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Contrasting socio-economic influences on colorectal cancer incidence and survival in England and Wales

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A B S T R A C T

Colorectal cancer (CRC) is the third most commonly diagnosed cancer in the world and second most common cause of cancer death. The relationship between socio-economic deprivation and CRC incidence is unclear and previous findings have been inconsistent. There is stronger evidence of an association between area-level deprivation and CRC survival; however, few studies have investigated the association between individual-level socio-economic status (SES) and CRC survival.

Data from the Office for National Statistics Longitudinal Study (LS) in England and Wales was used. LS members aged 50+ were stratified by individual-level educational attainment, social class, housing tenure and area deprivation quintile, measured at the 2001 Census. Time-to-event analysis examined associations between indicators of SES and CRC incidence and survival (all-cause and CRC death), over a 15-year follow-up period.

Among 178116 LS members, incidence of CRC was lower among those with a degree, compared to those with no degree and higher among those employed in manual occupations compared to non-manual occupations. No clear relationship was observed between CRC incidence and the area-based measure of deprivation.

Disparities were greater for survival. Among 5016 patients diagnosed with CRC aged 50+, probability of death from all-causes was lower among those with a degree, compared to no degree and higher among those employed in manual occupations, compared to non-manual occupations and among those living in social-rented housing, compared to owner-occupiers. Individual indicators of SES were also associated with probability of death from CRC. Those living in the most deprived areas had a higher probability of death (from all-causes and CRC) compared to those in the least deprived areas.

Both individual and area-based indicators of SES were associated with CRC survival, and the relationships were stronger than those observed for CRC incidence. These findings could help inform more effective targeting of public health interventions for CRC.

1. Introduction

Colorectal cancer is the fourth most common cancer in the UK and the second most common cause of cancer death. Each year, over 42,000 people are diagnosed with colorectal cancer in the UK and there are over 16,000 deaths (Cancer Research UK, 2021).

For most cancer types in England, incidence is higher among those living in the most deprived areas compared to the least deprived areas (Cancer Research UK, 2021). The deprivation gap in incidence rates is largest for lung cancer, while conversely, there are some cancers for which incidence rates are highest among people living in the least deprived areas, for example breast cancer in females and prostate cancer in males (Tweed et al., 2018).

The association between area-based socio-economic deprivation and colorectal cancer incidence is less clear than for other cancer types and there is evidence that the direction of association has changed over recent decades. No association was found between area-based deprivation and incidence of colorectal cancer in England in patients followed-up between 1987 and 1992 (Pollock and Vickers, 1997), but subsequently, a deprivation gradient in rectal cancer for males was reported in England and Wales (Quinn et al., 2001). Since then, a clear association between colorectal cancer incidence and area-based deprivation in

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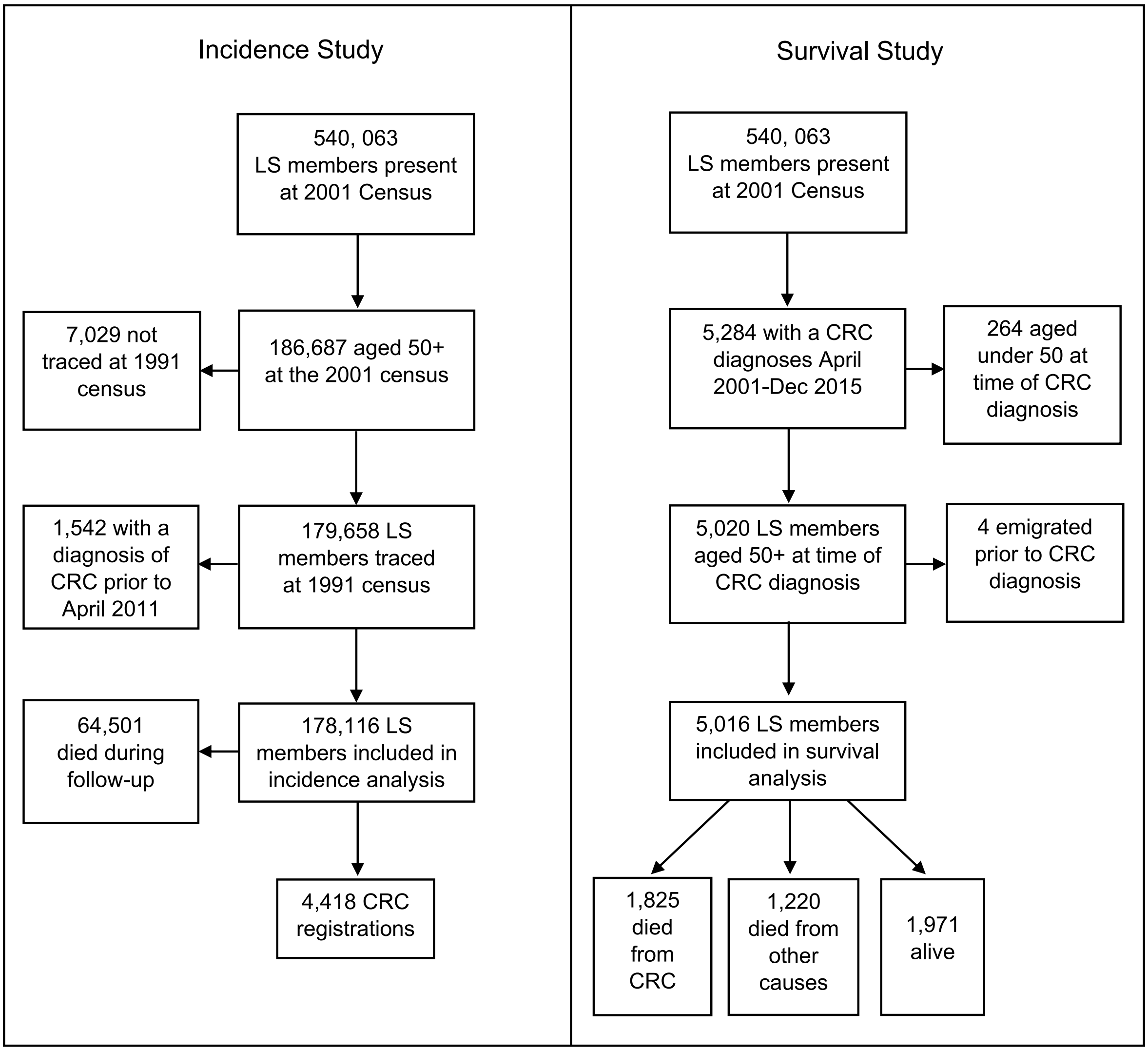

Fig. 1. Flow diagram outlining inclusions and exclusions to study cohorts.

men has emerged in England (National Cancer Intelligence Network, 2014) and Scotland (Oliphant et al., 2011). More recently, a deprivation gradient in colorectal cancer in women has been reported in Scotland (Tweed et al., 2018).

Most research on socio-economic disparities in cancer has looked at differences by indicators of deprivation measured at the area-level (largely because cancer registries do not collect data on individual-level indicators of socio-economic status), however, a study of colorectal cancer incidence by individual-level socio-economic status also found trends in colorectal cancer incidence in England and Wales were inconsistent over time (Brown et al., 1998). When social class based on occupation was measured at the 1971 Census, women in more advantaged social groups experienced higher colorectal cancer incidence, but when social class from the 1981 Census was used, the direction of the association appeared to have changed, with higher incidence in the least advantaged groups. Given the apparent shift in the relationship between socio-economic deprivation and colorectal cancer incidence, continued monitoring is needed with more recent data to see if the patterns are changing.

There is stronger evidence for socio-economic differences in cancer survival. Significantly lower survival rates among adults living in the most deprived areas compared to those living in the least deprived areas have consistently been reported in England and Wales across many cancer types (Coleman et al., 2004; Woods et al., 2006), including colorectal cancer (Pollock and Vickers, 1997). Furthermore, the deprivation gap in cancer survival has widened. Survival rates from colon and rectal cancer increased during the 1990s, but improvements in survival were notably faster among patients in the least deprived areas compared to those in the most deprived areas, and as a result the deprivation gap in survival became significantly steeper (Coleman et al., 2004). This suggests that more affluent patients may have benefited preferentially from progress in early diagnostic procedures and in access to optimal treatment over this period. Reducing socio-economic inequalities in cancer outcomes is a priority in public health policy in the UK (NHS England, 2019). It is estimated that removing cancer-related inequalities in survival would result in a substantial gain in life years (Syriopoulou et al., 2019) and an estimated annual reduction of nearly 700 deaths in England (Møller et al., 2012), which highlights the importance of efforts to eliminate these differences.

Again, while most studies on inequalities in cancer-survival have measured deprivation at the area-level, some studies have reported differences in cancer survival by individual-level indicators of socio-economic status. For example, Sloggett et al. (2007) found that socio-economic differentials in survival from colorectal cancer varied by indicator used, whereby household access to a car and housing tenure were significantly associated with colorectal cancer survival (poorer survival with lower socio-economic status) but no association was apparent by social class based on occupation or the Carstairs measure of

Table 1
Demographic characteristics of study cohort by colorectal cancer case/non-case during follow-up (April 2001–December 2015). Data source: ONS LS.

Variable	Category	Total	Missing		Case		Non-case	
		n	n	%	n	%	n	%
Total		1,78,116			4,418	2.5	1,73,698	97.5
Sex			0	0				
	Male	81,802			2,378	2.9	79,424	97.1
	Female	96,314			2,040	2.1	94,274	97.9
Age group			1	0.001				
	50–59	67,234			1,039	1.5	66,195	98.5
	60–69	50,317			1,508	3.0	48,809	97.0
	70–79	39,256			1,374	3.5	37,882	96.5
	80+	21,308			497	2.3	20,811	97.7
Ethnic group			48	0.03				
	White	1,70,367			4,313	2.5	1,66,054	97.5
	Black	1,686			35	2.1	1,651	97.9
	Indian/Pakistani/Bangladeshi	4,887			51	1.0	4,836	99.0
	Chinese/Mixed/Other	1,128			19	1.7	1,109	98.3
Marital status			1	0.001				
	Married	1,14,434			2,942	2.6	1,11,492	97.4
	Separated/Divorced/Widowed	52,024			1,226	2.4	50,798	97.6
	Single	11,657			250	2.1	11,407	97.9
Educational attainment			1409	0.8				
	No degree	1,54,152			3,891	2.5	1,50,261	97.5
	Degree	22,555			497	2.2	22,058	97.8
Occupational social class			34,431	19.3				
	Non manual	78,804			1,884	2.4	76,920	97.6
	Manual	64,881			1,694	2.6	63,187	97.4
Housing tenure			4271	2.4				
	Owner occupied	1,36,239			3,437	2.5	1,32,802	97.5
	Privately rented	9,503			229	2.4	9,274	97.6
	Social rented	28,103			713	2.5	27,390	97.5
Area deprivation			32	0.02				
	1- Least deprived	78,444			2,021	2.6	76,423	97.4
	2	42,669			1,068	2.5	41,601	97.5
	3	27,624			655	2.4	26,969	97.6
	4	20,022			452	2.3	19,570	97.7
	5 - Most deprived	9,325			222	2.4	9,103	97.6

relative area deprivation. A recent study found both individual and area-level effects on colorectal cancer survival in both men and women but no evidence of contextual effects for this cancer type (Ingleby et al., 2022).

More research is needed using a range of both individual-level indicators of socio-economic status and area deprivation to better understand whether differences are due to individual-level factors (such as health literacy, occupational health, barriers to accessing healthcare due to income) or area-level factors (such as resource allocation and transport links). This will enable more effective targeting of public health interventions towards particular groups of people or types of places. The nature of these disparities needs to be understood for both incidence of colorectal cancer and survival, to inform public health messaging around disease risk factors, prevention, and treatment.

This study aims to investigate the association between both individual-level socio-economic indicators and area-based deprivation and colorectal incidence and survival using population-based cancer registration data linked to detailed socio-demographic information from the census.

2. Methods

2.1. Data sources

This analysis used data from the Office for National Statistics (ONS) Longitudinal Study (the LS), a census-based multi-cohort study. The census is a survey of all people and households in England and Wales that takes place every 10 years. The LS uses four undisclosed birth dates to select a random, 1% sample of the population of England and Wales (Shelton et al., 2018). New members enter the study via birth or by immigration (if born on an LS birth date) and existing members exit the study through death or emigration. Census data from five successive censuses (1971–2011) are currently available for both LS members and their households. Administrative data regarding life events, such as cancer registrations, death registrations and embarkations, can be individually-linked to LS members. To link a cancer registration to a LS record, the LS member must be traced (have an NHS number recorded at NHS Central Register) at the time of the cancer registration. Cancer diagnoses are categorised using the World Health Organisation International Classification of Diseases and Related Health Problems (ICD) coding system (World Health Organisation, 2019).

The LS database is updated with death registrations annually by year of registration with a two-year delay. The death data in the LS was available for information on deaths up to and including 2016. Cause of death information is coded using the WHO ICD coding system.

The incidence analysis cohort included LS members in England and Wales who were present at the 2001 Census and who were aged 50 years or over in April 2001. This age group was chosen as incidence of colorectal cancer among people aged under 50 is very low and hence there were only a small number of colorectal cancer registrations among LS members in this age group. Furthermore, there is some evidence that disease aetiology is different among younger adults (under 50) than older adults (Araghi et al., 2019). The cohort were followed-up and first primary colorectal cancer (ICD-10 codes C18-21) registrations recorded until December 31, 2015 (the latest available full-year of linkage to cancer registry data). Only LS members traced to the NHS Central Register were included in the study cohort. LS members with a colorectal cancer diagnosis prior to the start of the follow-up period were excluded from the analysis.

For the analysis of colorectal cancer survival, the study cohort comprised LS members diagnosed with colorectal cancer at age 50 and over between April 2001 and December 2015 and followed-up until

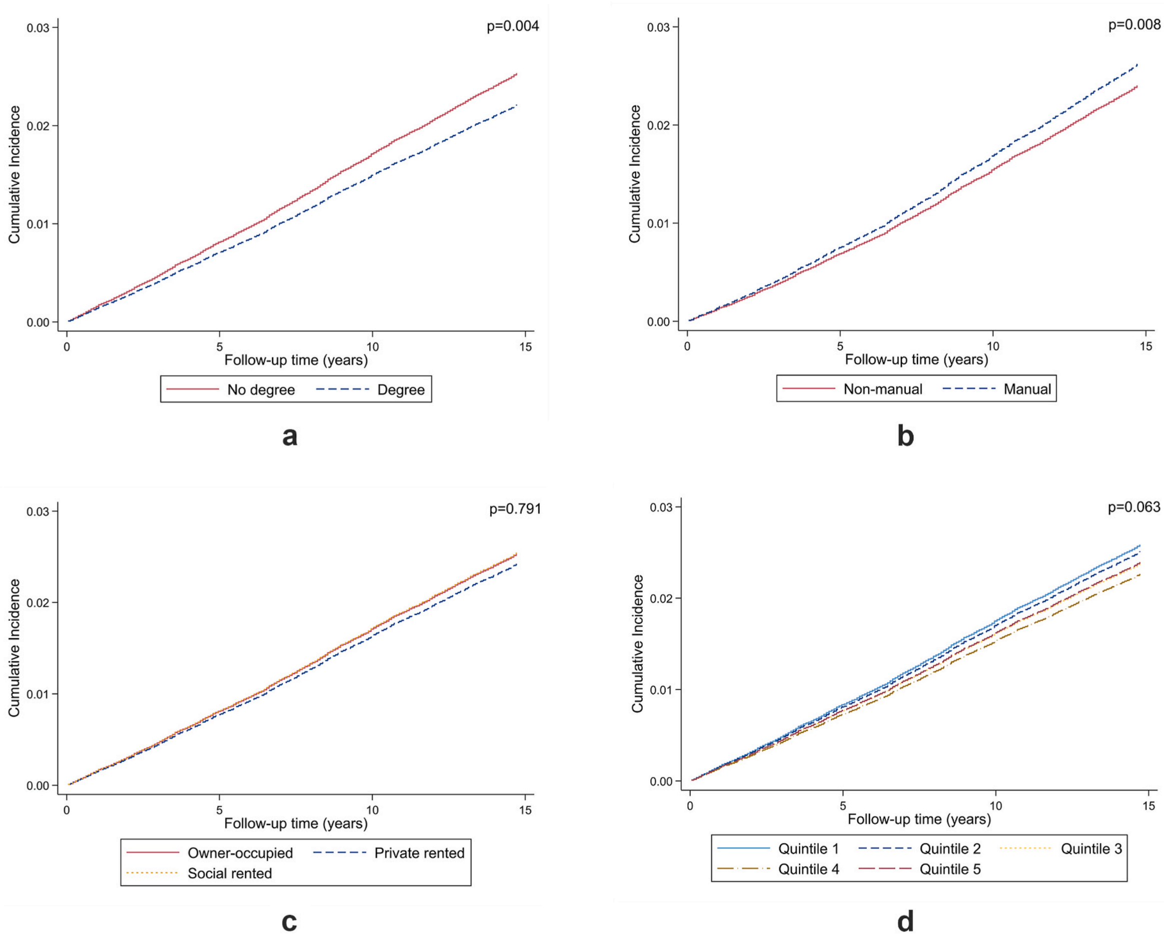

Fig. 2. Cumulative incidence (CIF) estimates of colorectal cancer registration by: educational attainment (a); social class (b); housing tenure (c); and area deprivation (d). Data source: ONS LS.

December 2016. Deaths of LS members were identified from the linked death registration event data and those deaths for which colorectal cancer (ICD10 C18-21) was recorded as the underlying cause of death were flagged.

Data from the 2001 Census was used to group LS members according to three established individual-level indicators of socio-economic status: educational attainment, occupational social class and housing tenure. These measures were chosen to capture the range of socio-economic circumstances which may influence health outcomes.

Educational qualifications were categorised into two groups based on higher education attainment: degree and no degree. Information regarding educational attainment was infilled from the previous census in 1991 for study members aged 75 and over for which this question was not applicable in 2001. Only those LS members aged 50+ in 2001 were included in this study, therefore it is unlikely that someone's level of educational attainment would have changed since the previous census, so this was considered an appropriate method to increase the proportion of members allocated to a category.

Occupational social class was categorised as one of two broad types, based on the Registrar General Social Class classification: non-manual (professional, intermediate, skilled non-manual) and manual (skilled manual, semi-skilled manual, unskilled manual). Again, this information was infilled from the 1991 Census for study members aged 75 and over in 2001.

Housing tenure was categorised as: owner-occupied (owned outright, owned with a mortgage or loan, shared ownership), privately rented (private landlord or letting agency, employer of a household member, relative or friend of household member, other, lives rent free) or social rented (rented from council, other social rented). People living in communal establishments or missing housing tenure information were not included in the analysis.

Marital status was grouped into three categories: married (including first marriage and re-marriage); separated, divorced or widowed; and single (never married).

The 16 ethnic groups in the 2001 classification were combined into four categories (White, Black, Indian/Pakistani/Bangladeshi, Chinese/Mixed/Other) due to low numbers of cancer registrations in some ethnic groups.

In addition, area-based deprivation was measured using the Townsend Deprivation Index, a census-based composite score based on levels of unemployment, non-home ownership, household over-crowding and non-car-ownership (Townsend et al., 1988). The Townsend Deprivation Index scores were categorised into quintiles (1 = least deprived, 5 = most deprived) based on relative deprivation of areas over time (Norman and Riva, 2012). A Townsend quintile was appended to each LS member's record based on their small-area of residence, Lower Layer Super Output Area (LSOA).

2.2. *Statistical analysis*

Time-to-event analysis was used to examine the association between indicators of socio-economic status and three outcomes: colorectal cancer registration, death from all-causes and death from colorectal cancer.

In the analysis of colorectal cancer incidence, the 'event' was a registration of colorectal cancer. Time (in months) was calculated for

Table 2
Subhazard ratios of risk of colorectal cancer registration for study sample followed-up April 2001–December 2015. Data source: ONS LS.

Variable	Category	Model 1		Model 2	
		SHR [95% CI]	p-value	SHR [95% CI]	p-value
Educational attainment	No degree	1		1	
	Degree	**0.87 [0.79–0.96]**	**0.004**	0.94 [0.86–1.04]	0.229
Social class	Non manual	1		1	
	Manual	**1.09 [1.02–1.17]**	**0.008**	1.00 [0.93–1.07]	0.979
Housing tenure	Owner occupied	1		1	
	Private rented	0.96 [0.84–1.09]	0.512	0.99 [0.85–1.17]	0.95
	Social rented	1.01 [0.93–1.09]	0.898	1.01 [0.91–1.12]	0.84
Area deprivation	1 - Least deprived	1		1	
	2	0.97 [0.90–1.05]	0.444	0.96 [0.89–1.03]	0.287
	3	0.92 [0.84–1.00]	0.061	**0.91 [0.83–0.99]**	**0.038**
	4	**0.87 [0.79–0.97]**	**0.01**	**0.88 [0.80–0.98]**	**0.017**
	5 - Most deprived	0.92 [0.81–1.06]	0.27	0.97 [0.85–1.12]	0.716

Model 1 is unadjusted. Model 2 is adjusted for: age, sex, ethnicity and area deprivation (Educational attainment model); age, sex, ethnicity, educational attainment, area deprivation (Social class model); age, sex, education, social class, marital status and area deprivation (Housing tenure model); age and ethnicity (Area deprivation model).

each member of the study cohort from the start of the follow-up period (April 2001) to the earliest date of either diagnosis of colorectal cancer, exit from the study or the end of follow-up (December 2015). If an individual died during follow-up (before being diagnosed with colorectal cancer) this was regarded as a competing event.

Competing risks regression models using the Fine and Gray approach were used to assess the probability of being diagnosed with colorectal cancer in the presence of competing events (death during follow-up). The cumulative incidence function (CIF) was calculated by indicator of socio-economic status using the stcrreg command in Stata and unadjusted CIFs were plotted. Multivariable competing risk regression models were then constructed to examine the hazard (expressed as the subhazard ratio) of colorectal cancer registration by indicator, adjusted for confounders.

When the outcome of interest was death from all-causes, time (in months) was calculated from diagnosis of colorectal cancer to death or exit from the study or the end of follow up (December 2016). Differences in survival by socio-economic group were initially assessed using Kaplan-Meier (KM) estimation and univariate log-rank tests for difference. KM survival curves were produced to display the survival probability by socio-economic group. Cox Proportional Hazards regression modelling was performed to assess the impact of socio-economic group on the time-to-event for all-cause death for each indicator of socio-economic status, adjusting for confounders. The proportional hazards assumption (that the effect of the factors being investigated on the hazard is the same over the follow-up time) was assessed graphically using complimentary log-log plots.

When death from colorectal cancer was the outcome of interest, time (in months) was calculated from diagnosis of colorectal cancer to death from colorectal cancer or exit from the study or the end of follow-up (December 2016). If a study member died of causes other than colorectal cancer during follow-up this was regarded as a competing event. The crude probability of death (cumulative incidence function) was calculated using the stcrreg command in Stata to assess the probability of death from colorectal cancer in the presence of competing events (death from other causes) and unadjusted CIFs plotted. Multivariable competing risks regression models, adjusted for confounders, were used to estimate the hazard of death due to colorectal cancer. Crude probabilities of death due to colorectal cancer and due to other causes were calculated for each socio-economic group and displayed on stacked cumulative incidence plots to allow for a visual assessment of the probability of dying from colorectal cancer in the presence of competing risks. All calculations were performed in Stata version 17.0.

Causal diagrams were used to inform the statistical modelling and identify appropriate confounders to adjust for in the models. Separate diagrams were produced for each exposure of interest: education, social class, housing tenure and area of residence (Supplementary Information A) using DAGitty software (Textor et al., 2016). All possible variables

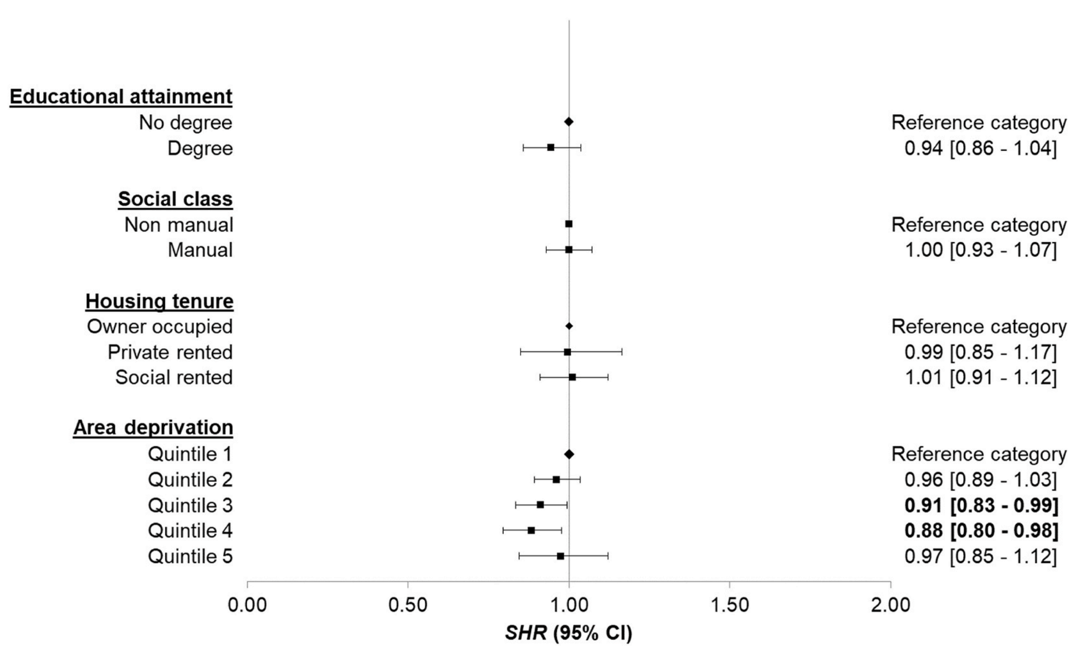

Fig. 3. Forest plot of adjusted subhazard ratios for colorectal cancer registrations. Each variable modelled separately. Data source: ONS LS.

Table 3
Demographic characteristics of study cohort by outcome at end of follow-up, for those diagnosed with colorectal cancer (CRC) April 2001–December 2015. Data source: ONS LS.

Variable	Category	Total	Missing		Survived		Died (all-causes)		Died (CRC)	
		n	n	%	n	%	n	%	n	%
Total		5016			1971	39.3	3045	60.7	1825	36.4
Sex			0	0						
	Male	2696			1081	40.1	1615	59.9	928	34.4
	Female	2320			890	38.4	1430	61.6	897	38.7
Age group			0	0						
	50–59	590			353	59.8	237	40.2	168	28.5
	60–69	1244			684	55.0	560	45.0	359	28.9
	70–79	1654			676	40.9	978	59.1	562	34.0
	80+	1528			258	16.9	1270	83.1	736	48.2
Ethnic group			1	0.02						
	White	4862			1902	39.1	2960	60.9	1772	36.4
	Black	46			17	37.0	29	63.0	20	43.5
	Indian/Pakistani/Bangladeshi	78			39	50.0	39	50.0	20	25.6
	Chinese/Mixed/Other	29			13	44.8	16	55.2	12	41.4
Marital status			0	0						
	Married	3337			1466	43.9	1871	56.1	1120	33.6
	Separated/Divorced/Widowed	1352			387	28.6	965	71.4	578	42.8
	Single	327			118	36.1	209	63.9	127	38.8
Educational attainment			61	1.2						
	No degree	4347			1651	38.0	2696	62.0	1602	36.9
	Degree	608			317	52.1	291	47.9	192	31.6
Occupational social class			920	18.3						
	Non manual	2183			1063	48.7	1120	51.3	690	31.6
	Manual	1913			786	41.1	1127	58.9	679	35.5
Housing tenure			44	0.9						
	Owner occupied	3875			1654	42.7	2221	57.3	1331	34.3
	Privately rented	279			97	34.8	182	65.2	103	36.9
	Social rented	818			218	26.7	600	73.3	364	44.5
Area deprivation			1	0.02						
	1- Least deprived	2262			957	42.3	1305	57.7	775	34.3
	2	1203			448	37.2	755	62.8	457	38.0
	3	759			280	36.9	479	63.1	281	37.0
	4	527			206	39.1	321	60.9	200	38.0
	5 - Most deprived	264			80	30.3	184	69.7	111	42.0

were included in the diagrams, as is convention, even though some of them are not available in this data set. The direction of association is shown with an arrow in the diagram. This was based on the temporal order of the variables and the hypothesised pathways between the variables, which were based on evidence in the literature. Two models were run for each exposure variable. Model 1 was unadjusted and Model 2 was adjusted for all variables (available in the data set) identified in the corresponding causal diagram.

3. Results

3.1. Colorectal cancer incidence

There were 178,116 LS members who were present at the 2001 Census and aged 50+ included in the analysis cohort (Fig. 1). Of these, 4418 were diagnosed with colorectal cancer during a mean follow up time of 11.8 years. 64,501 individuals died during follow-up (before being diagnosed with colorectal cancer).

The demographic characteristics of the study cohort and proportions diagnosed with colorectal cancer are shown in Table 1. There were slightly more males (54%) than females. The majority of the cohort were of White ethnicity (96%), married (64%), did not have degree level qualifications (87%), employed in non-manual occupations (55%) and lived in owner-occupied housing (77%).

Cumulative incidence functions (CIFs) by indicator of socio-economic status are displayed in Fig. 2. There was a significant difference in the incidence of colorectal cancer by educational attainment, whereby individuals with a degree had consistently lower incidence than those without a degree ($p = 0.004$). The 14-year cumulative incidence rate among those with a degree was 2.1%, compared to 2.4% for those without a degree (Supplementary Information B). Significant differences in colorectal cancer incidence were also observed by social class, with consistently lower incidence among those in non-manual occupations compared to those in manual occupations ($p = 0.008$). The 14-year cumulative incidence rates for those in non-manual and manual occupations were 2.3% and 2.5% respectively. There were no significant differences in cumulative incidence observed by housing tenure ($p = 0.79$) or by area deprivation quintile ($p = 0.06$).

The results of the competing risks regression modelling are shown in Table 2. Individuals with a degree had a reduced risk of a colorectal cancer registration compared to those without a degree (SHR 0.87, 95% CI 0.79–0.96), however this association was no longer significant when adjusted for confounders. Compared to those employed in non-manual occupations, people employed in manual occupations had an increased risk of a colorectal cancer registration (SHR 1.09, 95% CI 1.02–1.17), but this association was not significant when adjusted for confounders. No significant differences in colorectal cancer incidence were observed by housing tenure. When adjusted for age and ethnicity, people living in area deprivation quintiles 3 and 4 had a small but significantly reduced risk of colorectal cancer compared to those living in the least deprived areas (quintile 1), however, there was not a clear gradient in colorectal cancer incidence by area deprivation (see Fig. 3).

3.2. Colorectal cancer survival

A total of 5016 LS members had a colorectal cancer registration at age 50 or over between April 2001 and December 2015 (Fig. 1). There were 3045 (61%) deaths from all-causes among the cohort during a mean follow-up time of 3.8 years. Of these, 1825 (60%) deaths were from colorectal cancer as the underlying cause and 1220 deaths were

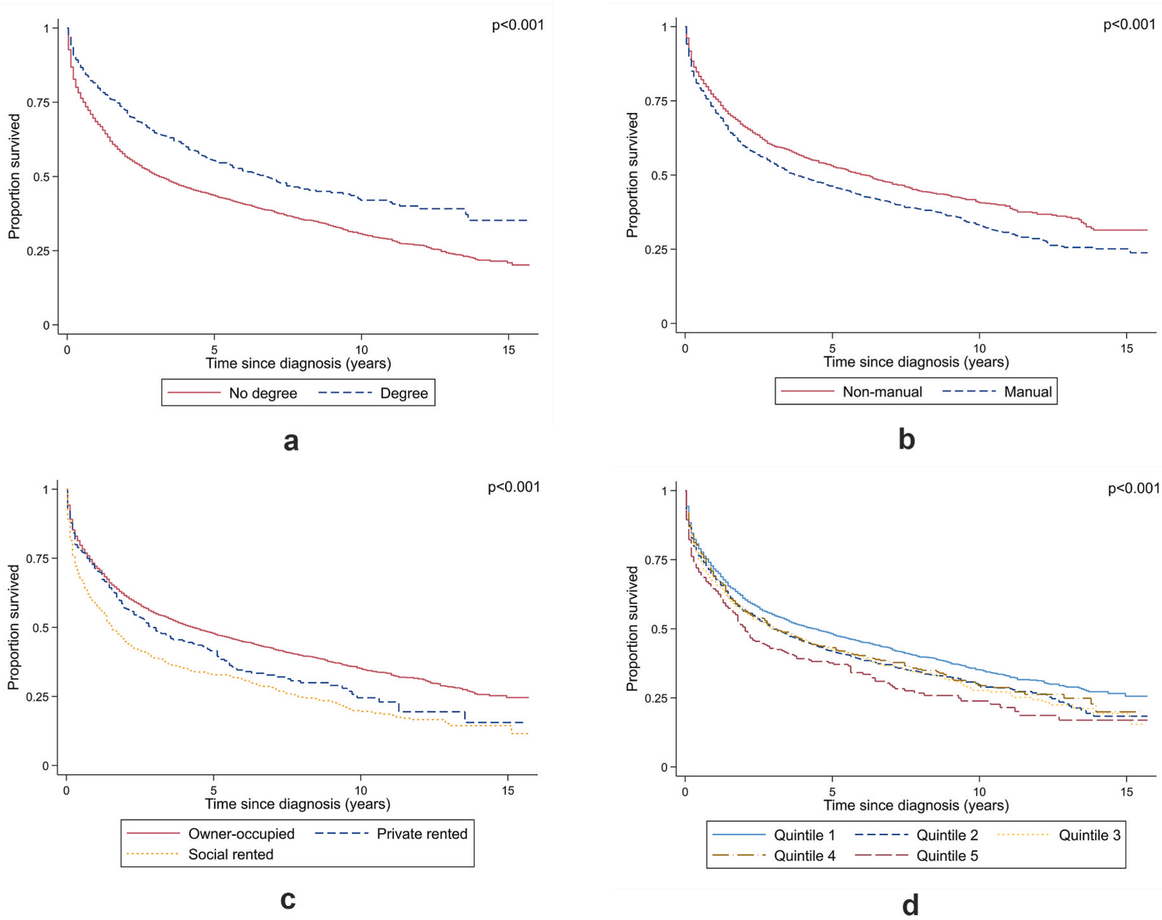

Fig. 4. Kaplan-Meier cumulative survival curves for probability of survival (all-cause) by: educational attainment (a); social class (b); housing tenure (c); area deprivation (d). Data source: ONS LS.

from other causes.

The socio-demographic characteristics of the cohort and proportion of deaths are reported in Table 3. There were slightly more males (54%) than females. The 70–79 age group had the largest proportion (33%) of colorectal cancer diagnoses. The majority of the cohort were of White ethnicity (97%), married (67%), did not have a degree (88%), employed in non-manual occupations (53%) and lived in owner-occupied housing (78%). A greater proportion of the cohort lived in the less deprived areas compared to the most deprived areas.

Overall, all-cause survival at 5, 10 and 15 years was 45%, 32% and 22% respectively among the study cohort. Univariate KM all-cause survival estimates are shown in Fig. 4, displaying the proportion of the study cohort surviving over the follow-up period by indicator of socio-economic status. Log-rank tests indicated a significant difference in all-cause survival by educational attainment ($p < 0.001$), social class ($p < 0.001$), housing tenure ($p < 0.001$) and area deprivation ($p < 0.001$). Study members with a degree exhibited consistently higher survival rates compared to those without a degree. The 5-year survival rate for those with a degree was 55% (95% CI 51–60%), compared to 44% (95% CI 42–45%) for those without a degree (Supplementary Information B). Similarly, survival rates were consistently higher among those in non-manual occupations compared to those in manual occupations, with five-year survival rates of 53% (95% CI 51–55%) and 46% (95% CI 44–49%) respectively. Survival rates by housing tenure showed owner-occupiers consistently higher survival rates compared to those living in social-rented housing, with five-year survival rates of 48% (95% CI 46–50%) and 33% (95% CI 29–36%) respectively. Study members living in the least deprived areas has consistently higher survival rates than those living in the most deprived areas (five-year survival of 48% (95% CI 46–50%) and 38% (95% CI 32–44%) respectively), but there was little variation in survival between the intermediary quintiles of area deprivation.

Crude probabilities of death from colorectal cancer by indicator of socio-economic status are shown in Fig. 5. There was a significant difference in the probability of colorectal cancer death by educational attainment ($p = 0.005$), social class ($p = 0.012$), housing tenure ($p < 0.001$) and area deprivation ($p = 0.017$). Individuals with a degree had consistently lower probability of colorectal cancer death compared to those without a degree; those employed in manual occupations had a consistently higher probability of colorectal cancer death than individuals employed in non-manual occupations; people living in social rented and private rented housing had consistently higher probability of colorectal cancer death compared to owner-occupiers; and those living in the most deprived areas had a consistently higher probability of colorectal cancer death compared with those living in the most deprived areas.

The results of the Cox proportional hazard regression modelling are shown in Table 4. Significant differences in survival were observed by educational attainment, social class, housing tenure and area deprivation. Those with a degree were less likely to die from all-causes compared to those without a degree (HR 0.67, 95% CI 0.60–0.76). This pattern remained but the magnitude of the association reduced when adjusted for confounders (HR 0.82, 95% CI 0.72–0.92) (Fig. 6). Conversely, those employed in manual occupations were more likely to die than those employed in non-manual occupations (adjusted HR 1.17, 95% CI 1.07–1.28). Those living in social-rented and private-rented housing were more likely to die from all-causes than owner-occupiers, but in the model adjusted for confounders the association was only

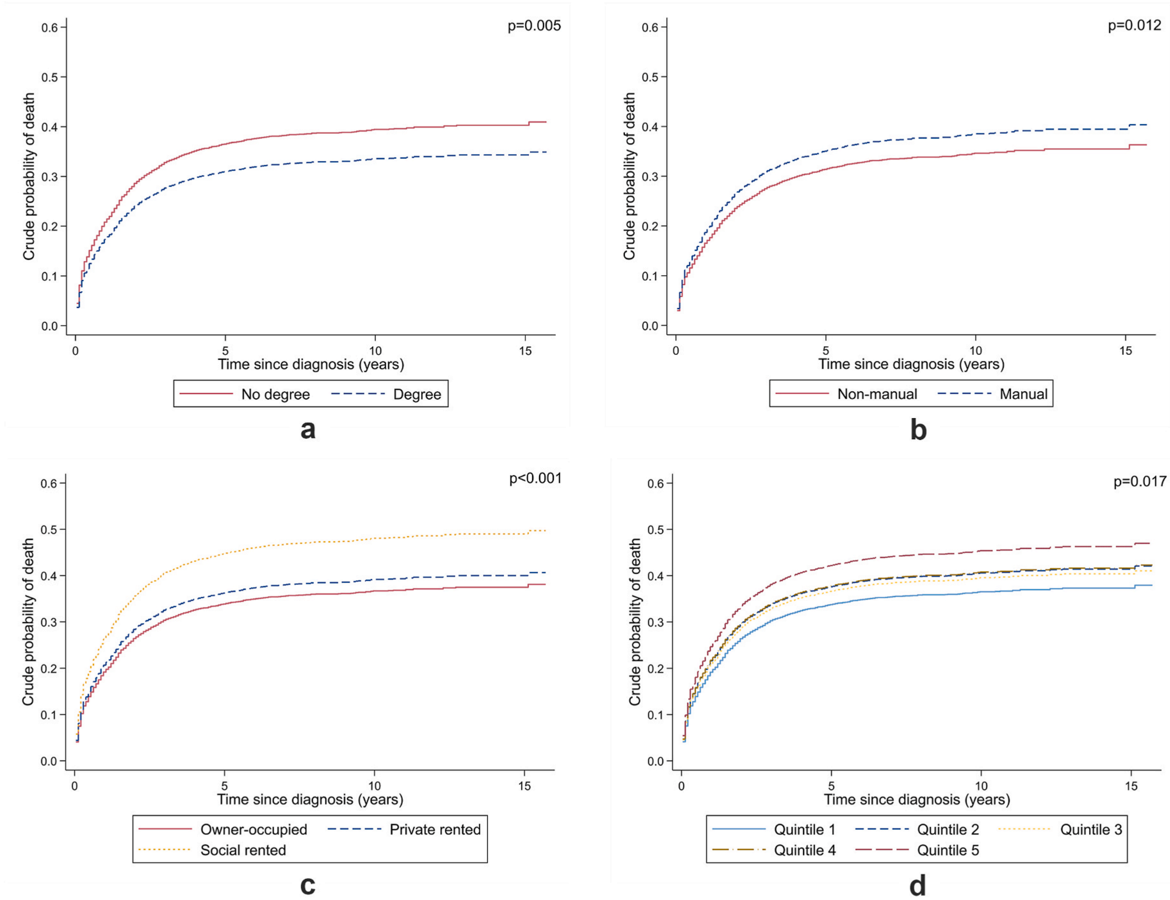

Fig. 5. Crude probability of colorectal cancer death by: educational attainment (a); social class (b); housing tenure (c); and area deprivation (d). Data source: ONS LS.

Table 4
Hazard ratios and subhazard ratios of risk of death from all-causes and death from colorectal cancer for study cohort followed-up April 2001–December 2016. Data source: ONS LS.

		All-cause				Colorectal cancer			
		Model 1		Model 2		Model 1		Model 2	
Variable	Category	HR [95% CI]	p-value	HR [95% CI]	p-value	SHR [95% CI]	p-value	SHR [95% CI]	p-value
Educational attainment	No degree	1		1		1		1	
	Degree	**0.67 [0.60–0.76]**	**<0.001**	**0.82 [0.72–0.92]**	**0.001**	**0.82 [0.71–0.94]**	**0.005**	0.94 [0.81–1.08]	0.373
Social class	Non-manual	1		1		1		1	
	Manual	**1.23 [1.13–1.33]**	**<0.001**	**1.17 [1.07–1.28]**	**0.001**	**1.15 [1.03–1.27]**	**0.011**	**1.15 [1.02–1.28]**	**0.021**
Tenure	Owner occupied	1		1		1		1	
	Private rented	**1.22 [1.05–1.42]**	**0.010**	1.16 [0.96–1.40]	0.125	1.09 [0.89–1.32]	0.399	1.03 [0.81–1.32]	0.814
	Social rented	**1.55 [1.42–1.70]**	**<0.001**	**1.31 [1.16–1.49]**	**<0.001**	**1.43 [1.28–1.61]**	**<0.001**	**1.22 [1.04–1.44]**	**0.015**
Area deprivation	1 - Least deprived	1		1		1		1	
	2	**1.16 [1.06–1.27]**	**0.001**	**1.16 [1.06–1.27]**	**0.001**	**1.15 [1.02–1.28]**	**0.020**	**1.13 [1.01–1.27]**	**0.034**
	3	**1.18 [1.07–1.31]**	**0.002**	**1.18 [1.06–1.31]**	**0.002**	1.11 [0.97–1.27]	0.137	1.09 [0.95–1.25]	0.212
	4	**1.14 [1.01–1.28]**	**0.040**	**1.17 [1.04–1.33]**	**0.010**	1.15 [0.99–1.34]	0.069	**1.18 [1.01–1.38]**	**0.033**
	5 - Most deprived	**1.39 [1.19–1.62]**	**<0.001**	**1.36 [1.16–1.59]**	**<0.001**	**1.33 [1.09–1.63]**	**0.005**	**1.32 [1.08–1.63]**	**0.008**

Model 1 is unadjusted. Model 2 is adjusted for: age, sex, ethnicity and area deprivation (Educational attainment model); age, sex, ethnicity, educational attainment, area deprivation (Social class model); age, sex, education, social class, marital status and area deprivation (Housing tenure model); age and ethnicity (Area deprivation model).

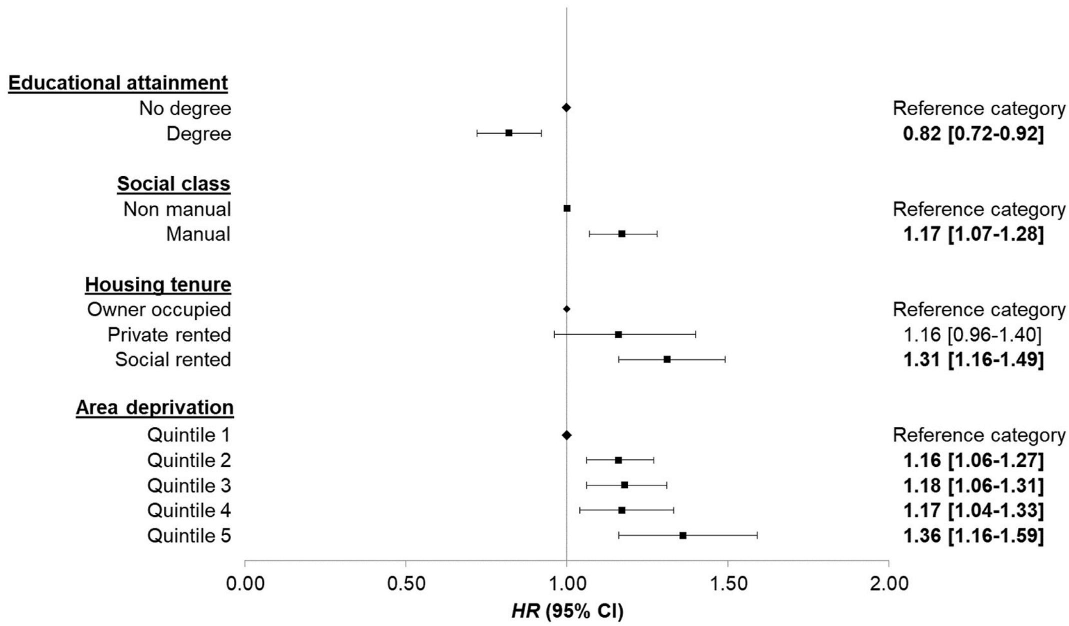

Fig. 6. Forest plot of adjusted Cox proportional hazards models for death from all-causes. Each variable modelled separately. Data source: ONS LS.

significant among those in social-rented housing (HR 1.31, 95% CI 1.16–1.49). Those living in the most deprived areas were 36% more likely to die than those living in the least deprived areas. Those living in Townsend quintiles 2, 3 and 4 also had a significantly increased risk of death compared to the least deprived quintile but there was not a clear gradient in risk of death among these groups.

Differences in the probability of death from colorectal cancer (Table 4) were observed by social class, housing tenure and area deprivation. When adjusted for confounders, individuals employed in manual occupations has an increased risk of colorectal cancer death compared to those employed in non-manual occupations (SHR 1.15, 95% CI 1.02–1.28). People living in social rented housing had an increased risk of colorectal cancer death compared to owner-occupiers (SHR 1.22, 95% CI 1.04–1.44). Living in the most deprived areas compared to the least deprived areas was associated with an increased risk of colorectal cancer death (SHR 1.32, 95% CI 1.08–1.63). Individuals with a degree had a lower risk of colorectal cancer death compared to those without a degree, but this association was not significant when adjusted for confounders.

The probability of death due to colorectal cancer rose sharply in the first 3-years of follow-up (Fig. 7). This then levelled off at around 5-years of follow-up, but the proportion of deaths from other causes continued to rise, making up a larger proportion of the overall deaths. A similar pattern was observed for all indicators of socio-economic status.

4. Discussion

This study found evidence of disparities in both colorectal cancer incidence and survival by individual-level indicators of socio-economic status. Differences by area-based deprivation were observed for death from all-causes and death from colorectal cancer but no clear differences in incidence of colorectal cancer were observed by area type.

The disparities in colorectal cancer incidence varied by indicator of individual socio-economic status. A small but statistically significant decreased risk of colorectal cancer was observed among people with a degree, compared to those without a degree. Conversely, a small but significant increase in risk of colorectal cancer was observed among individuals employed in manual occupations, compared to those employed in non-manual occupations, however neither of these associations were significant after adjustment for confounders. In a previous study using the LS, incidence of colorectal cancer was also found to be higher among women in the manual classes, based on social class measured at the 1981 Census (Brown et al., 1998).

A possible mechanism for the association between colorectal cancer incidence and socio-economic status is differential exposure to modifiable risk factors (Brown et al., 2018). Adherence to healthy lifestyle recommendations encompassing diet, physical activity, alcohol consumption and smoking is associated with a lower risk of colorectal cancer (Byrne et al., 2021). Furthermore, there is strong evidence to link socio-economic disadvantage with exposures known to increase risk of colorectal cancer such as unhealthy diet and smoking (Office for National Statistics, 2017). Moreover, there have been changes over time in the distribution of risk factors, which is likely to have an influence on colorectal cancer trends (Brown et al., 2018). Therefore, stronger associations may have been expected between individual-level indicators of socio-economic status and colorectal cancer than were observed in this study.

The lack of clear association observed between area deprivation and colorectal cancer incidence is contrary to recent research which has reported an emerging association between colorectal incidence and deprivation measured at the area-level (Oliphant et al., 2011; National Cancer Intelligence Network, 2014; Tweed et al., 2018). Different measures of area deprivation were used which use different variables to generate the indices, however, it is unlikely to be the specifics of the deprivation measures which lead to variations in findings since there are strong correlations between the Townsend index (used here) and the multiple deprivation indices (IMDs) (Norman, 2010). Previous studies used cross-sectional methods whereas the longitudinal nature of the LS data enabled time-to-event analysis to be employed. Furthermore, recent research suggests area-level deprivation is not necessarily a good indicator of individual socio-economic circumstances (Ingleby et al., 2020), which could explain the lack of area effects on colorectal cancer incidence observed in this study despite associations between some individual indicators of socio-economic status and colorectal cancer incidence.

In the analysis of survival, all three indicators of individual socio-economic status and area deprivation were associated with death from all-causes, and educational attainment and housing tenure were associated with colorectal cancer death. The largest individual-level disparities in survival were found by housing tenure, with those living in

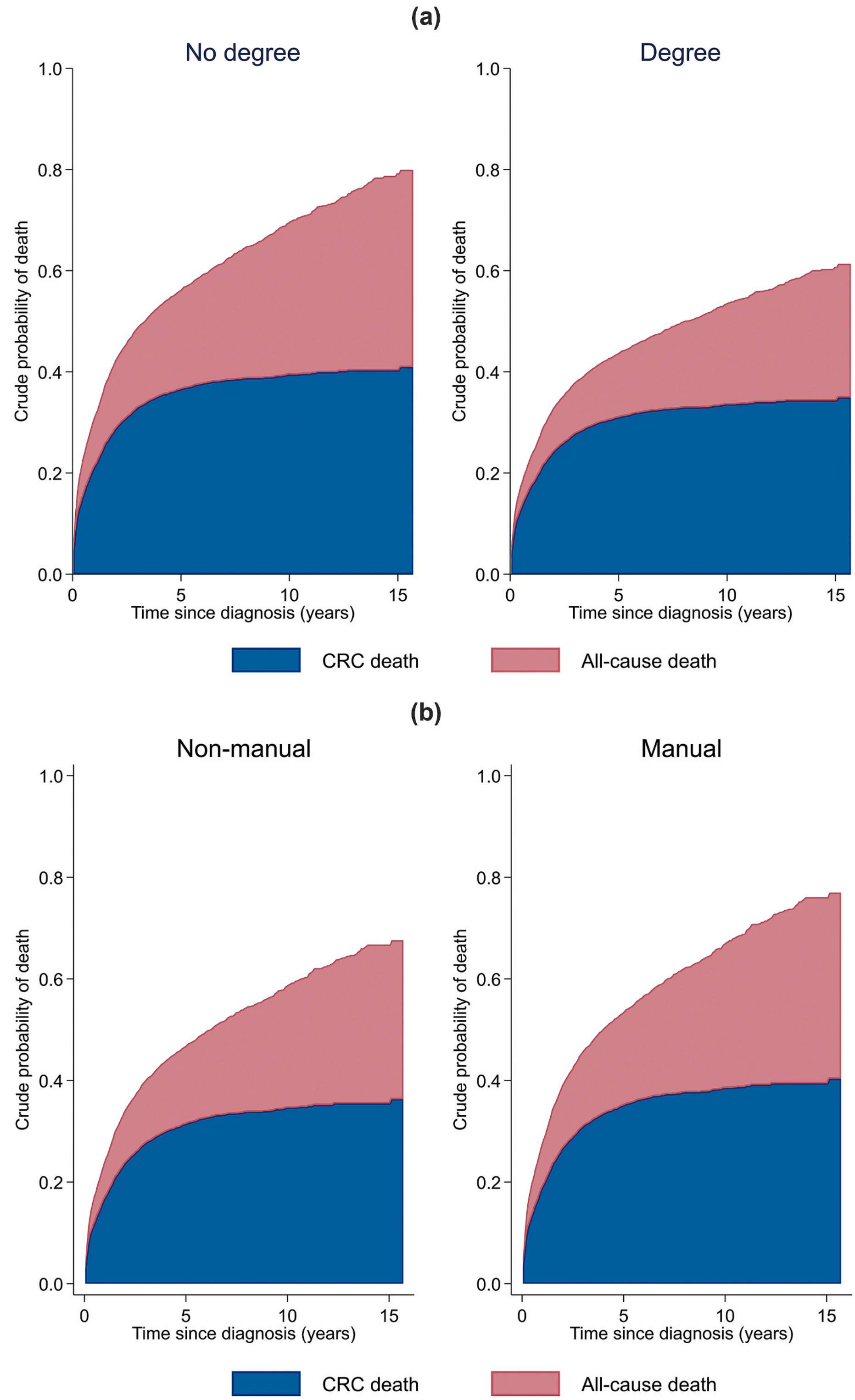

Fig. 7. Crude probability of death from colorectal cancer and other causes by: educational attainment (a); social class (b); housing tenure (c); and area deprivation (d). Data source: ONS LS.

social-rented housing more likely to die than those in owner-occupied housing. Previous research using the LS also found an association between colorectal cancer survival and housing tenure and car access, but not by social class or the Carstairs index of area deprivation (Sloggett et al., 2007). However, a more recent study also found strong evidence of area effects for colorectal cancer survival (Ingleby et al., 2022).

While a common finding among recent studies is that survival differences for colorectal cancer by deprivation are greater in the early period following diagnosis (Møller et al., 2012; Syriopoulou et al., 2019; Belot et al., 2019), in this study survival differences by socio-economic group persisted throughout the follow-up period for all indicators.

For all three individual-level indicators of socio-economic status the

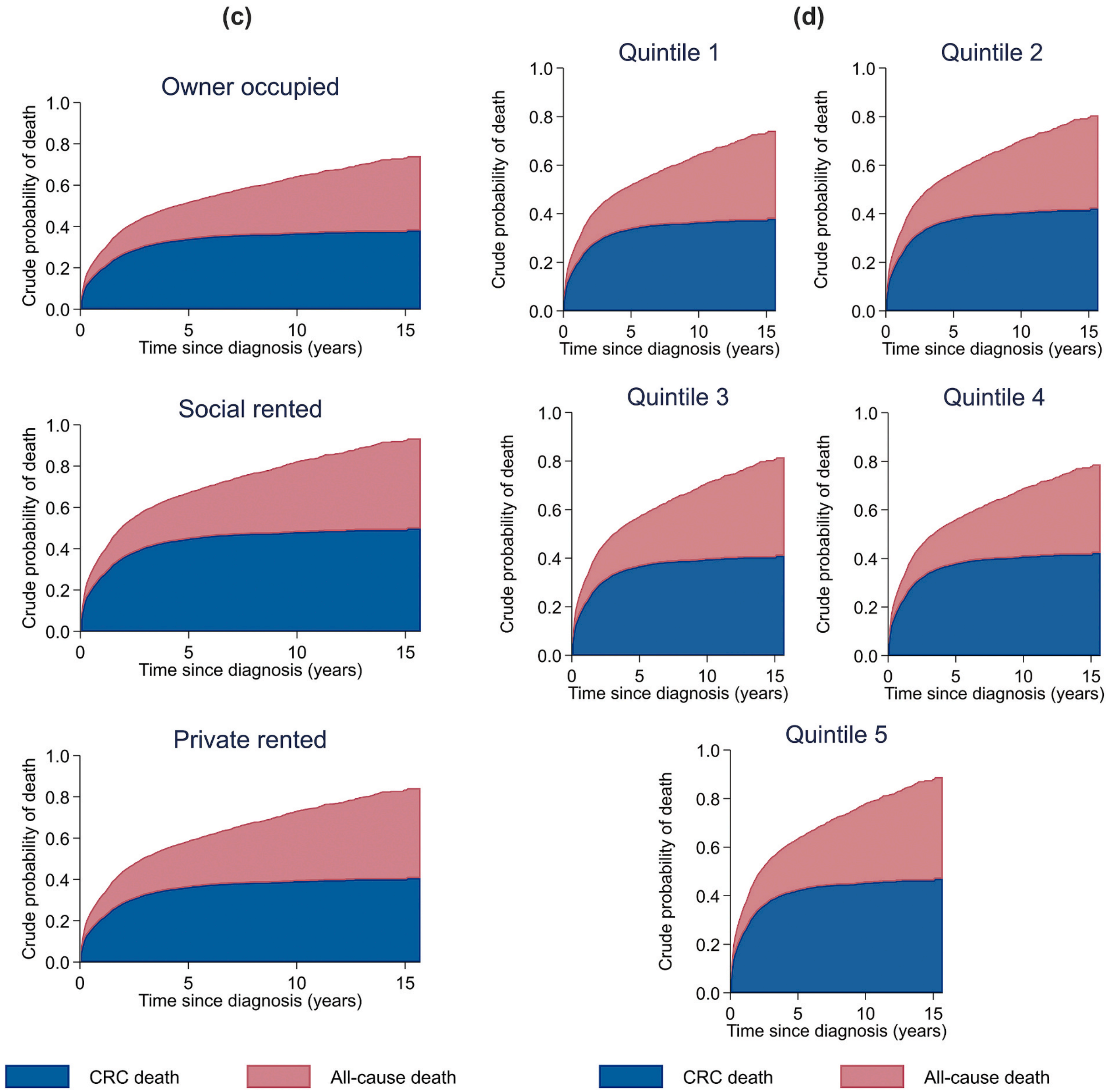

Fig. 7. (*continued*).

association with survival was stronger than that for incidence, therefore disparities in survival cannot be explained by differences in incidence alone. One explanation for variations in survival observed in this study could be differences in stage at diagnosis by socio-economic status. Evidence for an association between socio-economic status and stage at diagnosis is, however, inconsistent and the relationship between deprivation and survival from colorectal cancer has been found to remain significant after controlling for stage (Dejardin et al., 2014). This suggests there are other factors to explain this relationship. This could include lifestyle factors, co-morbidities, access to and uptake of treatment and participation in screening. There is evidence that there is a social gradient in uptake of the Bowel Cancer Screening Programme (von Wagner et al., 2011), but it was not possible to investigate this in this data set as information on cancer screening is not available in the LS.

4.1. Strengths

A strength of this study is the large, representative sample in the Longitudinal Study population. This improves both the reliability and generalisability of the results. The tracing rate of the LS sample to the NHS Central Register is high and there is minimal loss to follow-up, due to the quality of the data sources (census data, vital statistics and cancer registration data) and methods of linkage (Shelton et al., 2018). A key strength of the LS data is the ability to investigate cancer outcomes by a range of individual-level indicators of socio-economic status. Most cancer registry-based studies only include area-based measures of deprivation as proxies for individual socio-economic status, which can lead to misclassification. Furthermore, the LS has a long follow-up period for analysing cancer outcomes which is an advantage over other cohort studies.

Robust, well established (time-to-event) methods were used to investigate the association between indicators of socio-economic status and colorectal cancer incidence. The impact of competing risk events were taken into account in the analysis of colorectal cancer death, which is especially important in studies of cancer patients who are likely to be older and have higher mortality rates from other causes. A novel aspect of the methodological approach was the use of DAGs to inform the statistical models (Tennant et al., 2021).

4.2. Limitations

A limitation of the LS is that it does not include lifestyle information, as this type of information is not collected by the census. Lifestyle factors, including diet, overweight and obesity, alcohol consumption and smoking, are associated with colorectal cancer risk (Lauby-Secretan et al., 2016; World Cancer Research Fund, 2018) and are one of the mechanisms by which socio-economic status may influence colorectal cancer incidence, but it was not possible to investigate this using this data set. A possible weakness of the Townsend Index of Deprivation is the inclusion of car ownership, which may not be an applicable measure of deprivation in very rural, or very urban areas. Changes in society may also affect comparability of measures over time, for example in the proportion of people obtaining a degree and the increase in the proportion of people renting their homes versus home ownership. However, the use of census variables in the Townsend Index means it can be calculated consistently over time which would enable further work investigating whether a change in relative area deprivation over time is association with colorectal cancer survival. The Townsend index is also comparable across England and Wales, unlike IMD which is calculated separately in each country of the UK.

For the educational attainment and social class variables, where this information was not collected at the 2001 census, it was infilled from the previous census. Only those LS members aged 50+ in 2001 were included in this study, therefore it is unlikely that someone's level of educational attainment or occupational social class would have changed since the previous census so this was considered an appropriate method to increase the proportion of members allocated to a category. Despite infilling, however, there was still a nearly a fifth of study members missing social class information as this is only recorded if they have had an occupation and there will be some people, particularly women of this age group, who have never worked.

An interesting next step would be to investigate if and how changes in individual socio-economic status over the life course influences the likelihood of a colorectal cancer registration and survival after a colorectal cancer diagnosis. Furthermore, the effect of change in area deprivation over time could be investigated. This is particularly relevant to cancer outcomes as there is a long lag time between development and diagnosis of cancer, during which people may have moved between different areas. Stratifying the LS study sample by those persons with and without limiting long-term illness, as self-reported in the censuses since 1991, could also provide insights into the impact of co-morbidities on cancer survival.

5. Conclusion

In conclusion, this study found that socio-economic differences in colorectal cancer incidence and survival varied by indicator used. Individual measures of socio-economic status based on educational attainment and social class were associated with colorectal cancer incidence, but no clear association was observed with area-based measures of deprivation, whereas both individual-level and area-based indicators of deprivation were associated with survival. This highlights the complexity of the relationship between socio-economic circumstances and cancer outcomes. Public health interventions to reduce the underlying causes of inequalities in colorectal cancer outcomes should consider both individual and area-based initiatives, as well as disparities in access to and quality of cancer care.

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CRediT authorship contribution statement

Charlotte Sturley: Conceptualization, Methodology, Formal analysis, Writing – original draft. **Paul Norman:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Michelle Morris:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Amy Downing:** Conceptualization, Methodology, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare no competing interests.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2023.116138.

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