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Future trends and inequalities in premature coronary deaths in England: Modelling study

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ABSTRACT

Background: Coronary heart disease (CHD) is a major cause of premature mortality, particularly in deprived groups. Might recent declines in overall mortality obscure different rates of decline among social strata, creating potentially misleading views on inequalities?

Methods: We used a Bayesian analysis of an age–period–cohort model for the English population. We projected age-specific premature CHD mortality (ages 35–74) by gender and area-based deprivation status for the period 2007–2035, using 1982–2006 as the input. Deprivation status was measured by Index of Multiple Deprivation quintiles, which aggregate seven types of deprivation, including health and income.

We analysed inequality in premature CHD mortality. We investigated the annual changes in inequality and the contributions of changes in each IMDQ to the overall annual changes, using both absolute (probability) and relative (logit) scales. We quantified inequality using the statistical variance in the probability of premature death among deprivation quintiles.

Results: The overall premature CHD mortality trends conceal marked heterogeneities. Our models predict more rapid declines in premature CHD mortality for the most affluent quintiles than for the most deprived (annualized rate of decline 2006–2025, 7.5% [95% Credible Interval 4.3–10.5%] versus 5.4% [2.2–8.7%] for men, and 6.3% [3.0–9.9%] versus 5.9% [1.5–10.8%] for women). For men, the posterior probability that the rate of decline is greater for the most affluent was 82%.

Variance in premature CHD mortality across deprivation quintiles was projected to decrease by approximately 81% [28–95%] among men and by 89% [30–99%] among women. This decrease was particularly driven by the most deprived groups due to their higher premature death rates. However, relative inequality was projected to rise by 93% among men [81–125%] and rise by 13% [−25–58%] among women. These increases are also mostly influenced by the most deprived, reflecting their slower declines in premature deaths.

Conclusions: Overall, premature coronary death rates in England continue to decline steeply. Absolute inequalities are decreasing, reflecting declines in the high premature mortality in deprived groups. However, relative inequalities are projected to widen further, reflecting slower mortality declines in the most deprived groups. More aggressive and progressive prevention policies are urgently needed.

1. Background

Coronary heart disease (CHD) is a leading cause of mortality globally. The World Health Organisation has therefore prioritised a 25% reduction in premature CHD mortality by 2025 [1], in addition to declines of 20% observed from 1990 to 2010 [2]. The recent declines in CHD mortality suggest that this target is achievable in England [3,4] and elsewhere in Europe [5]. However, there is substantial socio-economic inequality in rates of premature (age < 75 years) coronary heart disease and death [6–8], which could be hidden if the focus is on a population-level goal. The reduction of inequality is a widely recognized focus for development [9–11] and a policy goal in England [12]. Although this process can be described in terms of absolute and relative socioeconomic differences in CHD mortality, less is known about how changes in each social group contribute to the overall trend.

It has long been established that the lower social classes have higher rates of CHD mortality, even when controlling for prominent risk factors [6]. It is a challenge to maintain rapid progress against CHD in the most deprived socio-economic groups [13,14]. For example, from 1982 to 2006, the absolute difference in age-adjusted CHD mortality between

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the least and most deprived decreased by 37% in men and 46% in women. Meanwhile, the ratio of the age-adjusted CHD mortality between the least and most deprived increased by 80% in men and 40% in women [14]. Maintaining progress against inequality means protecting the access of the most deprived to public health and medical developments.

Recent demographic analyses have highlighted the variance as a useful summary statistic with which to quantify dispersion and understand its change over time [15,16]. It is therefore a promising statistic on which to base investigations of the contributions that changes in population health traits within specific socio-economic groups make to changes in the overall socio-economic inequality in these traits. While much is known about the socioeconomic differentials in past trends of CHD mortality in England, no work has presented the future projections of these trends nor their contribution to inequality change.

In the present study we forecast CHD mortality in England by deprivation status. We apply an age–period–cohort model, which extrapolates past age-specific trends in CHD mortality. We stratified analyses by gender and deprivation status. This model was previously fit for the population of England as a whole (without analysis by deprivation status) [17]. We then apply demographic methods based on the variance to show the contribution of each deprivation status to changes in the inequality of premature CHD mortality, both absolutely and relatively.

2. Methods

2.1. Data

We modelled CHD mortality in England from 1982–2006 by age group, gender, and socioeconomic status and projected the model onto the period 2007–2035 along the same strata. The modelled period (1982–2006) was selected due to data availability, and the projection represents approximately 20 years from the present. Analyses were performed separately for each sex and socio-economic group, using a model that incorporates age-specific CHD mortality rates (described below). We used the Index of Multiple Deprivation (IMD) as a proxy for socioeconomic status. IMD is an area-based metric defined by the United Kingdom's (UK) Office for National Statistics (ONS), which aggregates seven types of deprivation (income, employment, health, education, crime, access to services, living environment) into one number. IMD is defined for 32,482 small areas in England and Wales, having an average population of around 1500 per small area [18]. IMD is typically divided into quintiles (IMDQ) at the small area level, where IMDQ1 is the least deprived and IMDQ5 is the most deprived.

The ONS provided the following information for the English population. First, annual central CHD death rates from 1982–2006 and stratified by 5-year age band (age 35+), sex, and IMDQ were defined by codes 410–414 in the 9th version and I20–I25 in the 10th version of the International Classification of Diseases (ICD). Second, past population counts (1982–2011) and projections (2012–2035, constant fertility assumption) were provided, for both sexes and in 5-year age bands, though not by IMDQ. We grouped data into six age bands (35–44, 45–54, 55–64, 65–74, 75–84, and 85+) for both men and women. More details of the data sources can be found in [14].

Denominators for the mortality calculations are the population in each age group, IMDQ, and gender. For each age group and each sex, the population is not necessarily evenly spread among the IMDQs. Therefore, we calculated the proportion of each age-sex group in each IMDQ in 2007, the most recent year for which we have reliable data. These IMDQ data are in 10-year age bands, which is why we grouped the data for population and CHD mortality in this way. We standardised the age-sex population counts in all other years (1982–2035) to the 2007 values. For example, in 2007, 22.2% of Men 65–74 were in IMDQ1. Therefore, we assumed that 22.2% of Men 65–74 are in IMDQ1 in all years. Setting a standard in this way allowed us to ignore year-to-year fluctuations in IMDQ estimates and to extrapolate the most recent year to all future years.

2.2. Forecast methodology

To model and project CHD death rates, we used an *age–period–cohort* (APC) model [19], which accounts for three effects. First, *age* is the time since birth and captures increasing CHD death rates due to physiological factors associated with aging. Second, *period* is the calendar time and accounts for factors that affect everyone alive at the time. Finally, *cohort* effects are specific to a group born at the same time.

For each IMDQ and gender, CHD mortality [number of deaths in each 10-year age band divided by population in each 10-year age band] from 1982–2006 was used to fit the model, and projections of the number of deaths were made for 2007–2035 based on population estimates. Analysis was conducted using the BAMP software [20], which uses a Bayesian approach to fit an APC model (BAPC). We used an age, period and cohort approach (rather than just age and period [AP]) due to the potential relevance of cohort effects to future trends in CHD death rates, e.g., generational attitudes to diet and lifestyle, especially to allow for the possibility that these have socioeconomic patterns. The APC model fit better than the simpler AP, according to the Deviance Information Criterion (DIC) on the observed period. Details are provided in the Supplementary Information.

BAMP outputs provided samples from the posterior distribution of the age-specific CHD mortality rates. We performed all subsequent calculations (described below) on all posterior samples. We report the median value of these metrics and where applicable the 95% credible interval using the 2.5% and 97.5% percentiles.

2.3. Premature mortality

Our primary metric of interest is premature CHD mortality. We converted the central death rates m_x for each age x ($35 \geq x \leq 65$) over age interval $n = 10$ into the probability of death during each age interval, q_x, assuming that deaths occur on average half-way through the interval, using the formula [21]:

$$q_x = \frac{m_x n}{1 + m_x \frac{n}{2}}. \tag{1}$$

We then computed the probability of survival over the age interval [35, 75) by first computing the probabilities of survival over each age interval, $p_x = 1 - q_x$. The probability of premature death from CHD for each gender and IMDQ in each year was then:

$$P(\text{death before } 75 \mid \text{alive } 35) = 1 - \prod_{x=35}^{75} p_x. \tag{2}$$

Premature mortality and subsequent calculations were performed in R version 3.1.0.

2.4. Measures of inequality

We analysed inequality in premature CHD mortality in several ways. As simple metrics, we report the absolute difference as the difference between IMDQ5 and IMDQ1 and the relative difference as the ratio of IMDQ5 to IMDQ1, all for a given year. Comparisons between other IMDQs and IMDQ1 are provided in Table S2. The lag is also reported, representing the number of years that IMDQ5 is behind IMDQ1. For example, a lag of 10 years would mean that the premature mortality of IMDQ5 does not fall below the premature mortality of IMDQ1 in 2006 until 2016.

We use the variance as a measure of inequality between all groups. We focus on the annual change in variance and decompose the change into the additive contribution from each socioeconomic group. The contribution of group i to the change in variance from time t to time $t+1$ is approximately:

$$\Delta Var[M_t]_i = \frac{2}{N}\left(M_{i,t} - \overline{M}_t\right)\left(\Delta M_{i,t} - \Delta\overline{M}_t\right) \tag{3}$$

where M is any health metric of interest (premature CHD mortality probability in our case), N is the number of groups (5 IMDQs for each gender), and Δ is the change from time t to time $t+1$. The sum of the group-specific components equals the overall change in variance. Formula (3) describes the contribution of group i to the change in variance due to its effect on the dispersion among groups, and its effect on the overall population mean. Supplementary Information shows the derivation of formula (3) and the exact version used to produce Fig. 4.

2.5. Removing the influence of population-level trends

We define a population-level change in premature mortality as a change among all socioeconomic groups. Underlying this population-level effect, there can be variation in the group-specific rates of change. This defines the difference between changes in absolute and in relative inequality among multiple groups: absolute inequality is sensitive to all changes; relative inequality is sensitive only to differences in the rates of change among groups.

To analyse changes in relative inequality, we use the *logit* transformation of the probabilities of premature death from CHD. In the Supplementary Information, we show by simulation that this has the effect of removing scale dependence. In terms of formula (3), absolute inequality is assessed using premature CHD mortality as the metric M, while relative inequality is represented by the *logit* of the premature CHD mortality as M. We are thus able to apply formula (3) to investigate the changes in both absolute and relative inequality.

3. Results

3.1. Forecasts by socioeconomic group

Since 1982, coronary heart disease (CHD) mortality has declined dramatically for both men and women aged over 35 years in all socioeconomic groups. Fig. 1 shows the CHD deaths per 100,000 by age group, gender, and IMDQ for the first and last years of available data (1982 and 2006) and projected a further 24 years (2030). In the