Association of neighbourhood socioeconomic status and diabetes burden using electronic health records in Madrid (Spain): the HeartHealthyHoods study

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ABSTRACT

Objective To study the association between neighbourhood socioeconomic status and diabetes prevalence, incidence, and control in the entire population of northeastern Madrid, Spain.

Setting Electronic health records of the primary-care system in four districts of Madrid (Spain).

Participants 269,942 people aged 40 or older, followed from 2013 to 2014.

Exposure Neighbourhood socioeconomic status (NSES), measured using a composite index of seven indicators from four domains of education, wealth, occupation and living conditions.

Primary outcome measures Diagnosis of diabetes based on ICPC-2 codes and glycated haemoglobin (HbA1c %).

Results In regression analyses adjusted by age and sex and compared with individuals living in low NSES neighbourhoods, men living in medium and high NSES neighbourhoods had 10% (95% CI: 6% to 15%) and 29% (95% CI: 25% to 32%) lower prevalence of diabetes, while women had 27% (95% CI: 23% to 30%) and 50% (95% CI: 47% to 52%) lower prevalence of diabetes. Moreover, the hazard of diabetes in men living in medium and high NSES neighbourhoods was 13% (95% CI: 1% to 23%) and 20% (95% CI: 9% to 29%) lower, while the hazard of diabetes in women living in medium and high NSES neighbourhoods was 17% (95% CI: 3% to 29%) and 31% (95% CI: 20% to 41%) lower. Individuals living in medium and high SES neighbourhoods had 8% (95% CI: 2% to 15%) and 15% (95% CI: 9% to 21%) lower prevalence of lack of diabetes control, and a decrease in average HbA1c % of 0.05 (95% CI: 0.01 to 0.10) and 0.11 (95% CI: 0.06 to 0.15).

Conclusions Diabetes prevalence, incidence and lack of control increased with decreasing NSES in a southern European city. Future studies should provide mechanistic insights and targets for intervention to address this health inequity.

INTRODUCTION

The burden of diabetes has seen a large increase in Western countries in recent decades.1 Diabetes-attributable costs in the European Union have been estimated to be over $100 billion per year and are predicted to continue increasing in the following decades.2 Population preventive strategies are needed to decrease this burden,3 taking into consideration mass influences that differ across populations.

Among these mass influences are neighbourhood characteristics. A large body of literature has explored contextual socioeconomic influences on health. In particular, the association between neighbourhood socioeconomic status (NSES) and several measures of diabetes (prevalence, incidence
Neighbourhood socioeconomic status

The main exposure of this study was NSES. To measure NSES, we considered the four domains of the Spanish Commission to Reduce Health Inequalities: education, wealth, occupation and living conditions. To search for indicators to measure these four domains, we explored all available data sources, to our knowledge, on social, economic and contextual factors in Madrid, Spain. We looked for readily available indicators (to ease replicability) that were measured at the neighbourhood or census section level (to improve granularity) and that were available for several years (to allow for further studies looking at longitudinal changes). After this process we selected seven indicators that represent the four domains: education—(1) primary education (% people above 25 years of age with primary studies or below), (2) university education (% people above 25 years of age with university education or above); wealth—(3) average housing prices (per sq. m); occupation—(4) part-time employment (% workers in part-time jobs), (5) temporary employment (% workers in temporary jobs), (6) manual occupational class (% workers in manual or unqualified jobs); and living conditions—(7) unemployment rate (% registered unemployed individuals/people aged 16 to 64).

Indicator data were obtained from the Padrón (a continuous and universal census collected for administrative purposes), the social security and employment services registries and the IDEALISTA report (a report from a large real estate corporation in Spain). All data were available by January 2013. The online resource contains a detailed description of the operationalisation of indicators.

We computed a weighted index of the seven indicators by: (1) making the directionality of the associations consistent, by reversing some of the indicators (primary education, part-time employment, temporary employment, manual occupational class and unemployment rate) so that all indicators had a consistent association with the final index; (2) for each indicator, we centred by the mean and divided it by the SD in order to obtain a Z-score of each indicator; (3) in each domain, we averaged the Z-score of each indicator, resulting in a Z-score for each domain (education, wealth, occupation and living conditions) and (4) finally, we calculated the composite index of NSES by averaging the Z-score of each of the four domains. This composite NSES index was then operationalised in separate analyses as a categorical variable (NSES in tertiles) or as a continuous variable.

Diabetes prevalence, incidence and control

Diabetes diagnoses were extracted from the EHR for all individuals, as recorded by primary care physicians during their usual clinical practice. A type-2 diabetes diagnosis was defined using the T90 diagnosis code of the ICPC-2 (“diabetes non-insulin dependent”). A previous study has validated the diagnosis of diabetes in this dataset with a kappa of 0.99, with high sensitivity (99.5%) and specificity (99.5%). Prevalent cases were defined as diabetes diagnoses dated before 1 January 2013. Incident cases were
those occurring from 1 January 2013 to 31 December 2014 in people free of diabetes by baseline (1 January 2013). We operationalised lack of diabetes control as either a dichotomous variable (HbA1c \( \geq 7\% \)) or a continuous variable (HbA1c %). If more than one value of HbA1c was available, we used the last available measurement of the year.

**Statistical methods**

The overall goal of this analysis is to study the association between NSES and diabetes prevalence, incidence and control. We computed descriptive statistics by tertile of NSES.

To study the association between NSES and diabetes prevalence or lack of control (binary indicator) we used a log-binomial regression model with robust standard errors clustered at the census section level using a sandwich Huber–White estimator. These models were adjusted for age (in five categories; 40 to 49, 50 to 59, 60 to 69, 70 to 79 and 80 and older) and sex. Continuous HbA1c (for diabetes control) was examined using a linear regression with robust standard errors clustered at the census section level using a sandwich Huber–White estimator. Around 21% of the sample that had prevalent diabetes had no HbA1c % measured in 2013 or 2014. To assess whether this missing data affected our inferences, we did a sensitivity analysis using a conditional mean imputation of HbA1c % in people with diabetes. In this model, we predicted the HbA1c % value using age, sex, healthcare centre, NSES index and diagnosis of other cardiovascular risk factors or conditions (hypertension, dyslipidaemia, prevalent cardiovascular disease, chronic kidney disease and retinopathy). We then compared the point estimates of the association between prevalent lack of control and average HbA1c % obtained with and without conditional mean imputation.

In the analysis of diabetes incidence, each individual entered the sample on 1 January 2013 and exited on the date of diabetes diagnosis (outcome), date of death (censored), date of moving out of a health centre in the area (censored) or study end by 31 December 2014 (administrative censoring). We used Kaplan–Meier survival estimates to explore the differences in the hazard of diabetes incidence by NSES tertile. Cox proportional hazards models were used to estimate the adjusted association, with clustered standard errors on the census section. Since we censored individuals at death, a potential competing risk, our estimates from the model are analogous to cause-specific hazard ratios, and can therefore be interpreted as the increase in the hazard of diabetes if people that do not die. We checked the proportionality of hazards assumption by plotting Schoenfeld residuals and by checking their trend over time.

To graphically display the association between the exposure and the outcome variables, we also modelled the associations above using restricted cubic splines with four knots in the percentiles recommended by Harrell. A previous report in the Spanish setting highlighted a significant interaction by sex of contextual socioeconomic status and diabetes, so we explored whether this interaction existed in our analysis and displayed stratified results if this was the case. All analyses were conducted in R V.3.3.0 (R Software Foundation).

**RESULTS**

**Study population**

Table 1 shows a description of the study population by tertile of NSES and in the total population. The total sample size was 269,942 people, with around 25%, 30% and 45% of the population living in low, medium and high NSES areas. Overall, the median age was 56.5 (IQR=47.4 to 69.8) and 54.9% of the population were women. Of this, 8.8% of the population older than 40 years of age had diabetes, 1.0% developed diabetes during follow-up and the average HbA1c in diabetic people was 6.7 (IQR=6.2 to 7.5). Thirty-nine percent of all diabetic people had uncontrolled diabetes (HbA1c equal or above 7%). Stratifying the population by tertile of NSES revealed that younger people lived in neighbourhoods with higher SES. The prevalence of diabetes decreased sharply with NSES (11.9% in the lowest NSES, 9.6% in the medium NSES and 6.5% in the highest NSES), and the incidence of diabetes followed a similar gradient by NSES (1.3%, 1.1% and 0.9% in the lowest, medium and highest NSES areas).

**NSES and diabetes prevalence**

Table 2 shows the association between NSES and diabetes prevalence, control and incidence. Diabetes prevalence was associated in a dose–response manner to NSES. This association was significantly stronger in women as compared with men (P value for the interaction <0.001). In particular, compared with men living in low NSES neighbourhoods, those living in medium NSES neighbourhoods had 8% lower prevalence of having diabetes (PR=0.92, 95% CI 0.89 to 0.96), while those living in the highest NSES neighbourhoods had 24% lower prevalence of diabetes (PR=0.76, 95% CI 0.74 to 0.80). In the case of women, those living in medium and high NSES neighbourhoods had 24% and 46% lower prevalence of diabetes, respectively, as compared with those living low NSES neighbourhoods (PR=0.76, 95% CI 0.73 to 0.79, and PR=0.54, 95% CI 0.52 to 0.57). These associations were consistent in models looking at continuous NSES: a one SD increase in NSES was associated with 14% and 26% lower prevalence of diabetes in men and women, respectively (PR=0.86, 95% CI 0.84 to 0.87, PR=0.74, 95% CI 0.72 to 0.75). Figure 1 shows the association using continuous NSES with restricted cubic splines, where the steeper pattern for women is evident.

**NSES and diabetes control**

Table 2 also shows the association between NSES and diabetes control, operationalised as a dichotomous variable (lack of diabetes control, or HbA1c \( \geq 7\% \)) or
continuous variable (HbA1c %). There was no significant interaction by sex in the NSES and diabetes control (P value for the interaction=0.219 and 0.358 in the dichotomous and continuous model). As compared with people with diabetes living in the lowest NSES neighbourhoods, those living in medium NSES areas had 5% lower prevalence of lack of diabetes control (PR=0.95, 95% CI 0.91 to 0.99), while those living in the highest NSES areas had 9% lower prevalence of lack of diabetes control (PR=0.91, 95% CI 0.87 to 0.95). Moreover, a one SD increase in NSES was associated with 4% lower prevalence of lack of diabetes control (PR=0.96, 95% CI 0.94 to 0.98). These associations were maintained when looking at continuous HbA1c: diabetic people living in medium and high NSES had a lower average HbA1c % (see table 2). Figure 2 shows the prevalence of lack of diabetes control and average HbA1c levels across levels of NSES using restricted cubic splines, showing a linear decrease both in lack of control and in average HbA1c % with increasing NSES. In the sensitivity analysis using conditional mean imputation of HbA1c %, we found no change in our inferences after accounting for missing HbA1c % (see online appendix figure 2).

**NSES and diabetes incidence**

Overall, at 1 and 2 years of follow-up, the diabetes incidence was 5.7 per 1000 and 10.5 per 1000. Figure 3 shows the Kaplan–Meier estimate of diabetes incidence by tertile of NSES, showing a social gradient in diabetes incidence (lower NSES corresponding to higher diabetes incidence, P<0.001). Table 2 also shows the results of the adjusted Cox proportional hazards models. We found a significant interaction by sex (P value for interaction=0.004). The hazard of diabetes incidence in men living in medium and high NSES neighbourhoods was 13% and 20% lower compared with men living in low NSES neighbourhoods (HR=0.87, 95% CI 0.77 to 0.99, and HR=0.80, 95% CI 0.71 to 0.91). A stronger association was observed in women, as the hazard of diabetes incidence in women living in medium and high NSES neighbourhoods was 17% and

**Table 1** Study population by 1 January 2013

| Variable                        | Total          | Tertile 1 (Lowest NSES) | Tertile 2 (Mid NSES) | Tertile 3 (High NSES) | P values*          |
|---------------------------------|----------------|-------------------------|----------------------|-----------------------|-------------------|
| Sample Size (N)                 | 269,942        | 68,369                  | 81,072               | 120,501               | <0.001            |
| Median Age (IQR)                | 56.5 (47.4;69.8)| 56.6 (48.3;74.5)        | 58.1 (48.0;71.1)     | 54.7 (46.6;66.9)      | <0.001            |
| % Men                           | 45.1%          | 44.6%                   | 44.2%                | 45.9%                 | <0.001            |
| % Women                         | 54.9%          | 55.4%                   | 55.8%                | 54.1%                 |                   |
| % Death during follow-up        | 1.2%           | 1.4%                    | 1.3%                 | 1.0%                  | <0.001            |
| % Moved during follow-up        | 0.8%           | 0.8%                    | 0.8%                 | 0.8%                  | 0.673             |
| % With prevalent diabetes       | 8.8%           | 11.9%                   | 9.6%                 | 6.5%                  | <0.001            |
| % With incident diabetes†       | 1.0%           | 1.3%                    | 1.1%                 | 0.9%                  | <0.001            |
| Median HbA1c (IQR)              | 6.7 (6.2;7.5)  | 6.7 (6.2;7.5)           | 6.7 (6.2;7.5)        | 6.7 (6.2;7.4)         | <0.001            |
| HbA1c>=7%                       | 38.8%          | 40.5%                   | 38.7%                | 37.1%                 | 0.237             |
| HbA1c<5%                        | 0.3%           | 0.3%                    | 0.4%                 | 0.3%                  | 0.285             |
| HbA1c 5%–6.5%                   | 41.1%          | 40.0%                   | 40.5%                | 42.7%                 |                   |
| HbA1c 6.5%–7%                   | 20.1%          | 19.4%                   | 20.6%                | 20.3%                 |                   |
| HbA1c 7%–9%                     | 32.4%          | 34.0%                   | 32.2%                | 30.9%                 |                   |
| HbA1c>9%                        | 6.1%           | 6.3%                    | 6.3%                 | 5.7%                  |                   |
| Primary education, % (IQR)      | 24.6% (15.1;32.2)| 36.3% (30.7;40.3)      | 24.7% (20.8;27.9)    | 11.6% (7.1;19.5)      | <0.001            |
| University education, % (IQR)   | 20.8% (13.0;33.7)| 10.2% (7.4;13.0)       | 20.8% (16.8;24.7)    | 40.1% (29.9;52.5)     | <0.001            |
| Unemployment rate, % (IQR)      | 12.6% (10.6;13.8)| 13.8% (13.8;16.4)      | 12.6% (12.0;12.7)    | 8.9% (7.8;10.6)       | <0.001            |
| Part-time workers, % (IQR)      | 23.4% (18.7;25.9)| 26.7% (24.8;26.8)      | 23.4% (22.4;25.9)    | 16.5% (12.7;19.4)     | <0.001            |
| Temporary workers, % (IQR)      | 19.0% (17.3;20.9)| 20.9% (20.4;21.5)      | 20.4% (18.9;20.9)    | 16.7% (13.8;18.2)     | <0.001            |
| Manual class, % (IQR)           | 37.1% (27.4;40.0)| 40.3% (40.0;43.1)      | 37.1% (36.2;40.0)    | 22.4% (17.4;30.2)     | <0.001            |
| Property value, EUR/m²(IQR)     | 2286.0 (1975.0;2659.0) | 1776.0 (1561.0;1971.0) | 2243.0 (2128.0;2398.0) | 2832.0 (2608.0;3382.0) | <0.001            |
| SES index (IQR)                 | 0.0 (-0.6;0.6) | -0.8 (-1.2;−0.6)       | -0.2 (-0.3;0.1)      | 1.0 (0.6;1.6)         | <0.001            |

*P value -values for continuous individual-level characteristics were computed using a clustered Somers’ D comparison of medians; P-values for categorical individual-level characteristics were computed using Donner’s χ² adjusted for clustered data. P-values for contextual characteristics were conducted at the neighbourhood level using a Kruskal-Wallis test for the comparison of medians.

†Incident diabetes refers to new diagnoses of diabetes in 2013 or 2014 in people free of diabetes at baseline.

NSES, neighbourhood socioeconomic status index.
31% lower compared with women living in low NSES neighbourhoods (HR=0.83, 95% CI 0.71 to 0.97, and HR=0.69, 95% CI 0.59 to 0.80). These associations were consistent in models looking at continuous NSES: a one SD increase in NSES was associated with a 10% and 18% decrease in the hazard of incident diabetes in men and women, respectively (HR=0.90, 95% CI 0.85 to 0.94, and HR=0.82, 95% CI 0.77 to 0.87). We tested the assumption of proportionality of hazards and found no evidence to reject the null hypothesis of proportionality (P value for the global χ²-test=0.604 for the unadjusted model, and 0.365 for the fully adjusted model).

**DISCUSSION**

This study has shown a strong association between NSES and diabetes burden. In particular, there is a dose-response association: as NSES increases, diabetes prevalence, lack of control and incidence decrease in a linear fashion. This association is seen for both a categorical

**Table 2** Association of neighbourhood socioeconomic status (NSES) and diabetes outcomes

| Variable                  | Total Diabetes Prevalence | Men Diabetes Prevalence | Women Diabetes Prevalence |
|---------------------------|---------------------------|-------------------------|---------------------------|
| Tertile 1 of NSES (Low)   | PR (95% CI)               | P values                | PR (95% CI)               | P values                |
|                           | 1 (Ref.)                  | 1 (Ref.)                | 1 (Ref.)                  |                         |
| Tertile 2 of NSES (Middle)| 0.84 (0.82 to 0.87)       | <0.001                  | 0.92 (0.89 to 0.96)       | <0.001                  |
|                           |                           |                         | 0.76 (0.73 to 0.79)       |                         |
| Tertile 3 of NSES (High)  | 0.66 (0.64 to 0.68)       | <0.001                  | 0.76 (0.74 to 0.80)       | <0.001                  |
|                           |                           |                         | 0.54 (0.52 to 0.57)       |                         |
| Continuous NSES           | 0.80 (0.79 to 0.81)       | <0.001                  | 0.86 (0.84 to 0.87)       | <0.001                  |
|                           |                           |                         | 0.74 (0.72 to 0.75)       |                         |

| Variable                  | Lack of Diabetes Control (HbA1c ≥7%) | Men Lack of Diabetes Control (HbA1c ≥7%) | Women Lack of Diabetes Control (HbA1c ≥7%) |
|---------------------------|--------------------------------------|-----------------------------------------|-------------------------------------------|
| Tertile 1 of NSES (Low)   | PR (95% CI)                           | P values                                | PR (95% CI)                               | P values                                |
|                           | 1 (Ref.)                              | 1 (Ref.)                                | 1 (Ref.)                                  |                         |
| Tertile 2 of NSES (Middle)| 0.95 (0.91 to 0.99)                   | 0.014                                   | 0.94 (0.88 to 0.99)                       | 0.033                          |
|                           |                                      |                                        | 0.96 (0.90 to 1.02)                       | 0.158                          |
| Tertile 3 of NSES (High)  | 0.91 (0.87 to 0.95)                   | <0.001                                  | 0.88 (0.83 to 0.93)                       | <0.001                          |
|                           |                                      |                                        | 0.95 (0.89 to 1.01)                       | 0.117                          |
| Continuous NSES           | 0.96 (0.94 to 0.98)                   | <0.001                                  | 0.95 (0.93 to 0.98)                       | <0.001                          |
|                           |                                      |                                        | 0.97 (0.95 to 1.00)                       | 0.07                            |

| Variable                  | Lack of Diabetes Control (Continuous HbA1c %) | Men Lack of Diabetes Control (Continuous HbA1c %) | Women Lack of Diabetes Control (Continuous HbA1c %) |
|---------------------------|-----------------------------------------------|--------------------------------------------------|--------------------------------------------------|
| Tertile 1 of NSES (Low)   | Beta (95% CI)                                 | P values                                         | Beta (95% CI)                                 | P values                                         |
|                           | 0 (Ref.)                                      |                                                  | 0 (Ref.)                                      |                                                  |
| Tertile 2 of NSES (Middle)| −0.05 (-0.10 to −0.01)                       | 0.021                                            | −0.07 (-0.13 to −0.01)                       | 0.021                                            |
|                           |                                              |                                                  | −0.03 (-0.09 to 0.03)                       | 0.31                                            |
| Tertile 3 of NSES (High)  | −0.11 (-0.15 to −0.06)                       | <0.001                                           | −0.13 (-0.19 to −0.07)                       | <0.001                                           |
|                           |                                              |                                                  | −0.08 (-0.14 to −0.02)                       | 0.014                                           |
| Continuous NSES           | −0.04 (-0.06 to −0.02)                       | <0.001                                           | −0.05 (-0.07 to −0.02)                       | <0.001                                           |
|                           |                                              |                                                  | −0.03 (-0.06 to −0.01)                       | 0.011                                           |

| Variable                  | Diabetes Incidence | Men Diabetes Incidence | Women Diabetes Incidence |
|---------------------------|--------------------|------------------------|--------------------------|
| Tertile 1 of NSES (Low)   | HR (95% CI)        | P values               | HR (95% CI)               | P values               |
|                           | 1 (Ref.)           | 1 (Ref.)               | 1 (Ref.)                 |                         |
| Tertile 2 of NSES (Middle)| 0.85 (0.77 to 0.95) | 0.003                  | 0.87 (0.77 to 0.99)       | 0.041                  |
|                           |                    |                        | 0.83 (0.71 to 0.97)       | 0.021                  |
| Tertile 3 of NSES (High)  | 0.75 (0.68 to 0.83) | <0.001                 | 0.80 (0.71 to 0.91)       | <0.001                 |
|                           |                    |                        | 0.69 (0.59 to 0.80)       | <0.001                 |
| Continuous NSES           | 0.86 (0.83 to 0.90) | <0.001                 | 0.90 (0.85 to 0.94)       | <0.001                 |
|                           |                    |                        | 0.82 (0.77 to 0.87)       | <0.001                 |

*Models adjusted by age, sex and year and clustered on the census section. Results for diabetes prevalence and lack of diabetes control (binary) are shown in prevalence ratios (95% CI); results for lack of diabetes control (continuous) are presented as changes in average HbA1c % (95% CI); results for diabetes incidence are presented as hazard ratios (95% CI).
(tertiles) and a continuous operationalisation of the exposure. There seems to be an interaction by sex in the association with diabetes prevalence and incidence, which is stronger in women as compared to men.

Previous studies have shown analogous results to ours. A report by Larrañaga found an increase in the prevalence of diabetes in more deprived neighbourhoods in the Basque Country (northern Spain), using a sample of primary care practices, displaying a similar interaction by sex as our study. Other studies using EHR in other countries have found significant associations between area-level poverty, deprivation or socioeconomic status and diabetes prevalence, incidence and control. A study by Cox using EHR from a Scottish region found increased diabetes prevalence in more deprived areas, as measured using the Carstairs index of deprivation. Studies by Mezuk and Sundquist showed a significant increase in diabetes incidence in the Swedish population living in medium and high deprivation neighbourhoods, measured using four indicators of NSES. Several studies in the UK, USA and Israel have studied the association of NSES with diabetes control as measured by HbA1c % in EHR, finding a consistent gradient similar to ours (lower NSES associated with lower likelihood of control or higher HbA1c %). Other studies using data from cross-sectional surveys or cohort studies, but with similar spatial units as ours have also found significant associations in the USA, France and Sweden.

Figure 1  Estimated diabetes prevalence by levels of neighbourhood socioeconomic status index.

Figure 2  Estimated diabetes control by levels of neighbourhood socioeconomic status.
before and shown to have a very high validity with a kappa
in our EHR has been validated
Bilal U, et al. BMJ Open 2018;8:e021143. doi:10.1136/bmjopen-2017-021143
population of an area of a very large city (Madrid) where
Our study has several strengths. First, we study the entire
incidence by neighbourhood socioeconomic status (SES).
Results predicted from models adjusted by age, sex and year
and clustered on the census section. For prediction purposes
age was set to the third category (60 to 70 years of age).

Our study is the first in Spain (and to our knowledge in
southern Europe) to show an association between NSES
and diabetes control.

Strengths and limitations of this study
Our study has several strengths. First, we study the entire
population of an area of a very large city (Madrid) where
almost 600,000 people live.32 This results in a very large
sample size and decreased concerns for selection bias as
compared to regular cohort studies or surveys.31 Second,
the diagnosis of diabetes in our EHR has been validated
before and shown to have a very high validity with a kappa
of 0.90.31 Third, HbA1c represents a robust measure of
diabetes control and is the standard of care in clinical
practice. Finally, we used an exposure constructed from
publicly available indicators, increasing the replicability
of our findings and the applicability to other health
outcomes. Our study also has some limitations. First and
foremost, while the validity of our measures of diabetes
prevalence, incidence and control is high,34 we cannot
achieve the standardisation of measurements that cohort
studies do. While there exists the possibility of differential
measurement error, we have no reason to suspect that
the accuracy of the measure of diabetes prevalence varies
by socioeconomic status, given that Spain has a universal
healthcare system. Second, while our exposure is built
from publicly available indicators, this also restricts our
capacity to build a complex exposure that may capture
socioeconomic status better. Third, the available data
for individual level confounders were restricted to basic
socio-demographic variables, age and sex, which opens
the possibility for residual confounding in our inferences.
In particular, we do not have data on individual-level socio-
economic status. Unmeasured confounding by neigh-
bourhood selection may be an important source of bias in
our study. However, whether adjusting for individual-level
socioeconomic status brings estimates closer to the truth
or induces overadjustment may depend on the level of
social mobility of each country.38 Last, the generalisability
of these results to other Spanish or European cities may
be limited for cities that do not have similar segregation
patterns. Recent research has shown increased segrega-
tion in Madrid, with levels similar to London.30

The implications of our study are several. As this is the
first study, to our knowledge, to show strong contextual
gadients in diabetes burden in Spain, we believe these
findings should be incorporated in the National Health
Equity Strategy. Research wise, this study opens the possi-
bility to study the connection between contextual factors
(food, physical activity, tobacco and alcohol environment)
and diabetes. Future studies may consider providing
specific mechanistic insights into the contextual deter-
mintants of diabetes in southern Europe. For example,
Auchincloss and Christine have reported over several
studies39 40 increased prevalence and incidence of diabetes
with lower availability of healthy foods or physical-activi-
ty-promoting resources, but research on these mecha-
nistic pathways is lacking in Spain and southern Europe
in general. In particular, the association of contextual
socioeconomic status and unhealthy food environments
has not been thoroughly replicated in Europe and may
actually follow a different gradient.41 We have previously
shown that neighbourhoods in Madrid with improving
socioeconomic status indicators have an increased propor-
tion of supermarkets and decreased proportion of fruit
and vegetable stores,42 a contextual change undesired
by neighbours and perceived as not conducive to better
diets.43 We have also previously shown that walkability
may follow an inverse social gradient in Madrid45 (worse
walkability in higher NSES areas), but that this association
may not hold in gentrifying areas.45 In summary, under-
standing the mechanisms (and therefore potential inter-
vention targets) linking NSES to diabetes may require
studies that take into consideration changes in both the
exposure and the outcome side.

WHO has identified social determinants as underlying
many of the health inequities observed within countries,46
and resulting strategies to ameliorate social determinants
through a system change are under way in countries
including Spain.47 For diabetes, an unhealthy diet, lack of
physical activity, and subsequent obesity are some of the
main modifiable risk factors that are adversely impacted
by social determinants. Understanding the contextual
contributors to the social patterning of diabetes we
have described in this study can offer opportunities for
prevention through structural changes.48 Nonetheless,
these strategies need not be restricted to macro-level
changes. Globally, intensive lifestyle diabetes prevention
programmes49 present an evidence-based opportunity
that is not reliant on environmental structural change.
Diabetes prevention programmes using this model have
proven effective in reducing diabetes incidence in persons
in lower income communities in the USA.50 There is also
initial evidence that patient diabetes self-management

Figure 3 Adjusted Kaplan-Meier survival curve of diabetes incidence by neighbourhood socioeconomic status (SES).

People at Risk

| Neighborhood SES | Low | Medium | High |
|------------------|-----|--------|------|
|                  | 60206 | 59957 | 59791 |
|                  | 57506 | 56999 |      |

| Medium | 73293 | 73050 | 72834 |
|--------|-------|-------|-------|
|        | 70437 | 69551 |      |

| High   | 112641| 112325| 112069|
|--------|-------|-------|-------|
|        | 108687| 107647|       |

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programmes focused on barriers to care and social determinants can improve diabetes self-management skills, health behaviours and HbA1c in low-income patients and communities.\textsuperscript{53,56} For reference, our results regarding the 2-year incidence of diabetes in high socioeconomic status as compared with low socioeconomic status areas (HR=0.80 and 0.69 in men and women, respectively) have an association with reduced diabetes incidence similar to a 1.2 kg and 2.1 kg reduction in body weight in the DPP trial.\textsuperscript{55} Focusing diabetes prevention efforts in lower NSES areas may help in ameliorating health inequalities. Our study provides a framework to identify areas that may require more intensive efforts by linking diabetes outcomes with readily measurable NSES.

CONCLUSION

To conclude, our study is the first to show a social gradient in diabetes burden by contextual measures of socioeconomic status in southern Europe. The use of universal EHR of an entire population improves representability and statistical power, providing a rich representation of population health patterns. Future studies should provide targets for intervention to address this population health inequity.

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Contributors

UB and MF conceptualized the study. UB conducted the statistical analysis and drafted the first version of the manuscript. UB, MF and FHB interpreted results and revised the first version of the manuscript. LSP and IC organized and conducted health data collection. MF obtained funding for the study. All authors approved the final version of the manuscript.

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Competing interests

None declared.

Patient consent

Not required.

Ethics approval

This study was approved by the Madrid Primary Care Research Committee.

Provenance and peer review

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Data sharing statement

Neighborhood SES indicators are available online as detailed in the appendix. Health data was obtained from the primary care system and cannot be shared due to privacy concerns.

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