Bayesian Disease Mapping and GIS-Based Spatiotemporal Iatrogenic Injury Surveillance

Ying C. MacNab PhD
Associate Professor¹²

Weimin Hu MB MSc PhD
Research Associate¹²
Senior Epidemiology and Health Geomatics Consultant³

1. Biostatistics and Geoinformatics Unit, Center for Healthcare Innovation and Improvement, British Columbia Child and Family Research Institute, Vancouver, Canada
2. Department of Health Care and Epidemiology, Faculty of Medicine, University of British Columbia, Vancouver, Canada
3. Aggregated Health Information Project (AHIP), Knowledge Management and Technology, British Columbia Ministry of Health, Victoria, Canada
Presentation Outline

- Research background and objectives
- Data sources
- Methodologies
  - GIS for information integration
  - Ecological regression analysis
  - Bayesian statistics in spatial/temporal smoothing
- Results
- Discussion and conclusions
Background and Objectives

- Patient safety surveillance for prevention of adverse medical events (AME) in health setting is an emerging issue across the world.
- We investigate spatial, temporal, and spatiotemporal distributions of AME across the province of British Columbia, and their association with regional risk factors.
- We propose an appropriate disease mapping methodology that remove the chance variation in crude rates and ratios that often exhibits in small area rare medical events mapping and misleads to inappropriate spatial and temporal patterns of the events.
- The findings will provide evidence to support for a population-based AME surveillance system that will focus on regions with significant high and low AME incidences.
Data Sources

- AME incidence rate was derived from hospital discharge abstract database of the Province of British Columbia.
- An AME is defined by a discharge record with any of the following ICD9-CM codes:
  - E870-E876: Misadventures to patients during surgical and medical care
  - E878-E879: Surgical and medical procedures as the causes of abnormal reaction of patient or later complication, without mention of misadventure at the time of procedure
  - E930-E949: Drugs, medicinal and biological substances causing adverse effects in their therapeutic use
- All hospital patients discharged in the province were extracted as the denominator for AME incidence rate calculation
- The AME incidence rate were calculated by 5-year age groups, by male and female, by year from 1991 to 2000, and for the entire 10 years period
Data Sources

Regional risk factors were derived from Statistics Canada’s 1996 Census data. Having considered multicollinearity among these variables, we selected the following individual factors for this study:

1) Percentage of single parent families
2) Percentage of low income families
3) Percentage of population aged 0-64 receiving income from government transfers
4) Percentage of population receiving income from other sources
5) Percentage of households with housing costs equal to 30% or more household income
6) Percentage of population aged 25-54 without high school education
7) Percentage of population aged 15-24 attending school fulltime
8) Percentage of labor force in lesser skilled jobs
9) Percentage of labor force in full year full time employment
10) Percentage of low birth weight births
11) Percentage of births to teenage mothers
Methodology

- GIS used to integrate AME incidence and regional risk factor data

Diagram:
- Hospitalized Individuals with addresses
- Census Variables by Local Health Area
- Integrated Hospitalized Individuals and LHA Risk Factors
Methodology

- Ecological regression model: AME incidence rate as dependent variable, while patient age, gender, regional risk factors as independent variables, plus a component of spatial effect

\[
\log(\mu_{ij}^b) = \log(n_{ij}) + a_0 + a_1 \times \text{Age}_1 + a_2 \times \text{Age}_2 + a_3 \times \text{Age}_3 + \sum_{q=1}^{Q} \beta_q X_{qj} + b_j
\]

- \(b_j\) represents the component of random-latent spatial effect. Its contribution to residual regional relative risk variation is modeled by Bayesian hierarchical model, governed by two parameters: \(\sigma^2\), dispersion parameter and \(\lambda\), spatial autocorrelation parameter.

\[
\begin{align*}
\mathbf{b} & \sim \text{MVN}(\mathbf{0}, \Sigma(\sigma^2, \lambda)) \\
\Sigma(\sigma^2, \lambda) &= \sigma^2 D^{-1}, \quad D = \lambda R + (1-\lambda)I_N
\end{align*}
\]
Methodology

- Detailed statistical and methodological discussions on the Bayesian spatial and spatiotemporal modeling, see:
  
  
  
  
  
  - MacNab YC and Gustafson P. Regression B-spline smoothing in Bayesian disease mapping: with an application to patient safety surveillance. Manuscript submitted
## Results

This table presents the descriptive statistics of AME incidence rates (%) from 1991 to 2000 by Local Health Area (LHA) for patients aged 1-19 years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Min</th>
<th>Mean</th>
<th>Max</th>
<th>SD</th>
<th>Min</th>
<th>Mean</th>
<th>Max</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Males</td>
<td></td>
<td>Females</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>Mean</td>
<td>Max</td>
<td>SD</td>
<td>Min</td>
<td>Mean</td>
<td>Max</td>
<td>SD</td>
</tr>
<tr>
<td>1991</td>
<td>0.00</td>
<td>2.39</td>
<td>11.76</td>
<td>1.99</td>
<td>0.00</td>
<td>1.52</td>
<td>7.58</td>
<td>1.37</td>
</tr>
<tr>
<td>1992</td>
<td>0.00</td>
<td>2.29</td>
<td>7.21</td>
<td>1.59</td>
<td>0.00</td>
<td>2.11</td>
<td>20.69</td>
<td>2.41</td>
</tr>
<tr>
<td>1993</td>
<td>0.00</td>
<td>2.99</td>
<td>25.00</td>
<td>2.97</td>
<td>0.00</td>
<td>2.11</td>
<td>8.23</td>
<td>1.46</td>
</tr>
<tr>
<td>1994</td>
<td>0.00</td>
<td>3.10</td>
<td>16.42</td>
<td>2.42</td>
<td>0.00</td>
<td>1.83</td>
<td>6.02</td>
<td>1.27</td>
</tr>
<tr>
<td>1995</td>
<td>0.00</td>
<td>2.24</td>
<td>9.33</td>
<td>1.45</td>
<td>0.00</td>
<td>2.17</td>
<td>11.76</td>
<td>1.74</td>
</tr>
<tr>
<td>1996</td>
<td>0.00</td>
<td>2.30</td>
<td>6.99</td>
<td>1.56</td>
<td>0.00</td>
<td>1.98</td>
<td>6.45</td>
<td>1.40</td>
</tr>
<tr>
<td>1997</td>
<td>0.00</td>
<td>2.84</td>
<td>13.98</td>
<td>2.16</td>
<td>0.00</td>
<td>2.35</td>
<td>7.14</td>
<td>1.59</td>
</tr>
<tr>
<td>1998</td>
<td>0.00</td>
<td>3.68</td>
<td>17.39</td>
<td>2.89</td>
<td>0.00</td>
<td>2.39</td>
<td>10.26</td>
<td>1.75</td>
</tr>
<tr>
<td>1999</td>
<td>0.00</td>
<td>2.97</td>
<td>12.73</td>
<td>2.33</td>
<td>0.00</td>
<td>2.39</td>
<td>18.60</td>
<td>2.48</td>
</tr>
<tr>
<td>2000</td>
<td>0.00</td>
<td>2.96</td>
<td>9.80</td>
<td>1.88</td>
<td>0.00</td>
<td>2.36</td>
<td>8.57</td>
<td>1.68</td>
</tr>
</tbody>
</table>

The values are AME incidence rates amongst total 89 Local Health Areas.
Results

Table 2: Descriptive Statistics of Regional Risk Factors (Standardized Scores)

<table>
<thead>
<tr>
<th>Regional Risk Factors</th>
<th>Standardized Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>1. % single parent families</td>
<td>-1.63</td>
</tr>
<tr>
<td>2. % of low income families</td>
<td>-1.96</td>
</tr>
<tr>
<td>3. % population 0-64 receiving income from government transfers</td>
<td>-1.68</td>
</tr>
<tr>
<td>4. % population receiving income from other sources</td>
<td>-1.65</td>
</tr>
<tr>
<td>5. % households with housing costs equal to 30%+ household income</td>
<td>-4.56</td>
</tr>
<tr>
<td>6. % population 25 - 54 without high school education</td>
<td>-2.96</td>
</tr>
<tr>
<td>7. % population 15 - 24 attending school fulltime</td>
<td>-2.61</td>
</tr>
<tr>
<td>8. % labour force in lesser skilled jobs</td>
<td>-4.43</td>
</tr>
<tr>
<td>9. % labor force in full year full time employment</td>
<td>-3.36</td>
</tr>
<tr>
<td>10. % low birth weight births</td>
<td>-2.36</td>
</tr>
<tr>
<td>11. % births to teenage mothers</td>
<td>-1.23</td>
</tr>
</tbody>
</table>
## Results

### Table 3: Relationship between Regional Risk Factors and AME Incidence Rate, Males and Females Aged 1-19, 1991-2000

<table>
<thead>
<tr>
<th>Covariates</th>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Percentage of single parent families</td>
<td>-0.06 0.05</td>
<td>-0.08 0.04</td>
</tr>
<tr>
<td>2. Percentage of low income families</td>
<td>0.00 0.05</td>
<td>0.06 0.04</td>
</tr>
<tr>
<td>3. Percentage of population 0-64 receiving income from government transfers</td>
<td>0.11 0.07</td>
<td>0.01 0.06</td>
</tr>
<tr>
<td>4. Percentage of population receiving income from other sources</td>
<td>0.00 0.07</td>
<td>-0.03 0.06</td>
</tr>
<tr>
<td>5. Percentage of households with housing costs equal to 30% or more household income</td>
<td>0.04 0.05</td>
<td>0.09 0.05</td>
</tr>
<tr>
<td>6. Percentage of population 25-54 without high school education</td>
<td>-0.10 0.07</td>
<td>-0.19 0.06</td>
</tr>
<tr>
<td>7. Percentage of population 15-24 attending school fulltime</td>
<td>0.02 0.04</td>
<td>-0.06 0.04</td>
</tr>
<tr>
<td>8. Percentage of labour force in lesser skilled jobs</td>
<td>0.04 0.06</td>
<td>0.05 0.05</td>
</tr>
<tr>
<td>9. Percentage of labour force in full year full time employment</td>
<td>0.11 0.05</td>
<td>-0.04 0.04</td>
</tr>
<tr>
<td>10. Percentage of low birth weight births</td>
<td>-0.02 0.03</td>
<td>-0.03 0.03</td>
</tr>
<tr>
<td>11. Percentage of births to teenage mothers</td>
<td>0.08 0.05</td>
<td>0.10 0.04</td>
</tr>
</tbody>
</table>

The variance parameter ($\sigma^2$)  

The correlation parameter ($\lambda$)  

The variance parameter ($\sigma^2$), empty model  

The correlation parameter ($\lambda$), empty model
Males age 1-19

East Kootenay

Kootenay/Boundary

Okanagan

Thompson Cariboo

East Kootenay

Kootenay/Boundary

Okanagan

Thompson Cariboo

Males age 1-19

Fraser East

Fraser North

Fraser South

Richmond

Fraser East

Fraser North

Fraser South

Richmond

Males age 1-19

Vancouver

North Shore/Coast Garibaldi

South Vancouver Island

Central Vancouver Island

Vancouver

North Shore/Coast Garibaldi

South Vancouver Island

Central Vancouver Island

Males age 1-19

North Vancouver Island

Northwest

Northern Interior

Northeast

North Vancouver Island

Northwest

Northern Interior

Northeast

Males age 1-19

BS Ratio__, Crude ratio_ __


BS Ratio__, Crude ratio_ __


BS Ratio__, Crude ratio_ __


BS Ratio__, Crude ratio_ __


BS Ratio__, Crude ratio_ __


BS Ratio__, Crude ratio_ __


BS Ratio__, Crude ratio_ __


BS Ratio__, Crude ratio_ __


BS Ratio__, Crude ratio_ __


BS Ratio__, Crude ratio_ __


BS Ratio__, Crude ratio_ __


BS Ratio__, Crude ratio_ __


BS Ratio__, Crude ratio_ __


BS Ratio__, Crude ratio_ __

Adverse Medical Events, male, age 1-19
1991-2000

- **Relative risk high**
- **Relative risk Low**
Discussion and Conclusions

- The primary objective of this study is:
  - To assess geographic variation of the AME rates
  - To identify geographic areas with significantly high or low AME rates
  - To explore the relationship between AME rate and regional characteristics such as socio-economic status, educational attainment, family, and employment and unemployment rates
  - To identify spatiotemporal trend of the AME rates over past 10 years
Discussion and Conclusions

- The AME incidence analyses suggested significant rate and risk variations at Local Health Area level.
- The analyses also suggested that a large portion of the AME variation could be explained by selected regional risk factors.
- Our study showed that Bayesian hierarchical model may successfully separate regional AME variation into systematic and random components:
  - The systematic component can be attributed to selected risk factors.
  - The random component may become insignificant after adequately quantifying the systematic component, indicating that regional variation in the LHA AME incidence rates was largely determined by the regional characteristics.
Discussion and Conclusions

- Spatiotemporal AME risks showed interesting patterns, both across space and overtime:
  - Regions with high/low AME incidence often showed decreasing/increasing nonlinear trends in rates and risks
  - A high risk cluster-pattern was uncovered in the neighborhood of Fraser and Interior Health Authorities, indicating a south-west to north east high risk cluster-pattern of southern regions of the Fraser valleys to the regions in the interior north
  - This cluster-pattern, however, began to fade away in 1996, about half way of the 10-year period
  - An emerging low risk spatial cluster-pattern is unveiled that stretched from 1992 to 1995, re-emerged (with a slight shift to the north) in 1997, and finally disappeared in 2000
Questions?

Contact emails

Dr. Ying C. MacNab: ymacnab@ubc.interchange.ca
Dr. Weimin Hu: weimin.hu@gov.bc.ca