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Regional Variation in the Severity of Pesticide Exposure Outcomes: Applications of Geographic Information Systems and Spatial Scan Statistics

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Abstract

Introduction—In a previous study, Geographic Information Systems (GIS) and spatial scan statistics were utilized to assess regional clustering of symptomatic pesticide exposure incidents that were reported to a state Poison Control Center (PCC) during a single year. In the current study, we analyzed five subsequent years of PCC data to test whether there are significant geographic differences in pesticide exposure incidents resulting in serious (moderate, major, and fatal) medical outcomes.

Methods—A Poison Control Center provided data on unintentional pesticide exposure incidents for the time period 2001–2005. Data were abstracted to identify the geographic location of the caller, the location where the exposure occurred, the exposure route, and the medical outcome.

Results—The results yielded 273 incidents resulting in moderate ($n=261$), major effects ($n=10$), or fatalities ($n=2$). Analysis of these data using spatial scan statistics resulted in the identification of a geographic area consisting of 2 adjacent counties (one urban, one rural) where statistically significant clustering of serious outcomes was observed. The relative risk of moderate, major, and fatal outcomes was 2.0 in this spatial cluster ($p=0.0005$).

Conclusions—Poison Control Center data, GIS, and spatial scan statistics can be effectively utilized to identify clustering of serious incidents involving human exposure to pesticides. These analyses may be useful for public health officials to target preventive interventions. Further investigation is warranted to better understand the potential explanations for geographical clustering, and to assess whether preventive interventions have an impact on reducing pesticide exposure incidents resulting in serious medical outcomes.

Introduction

Geographic information systems (GIS) are automated processes for the storage, analysis, and display of spatial data (1). In the past ten years, GIS has become an increasingly important tool used in public health and environmental epidemiology (2,3). In combination with GIS, spatial scan statistics have been utilized to investigate for temporal and geographic clustering of events including exposure incidents and health outcomes (4-6). More recently, several investigators have utilized GIS as a tool to estimate exposure and potential health effects associated with the agricultural use of pesticides (7-9).

There is growing interest in the application of GIS towards the epidemiological surveillance of human poisoning incidents of public health significance (10). Poison Control Center (PCC) data can serve an important role in surveillance studies, as they are a toll-free resource covering wide geographic areas across the United States (11,12). In a previous investigation (13), an

analysis was conducted of all symptomatic pesticide exposure incidents reported to a regional PCC during a single year. The results of that investigation identified a large, predominantly rural geographic region of the state where there was a significantly higher risk of reporting a symptomatic pesticide exposure.

In the current study, we extended our analysis to include five subsequent years of PCC data. In addition, instead of investigating all symptomatic exposures (irrespective of severity) we limited the scope of medical outcomes to target unintentional exposure incidents resulting in moderate and major effects as well as fatalities. While intentional pesticide exposure incidents are more likely to result in serious medical outcomes, such incidents are difficult to prevent and our intention was to identify accidental exposure scenarios resulting in significant morbidity. We sought to evaluate whether there are regions within the state where there is a significantly higher risk of serious outcomes from unintentional pesticide exposures, and to better understand the circumstances and active ingredients associated with these incidents.

Experimental Methods

The Oregon Poison Control Center provided data on unintentional pesticide exposure incidents for the time period 2001–2005. These data were abstracted to identify the geographic location of the caller (by zip code and county), the location where the exposure occurred (residential, workplace, or other), the location of the caller (residence, workplace, health care facility or other), the medical outcome (no effect, minor, moderate, major effects, death), the exposure route (dermal, inhalation, ingestion, ocular, aspiration), age (younger or older than 6 years) and the active ingredient in the pesticide (classified by generic category by the PCC).

Medical outcomes from pesticide exposure incidents were determined by the Poison Control Center, using criteria defined by the American Association of Poison Control Centers (14). As our aim was to study accidental exposure incidents, only unintentional exposure incidents involving moderate effects, major effects, and deaths were included in the analysis. Moderate outcomes included symptomatic incidents that were not transient in nature, required some form of medical treatment, but were not life-threatening or resulting in prolonged disability. Major outcomes included symptomatic incidents resulting in life-threatening signs or symptoms (e.g. seizures, hemodynamic instability, and respiratory distress) where emergency medical was indicated.

Pesticide exposure incidents containing data on the location of exposure were analyzed using SaTScan™ Version 7.0, a computer software program that has been widely used in epidemiological studies to investigate spatial and temporal clustering (15). SaTScan™ was utilized to generate a spatial scan statistic to analyze incidents involving serious medical outcomes (moderate, major outcomes, and fatalities), and assess whether incidents were clustered in different geographic counties within the state during the five year study period. For statistical inference, 9999 Monte Carlo simulations were performed using SaTScan™, and a p-value < 0.05 was considered statistically significant. The location of each county was defined by its county population centroid (16,17), and county populations were taken from the 2000 U.S. Census.

Results

During the five year study period, 6,312 unintentional pesticide exposure incidents were reported to the PCC. Ninety-eight percent (98%) of incidents included a spatial identifier. 273 (4.3%) of these incidents resulted in serious outcomes including moderate (n=261), major effects (n=10), or fatalities (n=2). The majority of these incidents occurred in residences (81%), and the majority of calls to the PCC originated from the caller's own residence (57%). A smaller proportion of serious outcomes were reported to have occurred in workplaces (13%), or other

public areas (2%). The majority of serious outcomes occurred in adults (87%, ages greater than 19 years), while 8% involved children under the age of six. Most of the incidents with serious outcomes resulted from inhalation (30%), inhalation and dermal (20%), dermal (18%), and ingestion (12%) routes of exposure.

Analysis using SaTScan™ resulted in the identification of a most likely geographic cluster consisting of 2 adjacent counties, one urban (Lane) and one rural (Linn), where statistically significant clustering of serious outcomes was observed. The relative risk of moderate, major, and fatal outcomes was 2.0 in this geographic cluster ($p=0.0005$). Table 1 contains a descriptive summary of serious outcomes from unintentional pesticide exposure incidents during the study period, for the entire state as well as the counties where clustering was observed. Figure 1 displays the geographic location of those counties where serious outcomes were clustered, including major outcomes and fatalities.

Insecticides were the classification of pesticides most frequently associated with serious outcomes across the state, as well as in the cluster counties. Pyrethroid insecticides were the most frequently identified active ingredients in incidents resulting in moderate, major, and fatality outcomes. Table 2 summarizes the pesticides associated with serious outcomes for the entire state as well as the cluster counties. Table 3 summarizes the location, exposure pathway, and pesticides associated with major outcomes and fatalities from unintentional incidents during the study period. A relatively small number of intentional exposure incidents were reported during the study period ($n=25$). Inclusion of these intentional exposure incidents in our analysis did not change the spatial clustering of serious outcomes that were observed in this study (data not shown).

Discussion

It is of interest to note that the counties identified in the most likely geographic cluster from 2001–5 were also included in the clustering observed in our previous analysis of the 2000 data from the PCC (13). The relative risk observed in the current investigation spanning five years ($RR=2.0$) was slightly higher than what was observed during a single year of data collection ($RR=1.8$). The consistency of these findings suggests a need to better understand why the risk of serious outcomes is significantly higher in this region of the state. The spatial analysis of retrospective data spanning several years may result in enhanced ability to detect clusters of elevated risk in time and space.

When evaluating this type of approach towards toxicosurveillance activities, the relative risk estimates need to be considered within a broader context including data quality, sensitivity, representativeness, consistency, timeliness, and simplicity (18). With respect to data quality, this study focused on moderate, major, and fatality outcomes, which could introduce biased reporting (higher relative risk) from counties having major hospitals or health care facilities within their boundaries. The results of the current investigation, however, do not appear to have been biased by the presence or absence of health care facilities. The proportion of incidents reported by health care facilities in the geographic cluster was similar to what was observed across the rest of the state.

There are other limitations to PCC data that need to be considered when evaluating spatial clustering and risk estimates. Incident reports to poison control centers are by self-report, and there may be errors in coding and documentation leading to misclassification bias. Another limitation, which is consistent with our previous study of pesticides and PCC data, is that the majority of incident reports arise from residential exposure to pesticides. It has previously been observed that PCC's may not effectively capture data relating to occupational exposure incidents (19). This is an important segment of exposures for surveillance given that mixers,

loaders, and applicators of pesticides are at higher risk of exposure to pesticides. In combination with other sources of occupational exposure incident data (such as the Sentinel Event Notification System for Occupational Risk, National Institute of Occupational Safety and Health), PCC data may provide a more accurate assessment of pesticide exposure incidents in the general population.

While these limitations are acknowledged, there are other aspects of PCC data that make them potentially very important attributes of a public health surveillance system for pesticide exposures. This would include the consistency of methods used by the PCC to collect and report data (including the temporal and spatial identifiers), and the timeliness of reporting. Pesticide poisoning is a reportable public health condition in Oregon, and the PCC has developed and implemented an automated electronic system for same-day reporting such incidents to the state department of public health. The methods used in the current study to retrospectively assess for spatial clustering of serious outcomes could also be applied in a prospective manner for toxicsurveillance activities. These methods could be utilized to target preventive interventions towards high-risk communities, and study the effectiveness of such interventions.

The results of our study revealed some unexpected findings. Pyrethroid insecticides were most frequently associated with serious outcomes, in the geographic cluster as well as throughout the state. The finding that pyrethroid insecticides were frequently implicated in association with moderate, major, and fatality outcomes was unexpected, given the relatively low toxicity that these insecticides pose to humans (20). However, 98% of the pyrethroid and pyrethrin exposures in this study resulted in moderate effects, while only 2% resulted in major effects or death. One factor that may explain the higher prevalence of pyrethroid insecticides in this analysis is the phase-out of organophosphate insecticides from residential uses, and the concurrent increase in human exposure incidents involving pyrethroid insecticides (21,22).

The single fatality incident associated with pyrethroid insecticides in this investigation occurred in an elderly female with a previous history of coronary artery disease and chronic atrial fibrillation, who experienced a respiratory and cardiac arrest immediately after returning to her home after a pest control operator had applied formulations containing esfenvalerate and pyrethrins to the interior of the residence. The product labels of the pesticide formulations instruct to ventilate thoroughly before occupants are allowed to re-enter, however in this incident no ventilation took place after the application. Additional work is needed to better understand the circumstances surrounding exposure incidents involving pyrethroid insecticides, and to identify factors that may contribute to higher severity outcomes.

Conclusions

The results of the current study provide additional evidence demonstrating the potential applications of GIS, spatial scan statistics, and PCC data in localizing trends in significant human exposure incidents resulting from pesticides. These types of data may be useful in toxicsurveillance activities, and in the development of preventive interventions to mitigate risks from pesticide exposures. By targeting prevention resources towards communities at higher risk, it may be possible to mitigate incidents resulting in serious medical outcomes.

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Moderate, Major, and Fatality Outcomes for Oregon Counties

Figure 1.
Moderate, Major, and Fatality Outcomes by County (Geographic Cluster in Dashed Outline,
Relative Risk = 2.0)

Table 1

Medical Outcomes of Exposure Incidents, 2001–5

Medical Outcomes	All Counties	Cases (*) Lane County	Linn County
No effect	2460 (59%)	292 (59%)	113 (57%)
Minor effect	1451 (35%)	163 (33%)	70 (35%)
Moderate effect	261 (6%)	40 (8%)	17 (9%)
Major effect	10 (<1%)	1 (<1%)	0 (0%)
Death	2 (<1%)	1 (<1%)	0 (0%)
Not followed, judged as nontoxic exposure (clinical effects not expected)	352	38	15
Not followed, minimal clinical effects possible	1591	193	73
Unable to follow, judged as a potentially toxic exposure	185	19	11

* Percent of cases where the medical outcome was reported as either no, minor, moderate, major effect, or death

Table 2

Pesticides Associated with Moderate, Major, and Fatal Outcomes for Exposures, 2001–5

Pesticides by Generic Category and Active Ingredient	All Counties	Lane County	Linn County
<i>Fungicides</i>	13 (5%)	2 (5%)	0 (0%)
Nonmercurial fungicides	2	1	0
Other/Unknown fungicides	9	1	0
Cooper compound	1	0	0
Wood preservatives	1	0	0
<i>Herbicides</i>	55 (19%)	10 (23%)	3 (18%)
2,4-D or 2,4,5-T or chlorophenoxy	19	3	0
Diquat, paraquat, and dithiocarbamates	2	1	0
Glyphosate	12	2	2
Other herbicide	17	3	1
Triazine	2	0	0
Unknown herbicide	2	1	0
Urea	1	0	0
<i>Insecticides</i>	193 (68%)	28 (65%)	13 (76%)
Borate/boric acid	0	0	0
Carbamates	8	1	0
Chlorinated hydrocarbon	3	0	0
Organophosphates	31	3	2
Other insecticide	30	2	0
Pyrethrins	26	3	1
Pyrethrins with piperonyl butoxide	9	0	1
Pyrethroid	66	15	9
Unknown insecticide	20	4	0
<i>Repellents and Molluscicides</i>	15 (5%)	3 (7%)	1 (6%)
Unknown moth repellent	5	0	0
Insect repellent with DEET	6	2	0
Insect repellent: unknown	1	0	0
Metaldehyde	3	1	1
<i>Rodenticides</i>	6 (2%)	0 (0%)	0 (0%)
Anticoagulant	3	0	0
Bromethalin	0	0	0
Other rodenticide	2	0	0
Strychnine	1	0	0
Zinc phosphide	0	0	0
Veterinary Pesticides	1	0	0
<i>TOTAL</i>	283	43	17

Table 3
Summary of Incidents Resulting in Major Outcomes and Fatalities

County	Medical Outcome	Pesticide Active Ingredient/Class	Exposure Route	Clinical Effects
not reported	major effect	strychnine	inhalation, dermal	tachycardia, vertigo
Multnomah	major effect	Anticoagulant: long-acting, superwarfarin	ingestion	abdominal pain, anemia
Coos	major effect	permethrin	inhalation, dermal	dysrhythmia (ventricular tachycardia)
Multnomah	major effect	unknown insecticide	inhalation, dermal	erythema, skin irritation, nausea, dyspnea
Lane	major effect	other herbicide	ingestion, ocular, dermal	blurred vision, eye irritation/pain, papilledema
Multnomah	major effect	carbamate	unknown	agitated, irritable, confusion, acidosis, alkalosis
Clackamas	major effect	diazinon	inhalation	bradycardia, hypotension, diarrhea, vomiting
Multnomah	major effect	other insecticide	ocular	eye irritation/pain, papilledema
Multnomah	major effect	other/unknown fungicide	ingestion	bradycardia, hypotension, hypertension, tachycardia, hematemesis, coma, dyspnea, pneumonitis, respiratory depression
Multnomah	major effect	mothballs	inhalation	cyanosis
Multnomah	death	Organophosphate/other insecticide	unknown	cardiac arrest, dysrhythmia, diarrhea, agitated, irritable, respiratory arrest, respiratory depression, excessive secretions
Lane	death	esfenvalerate, pyrethrins with synergists	inhalation, dermal	cough, dyspnea, excessive secretions, respiratory arrest, cardiac arrest