Spatial analysis to locate new clinics for diabetic kidney patients in the underserved communities in Alberta

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Abstract

Background. Canadians with chronic diseases often live far away from healthcare facilities, which may compromise their level of care. We used a new method for selecting optimal locations for new healthcare facilities in remote regions.

Methods. We used a provincial laboratory database linked to data from the provincial health ministry. From all patients with serum creatinine measured at least once between 2002 and 2008 in Alberta, Canada, we selected those with diabetes and an estimated glomerular filtration rate (eGFR) of 15–60 mL/min/1.73 m². We then used two methods to select potential locations for new clinics that would serve the greatest number of remote-dwelling patients: plots showing the unadjusted density of such patients per 100 km² and SatScan analysis presenting the prevalent clusters of patients on the basis of chronic kidney disease (CKD) rates (adjusted for population size).

Results. We studied 32 278 patients with concomitant diabetes and CKD. A substantial number of patients (8%) resided >200 km from existing nephrologists’ clinics. Density plots mapped with ArcGIS were useful for localizing a large cluster of underserved patients. However, objective assessment with SatScan technique and ArcGIS permitted us to detect additional clusters of patients in the northwest and southeast regions of Alberta—and suggested potential locations for new clinics in these areas.

Conclusions. Objective techniques such as SatScan can identify clusters of underserved patients with CKD and identify potential new facility locations for consideration by decision-makers. Our findings may also be applicable to patients with other chronic diseases.

Keywords: new clinics; spatial; underserved

Introduction

Patients with concomitant diabetes and chronic kidney disease (CKD) are at high risk for cardiovascular events [1–4], due to the higher burden of uncontrolled hypertension [5, 6], dyslipidemia [7], anemia [8, 9] and older age [10]. Canadians, including CKD patients, living further from care facilities are more likely to experience poor health outcomes [11–14] despite the universal healthcare system [15–18]. About 30% of Canadians live in rural, remote and northern communities which are served by only 17% of family physicians, 4% of specialists, and 18% of registered nurses [18]. In northern and remote regions of Canada, more than two-thirds of residents live more than 100 km from a physician [19].

As this ‘geographical barrier’ can adversely influence health outcomes, decision-makers must choose where to locate new facilities to maximize clinical benefits. However, the best method to locate potential new clinics for these facilities has not been identified. Such decisions are often based on political factors or guesswork, and a more objective method would be useful.

We used data from a population-based registry and objective analyses using the SatScan technique and ArcGIS software to identify potential locations for the new clinics that might serve the maximum number of high-risk patients. SatScan analysis can be used to determine whether an event or characteristic of interest (such as CKD prevalence) is randomly distributed over space in a defined geographical region. Thus, this technique can be used to identify significant spatial clustering of patients with certain clinical characteristics [20]. Our goal was to investigate the spatial distribution of remote dwellers with both diabetes and CKD in Alberta (a group at very high...
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risk of adverse outcomes) to identify the optimal locations for new nephrology clinics that could serve this population.

Materials and methods

We used data from the Alberta Kidney Disease Network [21] and the provincial health ministry (Alberta Health and Wellness; AHW) to identify prevalent patients with CKD and concomitant diabetes, and locate their residence relative to existing nephrology clinics. Our initial analyses used a commonly applied crude method (maps using shading to illustrate population density) to represent the geographical distribution of the target population. However, this method does not provide sufficient spatial resolution to localize new clinics. Therefore, we performed SatScan analysis—a more complex method that provides more detailed results such as expected number of cases, annual rates, relative risk and log likelihood ratio—to detect clusters of patients who lived at greater distances from existing facilities, and then plotted the results geographically.

Identification of patients with chronic kidney disease and diabetes

From all outpatients aged >18 years who had serum creatinine measured in Alberta at least once between 1 May 2002 and 31 December 2008, we selected cases with Stage 3–4 CKD [defined as estimated glomerular filtration rate (eGFR) 15–59.9 mL/min/1.73 m²] and concomitant diabetes mellitus (DM) during the calendar years 1994–2008. We estimated eGFR using the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) study equation [22], using the date of the last serum creatinine available during the study period. We identified diabetes using validated algorithms (two physician billing claims in a 2-year period or one hospital discharge at any point in time with a diagnosis of diabetes, excluding gestational diabetes) [23].

Our focus was on people requiring pre-dialysis care in the province of Alberta during the study period. Therefore, of 33 647 cases with diabetes and eGFR 15–59.9 mL/min/1.73 m², we excluded 36 (0.11%) people who during the study period were treated with chronic dialysis or had a kidney transplantation, or who died (n = 1292, 3.84%) or out-migrated from Alberta (n = 41, 0.12%).

Comorbidity was assessed for the remaining 32 278 cases using physician claims and hospitalization data together with validated algorithms [24] for the Charlson score presented in Table 1. The total number of Alberta residents (n = 2 795 541) were retained in the data set for use in analyses requiring the total population in each postal code.

Identification of residence locations

We used the AHW registry file to identify the postal code associated with each participant’s home address during each calendar year. For participants whose records were associated with multiple postal codes, we used the last available postal code during the study period to represent the residence location. All except 159 (<0.1%) of the participants had valid postal code data. We then matched these postal codes to the 2008 Postal Code Conversion File to obtain the latitude and longitude coordinates associated with the centroid of each postal code. The resulting data set included residential postal code (with latitude and longitude) as well as demographic and clinical data for each person who was insured by AHW during the calendar years 2002–2008.

Disease mapping

We generated the shaded density plots by using ArcMap [ArcGIS Desktop Release 10, Environmental Systems Research Institutes (ESRI), Redlands, CA]. This image was the result of a simple point in raster operation using 100-km² grid cells in a 10 transverse Mercator projection commonly used with spatial data sets. We categorized patients according to the number of cases per 100-km² grid and plotted these categories on the map using different color shades. The yellow shades were used to represent the lower densities and the brown shades indicated higher densities of case patients per square grid. We displayed the locations of existing nephrology clinics on the map. Spatial analysis was performed using the buffer tool in ArcGIS 10.0 software.

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Comorbidity was assessed for the remaining 32,278 cases using physician claims and hospitalization data together with validated algorithms [24] for the Charlson score presented in Table 1. The total number of Alberta residents (n = 2,795,541) were retained in the data set for use in analyses requiring the total population in each postal code.

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However, in some communities, there might have been rapid population growth or seasonal variation in population counts which may contribute to errors in estimating higher than expected occurrence of disease burden for that community. Therefore, comparisons should be based on rates rather than case counts [25]. We calculated disease rates by using spatial analyses with SatScan software at the postal code level rather than density plots in the 100-km² grid scale with ArcGIS software. Therefore, we performed spatial analysis with SatScan software and plotted the maps using ArcGIS software—allowing us to map the density plots using a predefined scale. Thus, the use of SatScan and ArcGIS together was superior to the use of ArcGIS alone, as it allowed us to identify the prevalent clusters of CKD and diabetes mellitus in underserved communities without any predefined criteria for cluster size or radius. We identified disease rates in underserved communities by considering existing clinic locations in our analysis. A second advantage of SatScan is that its superior resolution allows more precise location of potential new clinics—rather than simply identifying large geographical areas (100-km² grids, or 10,000 km²) where new clinics might be needed.

Clinic locations

A list of all 17 existing clinics providing specialist nephrology care to Stage 3–4 CKD patients was obtained from the provincial renal programs. Because we were interested in patients residing at a distance from nephrology service, we established non-mutually exclusive categories of >50 and <100, >100 and <150, >150 and <200, and >200 km, each representing the distance between a patient’s residence and the closest nephrology clinic. Buffer zone analysis was used to identify group of participants in the underserved community who lived far away from existing nephrology clinics. Accordingly, when the 50-km buffer zone was created, we dropped postal codes of anyone living within the 50 km of existing clinics, retaining only postal codes of those who were residing >50 km away. A similar method was used to create non-mutually exclusive 100, 150 and 200-km buffer zones. We used ArcGIS 10.0 software (ESRI, Inc.) to carry out these analyses. We geocoded the postal codes of the patients’ residence based on latitude and longitude. Four buffer zones were created following the ‘crow fly buffer’ technique using the buffer tool in ArcGIS software.

Table 1. Characteristics of participants with chronic kidney disease and diabetes

<table>
<thead>
<tr>
<th>Characteristics (n = 32,278)</th>
<th>Proportion or mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (SD), years</td>
<td>74.9 ± 10.6</td>
</tr>
<tr>
<td>Female</td>
<td>17,261 (53.48)</td>
</tr>
<tr>
<td>Charlson scoreb</td>
<td>1.7 ± 1.6</td>
</tr>
<tr>
<td>eGFR, mL/min/1.73 m²c</td>
<td>3224 (9.99)</td>
</tr>
<tr>
<td>15–29.9</td>
<td>29,054 (90.01)</td>
</tr>
<tr>
<td>30–59.9</td>
<td></td>
</tr>
<tr>
<td>Income</td>
<td></td>
</tr>
<tr>
<td>Aboriginal</td>
<td>672 (2.08)</td>
</tr>
<tr>
<td>Normal</td>
<td>6394 (19.81)</td>
</tr>
<tr>
<td>Subsidy</td>
<td>1662 (5.15)</td>
</tr>
<tr>
<td>Assistance</td>
<td>1029 (3.19)</td>
</tr>
<tr>
<td>Pensioner</td>
<td>22,521 (69.77)</td>
</tr>
<tr>
<td>Distance from closest nephrology clinic, km²</td>
<td></td>
</tr>
<tr>
<td>&gt;50 and &lt;100</td>
<td>4234 (13.12)</td>
</tr>
<tr>
<td>&gt;100 and &lt;150</td>
<td>1571 (4.87)</td>
</tr>
<tr>
<td>&gt;150 and &lt;200</td>
<td>1080 (3.35)</td>
</tr>
<tr>
<td>&gt;200</td>
<td>2504 (7.76)</td>
</tr>
</tbody>
</table>

Values are n (%) or mean (SD) as appropriate.

bCharlson comorbidity [24].

ceGFR is a glomerular filtration rate estimated by the CKD-EPI equation [22].

Income as an indication of socioeconomic status: ‘Assistance’ refers to participants with health insurance premium paid under a program sponsored by Alberta Employment, Immigration and Industry. ‘Subsidy’ refers to participants who pay less than the full premium or no premium to Alberta Health and Wellness or in the premium is subsidized though a Government Sponsored Program. ‘Normal’ refers to all other participants.

Estimated based on the date of the first serum creatinine available.
Spatial analysis

For each of these four buffer zones, we did spatial analysis using SatScan software (Martin Kulldorff and Information Management Services Inc.) [26–28] as previously described for patients with other diseases [29–37] setting maximum population size at 0.5, 1, 5 and 10%. As we were only interested in clusters of patients who were prevalent at the end of 2008, we did not estimate the scan statistics for the spatial variation in temporal trends. This spatial scan statistic imposed a circular window on the map of Alberta. The window was centered one by one on each of the given grid points (in this analysis, we used the latitudes and longitudes of the postal codes) located throughout the study region. For each of the postal code, the radius of the window varied continuously in size from zero to the upper limit specified a priori (in this analysis, we specified the upper limit at 0.5, 1, 5 and 10% of the population size). For each postal code of interest, a circle radius of 0 implies that the window was defined solely by that single postal code. To test for the existence of clusters, the SatScan software progressively increased the circle radius up to the maximum size (meaning that surrounding postal codes were progressively included until the maximum population size for the cluster was reached). In this way, the software was able to examine a large number of distinct geographical windows to test for the presence of CKD clusters.

For each window, our analyses used Monte Carlo simulation to test the null hypothesis that there was no statistically significant cluster of diabetic kidney prevalent cases within the window in question. The alternative hypothesis was that there was an elevated risk within the window as compared with outside for each of the scanning window locations and sizes. While gradually scanning a circular window across the entire map, the technique noted the number of observed and expected cases inside the circle at each location, and through this method the clusters were detected (see Supplementary appendix for details). Analyses used a Poisson probability model to estimate the rate of people with both diabetes and CKD within each potential cluster, and took the maximum likelihood function values for all window locations and sizes; the cluster with the greatest maximum likelihood ratio (reflecting the highest ratio of observed to expected cases) was considered as the primary cluster. Other statistically significant clusters that did not overlap with the primary cluster were identified as secondary clusters, and were ranked according to their likelihood ratio test statistic. We plotted polygon clusters in the map of Alberta by using the ‘point to polygon’ tool [38] of ArcGIS software. In maps, we used yellow rectangles for the top three clusters with (ranked by the number of cases), black stars for other clusters, faint gray circles for clusters not visible in ArcGIS maps and red polygons to represent the amalgamated clusters.

The institutional review boards for the Universities of Alberta and Calgary approved the study. Analyses were performed using STATA 11, SatScan, ArcGIS 10 and Stat Transfer software.

Results

A map of Alberta presenting the location of major cities (population > 50 000) and existing nephrology clinics is shown in Figure 1. Characteristics of the 32 278 included patients are presented in Table 1. This table also shows the number of postal codes, case counts and population counts are presented in Table 1. The shaded map illustrates the distribution of people with diabetes and chronic kidney disease in Alberta. The figure shows that a substantial number of patients reside in areas located far away from existing nephrology practice locations.

![Fig. 1. Major cities represented by stars and nephrology clinics by red dots (left panel) and other nearby cities (right panel) in Alberta. The left panel illustrates that the existing nephrology clinics are located in the major cities of Alberta; the right panel illustrates other medium-sized communities in the province.](https://academic.oup.com/ndt/article-abstract/27/11/4102/1812555/Spatial-analysis-to-locate-new-clinics-for)

![Fig. 2. Shaded map presenting the distribution of people with diabetes and chronic kidney disease in Alberta. The figure shows that a substantial number of patients reside in areas located far away from existing nephrology practice locations.](https://academic.oup.com/ndt/article-abstract/27/11/4102/1812555/Spatial-analysis-to-locate-new-clinics-for)

Maps showing the location of clusters under each scenario are shown in Figure 3. The tendency for smaller nephrology clinic; not mutually exclusive), the number of postal codes, case counts and population counts are presented in Table 2. This table also shows the number of clusters identified in each scenario, and the radius and case counts of the primary cluster. Setting the maximum population size at 10% tended to identify clusters that were too large to be serviced by a single clinic (largest primary cluster of 124.98 km). In contrast, setting the maximum cluster size at 0.5% or 1% of the population tended to identify small clusters (smallest primary cluster of 110 m including only 17 cases) that were too small to justify placement of a new clinic—even when grouped together. A maximum population size of 5% seemed to perform well, and was selected as the primary measure of suitability for this analysis. As expected, less stringent definitions of remote-dwelling patient (for example, the >50 km rather than the >200-km scenario) tended to identify larger numbers of patients.

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maximum population counts to identify impractically small clusters is clearly evident. When 5% was selected as the maximum population size, the primary cluster for the >50-km scenario was near the southern border of Alberta, and included the currently underserviced communities of Cardston, Pincher Creek and Fort Macleod (Figure 3).

For the >100-km scenario, we identified one primary cluster and two secondary clusters with higher case counts. The primary cluster was located in the vicinity of the currently underserviced communities of Camrose and Wainwright with a radius of 67.42 km; secondary clusters were near Bonnyville, Peace River and close to Grande Prairie. For the >150-km scenario, we identified a primary cluster in the currently underserved community of Vermillion, and secondary clusters in Wainwright, Peace River and close to Grande Prairie. For the >200-km scenario, the primary cluster was close to Grande Prairie, and secondary clusters were identified in Peace River, Wainwright and north of Grande Prairie (Figure 3).

Figure 4 shows the common themes in scenarios using the maximum cluster size of 5 and 10%. When comparing with 10% as the maximum population size, the locations of the clusters were consistent throughout all the scenarios although there was some slight variation in the cluster radii (Figure 4). When analyses were stratified on CKD stage (Stage 3; eGFR 30–59.9 mL/min/1.73 m² and Stage 4; eGFR 15–29.9 mL/min/1.73 m²), results were consistent with the primary analysis (supplementary table).

**Discussion**

Most (71%) Alberta patients with diabetes and CKD live within 50 km of the nearest nephrology clinic—although a substantial proportion (8%) live more than 200 km away. We identified the residence locations of prevalent patients with diabetes and CKD who lived in remote areas from the 17 established nephrology clinics in Alberta, and applied two methods for identifying underserved communities that would potentially benefit from new nephrology clinics. Simple density plots produced shaded maps with case counts and 100-km² grids, and were useful for rough identification of underserved areas, although this method does not permit accurate or precise localization of the potential new clinic locations. The more computationally intensive SatScan analysis was able to identify specific communities in the northwest and southeast region of the province with a higher-than-expected proportion of underserved patients. Our results were consistent across four different distance categories; the results were equally applicable for those living <50 km from the existing clinics, when compared with those who were residing >200 km from the clinics.

Previous work from our group suggests that the quality of care delivered to Alberta CKD patients is associated with their residential locations; patients living far away from the nephrologists were more likely to die or be hospitalized than those who were residing nearby—and were less likely to receive markers of good quality care [11]. Our findings offer an objective way to locate new clinics that will serve the maximum number of remote dwellers. The method described in the current article is potentially complementary to an approach based on minimizing net (total) travel time for underserved patient populations that our group previously developed [39].

The SatScan technique has been widely used in studies aimed at cluster detection [29, 30, 32, 37], outbreak investigation [40–42], disease surveillance and monitoring [43–45], evaluation of interventions [46, 47], risk factor assessment [48–51], network analysis [52] and spatio-temporal analysis [35, 53, 54]. To our knowledge, this is
Fig. 3. Location of clusters for four buffer scenario at 0.5, 1, 5 and 10% of population size. The figure shows 16 maps of Alberta in four rows. Each row represents different cluster distributions in four maps varying only the maximum population size for a single buffer scenario. The purpose of this figure is to identify areas that were consistently shown to include clusters of underserved patients.
the first study to use SatScan to identify new clinic locations aimed at improving access to healthcare. Used in this way, SatScan objectively identifies underserved communities, based on comparing the expected and observed distribution of patients who reside far away from existing health facilities. Although approaches based on estimated travel time can also be used to identify potential new clinic locations [39], such approaches optimize net travel time (for all patients within the province) rather than focus on underserved patients specifically. Potential advantages of SatScan include its ability to adjust for non-homogenous population density across different study regions, to reduce preselection bias without specifying spatial size and locations of a cluster a priori and to address bias related to multiple comparisons by likelihood ratio-based estimates [29].

Our study has several limitations. As we used postal code which is an ecological unit, so one can refer this analysis as biased to ecological fallacy [55] and argue to extrapolate the findings to the individual level. However, postal codes are the smallest geographical units which can be applicable to the individual level characteristics in most of the cases and as we are not focusing on estimating disease burden or identifying risk factors, this fallacy would not affect our inference so much. Secondly, data was missing on some postal codes, but the proportion was small (<0.1%) and would not be expected to affect our results. Third, another limitation was our failure to include patients with diabetes who could not access care in terms of physician visits or hospitalization, and who were thus excluded from our analysis. However, given the universal healthcare system in Canada, such patients are expected to be rare and thus are unlikely to have affected our conclusions. Moreover, we did not consider travel distance or transportation infrastructure in this analysis, and focused instead on the spatial distribution of the underserved communities. Finally, we specified the maximum population size and buffer zones for our analysis a priori but we presented sensitivity analysis for each of the population sizes and buffer analyses in four ways and the results were more or less similar for all scenarios.

Making these findings available to policymakers would be expected to facilitate more rational decision-making for underserved communities, rather than responding to extraneous factors (such as lobbying, media coverage or political influence) which may lead to inefficient decisions. The evidence-based decisions are key to improving the allocation and utilization of healthcare resources.

In conclusion, this is the first study to use SatScan analysis to objectively identify underserved communities that might be most suitable for new nephrology clinics. The results will be useful to clinicians and decision-makers responsible for the care of remote-dwelling patients. Future studies should identify other barriers to optimum care delivery in remote areas and develop intervention strategies for the underserved communities to improve the quality of care. This method is yet to be validated in CKD populations in other provinces and territories in Canada. In addition, long-term studies should be done to assess whether use of the SatScan method leads to clinically meaningful benefit for patients. Although...
focused on people with CKD, these methods are potentially applicable to other populations.

**Supplementary data**

Supplementary data are available online at [http://ndt.oxfordjournals.org](http://ndt.oxfordjournals.org).

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**Conflict of interest statement.** None declared.

**References**


Renal histology in HIV with outcomes


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The spectrum of renal histologies seen in HIV with outcomes, prognostic indicators and clinical correlations

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Abstract

Background. Two hundred and twenty-one HIV-positive renal biopsies were analysed from Groote Schuur Hospital to determine outcomes and prognostic indicators based on histology and clinical features.

Methods. The histology findings were compared with patient demographics, clinical and renal parameters, mortality, CD4 count and date of commencing combined anti-retroviral therapy (cART). Follow-up was between 1 and 3.5 years.

Results. We found a spectrum of renal histologies in HIV-positive patients of which HIV-associated nephropathy (HIVAN) was the most common histology. cART reduced the mortality in those with any feature of HIVAN by 57% [adjusted hazard ratio (AHR) 0.43, 95% confidence interval (CI) 0.22–0.85]. Of those patients with HIVAN who died, 79% died of renal failure as registered on their death certificate. Proteinuria and microcysts were shown to be poor prognostic indicators (AHR 1.36: 1.09–1.70 and 2.04: 1.24–3.37). In patients with HIVAN alone followed for up to 2 years on cART, estimated glomerular filtration rate remained stable and there was a trend towards decreased proteinuria. cART improved survival in patients with isolated immune complex disease.

Conclusions. As mortality is improved in patients with any feature of HIVAN or isolated immune complex disease, analyses of larger cohorts are necessary to confirm these findings.