8**: 191-210.

19. Bibby P, Brindley P. *Urban and rural area definitions for policy purposes in England and Wales: Methodology*. Office for National Statistics; 2013.

20. Rao JN, Scott AJ: The analysis of categorical data from complex sample surveys: chi-squared tests for goodness of fit and independence in two-way tables. J Am Statistical Assoc 1981; **76**: 221-230.

21. Heeringa SG, West BT, Berglund PA. *Applied Survey Data Analysis*. Chapman and Hall/CRC; 2010.

22. Greene WH. *Econometric analysis*. 7th edition. New York, NY: Prentice Hall. 2002.

23. Sterne JA, White IR, Carlin JB, Spratt M, Royston P, Kenward MG et al. Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls. BMJ 2009; **338**: b2393.

24. University College London, Department of Epidemiology and Public Health, NatCen Social Research. (2013). Health Survey for England, 2011. [data collection]. UK Data Service. SN: 7260, http://doi.org/10.5255/UKDA-SN-7260-1.

25. University College London, Department of Epidemiology and Public Health, NatCen Social Research. (2014). Health Survey for England, 2012. [data collection]. UK Data Service. SN: 7480, http://doi.org/10.5255/UKDA-SN-7480-1.

26. University College London, Department of Epidemiology and Public Health, NatCen Social Research. (2015). Health Survey for England, 2013. [data collection]. UK Data Service. SN: 7649, http://doi.org/10.5255/UKDA-SN-7649-1.

27. University College London, Department of Epidemiology and Public Health, NatCen Social Research. (2018). Health Survey for England, 2014. [data collection]. UK Data Service. SN: 7919, http://doi.org/10.5255/UKDA-SN-7919-3.

28. University College London, Department of Epidemiology and Public Health, NatCen Social Research. (2017). Health Survey for England, 2015. [data collection]. UK Data Service. SN: 8280, http://doi.org/10.5255/UKDA-SN-8280-1.

29. University College London, Department of Epidemiology and Public Health, NatCen Social Research. (2018). Health Survey for England, 2016. [data collection]. UK Data Service. SN: 8334, http://doi.org/10.5255/UKDA-SN-8334-1.

30. Jiang SZ, Lu W, Zong XF, Ruan HY, Liu Y. Obesity and hypertension. Exp Ther Med 2016; **12**: 2395-2399.

31. Moody A, Cowley G, Ng FL, Mindell JS. Social inequalities in prevalence of diagnosed and undiagnosed diabetes and impaired glucose regulation in participants in the Health Surveys for England series. BMJ Open 2016; **6**: e010155.

32. Keaver L, Pérez-Ferrer C, Jaccard A, Webber L. Future trends in social inequalities in obesity in England, Wales and Scotland. Journal of Public Health 2019; fdz022 [Epub ahead of print].

33. Booth HP, Charlton J, Gulliford MC. Socioeconomic inequality in morbid obesity with body mass index more than 40 kg/m^2 in the United States and England. SSM Popul Health 2017; **3**: 172-178.

34. Saydah S, Bullard KM, Cheng Y, Ali MK, Gregg EW, Geiss L et al. Trends in cardiovascular disease risk factors by obesity level in adults in the United States, NHANES 1999-2010. Obesity (Silver Spring) 2014; **22**: 1888-1895.

35. Lee HY. Socioeconomic disparities in the prevalence, diagnosis, and control of hypertension in the context of a Universal Health Insurance System. J Korean Med Sci 2017; **32**: 561-567.

36. King W, Lacey A, White J, Farewell D, Dunstan F, Fone D. Equity in healthcare for coronary heart disease, Wales (UK) 2004-2010: A population-based electronic cohort study. PLoS One 2017; **12**: e0172618.

37. King W, Lacey A, White J, Farewell D, Dunstan F, Fone D. Socioeconomic inequality in medication persistence in primary and secondary prevention of coronary heart disease - A population-wide electronic cohort study. PLoS One 2018; 13: e0194081.

38. Tolonen H, Koponen P, Mindell JS, Mannisto S, Giampaoli S, Dias CM et al. Under-estimation of obesity, hypertension and high cholesterol by self-reported data: comparison of self-reported information and objective measures from health examination surveys. Eur J Public Health 2014; **24**: 941-948.

39. National Institute for Health and Care Excellence. *Hypertension in adults: diagnosis and management, draft for consultation*. NICE; 2019.

40. Pike H. NICE proposes lower threshold for treating high blood pressure. BMJ; 2019; **364**:I1105.

41. Public Health England. *Health Matters*. London; Public Health England; 2019.

42. Egan BM, Zhao Y, Axon RN. US trends in prevalence, awareness, treatment, and control of hypertension, 1988-2008. JAMA 2010; **303**: 2043-2050.

43. Burgard SA, Chen PV. Challenges of health measurement in studies of health disparities. Soc Sci Med 2014; **106**: 143-150.