RESEARCH REPORT

Is the rate of biological aging, as measured by age at diagnosis of cancer, socioeconomically patterned?

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Study objective: To investigate the hypothesis that biological aging, as measured by age at diagnosis of some common cancers, is socioeconomically patterned.

Design: A cross sectional analysis of the association between an area based measure of material deprivation and age at diagnosis of four common cancers (breast, prostate, colorectal, and lung cancers).

A further analysis, restricted to breast and colorectal cancer, adjusted for stage and grade of cancer at diagnosis.

Setting: The Northern and Yorkshire cancer registry and information service, Northern and Yorkshire region, UK.

Participants: All people living in the Northern and Yorkshire region diagnosed with breast, prostate, colorectal, or lung cancer in 1986–1995. All people living in the Northern and Yorkshire region diagnosed with breast or colorectal cancer in 1998–2000 with data on stage and grade of cancer at diagnosis.

Main results: There was evidence that greater material deprivation was associated with younger age at diagnosis of cancer in prostate (β coefficient: −0.073), colorectal (women: −0.042; men: −0.063), and lung cancer (women: −0.214; men: −0.161). The opposite association was found in women with breast cancer (0.149). Adjusting for stage and grade at incidence, where possible, had little effect on the magnitude of the β coefficients.

Conclusions: Age at diagnosis of some common cancers seems to be socioeconomically patterned with people from more deprived areas being diagnosed with prostate, colorectal, and lung cancers earlier in life. The opposite was seen in women with breast cancer. Further work is required to investigate the socioeconomic distribution of more accurate measures of biological aging.

Socioeconomic differences in health (SEDH) have been widely reported and seem to be universal. However, the precise biological pathways linking socioeconomic position (SEP) and health remain unclear. Although differential exposure to specific risk and protective factors is often cited as one of the key determinants of SEDH, the relation between SEP and specific risk and protective factors is not straightforward and seems to vary across both time and space. This challenges risk factor specific explanations of SEDH—as soon as prevailing risk factors change, so too must associated explanations of SEDH.

An alternative explanation of SEDH is that more fundamental pathways to health and disease exist and that specific risk and protective factors feed into these fundamental pathways. While the socioeconomic distribution of specific risk and protective factors may vary over time, the socioeconomic distribution of overall risk seems to be fairly constant in developed countries. Sociologists have offered a number of explanations for why socioeconomically deprived groups tend to experience the least healthy risk factor profiles in society.

One possible fundamental, biological mechanism of SEDH is biological aging (fig 1). This is the progressive decrease in physiological ability to meet demands that occurs over time and is currently understood to be attributable to the accumulation of damage at the cellular level. The rate of accumulation of cellular damage is determined by the balance between cellular damage occurring and the action of cellular defence and repair mechanisms. Cellular defence and repair mechanisms include antioxidant vitamins and enzymes and DNA checking and repair enzymes.

Unlike chronological aging, there is considerable variation between individuals in the rate of biological aging. Both genetic and environmental factors play a part and numerous environmental factors, known to be socioeconomically patterned, are now known to influence the rate of cellular damage accumulation, including cigarette smoking, diet, and exposure to radiation.

Furthermore, there is good reason to believe that biological aging and the accumulation of cellular damage are important determinants of health. Population based research suggests that some crude markers of aging, such as total and healthy life expectancy, are socioeconomically patterned. However, no research, to date, has attempted to investigate the socioeconomic distribution of more accurate measures of biological aging. Cancers are attributable, at the most proximate level, to acquired or inherited mutations in genes that control growth—specifically, oncogenes and tumour suppressor genes. As genetic mutations are one, well recognised, type of cellular damage, the development of cancer can be understood as being closely related to the processes involved in biological aging. Chronological age of development of cancer can, therefore, be used as a comparative measure of biological aging.

Abbreviations: SEP, socioeconomic position; SEDH, socioeconomic differences in health; NYCIRS, Northern and Yorkshire Cancer Registration and Information Service.
Is biological aging socioeconomically patterned?

We investigated the effect of SEP on the age of development of some common cancers using data from a population based cancer registry.

METHODS
The Northern and Yorkshire Cancer Registration and Information Service (NYCRIS) is one of nine regional cancer registries in England that aims to collect data on all incident cancers as they occur. We used data held by NYCRIS to investigate the effects, if any, of SEP on age at diagnosis of cancer.

Variables of interest
SEP was measured using Townsend deprivation scores (TDS) of the enumeration district of residence at date of diagnosis of cancer calculated from full seven digit postcode data and standardised to the NYCRIS region as a whole using data from the 1991 census. A positive TDS represents more material deprivation while a negative score represents less material deprivation.

Age at diagnosis of cancer was calculated from incident date and date of birth. As is routine in UK cancer registries, incident date was defined as the first available (not necessarily earliest) date from: date of pathologically confirmed diagnosis, date of first hospital attendance during which a clinical diagnosis was made, date of diagnosis by a GP, and date of death.

Cancer site was assigned using three figure codes from the 10th revision of the International Classification of Diseases (ICD-10) as extrapolated from clinical records and recorded in the NYCRIS database. We restricted the analysis to the four commonest non-skin cancer sites: breast (ICD-10 C50), colorectal (ICD-10 C18, C19 or C20), lung (ICD-10 C33 or C34), and prostate cancer (ICD-10 C61).

Sample size and study years
As no previous work in this area has been reported, we were unable to perform sample size or power calculations. Instead, we adopted a pragmatic approach aiming to use as large a sample size as possible. This was, however, restricted by our measure of SEP, TDS, which are calculated from decennial UK census data. To avoid using data from more than one census, we restricted ourselves to 10 years of NYCRIS data and chose to centre our data collection years around a census year so that the maximum temporal extrapolation of census data would be five years. The most recent census year for which data could be extrapolated five years both backwards and forwards was 1991. We therefore chose 1986–1995 inclusive as our study years.

Further analysis to assess the effects of adjusting for stage and grade at diagnosis
Using the method described to determine incident date, and therefore age at diagnosis, does not necessarily result in comparable data for all individuals. To minimise any bias or error introduced by this method, we wished to adjust for stage and grade of cancer at diagnosis. However, these data were far from complete for the main study cohort and it was estimated that the only cohorts with more than 50% complete data on stage and grade were individuals registered with colorectal and breast cancers since 1998. We, therefore, performed a further analysis, using similar methods as the main study, which investigated the effect of adjusting for stage and grade at diagnosis on the relation between age and TDS at diagnosis. This analysis used data on colorectal and breast cancers registered between 1998 and 2000 inclusive.

Exclusions
People were excluded from the analysis if: key data were missing, registration had been by death certification only.

Table 1 Distribution of age and Townsend deprivation score at diagnosis of cancer (1986–1995 cohort)

<table>
<thead>
<tr>
<th>Cancer Type</th>
<th>Before exclusion of youngest 25% at diagnosis</th>
<th>After exclusion of youngest 25% at diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age Median</td>
<td>TDS IQR</td>
</tr>
<tr>
<td>Prostate cancer</td>
<td>7107</td>
<td>74 80</td>
</tr>
<tr>
<td>Breast cancer, women</td>
<td>34265</td>
<td>62 63</td>
</tr>
<tr>
<td>Colorectal cancer, women</td>
<td>14872</td>
<td>74 29</td>
</tr>
<tr>
<td>Colorectal cancer, men</td>
<td>18053</td>
<td>70 30</td>
</tr>
<tr>
<td>Lung cancer, women</td>
<td>18116</td>
<td>69 78</td>
</tr>
<tr>
<td>Lung cancer, men</td>
<td>35273</td>
<td>70 03</td>
</tr>
</tbody>
</table>

IQR, interquartile range; TDS, Townsend deprivation score.
and therefore the date of incidence had been recorded as the date of death), or the incident cancer was a second primary. Men with breast cancer were excluded because of the rarity of this condition.

A proportion of individuals inherit a specific genetic defect that puts them at high risk of developing a cancer early in life. We felt that such individuals formed a distinct group and should not be included in the present analyses because of our focus on environmental factors. As cancer registries do not routinely record information on inherited susceptibilities to cancer, we excluded the youngest 25% of individuals, at diagnosis, from each cancer and gender specific group as a conservative approach to removing all those whose cancer may include a substantial inherited component.

**Analysis**

Data were analysed in gender and cancer site specific groups throughout. Linear regression techniques were used to assess the ability of TDS at diagnosis to predict age at diagnosis of cancer both before, and in the case of the 1998–2000 cohort, after adjustment for stage and grade of cancer at diagnosis. Neither age nor TDS was normally distributed in any of the gender and cancer site specific groups. As simple transformation did not result in appreciably more normal distributions of these variables, bootstrapping methods, with 1000 repetitions, were used to generate confidence intervals for \( \beta \) coefficients derived from linear regression techniques. All analyses were performed in Intercooled Stata version 8.0.

**RESULTS**

**The 1986–1995 cohort**

Between 1 January 1986 and 31 December 1995, 144 627 cases of lung, colorectal, prostate, and breast cancer were registered with NYCRIS. Of these, 39 301 (27.2%) met one of the exclusion criteria, including the age cut off, leaving 105 326 individuals in the analysis.

Table 1 shows the distribution of age and TDS at diagnosis in the 1986–1995 cohort before and after exclusion of the youngest 25% of individuals at diagnosis. In the cohort included in the analysis, women with breast cancer were youngest (median age 67.84) and women with colorectal cancer oldest (median age 78.05) at diagnosis. In addition, women with breast cancer were least deprived (median TDS = 0.50) and women with lung cancer most deprived (median TDS 1.28) at diagnosis. While exclusion of the youngest 25% at diagnosis led to an overall increase in the affluence of the cohorts with lung cancer, the opposite was seen in the other groups.

Table 2 shows the results of simple linear regression analysis of the ability of TDS at diagnosis to predict age at diagnosis. The 95% confidence intervals of the \( \beta \) coefficients of TDS at diagnosis excluded unity in all cases. The negative \( \beta \) coefficients seen in relation to prostate (\( \beta \) coefficient = 0.073), colorectal (women: −0.042; men: −0.063), and lung cancer (women: −0.214; men: −0.161) suggest that people living in more deprived areas tended to have these cancers diagnosed earlier in life than those living in more affluent areas. These coefficients equate to a variation in age at diagnosis of cancer of between 0.21 (colorectal cancer, women) and 1.07 years (lung cancer, women) across the interquartile range of TDS.

Among women with breast cancer, the \( \beta \) coefficient of TDS at diagnosis was positive (0.149) suggesting that women living in more deprived areas tend to have breast cancer diagnosed later in life than those living in more affluent areas. This equates to a variation of 0.72 years in age at diagnosis across the interquartile range of TDS.

**The 1998–2000 cohort**

There were 25 314 cases of colorectal and breast cancer registered with NYCRIS between 1 January 1998 and 31 December 2000. Of these, 11 445 (45.2%) were excluded from the analysis—almost half of these exclusions were made on the grounds of missing stage or grade data. There was evidence that those excluded from the analysis on the grounds of missing stage or grade data were from more deprived neighbourhoods than those included (p<0.0001) and were older (p<0.0001). Table 3 shows the distribution of

Table 2. Linear regression models of the ability of Townsend deprivation score to predict age at diagnosis of cancer (1986–1995 cohort).

<table>
<thead>
<tr>
<th>Cancer Site</th>
<th>( \beta ) coefficient</th>
<th>95% CI</th>
<th>( t ) Test</th>
<th>( p ) value</th>
<th>Adjusted ( r^2 )</th>
<th>Change in age (y)/</th>
<th>TDS IQR†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast cancer</td>
<td>−0.073</td>
<td>−0.106 to −0.041</td>
<td>−4.446</td>
<td>&lt;0.0001</td>
<td>0.001</td>
<td>−0.36</td>
<td></td>
</tr>
<tr>
<td>Breast cancer, women</td>
<td>0.149</td>
<td>0.109 to 0.193</td>
<td>7.018</td>
<td>&lt;0.0001</td>
<td>0.002</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>Colorectal cancer, men</td>
<td>−0.042</td>
<td>−0.081 to −0.004</td>
<td>−2.070</td>
<td>0.039</td>
<td>&lt;0.001</td>
<td>−0.21</td>
<td></td>
</tr>
<tr>
<td>Colorectal cancer, women</td>
<td>−0.053</td>
<td>−0.100 to −0.027</td>
<td>−3.367</td>
<td>0.001</td>
<td>0.001</td>
<td>−0.33</td>
<td></td>
</tr>
<tr>
<td>Lung cancer, women</td>
<td>−0.214</td>
<td>−0.252 to −0.177</td>
<td>−11.350</td>
<td>&lt;0.0001</td>
<td>0.009</td>
<td>−1.07</td>
<td></td>
</tr>
<tr>
<td>Lung cancer, men</td>
<td>−0.161</td>
<td>−0.185 to −0.136</td>
<td>−12.886</td>
<td>&lt;0.0001</td>
<td>0.006</td>
<td>−0.82</td>
<td></td>
</tr>
</tbody>
</table>

*95% Confidence intervals (bias corrected) of \( \beta \) derived from bootstrapping with 1000 repetitions; †change in age at diagnosis of cancer across the interquartile range in Townsend deprivation score from lower (most affluent) quartile to upper (most deprived quartile).
Table 4  Linear regression models of the ability of Townsend deprivation score to predict age at diagnosis of cancer before and after adjustment for, stage and grade at diagnosis (1998–2000 cohort)

<table>
<thead>
<tr>
<th>Cancer Type</th>
<th>Unadjusted</th>
<th>Adjusted for stage and grade at diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>95% CI</td>
</tr>
<tr>
<td><strong>Breast cancer</strong></td>
<td>0.227</td>
<td>0.159 to 0.296</td>
</tr>
<tr>
<td><strong>Colorectal cancer</strong></td>
<td>0.009</td>
<td>-0.074 to 0.079</td>
</tr>
<tr>
<td><strong>Women</strong></td>
<td>-0.056</td>
<td>-0.119 to 0.012</td>
</tr>
</tbody>
</table>

| 95% Confidence intervals (bias corrected) of $\beta$ derived from bootstrapping with 1000 repetitions; $t$ change in age at diagnosis of cancer across the interquartile range in Townsend deprivation score from lower (most affluent) quintile to upper (most deprived) quintile. |

**Key points**
- Rate of biological aging may mediate the relation between socioeconomic position and health and age at diagnosis of cancer may be a comparative marker of biological aging with earlier age at diagnosis being indicative of faster biological aging.
- More deprived people tended to develop colorectal, lung, and prostate cancer earlier in life than more affluent people. The opposite trend was seen in relation to breast cancer.

**Policy implications**
If the rate of biological aging is confirmed as mediating the relation between socioeconomic position and health, targeting interventions that reduce the rate of biological aging at deprived populations may help reduce socioeconomic variations in health.
large prospective screening study with a short time span between screens. Our analyses have provided preliminary data in this area without recourse to such a lengthy and resource intensive study.

In addition to using date of diagnosis as a proxy for date of development of cancer, we also used it as a proxy for biological aging. Although we believe that age at diagnosis of cancer is a useful comparative clinical marker of the rate of biological aging, the pathways between biological aging and diagnosis of cancer are long and complex and the cellular damage responsible for cancer is not necessarily the same cellular damage responsible for biological aging. The results presented here can only begin to untangle the relations, if any, between SEP and biological aging.

Because our hypothesis focuses on environmental risk and protective factors, we felt that it was important to exclude individuals with cancers that had a substantial inherited component. This was done, somewhat arbitrarily, by excluding the youngest 25% of each gender and site specific group on the basis that inherited cancers are likely to occur earlier in life than sporadic ones, with inevitable knock on effects on the age and TDS distributions of the cohorts used in the analyses.

However, the division between cancers with a large inherited component and those that are primarily sporadic is not clear cut and not all of the 25% of cancers occurring at the youngest ages will necessarily have a predominant inherited component, nor will all cancers with a strong inherited component necessarily occur within this age group.

Furthermore, despite the statistical significance of the influence of TDS on age at diagnosis found, the effect sizes seen were small with a standard deviation change in TDS at diagnosis resulting in less than a year change in age at diagnosis of cancer. The inaccuracies in our measure of biological aging and the effects of unknown confounders may contribute to the minimal effect size seen and further research investigating socioeconomic variations of more accurate markers of biological aging is warranted.

We have identified two possible explanations for the main finding that age at diagnosis of prostate, colorectal, and lung cancer decreases with increasing deprivation of the area of residence. Firstly, it is possible that the cancers that individuals across the socioeconomic range develop are biologically different in some way that leads to variations in age of onset. It has been highlighted that not all cancers, even of the same tissue, involve the same disease process.

Given the different environmental risks and hazards, and therefore carcinogens, that individuals across the socioeconomic range are exposed to, it is possible that the cancers that occur at the youngest ages will necessarily have a predominant inherited component, nor will all cancers with a strong inherited component necessarily occur within this age group.

Conclusions

By providing evidence that the age at diagnosis of some common cancers is socioeconomically patterned, this study provides preliminary evidence that the rate of biological aging may also be socioeconomically patterned. Furthermore, we found little evidence that socioeconomic variations in diagnostic delay—as measured by stage or grade of cancer at diagnosis—were confounding the relations seen. To further investigate the relation between SEP and biological aging, studies using longitudinal measures of individual socioeconomic circumstances across the life course and measures of the actual process of biological aging at the cellular level, rather than the clinical outcomes of it, will be required.

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Conflict of interest: none declared.

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