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Using Geographic Information System (GIS) to explore the spatial association between neighborhood contexts and oral health outcomes in a pediatric population

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ABSTRACT: Aims: This study aimed to explore the impacts of neighborhood-level socioeconomic contexts (e.g., income, education) on the therapeutic and preventative dental quality outcome of children aged 3 to 15 years. Materials and Methods: Anonymized billing data of 842 patients reporting to a university Children's Dental over three years met the inclusion criteria. Their access to care (OEV-CH-A), topical fluoride application (TFL-CH-A) and dental treatment burden (TRT-CH-A) were determined by dental quality alliance (DQA) criteria. The three oral health variables were aggregated at a neighborhood-level and analyzed with census data provided by Statistics Canada within a GIS framework. The forward sortation area (FSA) was chosen as a neighborhood spatial unit and regression models were implemented both at the individual and neighborhood level. Results: The individual-level regression models showed significant negative associations between OEV-CH-A ($p=0.027$) and TFL-CH-A ($p=0.001$) and the cost of dental care. There was a significant negative association between TRT-CH-A and median household income. Neighborhood-level Ordinary Least Squares (OLS) linear regression models show negative associations of all three dental health variables (OEV-CH-A, TFL-CH-A, TRT-CH-A) with median household income and the number of households without a college degree. Conclusion: GIS and spatial quantitative approaches may be an effective tool to explore the impacts of socioeconomic variables on oral health outcomes.

Keywords: Dental treatment outcomes, Geographic Information System (GIS), Neighborhood contexts

1. Introduction

In recent years, there has been increased interest amongst both clinicians and researchers on the role of neighborhood socioeconomic and demographic contexts in children (1–3). This has led to the development of several theoretical models for caries risk prediction based on social and demographic variables (4–6). The Canadian Health Measures Survey (CHMS) estimates that dental caries affects nearly 60% of all Canadian children (7,8). Groups such as recent immigrants and First Nations Populations have been identified as having a higher caries risk, with estimates showing prevalence to be as high as 90% (7,9–11).

The concept of utilizing secondary data from patient records is not new. However, advances in technology, computing power, and the ease of access to digital records have resulted in rapid strides in the fields of data mining and knowledge discovery in database (KDD) (12). In the United States, data mining of electronic health records and billing data has been shown to serve as an accurate indicator of both caries risk as well as access to dental care (13). The dental quality alliance (DQA)

has proposed definite protocols to mine electronic dental records to identify the quality of care received by specific dental communities (12,13).

The adoption of electronic databases and billing systems by dental schools across North America has resulted in an increased capacity to mine these patient records and billing data (14). The Children's Dental Clinic at Schulich Dentistry has offered subsidized oral health care to the children (below 15 years of age) of London and the surrounding areas of Southwestern Ontario for over four decades. Since 2011 the clinics have adopted an electronic billing system, which documents all treatment rendered at the Children's Dental Clinic using standardized Ontario Dental Association (ODA) coding.

Statistics Canada provides various socio-economic and demographic data aggregated at the forward sortation area (FSA) level. While some efforts have been made to estimate the distribution of dental caries, there have been few attempts to explore the association between neighborhood factors and children's oral health outcomes using GIS that can help guide public health policy development (10,15,16).

Geographic Information System (GIS) enables gathering, managing, visualizing, and analyzing neighborhood socioeconomic, demographic data and health outcomes data in an integrated framework using software designed for the purpose (17,18). There are several methods of spatial analysis and GIS which have been used with varying degrees of success in dentistry (19). However, GIS and spatial analysis have been underutilized in exploring the association between neighborhood social contexts and dental health outcomes (20).

This study aimed to use GIS and three-year retrospective billing data to measure the impacts of income and education on the therapeutic and preventative dental quality outcome of children aged 3 to 15 years residing within the London Metropolitan Area (LMA) of Southwest Ontario, Canada.

2. Methodology

Ethical Approval

Approval was obtained from the Health Sciences Research Ethical Board (HSREB), Western University (ID-115567) to access anonymized billing data of patients reporting to the Children's Dental Clinic of the Schulich School of Medicine and Dentistry between March 2017 and March 2020. Parents of all children presenting to the clinic had given informed consent for the use of anonymized data for research purposes.

Screening of Patient Records

The patient billing from the electronic billing data from the Children's Dental Clinic of the Schulich School of Medicine and Dentistry from March 2017 to March 2020 were exported into anonymized Microsoft excel spreadsheets. Records of patients aged below 15 years at the time of the last dental visit were screened for the following inclusion criteria:

- a) Presence of key patient attendance metrics including, treatments, age, date of treatment, ODA treatment code, FSA code.
- b) Presence of at least one additional treatment code within a 180-day period- intended to avoid skew or bias in keeping with the protocol set by the DQA (14).
- c) At least 20 patients in each FSA code.

Measurement of Dental Quality Outcomes

Three outcome measures were chosen from the DQA outcome measures. Treatment Services (TRT-CH-A) was described as the percentage of patients who had received a treatment procedure in a one-year interval (14). Oral Evaluation (OEV-CH-A) (14) was described as the percentage of children who had at least one scheduled oral examination in a year. Topical Fluoride for Children at Elevated Caries Risk (TFL-CH-A) was described as the percentage of children having at least two topical fluoride applications (14).

Data Coding, Analyses, and Mapping

The three DQA outcome variables, treatment cost according to the ODA fee guide and the subsidized fee paid at the dental school by each patient were entered into a single spreadsheet (Microsoft Excel, Microsoft Corp. Palo Alto CA). Dental health outcomes and neighborhood contexts

variables (median household income, the number of low-educated households) were geovisualized and analyzed using a GIS software (ArcGIS 10.8.1, ESRI Canada, Toronto, Canada). Individual data was coded into the IBM-SPSS ver.25 data processing software (IBM Corp. Armonk, NY, USA).

Individual-level linear regression models using the cost of dental care (both subsidized and recommended cost), and median household income of the FSA as dependent variables and DQA measures as factors were developed.

Neighborhood-level OLS models were implemented using two covariates: 1) median household income and 2) the number of households without a college degree in 2017 provided by Statistics Canada (Figure 1, Figure 2). The level of significance for the OLS models was set at $p<0.01$.

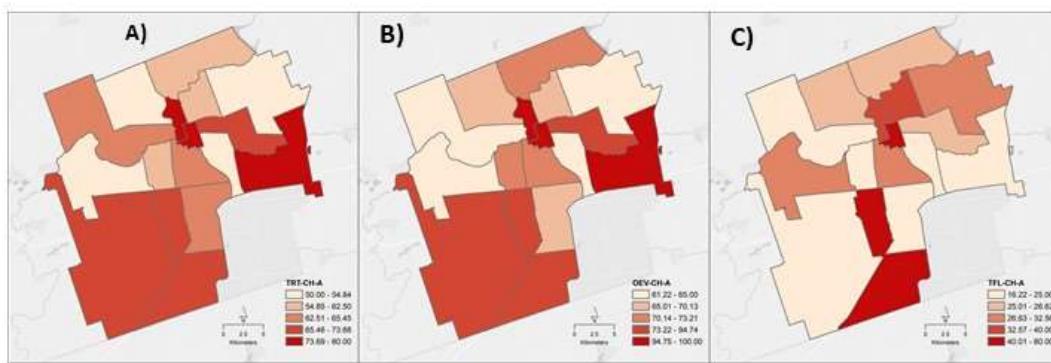


Figure 1. Geographic patterns of dental outcomes at FSA level: (A) Treatment received, (B) Visits to the dentist, and (C) Topical Fluoride Application

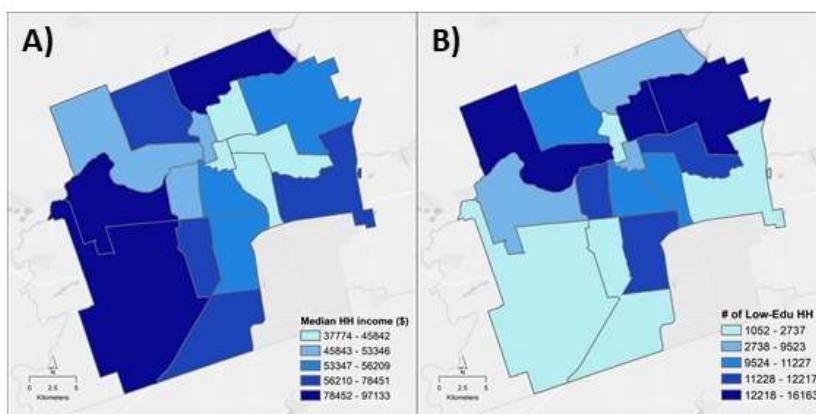


Figure 2: Geographic patterns of (A) median household income and (B) the number of households without a college degree at FSA level in London, Ontario

3. Results

Data from a total of 17 FSA codes in the London Metropolitan Area met the inclusion criteria. A total of 842 patients ($n=842$) were included, with a mean age of 9.5 years ($SD\pm3.6$). The population subset included 436 males (mean age 9.4 years, $SD\pm3.3$) and 406 females (mean age 9.5 years $SD\pm3.4$). ODA fees were calculated for each patient and the mean cost of treatment was \$53.2 ($SD\pm40.5$). The actual mean subsidized fee paid by the patients was \$17.2 ($SD\pm12.2$) per treatment. The DQA outcomes and cost of treatment was described for each FSA code (Table 1).

Table 1. Descriptive Statistics and DQA outcomes of the population

FSA Code	Number of Patients	Average Cost Per Patient (\$)	Treatment Utilization (TRT-CH-A) (%)	Oral Evaluation (OEV-CH-A) (%)	Topical Fluoride Application (TFL-CH-A) (%)
N5H	32	200	78	94	6
N5P	28	110	53	87	7
N5R	21	124	64	93	57
N5V	31	113	55	65	32
N5W	24	194	74	95	26
N5X	64	142	63	70	27
N5Y	77	123	61	70	34
N5Z	49	104	53	61	20
N6A	21	84	80	100	40
N6B	22	163	80	100	80
N6C	43	152	63	72	33
N6E	55	114	65	65	20
N6G	179	129	55	67	27
N6H	74	155	65	65	16
N6J	56	135	61	73	25
N6K	44	168	50	65	33
N6L	22	179	67	89	78

Individual-level linear regression with median income as the dependent variable found that there was a significant ($p=0.015$) negative association ($\beta=-0.112$) between median household income and TRT-CH-A suggesting that families with a higher median income had less need for treatment (**Table 2**). Both oral evaluation (OEV-CH-A) and topical fluoride application (TFL-CH-A) had no significant association with median household income (**Table 2**). Individual-level regression modelling with cost of treatment as the dependent variable showed an inverse trend to that of median household income. Utilization of treatment (TRT-CH-A) did not have a significant correlation to cost of treatment when both the cost of treatment and subsidized treatment were used as dependent variables (**Table 2**). In contrast, both oral evaluation ($\beta=-0.110$, $p=0.027$) and topical fluoride application ($\beta=-0.177$, $p=0.001$) had significant negative correlation to cost of treatment when the suggested fee guide was used. The associations remained valid even when the subsidized value was used as the dependent variable (**Table 2**).

Neighborhood level OLS results (**Table 3**) showed that TRT-CH-A and OEV-CH-A were inversely associated with median household income as well as the number of households without a college degree. TFL-CH-A was significantly associated with the level of education but not with income (**Table 3**). The Joint F and Wald Statistic demonstrated the overall significance of the models. However, Koenker Statistic and Moran's I value for residuals suggest further investigation on the spatial effects is needed. A statistically significant Koenker Statistic for the TFL-CH-A model suggests the relationships between children's oral health outcomes and neighborhood socioeconomic variables are not consistent across space (**Table 3**). Moran's I value for residuals of TRT-CH-A model demonstrates statistically significant spatial autocorrelation in the residuals. There is a less than 10% likelihood that the observed spatial pattern of residuals could be the results of random chance (**Table 3**). Overall, the neighborhood-level OLS analysis results showed that modeling the relationship between socio-economic factors and oral health outcomes might be erroneous when the characteristics of spatial data are ignored.

Table 2: Individual-level association between outcome measures and cost of treatment and median household income

Dependent	Variable	Unstandardized Coefficients*		Standardized Coefficients*		
		B	Std. Error	Beta	t	Sig.
Median Income	TRT-CH-A	-5221.290	2135.974	-.112	-2.444	.015**
	OEV-CH-A	-6703.283	3624.823	-.092	-1.849	.065
	TFL-CH-A	2533.506	1912.837	.068	1.324	.186
Cost of Treatment (ODA Fee)	TRT-CH-A	1.477	1.522	.044	.971	.332
	OEV-CH-A	-5.712	2.580	-.110	-2.214	.027**
	TFL-CH-A	-4.714	1.362	-.177	-3.461	.001**
Cost of Treatment (Subsidized Fee)	TRT-CH-A	1.638	1.498	.049	1.093	.275
	OEV-CH-A	-4.235	2.396	-.095	-1.951	.035**
	TFL-CH-A	-4.086	1.213	-.154	-3.368	.001**

*Calculated using linear regression modelling

** Associations Significant (p<0.05)

Table 3: Neighborhood-level OLS results

Dependent variable	Independent variable	Coefficient	Std. Error	t	P-value	Robust p-value	Koenker Statistic	Joint Wald Statistic	Joint Statistic	F-Statistic	Moran's I value for residuals
TRT-CH-A	Median										
	Income	-0.000289	0.0001	-3.406	0.0046*	0.0008*	0.6248	76.6904	13.0023		-0.309675
	Education	-0.001652	0.0003	-4.891	0.0002*	<0.0001*		(p=0.73167)	(p<0.001)	(p=0.0079)	(p=0.0722)
OEV-CH-A	Median										
	Income	-0.000027	0.0001	-2.165	0.0495*	0.0039*	1.3616	168.5177	16.0684		-0.073294
	Education	-0.00288	0.0005	-5.660	<0.0001*	<0.0001*		(p=0.5062)	(p<0.0001)	(p=0.0003)	(p=0.959)
TFL-CH-A	Median							6.1934			
	Income	-0.000036	0.0002	-1.587	0.1363	0.1208	8.1083	(p=0.01735)	4.404980		-0.199269
	Education	-0.002710	0.0009	-2.946	0.0113*	0.0308*		(p=0.0451)	(p=0.0346)		(p=0.343)

* Association significant at p<0.01

4. Discussion

The role of neighborhood socioeconomic and demographic contexts on oral health and dental care outcomes have been recognized in dental literature. However, the application of GIS and spatial analysis on these associations have not been fully studied in dentistry. One of the greatest advantages of neighborhood-level spatial analysis is that they help policy makers differentiate between individual needs and community needs (19).

We selected variables for individual-level models according to studies have shown that household income, patient access to care and treatment coverage are commonly cited as being major contributors to patient's oral health (21–23). The outcome variables chosen for this study sought to measure the access to care (OEV-CH-A), treatment burden of dental disease (TRT-CH-A) and regular preventative care (TFL-CH-A).

The results of the treatment burden showed that the burden of dental treatment (TRT-CH-A) was inversely associated with both the median income of the family and the cost of dental care at the individual level. This is in keeping with current literature that has shown that the burden of treatment in oral disease is higher on households with a lower income (24,25). This is particularly important as income is used as a screening criterion for eligibility to enroll in subsidized oral healthcare programs in Canada. (10) This finding is also in keeping with literature that suggests that income inequality and inequity alone is not a clear indicator of oral health discrepancy and disparity (23).

Preventative dental outcomes are widely understood to better the oral health of patients (26,27). The fact that TFL-CH-A was inversely associated with the overall cost of dental care supports literature that shows that regular preventative dental care can lower overall dental treatment costs.(25,28,29) The fact that TFL-CH-A was not only associated with cost of care at an individual level, but had significant spatial association with the number of low-educated households at a neighborhood level supports the fact household education is correlated to household oral health (30).

Although relatively new in dental caries epidemiology, Geographic Information System (GIS) has proven to be a valuable tool in evaluating and describing oral health inequities within a region (5,31,32). Neighborhood OLS results suggest the necessity of considering spatial heterogeneity and dependency in data when modeling dental outcomes with neighborhood social contexts. The spatial heterogeneity in TFL-CH-A implies local (rather than global like OLS) spatial models, such as geographically weighted regression (GWR), which can investigate the spatially varying associations among variables would be beneficial (33). Also, the evidence of spatial structure in residuals suggests a spatial error model would be appropriate when modeling TRT-CH-A (34, 35).

The results of this pilot study must be viewed keeping in mind certain limitations. The fact that the study was conducted over a relatively small area means that while the insights offered by this pilot study are useful, they are not generalizable. The limited size of the sample also meant that the study only explored two previously documented variables (income and education). There is a need for studies using a larger number of FSA codes to explore the different socioeconomic and demographic variables documented through census data in Canada.

5. Conclusion

Within the limitations of this pilot study, we can conclude that GIS and neighborhood-level OLS models may be an effective tool to explore the impacts of neighborhood socioeconomic factors on oral health outcomes. However, further investigations are needed with the considerations of spatial heterogeneity and dependency in the data to reveal local relationship between neighborhood contexts and children's oral health outcomes. The models also suggest that the forward sortation area (FSA) code can be used as a unit of spatial measurement for oral health and treatment outcomes in Canada.

Conflicts of Interest Statement: The authors declare that they have no conflict of interest

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