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Obesity and dental caries in young children in Plymouth, United Kingdom: A Spatial Analysis

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Objective: To examine the spatial clustering of obesity and dental caries in young children in Plymouth, United Kingdom, to evaluate the association between these conditions and deprivation, and explore the impact of neighbourhood-level characteristics on their distribution. ***Basic research design:*** Cross-sectional study analysing data from the National Child Measurement Programme (N=2427) and the Local Dental Health Survey (N=1425). The association of deprivation with weight status and caries was determined at individual and area level, using ANOVA and Poisson models. The overall spatial clustering was assessed using a modified version of the Global Moran's I, while clusters were located through Local Indicators of Spatial Association. Spatial autocorrelation was assessed using the variograms of the raw values. Log-linear Poisson models were fitted to assess the significance of neighbourhood characteristics on overweight/obesity and caries distribution. ***Results:*** At an individual level, deprivation was not associated with BMI z-scores but was a significant predictor of caries ($p<0.05$). However, at area level, deprivation related to the rates of both conditions. A significant positive autocorrelation was observed across neighbourhoods for caries. The variograms suggested spatial autocorrelations up to 2.5 km and 3 km for overweight/obesity and caries, respectively. Among several neighbourhood characteristics, the proportion of people on benefits was found to be a significant predictor of caries rates. ***Conclusions:*** Our results underline the importance of considering geographic location and characteristics of the broader environment when developing strategies to target obesity and caries.

Key words: Obesity, Caries, Children, Inequalities, Socioeconomic factors, Geographic location

Introduction

Obesity and dental caries are of public health concern worldwide and are two of the most common conditions affecting children (FDI World Dental Federation, 2015; WHO, 2016). Both are multifactorial in origin, can have a significant impact on a child's physical and psychosocial wellbeing and are costly to healthcare services (Alm et al., 2011; FDI World Dental Federation, 2015; WHO, 2016).

Obesity in children has increased more than two-fold in the last three decades (Ogden et al., 2014) giving rise to adverse health outcomes and costs. Despite a dramatic reduction in the average levels of dental caries in the last decades in several countries, this trend has reportedly reached a plateau or even reversed in the primary dentition (National Institute of Dental and Craniofacial Research, 2014). Evidence also indicates that social inequalities have widened, with disadvantaged children being affected more in terms of both prevalence and severity of the two conditions (Public Health England, 2016; White et al., 2016).

Given that obesity and caries share common aetiological factors, such as diet and lifestyle (Alm et al., 2011), there has been an increasing interest in the association between the two conditions. However, primary studies and systematic reviews of the relationship between childhood/adolescent nutritional status and dental caries have hitherto yielded conflicting results (Li et al., 2015). Notably, the great majority of studies examined only individual-level determinants of the two conditions such as individual characteristics and health behaviours.

It is increasingly recognised that where we live has an impact on our health. Everyday life conditions and the wider socioeconomic and political environment known as the 'Social Determinants of Health' (SDH) similarly affect the development of several non-communicable diseases, including obesity and caries (Commission on Social Determinants of Health, 2008; FDI World Dental Federation, 2015). The SDH have also been recognised as the fundamental drivers of health inequalities. Tackling these determinants in addressing the prevailing inequalities and 'social gradient' in health is paramount (Commission on Social Determinants of Health, 2008; Watt et al., 2016; Watt and Sheiham, 2012). However, in order to tackle them effectively, they need to be more profoundly understood.

Geographic information systems are a potentially 'powerful evidence-based practice tool' in community health, as they enable the identification of high-risk areas in need of intervention (Pouliou and Elliott, 2009) and can allow for effective allocation of resources. They can also help understand how aspects of the physical, political and socio-economic environment might interact

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with individual characteristics and behaviours to produce the emerging patterns. To date, despite sharing common features, obesity and caries have largely been studied separately. Furthermore, the application of geographical methods and spatial epidemiology in the study of both diseases is very limited.

Examining the spatial distribution and local clusters of childhood obesity and dental caries in small geographical areas and identifying their individual and broader common determinants could improve the effectiveness and efficiency of public health strategies targeting the two conditions. To our knowledge, there has been no study examining obesity and caries together using the spatial analysis methods used in the current study, nor has any other study examined the clustering of the two conditions in relation to neighbourhood-level characteristics.

Hence, the present study aimed to explore the spatial distribution and identify clusters of obesity and dental caries in four to six-year-old children in Plymouth, a relatively deprived area in the South West of England, UK. The study also aimed to examine the association between deprivation and the risk of developing each condition, and examine potential social, economic and structural determinants of poor oral health and obesity.

Method

This ecological study used data derived from two local population datasets: (1) the 2008/9 National Child Measurement Programme (NCMP), a UK government initiative that annually measures the weight and height of children aged 4-5 and 10-11 years at state-funded schools (N=2427) (The NHS Information Centre: Lifestyle Statistics, 2009) (in the current analysis, only data from the 4-5 year old cohort are being used) and (2) the 2009 Local Dental Health Survey (N=1425), carried out by Plymouth's National Health Service (NHS) on 5 year old children (Witton & Nelder, 2009). The methods used in each survey have been described elsewhere (The NHS Information Centre: Lifestyle Statistics, 2009; Witton and Nelder, 2009).

The selection of explanatory variables was based on existing scientific literature on the impact of the broader environment on obesity and caries, and the availability of information about these variables from the Local Authority. The variables examined can be broadly categorised into socioeconomic (i.e. deprivation) and neighbourhood-level characteristics (i.e. 1. the proportion of people on benefits in each neighbourhood; 2. crime rates; 3. density of fast food outlets; 4. density of grocery shops; and 5. presence of dental clinics). The neighbourhood-level characteristics included in the analysis have been previously shown to relate to the prevalence of the two conditions or to potentially affect the conditions by impacting related health behaviours (e.g. physical activity, diet etc) (Curtis et al., 2007; Glasgow Centre for Population Health, 2013; Olafsdottir et al., 2014). In all cases, values were corrected for different population sizes in each neighbourhood.

Deprivation was determined by the English Index of Multiple Deprivation (IMD) 2010, which measures relative deprivation in small areas across the country called Lower Super Output Areas (LSOAs). These have a population of approximately 1500 people (Department for Communities and Local Government, 2011). Using data from national registries, the deprivation score for each LSOA is computed after 38 indicators on different aspects of deprivation are aggregated into seven areas: 'income, employment, health, education, crime, access to services, and living environment' (Department for Communities and Local Government, 2011). In the present study, based on postcode, an IMD score was assigned to each household which was then grouped into 3 categories (1 being the most deprived and 3 being the least deprived).

Plymouth is made up of 39 neighbourhoods, which are aggregations of the city's 160 LSOAs (Public Health Plymouth: Plymouth City Council, 2012). When grouped together, the 39 neighbourhoods or 160 LSOAs then form the city's six localities (Public Health Plymouth: Plymouth City Council, 2012) (Figure 1).

The child's weight status was based on Body Mass Index (BMI) [BMI= weight(kg)/height(m)^2] and the age and gender-specific UK 1990 growth reference centiles, using cut-offs applied for population monitoring (Cole et al., 1995). Dental caries was assessed by the dmft index which is the sum of the number of the decayed, missing, and filled teeth (Pitts et al, 1997).

Children who were underweight were not included in the analysis (N=8). Forty-five children whose postcodes corresponded to LSOAs outside Plymouth and another two children with missing information were also excluded from the NCMP dataset. Nineteen children who lived outside the city boundaries and two with missing information were excluded from the Dental Health Survey dataset.

Statistical Analyses

Continuous characteristics are presented as means ± SD and categorical characteristics as frequencies (percentages). The difference in the number of teeth affected by decay between the most and least deprived areas was assessed using the Mann-Whitney U test. The relationships between deprivation and obesity and caries was determined using ANOVA and Poisson models, respectively. The associations between deprivation with overweight/obesity and caries rates at the LSOA level was assessed using Poisson regression models. The larger the number of children in a given LSOA, the larger the number of children with caries and overweight/obese children was. Therefore, the number of children in the sample in each LSOA was included as an offset in both models.
The Poisson model fitted was:

$$\log(Y_i) = \alpha + \beta \text{ x } IMD_i + \log(N_i)$$

where Y_i is the number of affected children (overweight/obese or with caries) in LSOA i, N_i is the number of children in LSOA i in the sample, and IMD_i is the index of multiple deprivation score in LSOA i, where $i = 1, ..., 160$. Using the process of backwards elimination, log-linear Poisson models were fitted to assess the significance of several covariates (neighborhood-level characteristics) on the rates of caries and overweight/obesity. The initial model included all available covariates listed above. Then starting with the least significant covariate (based on p-value) and using backwards elimination, the covariates were removed from the model one-by-one. Each time a covariate was removed, the model was refitted. This process was repeated until only significant covariates were left in the model (all with p-values < 0.05).

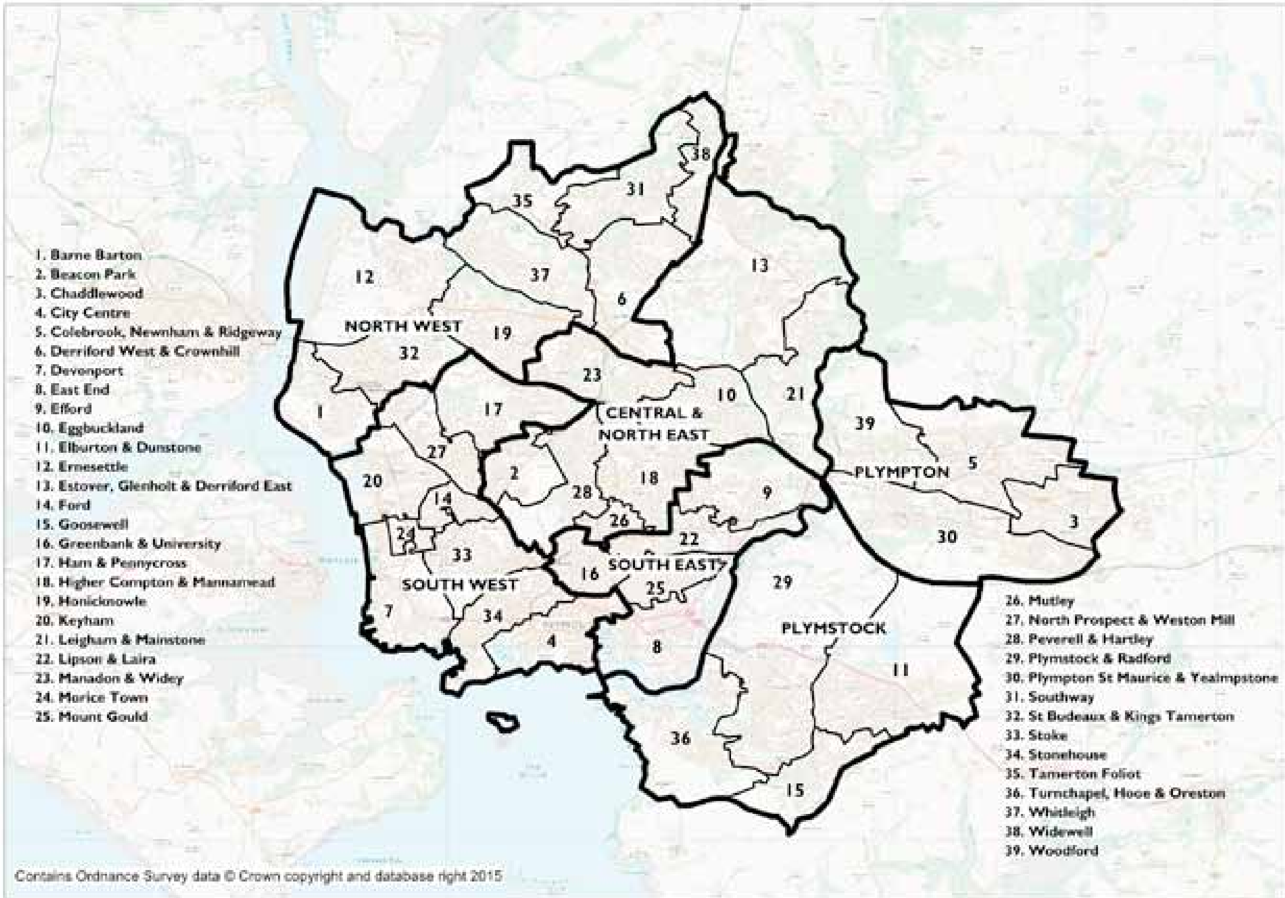

Figure 1: Plymouth by neighbourhood and locality
Plymouth currently consists of 39 neighborhoods, whose boundaries are shown by the thin lines. When grouped together, the neighbourhoods form the city's six localities the outlines of which are indicated by the bold lines. Reprinted with permission from Public Health, Office of the Director of Public Health, Plymouth City Council, copyright 2015.

The Global Moran's I, which varies between -1 and +1, was used to examine whether the overall spatial clustering of obesity and caries at the neighborhood level was random, disperse or clustered, and whether values observed at one location correlated to values observed at neighbouring locations (Pouliou and Elliott, 2009). A modified version of Moran's I was used, which adjusts the spatial clustering based on the population density (Jackson et al., 2010). When similar values of neighbouring areas cluster together (i.e. high-high or low-low), then a positive spatial autocorrelation is present. Conversely, high values clustering with low values, is termed negative autocorrelation (Pouliou and Elliott, 2009). Moran's I does not indicate the location of the clusters or whether the spatial autocorrelation, if present, is locally negative or positive. Hence, the Local Indicators of Spatial Autocorrelation (LISA) were used to identify spatial clusters and to examine for local spatial autocorrelation (Anselin, 1995). The extent to which data related to distance was assessed using empirical variograms of raw data at the LSOA level. If there is a spatial dependence, areas at close distance tend to have similar values and the space variogram is small (Diggle et al., 2003).

Data were analysed using IBM SPSS Statistics 21 and the R environment. All tests performed were two-tailed and a p-value (p) of less than 0.05 was used to indicate statistical significance.

As the study involved analysis of high-level and non-personal identifiable data that were already in the public domain, no ethics approval was required. However, an agreement policy (Third Party Use of Resources) was signed between Plymouth University and Plymouth City Council before the datasets were shared.

Results

National Child Measurement Programme

The NCMP sample included 2372 participants, who had a mean age of 5.2 ± 0.3 years (range=4.4 to 6.2 years). Most children (75%) were in the normal range of BMI centile; there were 246 obese (10.4%) and 348 (14.7%) overweight children, with both categories being above the national average (9.6% and 13.2%, respectively) (The NHS Information Centre: Lifestyle Statistics, 2009). No association between BMI z-scores and deprivation was found (p=0.07).

Dental Health Survey

There were 1404 participants in the Dental Health Survey, with a mean age of 5.3 ± 0.3 years (range=4.4 to 6.0 years). Children in this group had on average 0.9 ± 1.9 (95% CI: 0.81, 1.01) teeth affected by decay. Of the total sample, 28.8% had some experience of decay (i.e. they had at least one tooth that was decayed, missing or filled), with a mean number of 3.2 ± 2.4 (95% CI: 2.93, 3.40) affected teeth.

At the national level, the mean number of decay affected teeth among 5-year-olds was 1.11 (95% CI: 1.10, 1.12) (Rooney et al., 2009). Furthermore, nationally, 30.9% of children had some experience of decay (dmft>0) with a mean of 3.45 (95% CI: 3.42, 3.47) teeth affected.

Children in the most deprived areas of the city had a mean of 1.2 ± 2.1 (95% CI: 1.03, 1.33) teeth affected by decay, while those in the least deprived had 0.5 ± 1.4 (95% CI: 0.37, 0.64). The mean number of teeth affected teeth was higher in the most deprived areas ($p<0.01$). The IMD 2010 score was associated with dental caries ($p<0.01$).

Spatial distribution

Significant geographical variation was observed in the rates of childhood overweight/obesity and dental caries. Figure 2 shows the spatial distribution of obesity/overweight and dental caries rates (number of children affected per 100 children) in neighbourhoods and localities. Higher rates of overweight/obesity were identified in the North West, South West, and South East localities. In the City Centre, over one third of the children were either overweight or obese. Dental caries rates were also higher in the North West, South West and South East localities. Localised 'hotspots', with high values of both overweight/obesity and dental caries, were identified in areas of Plymouth's South West and South East localities. Fig. 2 also suggests increasing prevalence of caries from East to West Plymouth.

The Moran's I value was 0.334 ($p<0.05$) indicating a positive autocorrelation in caries rates across neighbourhoods, meaning that similar values of the condition were observed in adjacent areas (i.e. high-high or low-low). Hence, the overall spatial pattern of dental caries appears to be non-random with neighbouring areas having similar levels of caries. The value was lower for obesity/overweight rates ($I=0.07$) and the spatial autocorrelation was not statistically significant ($p=0.17$). Therefore, there was no strong evidence against complete spatial randomness for overweight/obesity.

The LISA cluster maps for obesity/overweight rates by neighbourhood (bottom row of Figure 3) suggested a high rate neighbourhood (City Centre), surrounded by neighbourhoods of low rates (i.e. high-low area), whereas for the same neighbourhood the opposite pattern emerged for caries (low-high area). Furthermore, a neighbourhood of high rate for both conditions (Mutley) was significantly associated with its adjacent neighbourhoods which are lower rates areas (i.e. high-low area). Finally, a 'cold-spot' (i.e. a cluster of low values) of overweight/obesity was identified in one neighbourhood (Chaddlewood).

The empirical variograms of the raw data for the number of children with caries (at the LSOA level) showed that rates in neighbouring LSOAs were similar up to a distance of 3 km, after which the variogram levelled off; thus neighbouring areas up to that distance had similar caries rates, whereas after 3 km the variability of caries rates in neighbouring areas was large and distance did not affect variability in values. For overweight/obese counts spatial autocorrelation was evident up to a distance of around 2.5 km [Figure (4a and b)]. A few points existed above the sill (horizontal line), suggesting a possible negative correlation (dissimilar values of the condition) after that distance.

When the impact of deprivation on the rates of overweight/obese children was examined at the LSOA level, the IMD 2010 was found to be significant ($p=0.018$). The size of the effect (b coefficient) was estimated to be 0.0053, suggesting that a 10 unit increase in the IMD would increase the rate of obese/overweight children by 1.053 times. For example, if the overweight/obesity rate in a LSOA with a mean IMD of 26.81 is 0.20 (20 in 100 children are overweight/obese), in a LSOA with an IMD of 36.81 the overweight/obesity rate would be 0.21 (21 in 100 children are predicted to be overweight/obese).

The IMD 2010 index predicted caries rates at the LSOA level ($p=0.01$). The effect size was 0.019, suggesting that a 10 unit increase in the IMD 2010 would result in a 1.19 increase in the rate of caries.

When overweight/obesity rates were included as a covariate in the spatial model for caries, a significant relationship between overweight/obesity and caries rates was found ($p=0.02$). However, this was no longer significant after controlling for covariates. From the neighbourhood characteristics examined, only the percentage of people on benefits was associated with caries rates ($p<0.01$). Thus a 1% increase in the percentage of people on benefits, would increase the caries rates by 1.04 times.

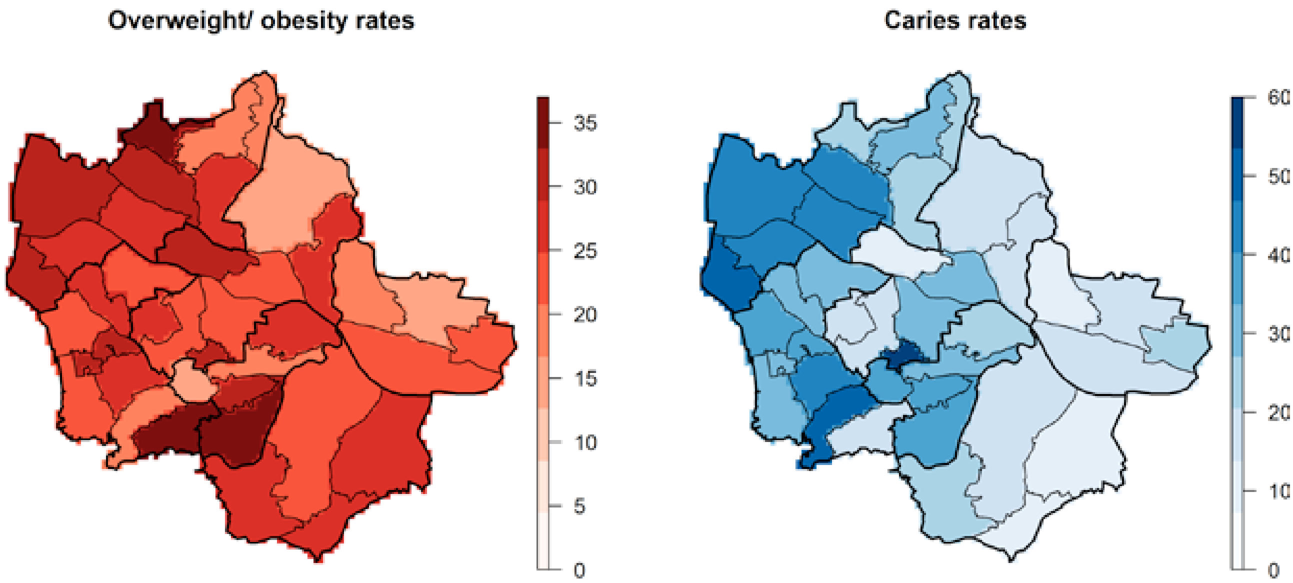

Figure 2: Overweight/obesity (left) and caries (right) rates by neighbourhood in Plymouth. The rates (shown on the legends), refer to the number of affected cases per 100 children. The darker the colour of a neighbourhood in the map, the higher the rate of the condition in the area.

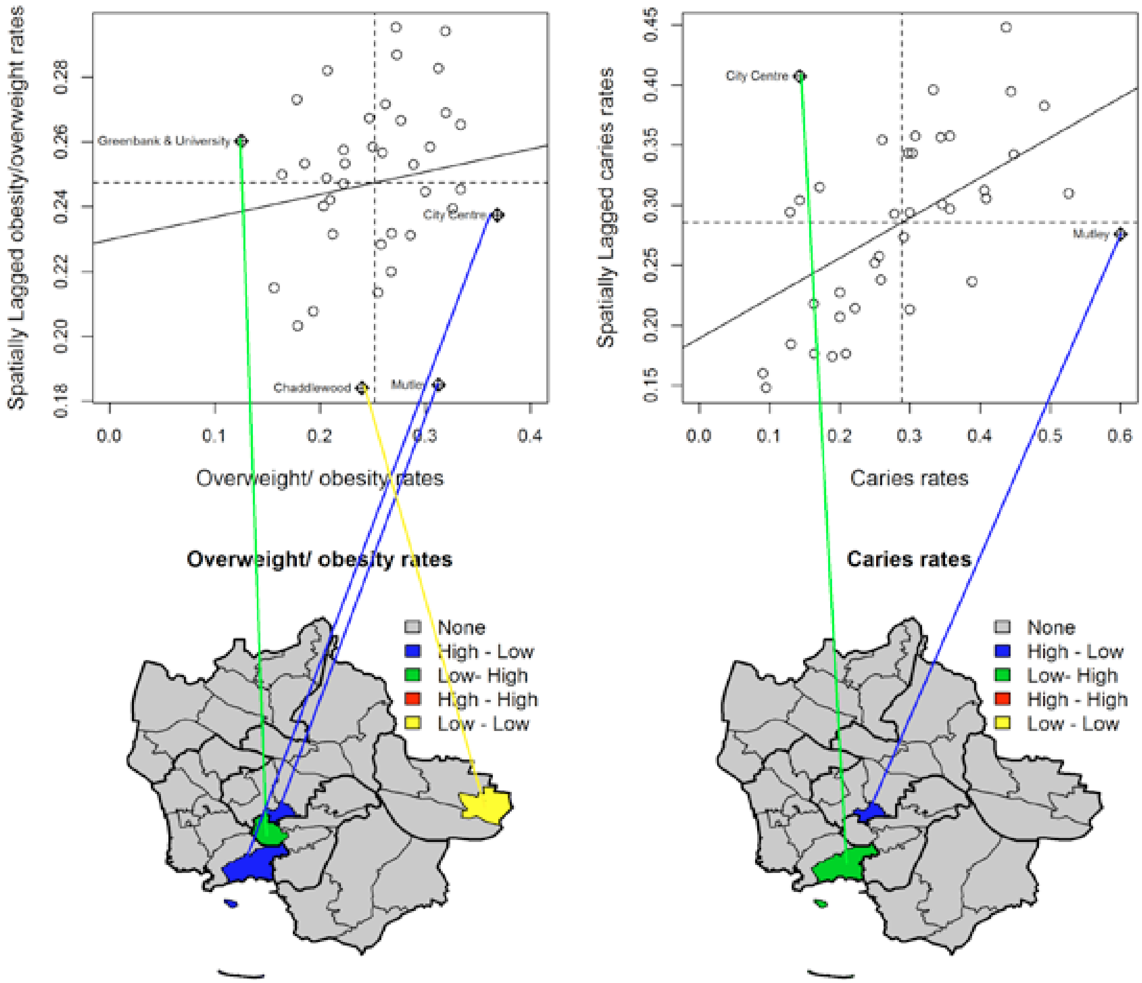

Figure 3: LISA cluster maps for overweight/ obesity (left) and dental caries (right) rates in Plymouth. The maps indicate the local clustering of the two conditions in Plymouth . The left axis (spatially lagged rates) indicates the weighted sum of the rates of the condition for an area based on its distance with its neighbours. The outliers (indicated by the diamond shapes), are areas in which the conditions' rates deviate significantly from the neighboring units. The solid line going through the intersection of the dotted lines (i.e. slope of regression line), indicates the extent to which distance influences the relationship of areas regarding the condition. The squares on the top left and low right indicate negative autocorrelation (i.e. areas having dissimilar values of the condition) and the top right and low left boxes show positive autocorrelation (areas having similar values of a condition).

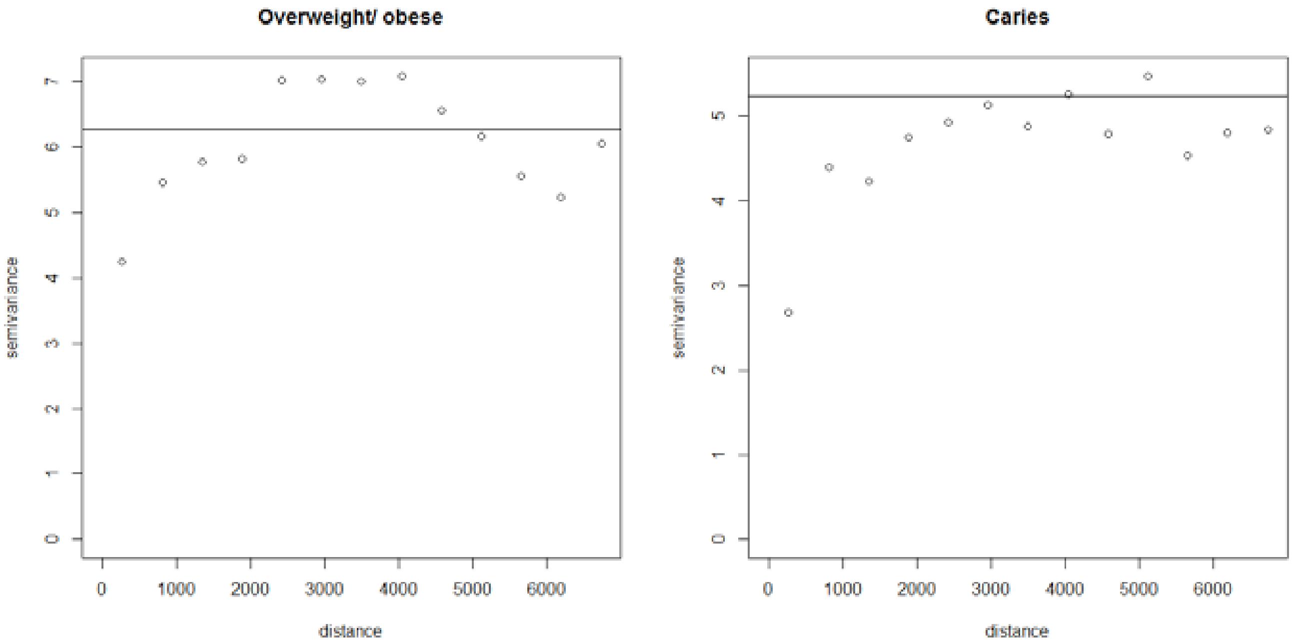

Figure 4: Empirical variograms for raw counts of overweight/ obese (left) and children with caries (right). The variograms measure the variability in raw rates values of the conditions as a function of distance. The dots indicate the variability of overweight/obesity or caries values in areas at different distances. The higher the dot on the vertical axis, the higher the variability of rates values at those distances. The horizontal line (sill) is the point where there is no spatial autocorrelation, meaning that areas at distance greater than the distance at which the sill is reached do not have similar values.

Discussion

The present study showed strong evidence of an association between deprivation and children's dental caries experience, with children of lower socioeconomic status experiencing a greater burden of disease. This finding is consistent with national data and indicates continuing inequalities in oral health. An association between deprivation and caries was also evident at the spatial level.

Although the exact mechanism by which socioeconomic status affects dental caries is not yet clearly understood, several potential theoretical pathways for inequalities in oral health have been provided (Sisson 2007). These range from differences in accessing services (i.e. materialist explanation), compromising health behaviours and choices (i.e. cultural/ behavioural perspective), psychological stress which can lead to the adoption of unhealthy lifestyle choices (i.e. psychosocial explanation) and the interaction of these pathways over time (i.e. life course model). The mechanism by which socioeconomic status (SES) affects dental caries in the present study could not be clarified, but it is evident from the results that when targeting dental caries, priority should be given to disadvantaged areas. Furthermore, risk factors for chronic diseases are commonly clustered in individuals of lower socioeconomic status and the behaviours that people adopt are largely driven by the social determinants of health (Watt et al., 2016; Watt and Sheiham, 2012). Yet, the precise actions required to alter these behaviours and influence the pooling of disease in areas of disadvantage are still not understood. Further research into the broader environmental influences on oral health inequalities, is warranted.

Although deprivation was not related to individual BMI, it was related to rates of overweight/obesity among children at area level. The absence of evidence of an association between excess weight and IMD 2010 at the individual level may be due to the various changes in children's social and built environments in recent years, which have resulted in an increased energy intake and decreased expenditure across the entire socioeconomic spectrum (Conrad and Capewell, 2012). This in turn would make it difficult to observe differences in the weight of children from different socioeconomic backgrounds. Furthermore, an extensive review of studies published between 1980 and 2010 that examined inequalities in obesity prevalence among UK children showed that the measure of deprivation used affected the relationship detected (El-Sayed et al., 2012). Thus, it could be that the measure used in the present study may have been partly responsible for the lack of observed association. More studies examining the impact on obesity of multiple indicators of deprivation, both at the area and individual level, will expand knowledge on the complex synergy between them.

Localised 'hotspots' of overweight/obesity and dental caries were identified in areas of Plymouth's South East and South West localities. This finding demonstrates the impact of location on the geographical distribution of obesity and caries, and suggests that spatial hetereogeneity should be taken into account in strategies against the two conditions. The spatial distribution of caries rates was associated with the percentage of families in these localities that rely on state benefits. Therefore, the proportion of people on benefits appears to explain at least partly the distribution of caries and could be used as an indicator to target caries in prevention programmes. This reinforces the notion that neighbourhood characteristics impact on the distribution of health conditions and should be explored further in relation to obesity and caries.

The observed clustering of neighbourhoods suggests that the specific areas somehow alter the risk of being affected by chronic conditions such as caries and obesity, and that individual and environmental determinants probably interact to contribute to the observed patterns (Pouliou and Elliott, 2009). As residents in neighbouring areas are likely to share similar lifestyles, it could be that residents of adjacent areas with similar obesity and/or caries rates, share behaviours that promote either condition (Penney et al., 2014). Information on individual lifestyles was not collected in this study and therefore this hypothesis cannot be directly examined here. Adjacent areas also share similar social and built characteristics and therefore the clustered areas may also share similar features. As such, it is possible that other features that were not investigated in the present study, and which could affect the two conditions directly or by impacting on related behaviours (e.g. policies on food, availability of parks/playgrounds etc) were partly responsible for the identified patterns. With regard to the neighbouring locations with different rates, the mechanisms are likely to be more complex (Penney et al., 2014). Overall these findings indicate the value of spatial analysis in identifying areas with a high prevalence of chronic disease that could be targeted in public health interventions. The study also provides support to the concept of 'proportionate universalism' (Marmot, 2010), where the scale and intensity of interventions should take into account the level of need both at geographical and individual level. Future research into the mechanisms by which area-level characteristics may interact with individual characteristics to produce the emerging patterns is warranted.

A limitation of the present study was its cross-sectional design, so only associations and not causal relationships can be inferred from the data. Although the findings yield significant information on the overall and local clustering of childhood obesity and caries, the present study cannot directly identify lifestyle factors contributing to the reported patterns. However, it has helped generate hypotheses on possible factors linking the two conditions at the small area level.

Furthermore, the IMD 2010 is a relative measure of deprivation. The main disadvantage of using this index is that it assesses deprivation at the LSOA level and therefore, as a result of the ecological fallacy, it may not reflect the socioeconomic status of each individual child. Despite these limitations, the IMD 2010 is considered the best available measure of comparing deprivation among different areas in England (Conrad and Capewell, 2012).

Conclusion

Our findings indicate the presence of spatial heterogeneity in the rates of childhood overweight/obesity and dental caries and provide valuable information on the geographical clustering of these conditions. The results confirm the inequalities in the distribution of the two conditions and reinforce the notion that area-level characteristics play an important role in population health. Finally, they underline the importance of developing initiatives that take into account broader determinants of health.

Examining the spatial clustering of obesity and caries in small geographical areas in relation to neighborhood-level characteristics could improve the effectiveness and efficiency of public health strategies targeting the two conditions. The study highlights the importance of 'proportionate universalism' which advocates for planning and delivering services according to the levels of need both at the area and individual level. Further research on how the broader environment interacts with individual behaviours and characteristics in obesity and caries rates is warranted.

Conflict of interest

The authors declare that there are no conflicts of interest to disclose.

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