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# Geographic variation in osteoarthritis prevalence in Alberta: A spatial analysis approach

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ABSTRACT

There is limited evidence on the geographic distribution of osteoarthritis (OA) in Alberta to inform planning of equitable access to health care services. This research aimed to explore the geographic variation in age-sex standardized OA prevalence rates by geographic areas across the rural-urban continuum, and by six-digit postal codes using global Moran's I and hot spot analysis. The results demonstrated a substantially higher OA prevalence rate in Rural Remote (134.7 cases per 1000 population) and Rural (128.5), compared to Metro (107.4) and Urban areas (107.3). Metro-Edmonton had a substantially higher OA prevalence rate (124.4) compared to Metro-Calgary (94.4). OA hot spots were identified in north rural communities and Metro-Edmonton. These variations should be considered when planning programs for health promotion and prevention of osteoarthritis and access to associated health care services. Further research is needed to identify the underlying factors contributing to this geographic variation.

## 1. Introduction

Osteoarthritis (OA) is a degenerative chronic condition affecting 10–15% of adults in Canada, causing severe pain and disability (Bombardier, Hawker, & Mosher, 2011). The prevalence of OA in Canada is expected to increase due to an aging population and an increase in obesity (Birtwhistle et al., 2015; Bombardier et al., 2011; Lagace, O'Donnell, & McRae, 2010). OA is managed mostly by primary care providers and, in late stages of the disease, by specialists such as orthopedic surgeons for total joint replacement (Wilson, Schneller, Montgomery, & Bozic, 2008; MacDonald, Sanmartin, Langlois, & Marshall, 2014). OA is more common in women than men, and costs increase with associated comorbidities, especially for elderly patients (Bombardier et al., 2011; Gabriel, Crowson, & O'Fallon, 1995).

There is limited evidence on the geographic distribution of OA in Alberta to inform planning of programs for health promotion and prevention of OA and for associated health care services when needed. Existing research is limited to age-sex standardized rates of OA prevalence and incidence at the provincial level, which does not account for geographic variations at higher spatial resolutions (Birtwhistle et al., 2015; Rahman et al., 2014; Plotnikoff et al., 2015; Marshall et al., 2015). Both the Canadian Medical Association at the national level, and Alberta Health Services (AHS) at the provincial level, have identified equitable access to health care services as a priority, with a focus on access to health care services for elderly patients and patients in rural/remote areas (Canadian Medical Association, 2013; Starke et al., 2015). In order to assess equitable access, it is critical to first assess geographic variation of OA prevalence to understand where patients with OA live

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and identify any significant clusters of OA rates across the province.

The Public Health Agency of Canada (PHAC) evaluated the geographic variation of age-standardized arthritis prevalence by province and health regions. Using 2007 health region boundaries, their results showed that age standardized arthritis prevalence in Alberta varied among health regions, with higher rates in the north compared to the south and higher rates in rural areas compared to urban areas (Lagace et al., 2010). However, the PHAC analysis included all forms of arthritis, including OA and all forms of inflammatory arthritis. In addition, arthritis prevalence by health regions did not capture local variations, which may reflect unmet local need and inequities in access to health care services. For example, rural Canadians had limited access to both general physician and specialist due to limited health care availability in rural areas (Canadian Medical Association, 2013). Identifying local areas with unexpected high prevalence may be helpful to address inequities and promote the best use of health care resources.

Spatial analysis using Geographic Information Systems is increasingly applied in health care services planning, especially when assessing and identifying public resource demands at local levels (Patel & Waters, 2012; Cromley & McLafferty, 2012; Nykiforuk & Flaman, 2011; Ricketts, 2003). Several Alberta studies have applied spatial analysis to explore the geographical variation of health outcomes such as myocardial infraction hospitalizations (Liu & Bertazzon, 2017) and measles, mumps and rubella (MMR) immunization uptake (Eccles & Bertazzon, 2015), but there are no studies of this type focusing on OA.

In this paper, we explored the geographic variation in OA prevalence at three levels: first by geographic areas across the rural-urban continuum, second by geographic sub-areas and finally by six-digit postal codes. Our aim is to provide evidence through spatial analysis to identify clustered areas with unexpectedly high OA rates within Alberta, which may inform planning of health promotion and prevention programs for OA and access to associated health care services.

## 2. Materials and method

### 2.1. Study area

With an area of 661,848 km$^2$, Alberta has a population of approximately 3.65 million based on the 2011 census (Statistics Canada, 2012a). The largest city in the province is Calgary, with a population of approximately 1.09 million in 2011. Edmonton is the capital city with a population of 0.81 million and is the second largest city in Alberta (Statistics Canada, 2012b). Most of the northern half of Alberta and the southwestern boundary along the Rocky Mountains are covered by forest. Almost 75% of the population in the province lives in the most urbanized region, namely, Calgary-Edmonton Corridor, including the census metropolitan areas of Calgary, Edmonton, and the census agglomerations of Red Deer and Wetaskiwin (Statistics Canada, 2012c). As of the 2011 census, 18.7% of the total population lived in rural areas outside of population centers, which are defined as areas with a population of at least 1000 and a population density of 400 persons or more per square kilometre (Statistics Canada, 2011b).

AHS, the single health authority for Alberta, and Alberta Health (AH) jointly created a set of standard geographic areas for planning, surveillance, monitoring and reporting activities (AHS and AH, 2017). The zone is used by AHS for directing operational issues, while the rural-urban continuum is used by AHS and the provincial government for the purposes of analysis and planning. Health services in the province are delivered within five zones: North Zone, Edmonton Zone, Central Zone, Calgary Zone and South Zone. The rural-urban continuum includes Metro, Moderate Metro influence, Urban, Moderate Urban influence, Rural Centre, Rural, and Rural Remote. Using these standard geographic areas defined by AHS, we identified 20 geographic sub-areas by stratifying the Rural-Urban Continuum by the five geographic zones described above, in order to capture potential variation associated with both zone and remoteness (Fig. 1).

### 2.2. OA prevalent cases

OA cases between April 1st, 1994 to March 31st, 2013 were identified using five AH administrative databases: the Alberta Health Care Insurance Plan (AHCIP) population registry, the Physician Claims Database, the Discharge Abstract Database (DAD), and the Ambulatory Care Classification System (ACCS)/National Ambulatory Care Reporting System (NACRS) (Marshall et al., 2015). Each patient had a unique patient identifier, which was used for linking the five databases, thus each patient was used only once in the calculation of the OA rates. OA cases were identified from the administrative databases using a validated case definition based on the International Classification of Diseases (ICD) codes in any of the 25 DAD diagnosis fields, 3 Claims diagnostic fields, and 16 ACCS diagnostic fields. OA-related ICD codes were identified as those with the first 3 digits 715 or M15 to M19 based on the ninth and tenth revisions of the ICD, respectively (Marshall et al., 2015). The criteria for individuals to be included in the prevalence cohort was that each patient should have at least one OA hospitalization (DAD), or at least two OA physician visits (claims) within two years, or at least two OA-related ambulatory care visits (ACCS/NACRS) within two years, assuming none of the physicians or ambulatory care visits had occurred on the same day (Felson et al., 2000; Kopec et al., 2008; Lix et al., 2006; Widdifield et al., 2013). The OA prevalent cases in 2013 included 359,638 adult patients ($\geq$18 years of age at diagnosis) who became an OA incident while residing in Alberta (1994–2013) and did not migrate out of the province or die between 1994 and 2013 fiscal years.

#### 2.2.1. Standard population

The Alberta health population registry data were extracted from the AHCIP dataset, which provided individual level demographic data on all insured persons as of the last day of each fiscal year (March 31). It covered all Albertans except Members of the Armed Forces and the Royal Canadian Mounted Police, federal penitentiary inmates, and Albertans who have opted out of the AHCIP (Marshall et al., 2015). All Albertans included in the AHCIP had a unique, 9-digit personal health care number, which was used when accessing health care services. These population data were weighted to the Statistics Canada population counts (Alberta Health, 2013a).

#### 2.2.2. Age-and-sex standardized prevalence rate

The crude rate of OA is the number of prevalent OA cases divided by the total population count. OA age-and-sex standardized prevalence rates per 1000 population were calculated using the direct standardization method (Boyle & Parkin, 1991). Both OA prevalent cases and standard population (Alberta Population Registry) for the year 2013 were stratified by sex and age group. The age groups were stratified as follows: 18–34, 35–44, 45–54, 55–64, 65–74, 75–84, and $\geq$85 years. We calculated the variance of the age-sex standardized rates with the method of binomial approximation. The standardized rate ratios (SRR) were calculated by comparing the rate for each geographic area with the rate in the rest of Alberta. To examine if the observed ratio was significantly different from unity, we calculated the statistical significance of the standardized rate ratio by calculating the 95% confidence interval with an approximation method:

$$(Rate1/Rate2)^{1\pm(Z_{\alpha/2}/X)} \tag{1}$$

where $X = \frac{(Rate1 - Rate2)}{\sqrt{(s.e.\,(Rate1)^2 + s.e.(Rate2)^2)}}$, and $Z_{\alpha/2} = 1.96$ at the 95% level.

If the estimated confidence interval does not contain 1.0, it can be concluded that the rates are significantly different at the 5% level (Boyle & Parkin, 1991).

### 2.3. Spatial analysis

Spatial analysis was applied to explore the geographic distribution

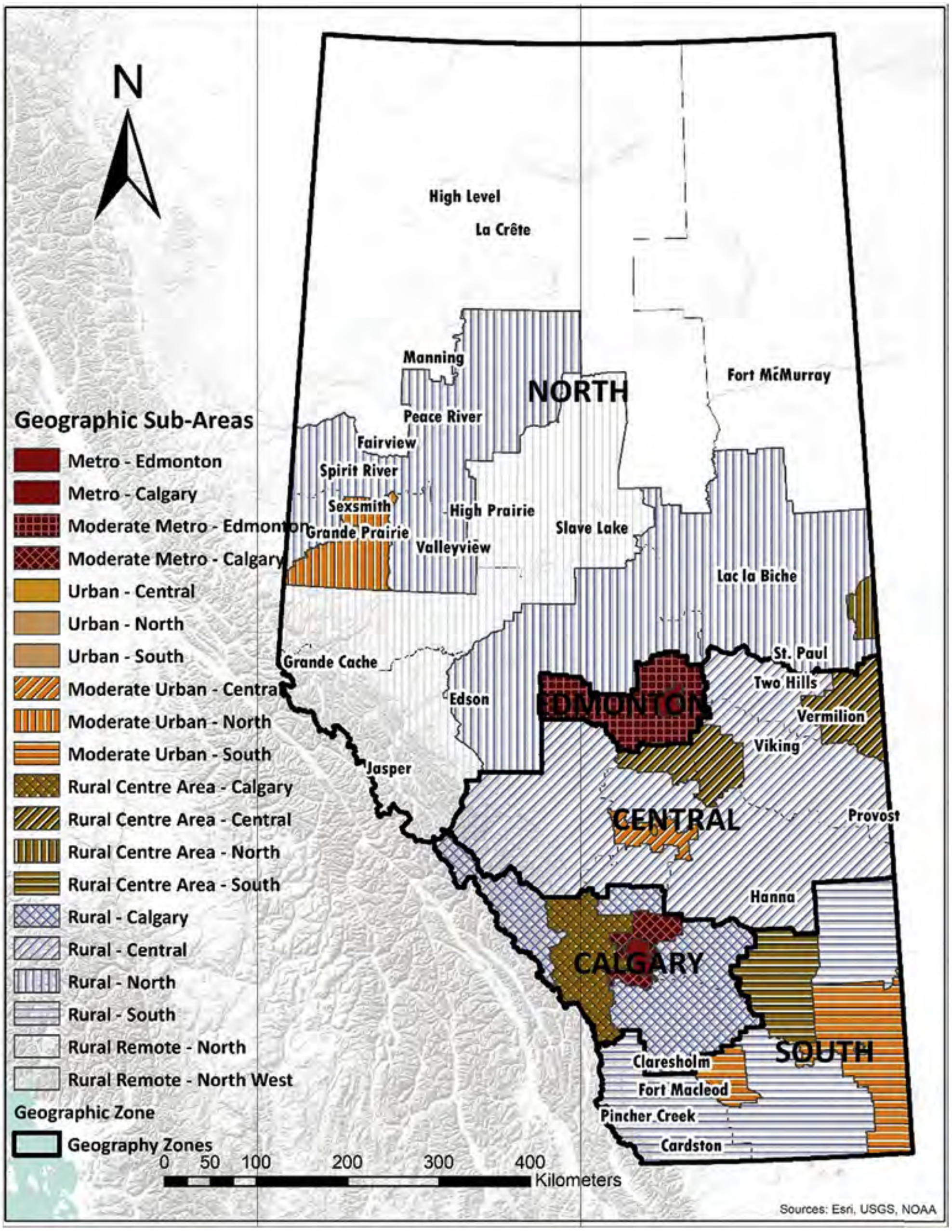


**Fig. 1.** Geographic sub-areas along rural-urban continuum.

of the age-and-sex standardized OA prevalence rate at the six-digit postal code level. The latitude and longitude of each postal code was obtained by linking the OA data and the Postal Code Translator Files (Alberta Health, 2013b) based on the common field of postal code. The distribution of postal codes across the rural-urban continuum was measured by nearest distance between each postal code to the nearest neighbors.

Spatial analysis in this study included global Moran's I (Moran, 1950; Li, Calder, & Cressie, 2007; Cliff & Ord, 1973), incremental spatial autocorrelation (Esri, 2017), and hot spot analysis (Anselin, 1995; Getis & Ord, 1992). The critical value of plus or minus 1.96 for Z scores and a p = 0.05 were applied to make decisions regarding accepting or rejecting the null hypothesis. ArcGIS 10.5 was used for GIS analysis. All data were projected using NAD_1983_10TM_AEP_Resource, an appropriate Universal Transverse Mercator (UTM) projection for Alberta.

As a basic measurement of spatial autocorrelation, global Moran's I produced a spatial autocorrelation index ranging from $-1$ to 1. The null hypothesis under Moran's I test was that OA prevalent cases in Alberta were distributed randomly over space. The Moran's I index was defined as (Li et al., 2007):

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} v_{ij}(x_i-\mu)(x_j-\mu)}{\sum_{i=1}^{n}\sum_{j=1}^{n} v_{ij}\sum_{i=1}^{n}(x_i-\mu)^2} \tag{2}$$

where $n$ is the number of postal codes indexed as $i$ and $j$, $x_i$ denotes the OA prevalence rate in each postal code, μ is the mean of all rates. $v_{ij}$ is the spatial weight function among locations $i$ and j.

A positive global Moran's I index demonstrates clustering in the data; while a negative index indicates a dispersed spatial pattern with dissimilar OA rates located next to each other. An index of 0 suggests a completely random spatial pattern. As a measure of standard deviation, the Z score is used to indicate whether the null hypothesis can be rejected.

Incremental spatial autocorrelation is a useful tool for defining distance threshold with significant spatial autocorrelation (Esri, 2017). It measures the strength of spatial autocorrelation by different distance threshold. By graphing the index against the corresponding Z scores, it is possible to detect the varying trend of Z scores by distance. The peak Z score suggested that the most significant spatial autocorrelation was observed at the corresponding distance. With the dataset of OA prevalent cases, the starting distance threshold for analysis was 2 km, which was selected due to too many postal codes having no neighbors within a distance of 2 km. With an incremental distance of 0.5 km for 20 increments, the maximum distance for Moran's I was 12 km.

Hot spot analysis based on the Getis-Ord Gi* statistic detected spatial patterns of clustered high or low OA rates (Anselin, 1995; Getis & Ord, 1992; Ord & Getis, 1995). As the areas with unexpectedly high rates of OA were of interest to identify areas with the greatest need for OA services, we reported hot spots only in the following analysis. The underlying null hypothesis was that the association of OA prevalence rate within the defined neighborhood followed a random distribution. It was defined as follows (Getis & Ord, 1992):

$$G_i^*(\boldsymbol{d}) = \frac{\sum_{j=1}^{n} \boldsymbol{w_{ij}}(\boldsymbol{d})\boldsymbol{x_j} - \bar{x}\sum_{j=1}^{n} \boldsymbol{w_{ij}}(\boldsymbol{d})\boldsymbol{x_j}}{S\left\{\left[\left(n\sum_{j=1}^{n} \boldsymbol{w_{ij}^2}\right) - \left(\sum_{j=1}^{n} \boldsymbol{w_{ij}}\right)^2\right]/(n-1)\right\}^{1/2}}, \tag{3}$$

where $d$ is the distance between postal code $i$ and $j$; $n$ denotes the number of postal code in the study area; $w_{ij}$ denotes the spatial weight function. $\bar{x}$ and $S$ denotes the average and variance of OA prevalence rates. The statistic compares the local sum of OA rate in the defined neighborhood and the expected local sum, and is then further standardized as Z scores to identify the statistical significance of associated spatial clusters.

Essential in the spatial analysis is the definition of a neighborhood set for each postal code (Anselin, 1999; Getis & Aldstadt, 2003). To account for the spatially varying distribution of postal code in Alberta, we proposed two different modeling approaches of spatial relationships: 1) inverse distance with 8 nearest neighbors (Anselin, 1980); and, 2) fixed distance with 8 nearest neighbors (Fotheringham, Charlton, & Brunsdon, 1998). For the inverse distance modeling, 8 nearest neighbors were included for calculation. Closer postal codes were assigned a higher weight than distant ones. The fixed distance modeling with 8 nearest neighbors specified the local neighborhood by the predefined distance band, ensuring that all postal codes can have at least 8 nearest neighbors. In the sparsely distributed areas such as rural remote areas where the minimum number of nearest neighbors was not met, the distance threshold was increased to meet the minimum requirement.

## 3. Results

### 3.1. Descriptive analysis

Among a total population of 3,159,062 included in the AHCIP in Alberta, over half of the people resided in Metro areas (53.9%, n = 1,701,568), followed by 14.9% in Rural areas (n = 469,086), 12.6% in Moderate Metro areas (n = 397,993) and 10.3% in Urban areas (n = 324,084). Rural Remote area had the least population of 69,993, accounting for 2.2% of total population.

Among 359,638 OA prevalent cases in 2013, 49.1% of OA cases resided in Metro areas, followed by Rural areas (19.6%) and Moderate Metro areas (13.6%) (Table 1). Moderate Urban and Rural Remote areas had the smallest number of OA cases with 2.1% and 2.3%, respectively. In the Metro areas, although Calgary had a larger population than Edmonton (978,418 and 723,150, respectively), Edmonton had a slightly larger number of OA prevalent cases compared to Calgary (89,606 in Edmonton vs. 86,896 in Calgary). Moderate Metro areas in Edmonton had 10.5% of OA cases, three times higher than Moderate Metro - Calgary of 3.1%.

Crude OA prevalence rates per 1000 population by rural-urban continuum and geographic sub-areas showed that Rural areas had the highest crude OA prevalence rate of 150.1 cases per 1000 population (Table 1). This was followed by the Rural Centre and Moderate Metro with a crude rate of 125.2 and 122.6, respectively. The Metro areas had the second lowest crude OA rate of 103.7, with the crude rate of Metro-Edmonton (123.9) being about 1.4 times higher than Metro-Calgary (88.8). In the Moderate Metro area, the crude rate in Moderate Metro-Calgary was 94.7 per 1000 population, lower than the crude rate of 134.1 in Moderate Metro-Edmonton.

Age-and-sex standardized OA prevalence rates per 1000 population were reported in Table 1 and Fig. 2. By rural-urban continuum, the highest OA prevalence rate were observed in the areas of Rural Remote (134.7) and Rural (128.5), with standardized rate ratios of 1.20 and 1.19 respectively (both $p < 0.05$). The rates in the Metro and Urban areas were 107.4 and 107.3 respectively, significantly lower than the rate for the rest of Alberta (standardized rate ratios of 0.85 and 0.93, respectively, $p < 0.05$).

By geographic sub-areas, as shown in Fig. 2, compared to the rate for the rest of Alberta, the age-sex standardized OA prevalence rates per 1000 population were statistically higher in Rural Remote-Northwest (140.3), Rural Remote-North (127.7), Rural-South (146.7), Rural-North (132.2), Rural-Central (124.1), Rural Centre– North (128.9), Moderate Urban–Central (130.9), Moderate Metro-Edmonton (128.2), and Metro-Edmonton (124.4). In contrast, the rates were significantly lower in Metro–Calgary (94.4) and Moderate Metro–Calgary (100.6) than the rest of Alberta. In the Rural and Rural Remote areas, all geographic sub-areas had a significantly higher rate than the rest of Alberta.

The descriptive analysis showed that people aged 55–74 years accounted for 48.9% of 359,638 OA prevalence cases in 2013. Females represented the majority of the total number of OA cases (58.3%). The age-standardized OA rate for females was 133.1 cases per 1000 population, which was approximately 1.4 times higher than males (94.7 cases per 1000 population).

### 3.2. Spatial analysis

The summary of the nearest distance between each postal code and its nearest neighbor was reported by geographical areas (Table 2). Among 57,874 postal codes identified with at least one OA case, the nearest distance ranged from < 0.01 km to 130 km, with an average nearest distance of 0.2 km over the province. Average nearest distance between postal codes was smallest in Metro and Urban (0.06 km), slightly larger in Moderate Metro and Rural Centre area (0.19 and 0.36 km, respectively), and largest in Rural and Rural Remote areas (1529 and 6623 km, respectively). Metro-Calgary and Metro-Edmonton had the largest number of postal codes (19,235 and 17,569, respectively) and the smallest distance to nearest neighboring postal code (0.06 km for both). OA cases per postal code ranged from 1 to 1, 341 per postal code. Remotely distributed postal codes with a distance to nearest neighbor greater than 3 km were likely to have a large count of OA cases than those postal codes closer the nearest neighbor. Generally, a single postal code in remote area was likely to have a larger size and a larger population than those in Metro and Urban areas. Given the widely varying area of postal codes in Alberta, we proposed both inverse distance with 8 nearest neighbors and fixed distance with 8 nearest neighbors to capture the spatial interactions among postal codes.

Incremental spatial autocorrelation was applied to explore the spatial autocorrelation at different distance thresholds. As shown in Fig. 3, the number of statistically significant Z scores of spatial autocorrelation (i.e. $Z > +1.96$) increased with the increase of distance, with up to the a peak value at 6 km, with relatively steady values between 6.5 km and 8 km, and a rapid decline thereafter. The results suggested, therefore, that spatial autocorrelation was most significant at a 6 km distance, which was selected as the appropriate scale for hot

**Table 1**
Counts, crude rate, and age-sex standardized prevalence rate of OA cases.

| Geographic Area Sub-Area | Study Population (2013 OA Cases) | | Standard Population (2013 Registry) | Crude Prevalence Rate | Age-&Sex-Standardized Prevalence Rate (95% CI) | Standardized Rate Ratio* |
|---|---|---|---|---|---|---|
| | Counts | % | Counts | per 1000 population | | (95% CI) |
| Metro - Edmonton | 89,606 | 24.9% | 723,150 | 123.9 | 124.4 (123.7–125.0) | 1.12 (1.11–1.13) |
| Metro - Calgary | 86,896 | 24.3% | 978,418 | 88.8 | 94.4 (93.8–94.9) | 0.75 (0.75–0.76) |
| **Metro** | **176,502** | **49.2%** | **1,701,568** | **103.7** | **107.4 (106.9–107.8)** | **0.85 (0.85–0.86)** |
| Moderate Metro - Edmonton | 37,749 | 10.5% | 281,525 | 134.1 | 128.2 (127.2–129.3) | 1.15 (1.14–1.16) |
| Moderate Metro - Calgary | 11,032 | 3.1% | 116,468 | 94.7 | 100.6 (99.0–102.28) | 0.88 (0.86–0.89) |
| **Moderate Metro** | **48,781** | **13.6%** | **397,993** | **122.6** | **120.6 (119.7–121.5)** | **1.07 (1.06–1.08)** |
| Urban - Central | 8449 | 2.4% | 82,462 | 102.5 | 109.1 (107.1–111.1) | 0.96 (0.94–0.98) |
| Urban - North | 6534 | 1.8% | 117,187 | 55.8 | 93.3 (91.2–95.4) | 0.80 (0.79–0.82) |
| Urban - South | 17,055 | 4.7% | 124,435 | 137.1 | 115.6 (114.1–117.1) | 1.02 (1.01–1.04) |
| **Urban** | **32,038** | **8.9%** | **324,084** | **98.9** | **107.3 (106.3–108.3)** | **0.93 (0.92–0.94)** |
| Moderate Urban - Central | 3422 | 0.9% | 28,767 | 119.0 | 130.9 (127.3–134.4) | 1.15 (1.12–1.18) |
| Moderate Urban - North | 819 | 0.2% | 10,643 | 77.0 | 89.1 (83.8–94.4) | 0.78 (0.74–0.82) |
| Moderate Urban - South | 3148 | 0.9% | 25,934 | 121.4 | 118.2 (114.7–121.7) | 1.04 (1.01–1.07) |
| **Moderate Urban** | **7389** | **2.1%** | **65,344** | **113.1** | **119.2 (116.9–121.4)** | **1.05 (1.03–1.07)** |
| Rural Centre Area - Calgary | 2098 | 0.6% | 19,152 | 109.5 | 117.1 (112.9–121.4) | 1.03 (0.99–1.07) |
| Rural Centre Area - Central | 10,726 | 3.0% | 77,396 | 138.6 | 118.9 (117.0–120.9) | 1.05 (1.03–1.07) |
| Rural Centre Area - North | 1388 | 0.4% | 13,741 | 101.0 | 128.9 (123.5–134.4) | 1.13 (1.08–1.18) |
| Rural Centre Area - South | 2187 | 0.6% | 20,705 | 105.6 | 116.8 (112.8–120.8) | 1.03 (0.99–1.06) |
| **Rural Centre Area** | **16,399** | **4.6%** | **130,994** | **125.2** | **119.0 (117.5–120.6)** | **1.05 (1.04–1.06)** |
| Rural - Calgary | 10,845 | 3.0% | 81,662 | 132.8 | 119.0 (117.1–120.9) | 1.05 (1.03–1.07) |
| Rural - Central | 27,198 | 7.6% | 177,762 | 153.0 | 124.1 (122.8–125.4) | 1.11 (1.10–1.13) |
| Rural - North | 22,458 | 6.2% | 151,644 | 132.2 | 132.2 (130.8–133.7) | 1.18 (1.17–1.19) |
| Rural - South | 9907 | 2.8% | 58,018 | 170.8 | 146.7 (144.2–149.1) | 1.30 (1.28–1.33) |
| **Rural** | **70,408** | **19.6%** | **469,086** | **150.1** | **128.5 (127.7–129.3)** | **1.20 (1.19–1.20)** |
| Rural Remote - North | 3375 | 0.9% | 31,270 | 107.9 | 127.7 (124.2–131.2) | 1.12 (1.09–1.15) |
| Rural Remote - North West | 4746 | 1.3% | 38,723 | 122.6 | 140.3 (137.0–143.5) | 1.23 (1.20–1.27) |
| **Rural Remote** | **8121** | **2.3%** | **69,993** | **116.0** | **134.7 (132.3–137.1)** | **1.18 (1.16–1.21)** |
| Overall | 359,638 | | 3,159,062 | 113.8 (113.5–114.2) | | |

CI: Confidence Interval; SE: Standard Error.
*Standardized Rate Ratio: the ratio between standardized prevalence rate of each geographic area/sub-area and the rest of Alberta.

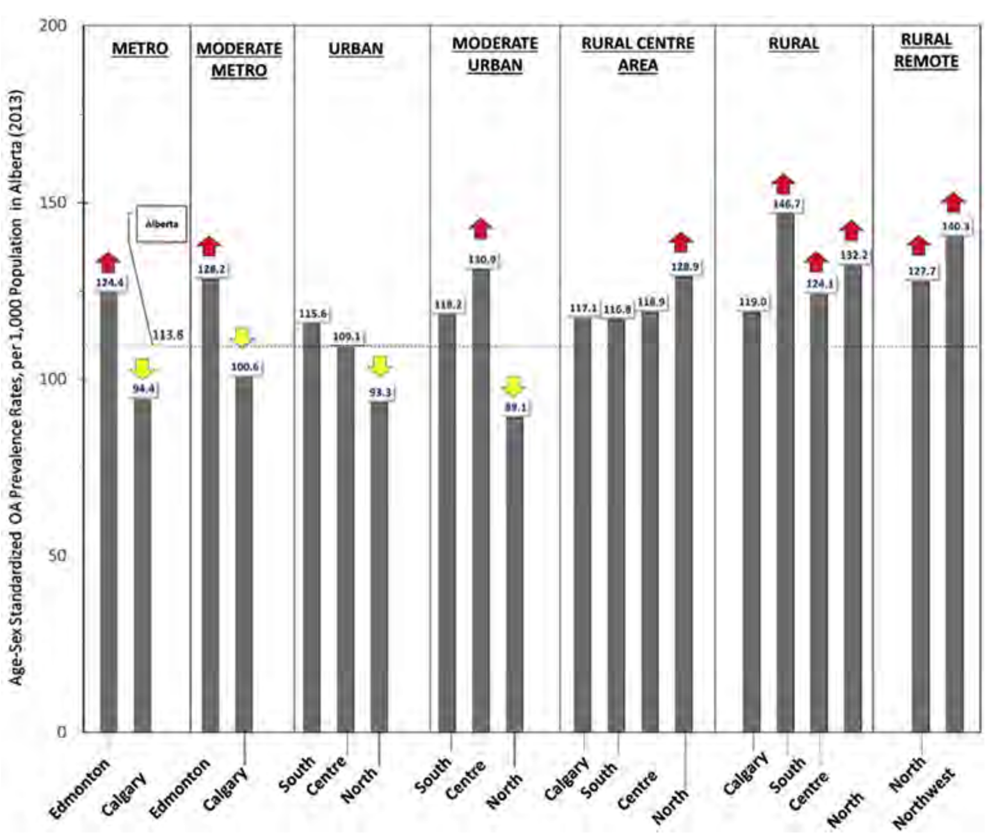


**Fig. 2.** Age-sex standardized OA prevalence rates per 1000 population by geographic sub-areas along the rural-urban continuum in Alberta. Yellow arrows show significantly lower rates and red arrows show significantly higher rates, compared to the rate in the rest of Alberta. Dotted horizonal line shows the overall OA rate in Alberta. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

**Table 2**
Distance to the nearest neighboring postal code by geographic areas.

| Geographic Area/Sub-area | Nearest Distance (m) between Postal Codes | | | | Population | |
|---|---|---|---|---|---|---|
| | n | Mean | Min | Max | OA cases | Std.Population |
| Metro – Calgary | 19,235 | 63 | 0.1 | 2777 | 86,896 | 978,418 |
| Metro – Edmonton | 17,569 | 56 | 0.1 | 1661 | 89,606 | 723,150 |
| **Metro** | **36,804** | **60** | **0.1** | **2777** | **176,502** | **1,701,568** |
| Moderate Metro – Calgary | 1775 | 184 | 0.1 | 13,751 | 11,032 | 116,468 |
| Moderate Metro – Edmonton | 5348 | 185 | 0.1 | 17,688 | 37,749 | 281,525 |
| **Moderate Metro** | **7123** | **185** | **0.1** | **17,688** | **48,781** | **397,993** |
| Moderate Urban – Central | 282 | 348 | 0.1 | 9970 | 3422 | 28,767 |
| Moderate Urban – North | 96 | 1436 | 0.1 | 8773 | 819 | 10,643 |
| Moderate Urban – South | 181 | 1406 | 0.1 | 33,163 | 3148 | 25,934 |
| **Moderate Urban** | **559** | **877** | **0.1** | **33,163** | **7389** | **65,344** |
| Rural – Calgary | 475 | 1004 | 0.1 | 50,497 | 10,845 | 81,662 |
| Rural – Central | 1299 | 1272 | 0.1 | 77,710 | 27,198 | 177,762 |
| Rural – North | 1250 | 1464 | 0.1 | 53,569 | 22,458 | 151,644 |
| Rural – South | 198 | 4891 | 0.1 | 48,362 | 9907 | 58,018 |
| **Rural** | **3222** | **1529** | **0.1** | **77,710** | **70,408** | **469,086** |
| Rural Centre Area – Calgary | 382 | 286 | 0.1 | 15,415 | 2098 | 19,152 |
| Rural Centre Area – Central | 1523 | 299 | 0.1 | 19,934 | 10,726 | 77,396 |
| Rural Centre Area – North | 190 | 167 | 0.1 | 8986 | 1388 | 13,741 |
| Rural Centre Area – South | 219 | 1033 | 0.1 | 26,758 | 2187 | 20,705 |
| **Rural Centre Area** | **2314** | **356** | **0.1** | **26,758** | **16,399** | **130,994** |
| Rural Remote – North | 38 | 27,432 | 0.2 | 130,317 | 3375 | 31,270 |
| Rural Remote – Northwest | 203 | 2727 | 0.1 | 104,787 | 4746 | 38,723 |
| **Rural Remote** | **241** | **6623** | **0.1** | **130,317** | **8121** | **69,993** |
| Urban – Central | 1727 | 64 | 0.1 | 697 | 8449 | 82,462 |
| Urban – North | 1910 | 71 | 0.1 | 2214 | 6534 | 117,187 |
| Urban – South | 3974 | 57 | 0.1 | 1534 | 17,055 | 124,435 |
| Urban | **7611** | **62** | **0.1** | **2214** | **32,038** | **324,084** |
| **Total** | **57,874** | **204** | **0.1** | **130,317** | **359,638** | **3,159,063** |

spot analysis.

Hot spot analysis was conducted with spatial relationships modelled by both inverse distance and fixed distances, to explore the geographical variation of OA prevalence rate revealed by the two different approaches. With inverse distance, the results showed that 3806 statistically significant hot spots were identified at significance level of $p \leq 0.05$. By rural-urban continuum geographic areas, Metro accounted for the majority of the total number of hot spots (65.5%), followed by Moderate Metro with 14.9% and Rural with 8.1%. Rural Remote accounted for the smallest number of hot spots (0.6%). By geographic sub-areas, almost 90% of the hot spots were identified in Metro-Edmonton (60.2%), Moderate Metro-Edmonton (14.5%), Urban-South (4.6%), Rural-Central (3.6%) and Rural-North (3.5%).

With a fixed distance of 6 km, hot spot analysis resulted in 514 significant hot spots at significant level of $p \leq 0.05$. By rural-urban continuum geographic areas, there were 61.7% of total hot spots identified in Metro area, followed by Rural areas (18.7%) and Moderate Metro (8.9%). By geographic sub-areas, areas with a large number of hot spots were ranked in the following order: Metro-Edmonton (57.6%), Rural-North (12.5%), Moderate Metro-Edmonton (8.8%), Urban-South (5.3%), and Rural-Central (4.7%).

We observed a consistent pattern of OA prevalence rates in Alberta with the two analytical approaches (Fig. 4 and Fig. 5). Metro Edmonton, Moderate Metro-Edmonton, Rural-North and Urban-South were identified with a large number of OA hot spots. By comparing Calgary zone and Edmonton zone, we found that more than 90% of the

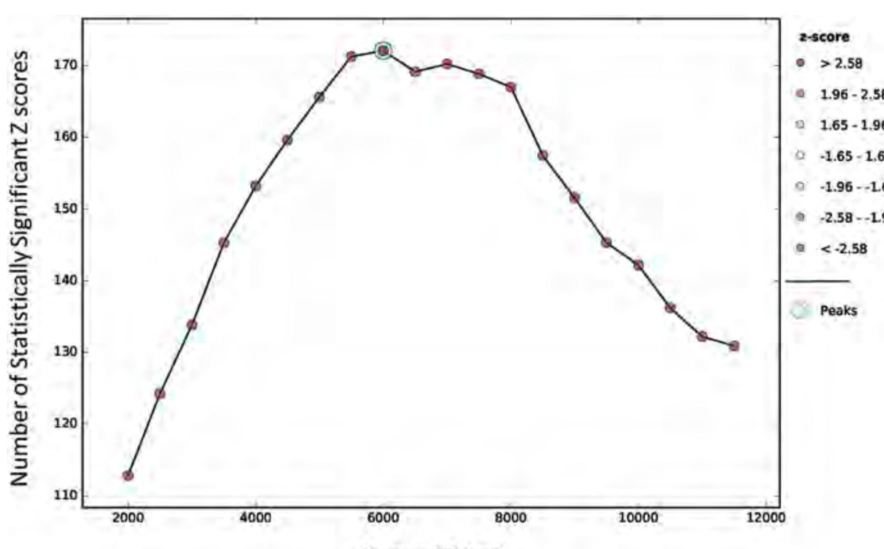


**Fig. 3.** Spatial autocorrelation by distance.

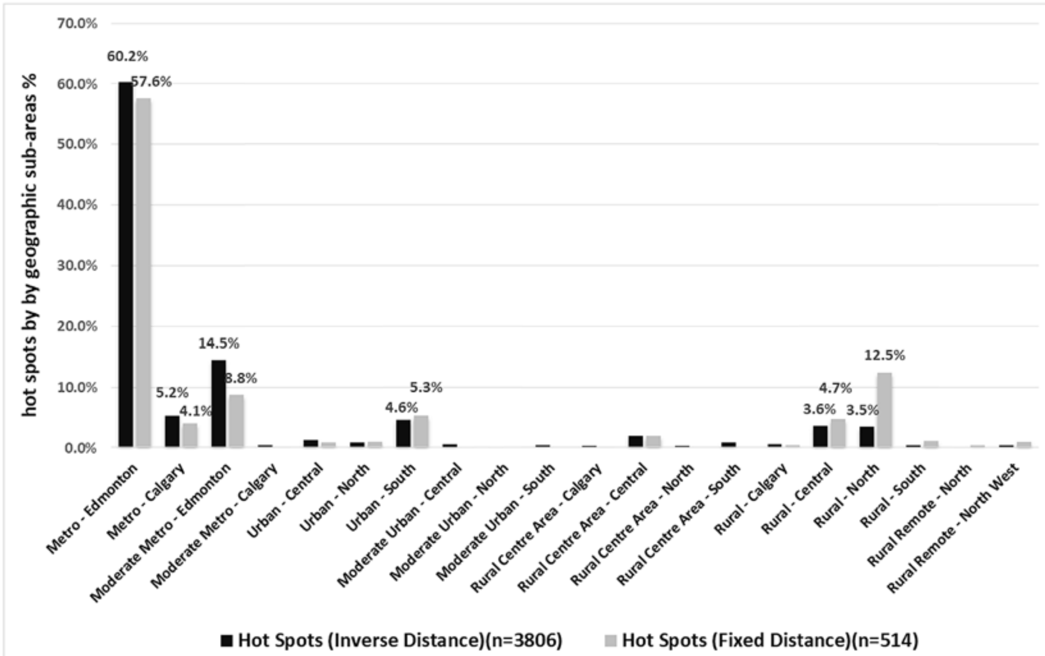


**Fig. 4.** Percentage of hot spots by geographic sub-areas.

hot spots were identified in Metro-Edmonton and Moderate Metro-Edmonton, while Metro-Calgary and Moderate Metro-Calgary accounted for only 5% of the total number of hot spots.

Local communities with OA hot spots were observed in Fig. 5, which showed hot spot results using both the inverse distance and the fixed distance approach. Areas with significant OA hot spots were mostly located in: 1) Metro-Edmonton; 2) Moderate Metro-Edmonton communities including Spruce Grove, Devon, Leduc, Sherwood Park and

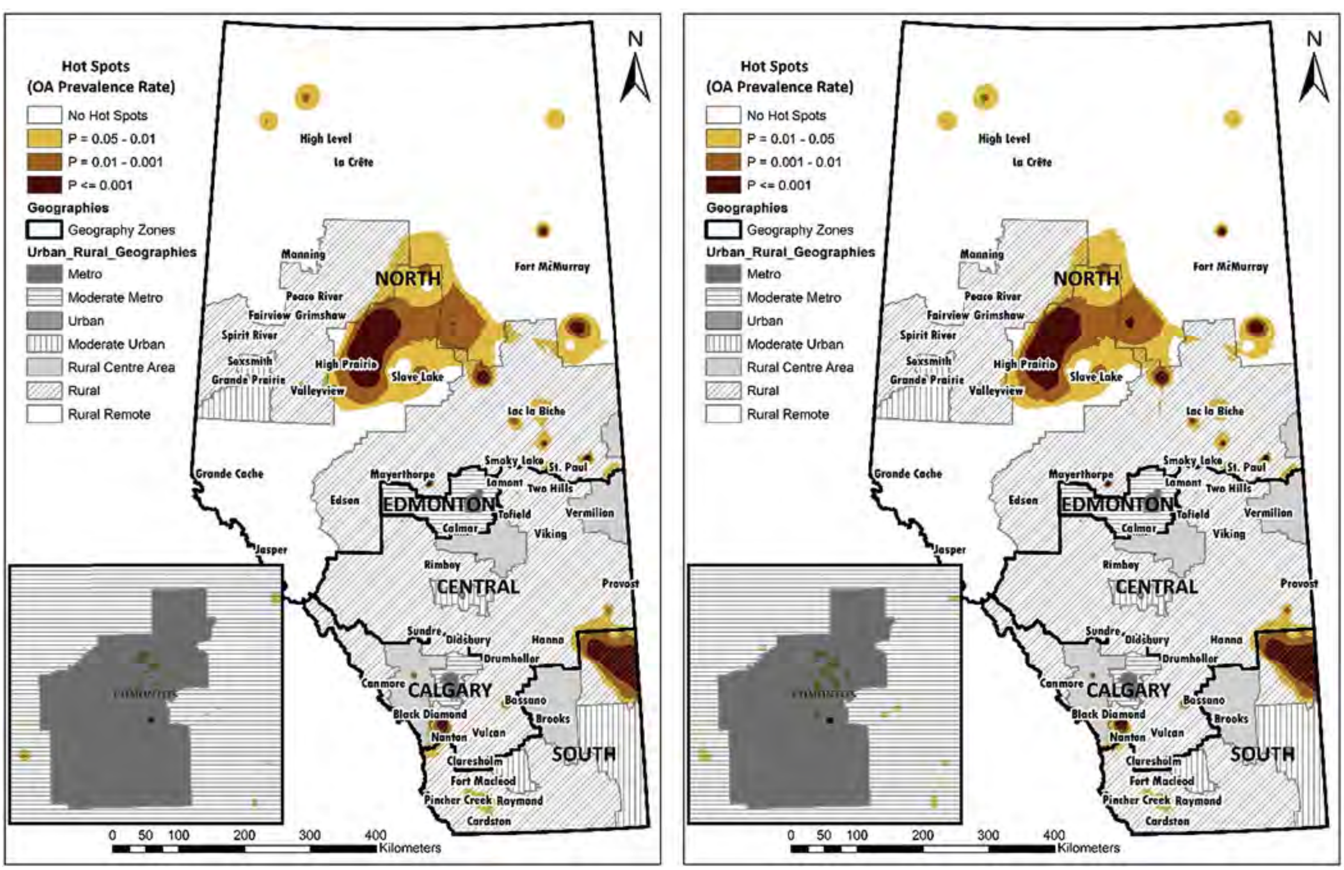


**Fig. 5.** Hot spots of OA prevalence rates. Left: Hot spots with spatial relationship of inverse distance. Right: Hot spots with spatial relationship of 6.0 km fixed distance.

Fort Saskatchewan; 3) Rural-North and 4) Rural-South. Metro-Edmonton constituted 60% of the total number of hot spots, which were located mainly in the northeastern part of Edmonton. Rural areas accounted for 18.7% of the total number of hot spots. Regarding the large areas in Rural Remote-North, though the population was small, constituting only 2.26% of the number of OA cases, it covered a large area with the highest age-and-sex standardized rate. The communities in the Rural and Rural Remote were mostly indigenous communities.

## 4. Discussion

Using administrative health data from the province of Alberta in 2013, we estimated that there were 359,638 prevalent cases of OA in people older than 18 years at age of diagnosis, and the OA prevalence rate was 113.8 cases per 1000 population. We found differences by sex and age – with 1.4 times higher prevalence of OA in women (133.1 per 1000 for women vs 94.7 per 1000 for men) and higher prevalence in the older population. The highest age-and-sex standardized OA prevalence rates by rural-urban continuum were observed in the Rural remote (134.7 per 1000 population) and Rural areas (128.5 per 1000 population), although only around 20% of OA cases resided in these areas. Conversely, Metro and urban areas had the majority of OA cases (58% in total), yet the OA prevalence rates were the lowest amongst the Rural-Urban continuum geographic areas. Spatial analysis to evaluate the geographic variation of OA prevalence using hot spot analysis at the postal code level identified clusters of areas with higher OA prevalence rates, particularly in the north rural communities.

Overall, our estimates were higher than some previous findings for other provinces based on administrative data. Kopec et al. (2007) estimated OA prevalence rates excluding population under the age of 20 years to be 107.8 per 1000 population in British Columbia in 2001. However, the OA case definition in the British Columbia study was based on claims data alone and did not include data from other sources, for example, the DAD and ACCS data sources used in our study. Furthermore, the OA case definition was based on only claims data and 1 physician visit, rather than 2 visits within 2 years applied in our study. The different case definition and the inclusion of DAD and ACCS data sources may explain the higher rate of OA estimated in our study. Marshall et al. (2015) found the crude prevalence rate of OA among Albertans to be 86.6 per 1000 population in 2008, which was lower than our estimates of 113.8 per 1000 population. Although the two studies applied the same case definition, the OA prevalence rate in our study was expected to be higher as our population excluded people under 18 years old, which accounted for approximately 24% of general population and 2% of the OA cases. The difference in the denominator for the standard population resulted in a higher OA prevalence rate than if we included people under 18 years. In addition, since our study included an additional five years of data (Marshall et al., 2015), it was reasonable that the prevalence rate in 2013 would be higher.

The geographical variations in OA prevalence between rural and urban areas suggested that the location of residence may affect the patterns of OA development and the associated health care and patient outcomes with a high demand for OA-related health care services in rural areas (Gamble et al., 2011; Tran, Wijeysundera, Qui, Tu, & Bhatia, 2014). In general, Canadians living in rural areas had less access to care due to geographical barriers (Canadian Medical Association, 2013; Marrone, 2007; The Ontario Rural Council, 2009). According data from the Society of Rural Physicians of Canada, only 9.4% of family physicians and 3% of specialists were considered rural, and yet they were responsible for the care of 21% of the Canadian population that resides in rural areas (Canadian Medical Association, 2013; Pong & Pitblado, 2005). Transportation was reported to be a critical barrier for rural patients to have access to necessary health care services from health care professionals (Starke et al., 2015), especially for specialist services which were mostly provided in urban centers, far away from rural communities (Pong & Pitblado, 2005).

Geographic differences in OA prevalence were also observed between Metro Edmonton and Metro Calgary. Although OA prevalence in the Metro area (107.4 cases per 1000 population) was below the OA prevalence at the provincial level (113.8 cases per 1000 population), Metro-Edmonton had a significantly higher OA prevalence (124.4 cases per 1000 population) than the rest of Alberta. The OA prevalence in Metro-Edmonton was 1.31 times higher than it was in Calgary (94.4 cases per 1000 population). A similar pattern was observed in the Moderate-Metro areas showing a higher OA prevalence in Moderate Metro-Edmonton (128.2 cases per 1000 population) than that of Moderate Metro-Calgary (100.6 cases per 1000 population). Overall, there was a substantial regional difference in OA prevalence between the Edmonton zone (including Metro Edmonton and Moderate Metro Edmonton) and the Calgary zone (including Metro, Moderate Metro and Rural-Calgary), which was consistent with the reported regional pattern of arthritis (which included OA) prevalence in Alberta. Alberta Health and Wellness (2006) reported that the prevalence of arthritis in Edmonton was substantially higher than the provincial average, while Calgary had a substantially lower rate than the provincial average. The pattern of higher arthritis prevalence in the Edmonton zone compared to the Calgary zone persisted in 2008 as reported by the Public Health Agency of Canada (Lagace et al., 2010).

Key factors that are known to be associated with OA prevalence after controlling for age and sex include obesity, prior trauma, dysplasia and physical activity, as well as demographic and socio-economic factors such as income level and education (Bombardier et al., 2011; Arden, Rheumatologist, & Nevitt, 2006). Although beyond the scope of this study, variations in these factors might explain the difference in OA prevalence between Edmonton and Calgary. According to the Alberta Health and Wellness report on the health of Albertans in 2006, the Edmonton zone had a higher percentage of obesity, ischemic heart disease and diabetes than the Calgary zone. Regarding physical activity, Calgary had a larger population than that of Edmonton that reported being active during leisure time (Alberta Health and Wellness, 2006). In addition, Edmonton had a lower median household income compared to Calgary ($90,874 versus $97,334) (Statistics Canada, 2017a). Overall, Edmonton had a higher prevalence of comorbidities, lower economic status, and greater physical inactivity than Calgary, which may explain the regional variations in OA prevalence between the cities (Statistics Canada, 2017b). Understanding these geographic differences can inform planning of programs for health promotion and prevention of OA. For example, given that obesity is a primary modifiable risk factor for OA, and approximately 24% of Canadians are obese (Statistics Canada, 2011a), there are patient education programs related to exercise, healthy diets, and strategies to avoid joint stresses that have been shown to be effective for managing symptoms and improving function, and are recommended in international arthritis care guidelines (Zhang et al., 2008, 2010). However, in an analysis of the Survey on Living with Chronic Diseases in Canada – Arthritis, MacDonald et al. (2014) reported that the percentage of people with OA in any joint who had ever taken a class to manage their arthritis was only 12%, suggesting that there is an opportunity to increase the use of educational programs for the management of pain from OA. Since musculoskeletal complaints make up 12–20% of primary health care visits and are a source of significant morbidity and health care expenditures, planning approaches should consider the role of health promotion and prevention strategies (O'Dunn-Orto et al., 2012).

Our results identified clusters of higher OA prevalence rates in the north rural communities. According to the Aboriginal Affairs and Northern Development Canada (2014), these are mostly indigenous communities. High OA prevalence rate points to the high need for OA related health care for indigenous people, including First Nations, Metis and Inuit (Alberta Aboriginal Relations, 2013). This finding is consistent with a study on OA prevalence and health service use for First Nations people in Alberta (Barnabe et al., 2015). That study documented that First Nations people had a higher rate of OA prevalence

(161 cases per 1000 population), which was twice that of non-First Nations Canadians (78 cases per 1000 population). The Canadian Medical Association 2013 Position Statement identified that geography was a significant barrier for indigenous peoples due to difficulties in access to necessary health care services. A shortage of health care professionals, facilities and services is an ongoing issue in rural indigenous communities (Cameron, Este, & Worthington, 2010), but rural location may not be the only barrier. Other factors such as social-economic status, communication barriers, and culture may all contribute to disparities in health burden and health services need (Marrone, 2007).

Spatial analysis, whether based on the inverse distance or fixed distance methods, produced a consistent pattern of high OA prevalence rates, largely clustered in the north rural areas, which suggested that the hot spot results were robust to alternative neighborhood definitions. The count of hot spots identified with inverse distance was three times that of fixed distance analysis, which may be explained by the large variation in postal code size in Alberta. The average distance to nearest neighbor (0.2 km) varied from 0.06 km in Metro areas to 6.62 km in rural remote areas. Neighborhoods defined by inverse distance analyzed the OA prevalence pattern within a small neighborhood in dense urban areas and large neighborhood in rural area, which captured detailed local high OA prevalence rates, especially in Metro and urban areas. Conversely, fixed distance spatial analysis defined the fixed neighborhood in both urban and rural areas, leading to thousands of neighbors included for analysis in urban area, which captured OA variation on a larger spatial scale than that of inverse distance by averaging out the OA prevalence rate in small local neighborhood.

Limitations of our study include the possibility that health administrative data likely underestimate the number of OA cases. First, the population registry does not include Members of the Armed Forces and the Royal Canadian Mounted Police, federal penitentiary inmates, and Albertans who have opted out of the AHCIP. Second, the administrative data do not capture OA patients who do not seek health services. Further, according to the OA case definition, OA patients who do not have more than one OA-related physician visit or a visit to hospital are not included as OA cases in our OA cohort. Finally, OA estimates based on administrative data are sensitive to alternative case definitions (Goldfield & Villani, 1996; Goff et al., 2008; Harrold, Li, Yood, Fuller, & Gurwitz, 2008; Sun, Gooch, Svenson, Bell, & Frank, 2007; Marshall et al., 2015; Lix et al., 2006). Consequently, when interpreting the OA geographical patterns, we need to be cautious, as our estimates likely underestimate the number of OA cases in Alberta. However, the estimated OA prevalence presented in this research was the best estimate possible using administrative datasets and validated case definitions. An additional limitation is that the results are only age and sex standardized, and it is likely that other risk factors may contribute to the variations in OA prevalence rates including obesity.

There are several strengths to our study. First, we used provincial administrative databases as the source for estimating the OA prevalence using a validated OA case definition designed for administrative health data. Second, we had 19 years of longitudinal data, which is important for estimating prevalence in a chronic disease such as OA in order to achieve stable estimates. Third, we conducted spatial analysis at the postal code level, the finest spatial scale available for spatial analysis, which allows for the greatest detail regarding local variations. No other published reports on the OA geographic variation in Alberta at this spatial scale were found. Lastly, the application of two different modeling of spatial relationships produced consistent OA spatial patterns, indicating the findings were robust with respect to neighborhood definition.

## 5. Conclusion

In conclusion, we analyzed OA prevalence rates by geographical areas across the urban-rural continuum, and by six-digit postal codes. We identified regional differences between rural and urban areas, and between Metro-Edmonton and Metro-Calgary. There was substantial variation in the rates of OA prevalence across geographic areas in Alberta. These variations should be considered when planning programs for health promotion and prevention of OA and access to associated health care services. Further research on geographic variation in OA-related health services utilization and accessibility for both primary health care and specialist service will potentially provide information for health care services planners targeting areas with high health care needs.

## Declaration of interests

All authors except RSharma and DM declare no conflicts of interest. RSharma has consultant agreements to declare as he is a consultant for the following companies: Zimmer-Biomet, Depuy-Synthes, Stryker and Mizuho OSI. DM reports Advisory Board Membership for Pfizer, consulting and non-financial support from Optum Insight, Roche, Novarits, Abbvie, Janssen, and non-financial support from Illumina outside the submitted work.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apgeog.2019.01.004.

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