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ABSTRACT

Acute and chronic effects of exposure to chlorine and chloramines can result in the irritation of the skin and mucous membranes, often leading to airway edema resulting in respiratory difficulties, burning in the throat, eyes and nose. Ingestion of bleach or bleach-containing products often results in adverse gastrointestinal effects. Data captured by the three centers comprising the Florida Poison Information Center Network (FPICN) between 2006 and 2008 was examined to characterize the extent of toxic effects from chlorine gas exposures related to misuse of household cleaners. A known outcome was determined in 48.4% of the 5315 cases. Of those with a known outcome, 0.2% (6) had a major effect. Children two and younger were the most frequently exposed population (22.7%). Children 19 and under accounted for 39.1% (2079), whereas children 2 and under accounted for 22.7% (1204) of the chlorine exposure population. Container confusion accounted for 12%, and mixing cleaning products accounted for 17% of the cases reviewed in 2006. The most common route of exposure in cases reviewed in 2006 was by-mouth and the most common symptom was gastrointestinal (GI). Fact sheets and educational outreach related to reducing the mixing of household cleaners, reading manufacturers safety instructions carefully, and storing the chemical cleaners safely away from children and in original containers is warranted to reduce chlorine exposures in children.

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Background

In the home, exposure to chlorine gas often occurs through the improper mixing of household chemicals, whereas ingestions of bleach are usually a consequence of unsafe storage and improper use of these chemicals. Children tend to be more vulnerable to bleach exposures than adults, and account for the highest frequency and percent of incidents reported nationwide by poison centers. Container confusion, a predominant factor of accidental ingestions, occurs when a product is put into a familiar container other than the original container that results in accidental ingestion in a variety of age groups. As such, container confusion is considered a significant exposure venue in children. When accidentally or intentionally ingested, bleach products predominantly cause adverse gastrointestinal effects. As children learn by exploration of their environment, significant hand-to-mouth behavior is common. Likewise, confusion resulting from inedible products being placed and stored in familiar containers that previously contained edible products is a major cause of accidental ingestions. Our study suggests that children aged 2 years and younger are a prime population exposed to chlorine bleach thorough container confusion in the home when compared to other age groups.

Increased selection and limited consumer knowledge of cleaning products and their exposures (Bugne, 1985) has upped the potential for poisonings and other health problems due to incorrect use, storage and incorrect mixing. Manufacturers are required to label products with information on use, caution for mixing, and toxicity danger because of the toxicity of cleaning products, although studies have suggested that few consumers actually read these labels (Nazaroff & Weschler, 2004).

Bleach is one of the most common household cleaners (Tanen, Graeme, & Raschke, 1999) and contains 4%-12% sodium hypochlorite. Bleach releases small amounts of chlorine gas and hypochlorous acid (Reisz & Gammon, 1986; Tanen, et al., 1999). However, when combined with ammonia-based cleaners, chloramine gas is produced (NH_3+HOCL→ NH_2CL (chloramines gas) + HCL) (Reisz & Gammon, 1986; Tanen, et al., 1999). When bleach is mixed with acid-based cleaners, chlorine gas is formed (HOCL + HCL→CL_2 (chlorine gas) +H_20 (tissue). Chlorine gas primarily reacts with the lung epithelial lining fluid (Squadrito, Postletwait & Matalon, 2010) creating hydrochloric acid and other damaging free radicals.

Ingestion is the most common route of accidental exposure in children from container confusion or from adults that are using the product to attempt suicide. When bleach is ingested, the hypochlorite reacts with stomach acids, producing chlorine gas which causes severe gastrointestinal upset. This gas is released from the stomach and can subsequently find its way into the trachea as a portal for lung exposure (Bugne, 1985). There is a relationship be-

tween the concentration of chlorine and the exposure time (ten Burg & Vis van Heemst, 1983) and this also related to severity of the effects. As observed in FPICN cases, lower concentrations found in laundry products (4%-5% hypochlorite) primarily cause stomach upset and vomiting. Higher concentrations of home products (6%-11% hypochlorite) increase the probability of damage to the lungs. Industrial and hair products containing greater than 20% hypochlorite are corrosive and cause more direct injury.

Inhalation of both chlorine and chloramine gases results in respiratory complications and cellular injury, depending on the concentration, duration of exposure and presence of preexisting cardiopulmonary conditions (Krenzelok & Mrvos, 1995). However, in higher concentrations the exposure is known to evolve from irritant to corrosive effects, resulting in cellular injury, pneumonitis, edema, tracheobronchitis, and ultimately respiratory failure (Krenzelok & Mrvos, 1995; Tanen, et al., 1999). A case of edema in a toddler reported severe respiratory sequelae related to a hypochlorite exposure (Babi, Kharsch, & Woolf, 1998). Deaths, however, are rare (Krenzelok & Mrvos, 1995), and are related to victim inability to escape gaseous exposures. In a limited study of 216 cases related to chlorine/chloramines home exposures (Mrvos, Dean, & Krenzelok, 1993), one patient needed to be admitted, 33% received further medical care, and 7% had symptoms more than 6 hours. Moreover 92% of these cases had resolved symptoms within 6 hours and 67% of these cases were treated at home. Of 39 patients evaluated in an emergency room, 74.4% were children and 15.4% of the patients were in the severely exposed category and required hospitalization (Sever, Mordeniz, Sever & Dokur, 2009).

Globally, children spend more than 80% of their time indoors, so indoor air factors are of interest related to respiratory chronic disease, particularly asthma (Heinrich, 2011). Chronic or repeated exposure to bleach was associated with asthma symptoms in domestic cleaning women (Medina-Ramon, Zock, Kogevinas, Sunyer, Torralba, Borrell, et al., 2005). Follow-up of health consequences associated with chlorine exposure associated in a Graniteville, South Carolina train derailment found that victims continued to experience physical symptoms and required medical care 5 months later (Duncan, Doucluk, Belflower, Thomas, Van Sickle, Gibson, et al., 2011).

With more understanding of chlorine bleach exposures in children, a direct educational awareness program can be developed and potentially impact the prevention of this problem. Outreach that includes dissemination of accurate and relevant health information should focus on traditional poison prevention. Training needs to emphasize the storage of bleach and other household products only in original containers, appropriate storage venues away from children's reach the absolute adherence to product use instructions, and the avoidance of mixing products.

Methods

A proposal for this project was submitted to and approved by the Florida A&M University (FAMU) Institutional Review Board (IRB) and forwarded to the Florida Poison Information Center Network (FPICN) for review through their IRB process. Data regarding chlorine exposures and poisonings were obtained from the FPICN's exposure records upon IRB approval. American Association of Poison Control Centers Codes (AAPCC) were reviewed and those deemed of interest were the categories of bleach, chlorine, pool products, cleaners with bleach, chlorine active compounds, and the other category, which included chloramines-T, Dakin's Solution, hypochlorite and related agent. Dataset queries were created and run using the online FPICN QueryBuilder to access their statewide data. Calls that were strictly informational were excluded from analysis.

De-identified data was imported into a Microsoft© Excel spreadsheet. This data was subsequently analyzed in Statistical Products for Social Sciences© (SPSS), used to generate descriptive statistics (frequencies). The online FPICN database was also used to create GIS maps of exposures in Florida, based on county level data. Maps were created for gross number of calls from 2006 to 2008, as well as exposure rates per 10,000 population for all county residents.

Descriptive analysis was conducted to analyze the data from 2006 to 2008. The variables included: the date of exposure, county of report, age and gender of the victim, medical outcome, chemical substance of exposure, and place of exposure.

The medical outcome for data from 2006 to 2008 was categorized into *major effect*, *moderate effect*, *minor effect* and *no effect*, as defined in the AAPCC, National Poison Data System (NPDS) manual. *Major effect* loosely defined as life threatening, prolonged effects, and that result in disability or disfigurement. *Moderate effect* is more pronounced, prolonged and systemic, but is not life-threatening. *Minor effect* minimally bothersome, but resolves rapidly without lasting effect. *No effect* is utilized when signs and symptoms did not develop from the exposure (American Association of Poison Control Centers, 2007).

The FPICN case descriptions were reviewed for 2006 to determine the route of exposure, resulting symptoms, and whether the exposure was the result of mixing household cleaners or the consequence of container confusion.

Results

There was a total of 5,315 exposure cases reported to the Florida poison control centers from 2006 to 2008 that met inclusion criteria. Chlorine exposures trended by peaking in the summer and troughing in the winter months. Mapped exposure data revealed that over the three-year period, the county with the highest number of exposures was Hillsborough County (627), followed by Orange County (453) (Figure 1). After the data were normalized for county population, the county with the highest rate of exposures was Hardee county with 8/10,000, followed by Desoto with 6.3/10,000 (Figure 2). Figure 1 and Figure 2 show a complete range of frequency and rates by county.

Figure 1. Three-year Chlorine Exposures in Florida by County, 2006-2008

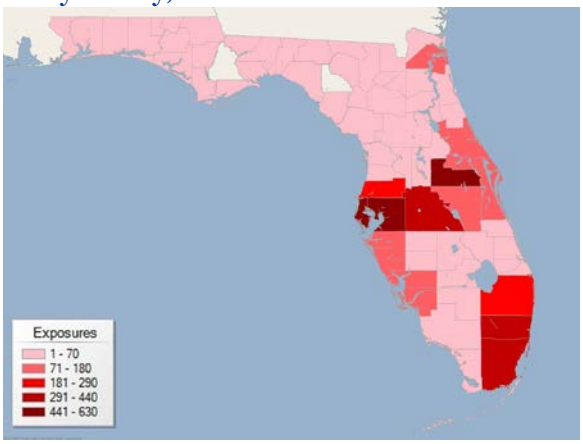
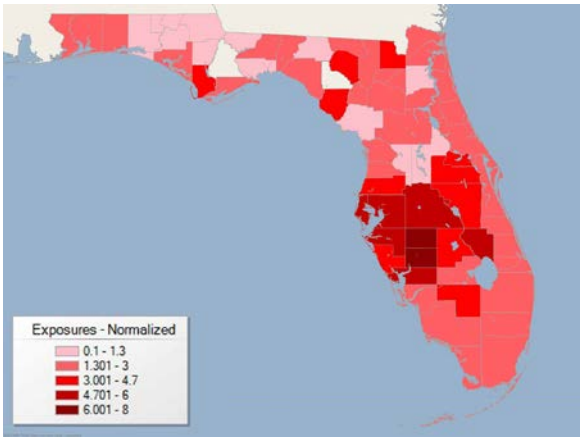


Figure 2. Three-year Chlorine Exposure Rates in Florida Normalized for County Population, 2006-2008



Children 2 years of age and younger appeared to be most at risk for chlorine exposure, totaling 22.7% (1204) of the exposure population. Children 19 and younger accounted for 39.1% (2079) of the exposure population (Table 1). Approximately 53 % of the time cases involved girls. Data were not collected by the FPICN for race/ethnicity (Table 1).

Table 1. Age and Gender Distribution of Chlorine Exposure Cases in Florida, 2006-2008

Age	Frequency	Percent
≤ 2	1204	22.7
3 to 5	326	6.1
6 to 11	224	4.2
12 to 19	325	6.1
20 to 29	659	12.4
30 to 39	665	12.5
40 to 49	669	12.6
50 to 59	503	9.5
60 to 69	318	6.0
70 to 79	196	3.7
80 to 89	64	1.2
90 to 99	6	0.1
Unknown-adult	70	1.3
Unknown-child	4	0.1
Unknown	82	1.5
Total	**5315**	**100**
Gender	**Frequency**	**Percent**
Male	2817	53
Female	2498	47
Total	**5315**	**100**

Detailed poison center case data and written progress notes for cases in 2006 were examined to determine the occurrence of container confusion, unsafe mixing, route of exposure and symptoms. We found that 12% were involved in container confusion, while 17% were due to mixing household chemicals. Fifty-three percent of the population exposures were due to ingestion, 24% were inhalation related, 15% were ocular, and 8% were dermal (Figure 3). Gastrointestinal problems (33%) were the most common adverse health effects reported, followed by ocular (24%) and respiratory (22%). Dermal, neurological, cardiovascular and other miscellaneous health problems accounted for the remaining 21% of the reported health effects (Figure 4).

The most common substance involved in those cases meeting inclusion criteria was bleach, representing 74.8% (3,975) of all exposures that

Figure 3. Routes of Exposure by Percent for Chlorine Cases in Florida, 2006-2008

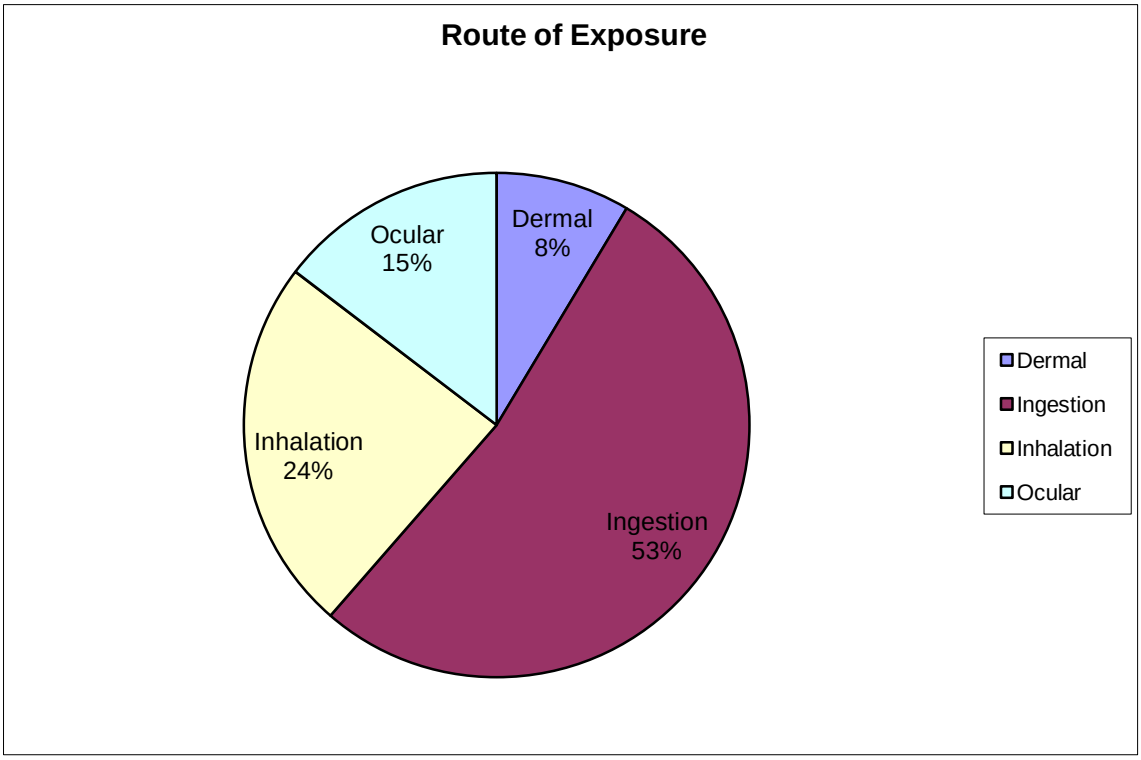
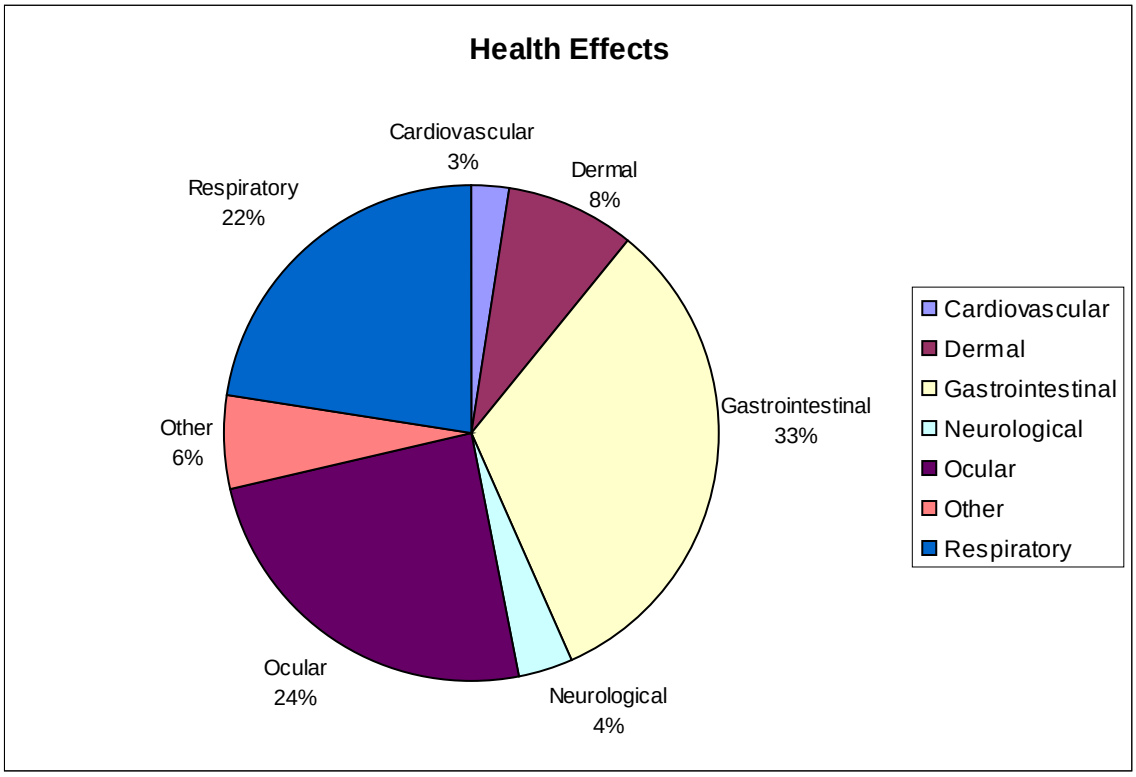


Figure 4. Health Effects by Percent of Chlorine Exposures in Florida, 2006-2008



met the criteria. Other major contributors were chlorine, which accounted for another 7.9% (418), pool products 6.9% (365), and cleaners containing bleach 6.5% (348) (Table 2). Most frequently, the site of exposure was residential, accounting for 93.3% (4960) of exposures. The workplace had the second highest number of exposures with 4.1% (218). Other exposure sites, all at less than one percent, included healthcare facilities, public areas, restaurant or food services, schools, and vehicles. Ninety-three percent of the exposures were accidental. The remaining 6.7% of exposures were intentional, and included willful misuse, abuse, and suspected suicide (Table 2). A known medical outcome was determined in 48.4% of the cases. Of these, 0.2% (6) had a major effect, 24.2% (623) had a moderate effect, 56.2% (1445) had a minor effect, and 19.4% (499) had no effect (Table 2).

Table 2. General Characteristics of Chlorine Exposure Related to Type of Chemicals, Location of Exposure, Intentional or Non-intentional Exposure and Health outcome in Florida, 2006-2008

Chlorine Exposures	**Frequency**	**Percent**
Bleach	3,975	74.8
Chlorine	418	7.9
Pool Products	365	6.9
Cleaners Containing Bleach	348	6.5
Chlorine Active Compounds	140	2.6
Other*	69	1.3
Total	5315	100
Place of exposure	**Frequency**	**Percent**
Residential Exposure	4,960	93.3
Occupational Exposures	218	4.1
Other**	137	2.6
Total	5315	100
Exposure Intention	**Frequency**	**Percent**
Unintentional	5,017	94.4
Intentional***	238	4.5
Other/Unknown	60	1.1
Total	5315	100
Outcomes	**Frequency**	**Percent**
Major Effect	6	0.2
Moderate Effect	623	24.2
Minor Effect	1445	56.2
No Effect	499	19.4
Known Outcomes	2567	48.3
Unknown Outcomes	2748	51.7
Total	5315	100

* Chloramines-T, Dakin's Solution, Hypochlorite and related agents
** Healthcare facilities, public areas, food Service, schools and vehicles
*** Misuse, abuse and suspected suicide

Discussion

Chlorine exposures represent a significant problem in Florida with children at high risk for exposure. Families and caregivers with small children need to strongly consider utilizing child resistant technology, either at the item level (child resistant cap) or at the storage level (appropriately high cabinet and/or cabinet/drawer locks). Household products should always be stored in their original containers and never transferred into a container that used to hold edible products. Children under two may not have the ability to escape from exposure of chlorine gas. Visits with the pediatrician and educational programs provided by poison center staff would be appropriate venues for parent and caregiver to learn about household chemical dangers of all kinds, appropriate child proofing, and inappropriate storage containers and cleaning practices.

The frequency of chlorine exposures in 2006 due to container confusion was surprising. Containers included used water bottles, soda bottles, glasses, cups, bowls, and various other containers. Container

confusion also occurs with other toxicants. From 1998 to 2003, the Sentinel Event Notification System for Occupational Risks (SENSOR), Pesticide Surveillance identified 13 lindane, an organochlorine, cases from unintentional ingestion, and 857 cases of unintentional lindane ingestion from the Toxic Exposure Surveillance System (TESS; Note: TESS was the precursor title to NPDS) (Centers for Disease Control and Prevention, 2005), when the containers were mistaken for cough syrup. In addition, a paraquat death of an 8-year-old occurred related to drinking the substance from a soda bottle (Chen, Eldridge, Lodeserto, Ming, Turner, Vanderford, et al., 2010).

Although the medical outcome was minor to moderate for the majority of the cases, it is still significant and avoidable morbidity which may be prevented by reading the label, taking precautions when mixing cleaners and reducing container confusion by keeping its chemical in the original container.

More directed factsheets and outreach programs are needed to raise awareness of chemical exposures affecting children's contact with chlorine containing products. With care and caution, nearly all of the accidental exposures reported by FPICN could be significantly reduced as could the cost associated with the medical management for this form of exposure. It is imperative that the original container be available for absolute documentation of the product in question for calls to the FPICN or to the health care facility, therefore pesticides and other household chemicals should be kept in the original container (Chen, Eldridge, Lodeserto, Ming, Turner, Vanderford, et al., 2010).

Limitations

The exposures reported on the FPICN system may only represent a portion of the total number of chlorine exposures that occur each year in Florida, as many exposures are go unreported. Race and ethnicity data is not collected by the FPICN. There were many cases with incomplete information on exposures.

Conclusions

Our study demonstrates that children 2 and younger are at significant risk for chlorine bleach exposures in the home. In the 2006 cases, the oral route of exposure was the predominant route of exposure most often, resulting in GI symptoms. Container confusion accounted for 12% of the cases in 2006. Seventeen percent of the cases from 2006 were due to mixing chemicals. Reducing mixing errors, storing bleach and other cleaning products safely in the original container, reading the safety labels, exercising good poison prevention techniques in the home and following manufacturer's instructions could potentially reduce exposure to household cleaning products. Innovative strategies that address these breakdowns in safety communication could be developed. Purchase point information or fact-sheets to disseminate to consumers where cleaning supplies are sold could help prevent these cases.

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