

Multi-source surveillance for work-related crushing injuries

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Background: Work-related crushing injuries are serious but preventable. For 2013 through 2015, the U.S. Bureau of Labor Statistics' (BLS) Survey of Occupational Injuries and Illnesses (SOII) reported 1260 crushing injuries in Michigan. In 2013, Michigan initiated multi-data source surveillance of work-related crushing injuries.

Methods: Records from all 134 of Michigan's hospitals/emergency departments (EDs), the Workers Compensation Agency (WCA) and Michigan's Fatality Assessment Control and Evaluation (MIFACE) program were used to identify work-related crushing injuries. Companies, where individuals were hospitalized or had an ED visit for a crushing injury, potentially had an OSHA enforcement inspection conducted.

Results: From 2013 through 2015, there were 3137 work-related crushing injury incidents, including two fatalities. The Michigan OSHA program completed inspections at 77 worksites identified by the surveillance system.

Conclusion: The Michigan multisource surveillance system identified two and a half times more crushing injuries than BLS and was useful for initiating case-based enforcement inspections.

KEYWORDS

crushing injuries, enforcement inspections, injury prevention, public health surveillance, work-related injuries

1 | INTRODUCTION

A crushing injury is one of the most severe and traumatic injuries an employee can sustain in a workplace. Crushing injury occurs when there is force or pressure on a body part.¹ With increasing severity, there may be damage to the skin tissue, to the nerves, to the muscles, a fracture, an amputation, or death.² Crushing injuries may have direct impact not only on an individual's immediate health, but also on an individual's future employment and long-term earnings because of a temporary or permanent impairment.

Michigan initiated surveillance for work-related crushing injuries in 2013, adding to existing surveillance for work-related amputations, burns, farm injuries, hospitalized injuries, and skull fractures.³ Comprehensive surveillance of work-related conditions is essential

for understanding industry hazards, targeting interventions, and reducing and eliminating the hazards. Michigan's surveillance system tracks all work-related crushing injuries, irrespective of the body part injured, the individual's work status (eg, self-employed, contractor), and the employer's industry that are treated at Michigan's hospitals/emergency departments, reported to the state's Workers Compensation Agency (WCA) or identified through the Michigan Fatality Assessment Control and Evaluation (MIFACE)⁴ program. Michigan's surveillance data on injured body parts greatly expands previous international⁵ and state⁶⁻⁸ studies that examined all work-related hand injuries, including crushing injuries, which accounted for 13.1-29.7% of all work-related hand injuries.

The main premise of work-related crushing injuries surveillance is to identify the incidence of known work-related injuries and initiate case-based investigations in order to prevent future injuries. The U.S. Bureau of Labor Statistics (BLS), the official source of work-related injury and illness statistics, that collects

data through the employer based Survey of Occupational Injuries and Illnesses (SOII), reported 1260 work-related crushing injuries resulting with days away from work for Michigan in 2013 through 2015.⁹ The SOII does not collect the diagnoses of injuries that do not cause lost work time, a job transfer or work restrictions. SOII only collects diagnoses for injuries with one or more days away from work.

While reducing the incidence of work-related fatalities and amputations is a national^{10,11} and in many states,^{12,13} including Michigan,¹⁴ priority, there have been no similar emphasis on work-related crushing injuries. As of January 1, 2015, the federal Occupational Safety and Health Administration (OSHA) revised the record keeping and reporting rule to include severe injuries that employers must report to OSHA.¹⁰ Employers are required to report all work-related inpatient hospitalizations, which would include hospitalized crushing injuries. Michigan OSHA implemented the Federal injury-reporting requirement on September 1, 2015.¹⁵

This article describes Michigan's multi-source crushing injuries surveillance system, summarizes the characteristics of the work-related crushing injuries and describes how the data are used in targeting Michigan OSHA inspections.

2 | METHODS

2.1 | Case definition

A crushing injury case was defined as an individual: (a) who had a work-related crushing injury (see specific ICD 9 and 10 codes below) and was treated at one of Michigan's 134 hospitals or Emergency Departments, or as an outpatient at a hospital based clinic; (b) in the Michigan Workers' Compensation Agency (WCA) computerized database as having received wage replacement for a "Crush/Contusion" injury (Nature of Injury codes)¹⁶; or (c) who died from a work-related crushing injury that occurred in Michigan.

Treatment for the work-related crushing injuries occurred during the 3 years from January 1, 2013 to December 31, 2015.

2.2 | Data sources

2.2.1 | Hospital/emergency department

All 134 of Michigan's acute care hospitals, including Veterans' Administration hospitals, are required by state regulation to identify and report work-related crushing injuries.¹⁷ Hospitals submitted discharge summaries and emergency department (ED) evaluations of individuals 16 years or older where one of the following diagnostic codes was either the primary or any of the secondary diagnostic codes (the International Classification of Diseases, 9th Revision [ICD-9])¹⁸ for crushing injuries January 1, 2013 to September 30, 2015:

- 925 (crushing injury of face, scalp, and neck),
- 926 (crushing injury of trunk),

- 927 (crushing injury of upper limb),
- 928 (crushing injury of lower limb),
- 929 (crushing injury of multiple an unspecified sites)

or ICD-10 diagnostic codes¹⁹ for crushing injuries October 1, 2015 to December 31, 2015:

- S07 (crushing injury of head),
- S17 (crushing injury of neck),
- S28 (crushing injury of thorax, and traumatic amputation of part of thorax),
- S38 (crushing injury and traumatic amputation of abdomen, lower back, pelvis, and external genitals),
- S47 (crushing injury of shoulder and upper arm),
- S57 (crushing injury of elbow and forearm),
- S67 (crushing injury of wrist, hand, and fingers),
- S77 (crushing injury of hip and thigh),
- S87 (crushing injury of lower leg),
- S97 (crushing injury of ankle and foot).

The discharge summaries of the medical records and emergency department histories and physicals were reviewed to differentiate work- and non-work-related crushing injuries. Further discussion of the records received from the hospitals/EDs can be found in previous publications using these records.²⁰⁻²²

2.2.2 | Workers' compensation agency

The Michigan WCA provided access to a database of all paid claims for wage replacement due to lost work time in 2013 through 2015. Individuals were eligible for wage replacement when they have had at least 7 consecutive days away from work (including 2 weekend days). Cases identified using Michigan's Workers' Compensation system were defined as an individual who was in the lost work time wage replacement database with an accepted claim for a "Crush/Contusion" to any part of the body, nature of injury code 160. Crushing injuries cannot be distinguished from the much more common contusion injuries in the WCA database as the nature of injury code in the database for both types of injuries was 160.

2.2.3 | Michigan fatality assessment control and evaluation program

The Michigan Fatality Assessment Control and Evaluation (MIFACE)⁴ program identified acute traumatic fatalities in Michigan by reviewing death certificates, police reports, medical examiner reports, and newspaper clippings. All deaths where a crushing injury was the underlying cause of death on the death certificate were included. Additional fatalities where the underlying cause of death was not a crushing injury were identified when crushing injury cases identified from the hospitals' medical records were later identified to have died from their injuries.

2.3 | Analysis

The following information from the hospital/ED reports and MIFACE reports was abstracted: reporting source(s), type of medical care (hospital overnight, ED, outpatient), hospital name, date of admission and discharge, patient demographics, city and county of residence, source of payment, information on whether the worker was self-employed, employer's name and address, type of work, injury date, ICD code, cause of injury, side injured, digit injured, information on whether a press injury. Additional information was abstracted from death certificates, police reports, and medical examiner reports for the MIFACE records: patient demographics, city and county of residence, employer's name and address, fatality date, part of body injured, and cause of injury. Industries were coded using the North American Industry Classification System (NAICS) Code.²³

Hospital/ED and MIFACE data were entered into a Microsoft Access database. Records were manually linked to records in the Workers' Compensation database. Matches were identified using each individual's first and last name, date of birth, date of injury, and employer information. Information from Workers' Compensation on matched cases was added to the database. Duplicates identified by more than one reporting source were eliminated. This protocol was approved by the Institutional Review Board of the participating institution.

Work-related crushing injury rates by age, gender, and industry were calculated as the total number of crushing injuries in a calendar year divided by the estimated number of workers during that calendar year and expressed as the number of crushing injuries per 100 000 workers per year. The U.S. Census/Department of Labor's Current Population Survey was used to calculate denominators.²⁴ The Current Population Survey is a monthly survey of the population representing the civilian non-institutionalized population of the United States. It provides information about workers' demographics, employment, occupation, industry, and other labor characteristics. Data analysis was performed using queries conducted in Microsoft Access. Data for 2013-2015 were combined. Individuals, who sustained two unique crushing injuries in the same calendar year and/or in two different calendar years, were counted only once.

2.4 | Michigan OSHA interventions

During review of the medical records for work-relatedness, and the name of the employer, the following criteria developed with the Michigan Occupational and Safety Health Administration (MIOSHA) were used for making a determination whether a MIOSHA inspection would be performed: (a) the individual had to be hospitalized, treated in an emergency department, or hospital outpatient clinic in 2013, 2014, or 2015; and (b) the crushing injury occurred in the last 6 months; and (c) the circumstances of injury appeared ongoing and MIOSHA had an enforceable standard related to the circumstances of the injury.

2.5 | Comparison of Michigan surveillance data with estimates data from BLS

Bureau of Labor Statistics estimates of the number of nonfatal crushing injuries involving days away from work in 2013, 2014, and

2015 in Michigan were generated using the BLS' Occupational Injuries and Illnesses and Fatal Injuries Profiles online tool.⁹ The BLS estimates were based on employer reporting through the Survey of Occupational Injuries and Illnesses (SOII). The BLS estimate included private industry and state and local government workers but not the self-employed or farms with fewer than 11 employees. Codes 1971XX (Crushing Injury—except internal organs or head), 194XXX (Crushing Injury—involving internal organs), and 160XXX (Crushing Injury—to the head) were used to generate the estimates and incidence rates. The BLS estimate was compared to the number of crushing injuries identified in the Michigan surveillance system.

3 | RESULTS

There were 3137 work-related crushing injury incidents in Michigan in 2013 through 2015, including two fatalities, in 3131 individuals. Four individuals each sustained two unique crushing injuries in the same calendar year and two individuals had two unique crushing injuries in two different calendar years. Five of the six workers with repeat crushing injuries had the repeat crushing injury at the same company where their first injury occurred (employer information was missing on the 6th individual for both of their crushing injuries).

Approximately, 6162 hospital/ED medical records on crushing injuries were reviewed to identify 3135 work-related cases. The MIFACE program identified two cases. One crushing injury case was only identified by the MIFACE program (Figure 1). Because of confidentiality restrictions, no attempt was made to match the Michigan data set with the BLS data set.

A total of 213 hospital/ED reports were matched with the WCA Crush/Contusion records. Another 512 crushing injuries, 511 identified from hospital/ED records, and one fatality, matched with the employee's first and last name, date of birth, date of injury, employee's

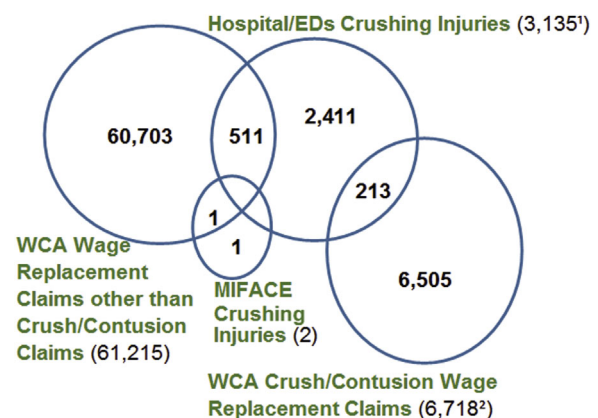


FIGURE 1 Reporting sources of work-related crushing injuries, Michigan 2013-2015.

¹Number of Individuals: 3129. ²The same code 160 is used for both crushing injuries and contusions so the two cannot be differentiated in the workers' compensation data base. There were 1,260 crushing injuries with days away from work in the BLS SOII data. Because of confidentiality restrictions, we do not know how much overlap there was with the hospital/ED or WCA data

zip code, and employer name and address in the overall WCA data base although they had an injury description in the WCA as something other than "Crush/Contusion" injury. The descriptions in WCA for these 512 were: 178 "Fracture," 118 "Cut/Laceration," 69 "Multiple Injuries," 48 "Unclassified," 42 "Amputation," 39 "Strains/Sprains," 5 "Dislocation," 5 "Infl-Joints," 4 "Burn," 3 "Other Injury/Nec," and 1 "No Injury." There were another 6505 crush/contusion injuries identified in the WCA's database, which were not identified by the hospital/ED records for crushing injuries.

3.1 | Demographics

The age of workers with crushing injury ranged from 16 to 83 years, and the average age was 37 years (Table 1). A total of 2513 (80.2%) of all crushing injuries were among men (Table 1). The highest rates were among 16-19 and 20-24 years old for both men and women, with rates among men being 3.2-4.0 times greater (Figure 2).

Among the 1595 (50.9%) individuals where race was available, 1359 (85.2%) were Caucasian, 171 (10.7%) were African-American, 12 (0.8%) were Asian, and 53 (3.3%) were "Other." Information on ethnicity was provided for 1064 (34.0%) individuals. A total of 70 individuals (6.6%) were of Hispanic origin and 994 individuals (93.4%) were not of Hispanic origin (Table 1).

3.2 | Part and side of body injured

Part of body injured was specified for all injuries. Crushing injuries of upper limbs occurred the most often (72.9%), followed by crushing injuries of lower limbs (21.1%) (Table 1).

Among the workers for whom the side of the body injured was available (1929, 61.5%), 971 (50.3%) had their left side injured, followed by 904 (46.9%) who had their right side injured, and 54 (2.8%) who had both sides of their body injured.

3.3 | Type of medical encounter

A total of 265 (8.6%) individuals were hospitalized overnight, 2411 (77.9%) individuals were only seen in the ED, and 418 (13.5%) individuals were seen in a hospital outpatient clinic (Table 1). For all crushing injuries that required hospitalization, male workers (89.4%) were more likely than female workers (10.6%) to be hospitalized. Among hospitalized individuals, 113 (42.6%) workers sustained crushing injuries to lower limb(s), followed by 97 (40.9%) of workers with upper limb(s) crushing injuries. Hospitalized individuals working in the manufacturing sector accounted for more than a third (36.8%) of individuals who were hospitalized.

3.4 | Source of payment

Workers' Compensation was the expected payer in 2008 (64.1%) of the 3135 crushing injuries identified by hospitals/EDs and among 76.0% of the 2641 cases where the payment source was provided in the medical records (Table 1). Commercial insurance was the expected source of payment in 357

TABLE 1 Summary characteristics of work-related crushing injuries, Michigan 2013-2015

	Number	(Percent)
Gender		
Male	2513	(80.2)
Female	617	(19.7)
Total	3130 ^a	(100.0)
Age group, yr		
16-19	174	(5.6)
20-24	496	(15.9)
25-34	820	(26.3)
35-44	648	(20.8)
45-54	568	(18.3)
55-64	343	(11.0)
65+	63	(2.0)
Total	3112 ^b	(100.0)
Race		
Caucasian	1359	(85.2)
African-American	171	(10.7)
Asian	12	(0.8)
Other	53	(3.3)
Total	1595 ^c	(100.0)
Hispanic ethnicity		
Yes	70	(6.6)
No	994	(93.4)
Total	1064 ^d	(100.0)
Medical encounter		
Overnight	265	(8.6)
Emergency only	2411	(77.9)
Outpatient	418	(13.5)
Total	3094 ^e	(100.0)
Part of body injured		
Upper limb	2287	(72.9)
Lower limb	663	(21.1)
Trunk	72	(2.3)
Face, scalp, neck	9	(0.3)
Multiple and unspecified	106	(3.4)
Total	3137	(100.0)
Source of payment		
Workers' compensation	2008	(76.0)
Commercial insurance	357	(13.5)
Self pay	188	(7.1)
Other	88	(3.3)
Total	2641 ^f	(100.0)

^aInformation for gender classification was missing for one individual.

^bInformation for age group, yr classification was missing for 19 individuals.

^cInformation for race classification was missing for 1536 individuals.

^dInformation for hispanic ethnicity classification was missing for 2067 individuals.

^eInformation for medical encounter classification was missing for 43 cases.

^fInformation for source of payment classification was missing for 494 cases.

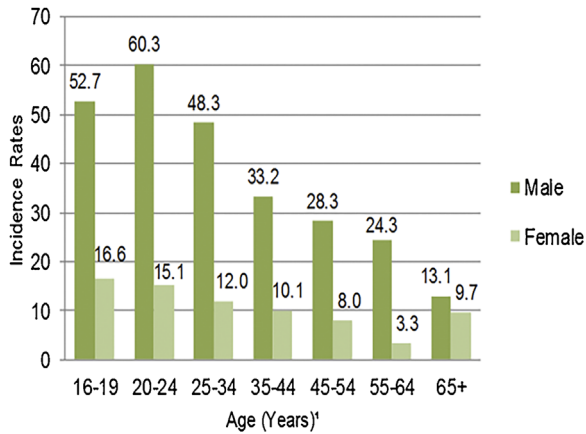


FIGURE 2 Work-related crushing injury rates per 100,000 workers by age group and gender, Michigan 2013-2015.

¹Information on age was missing for 16 males, 2 females, and one unknown gender

(13.5%) cases, followed by self-pay in 188 (7.1%) and “other” in 88 (3.3%). The “Other” category included Medicare and Medicaid insurance programs. For 494 crushing injuries, payment source could not be identified. Of the 633 cases for which Workers’ Compensation was not listed as a payment source in medical records, 74 (11.7%) were matched to a case in the Workers’ Compensation claims data.

3.5 | Industry

For 2603 (83%) individuals, there was sufficient information for industry classification (Table 2). A total of 53 workers were self-employed and there was sufficient information to determine the industry for 32 (60.4%) of them. Primary Metal Manufacturing Industry (NAICS: 33) had the highest number of work-related crushing injuries with 694 (26.7%) cases, followed by Construction (NAICS: 23) with 247 (9.5%) cases, and then Wood Product Manufacturing with 206 (7.9%) cases. These three industries combined accounted for almost half (44.1%) of all work-related crushing injuries.

TABLE 2 Work-related crushing injuries by industry, Michigan 2013-2015

Industry classification (NAICS)	2013-2015		
	Number	Percent	Annual average rate ^a
Primary metal manufacturing (33)	694	26.7	37.8 ^c
Construction (23)	247	9.5	37.9
Wood product manufacturing (32)	206	7.9	52.0 ^c
Administrative and support and waste management and remediation services (56)	183	7.0	33.1
Retail trade (44)	180	6.9	17.9 ^d
Wholesale trade (42)	173	6.6	57.1
Health care and social assistance (62)	135	5.2	6.7
Agriculture, forestry, fishing, and hunting (11)	111	4.3	59.7
Other services (except public administration) (81)	101	3.9	16.9
Transportation and warehousing (48)	90	3.5	25.5
Accommodation and food services (72)	67	2.6	7.6
Public administration (92)	63	2.4	16.2
Sporting goods, hobby, book, and music stores (45)	60	2.3	13.5 ^d
Food manufacturing (31)	59	2.3	31.1 ^c
Professional, scientific, and technical services (54)	54	2.1	7.1
Educational services (61)	40	1.5	3.6
General warehousing and storage (49)	31	1.2	20.3
Arts, entertainment, and recreation (71)	27	1.0	9.8
Utilities (22)	21	0.8	18.3
Finance and insurance (52)	20	0.8	3.7
Real estate and rental and leasing (53)	18	0.7	9.4
Mining, quarrying, and oil and gas extraction (21)	13	0.5	154.9
Information (51)	9	0.3	5.0
Management of companies and enterprises (55)	1	0.0	6.5
Total	2603 ^b	100.0	23.7

^aRates are the number of workers sustaining a crushing injury per 100 000 workers (number of workers by industry used to calculate rates: Bureau of Labor Statistics’ Current Population Survey).

^bInformation for industry classification was missing for 528 individuals.

^cThe denominator for this rate does not include 45 022 individuals from “not specified manufacturing industries (part of 31, 32, and 33)” because the rate of crushing injuries was calculated separately for NAICS 31, 32, and 33. This is 1.8% of workforce with NAICS 31, 32, and 33.

^dThe denominator for this rate does not include 33 628 individuals from “not specified retail trade (part of 44 and 45)” because the rate of crushing injuries was calculated separately for NAICS 44 and 45. This is 2.3% of workforce with NAICS 44 and 45.

Mining, Quarrying, and Oil and Gas Extraction (NAICS: 21) had the highest rate of crushing injuries with 154.9 per 100 000 workers, followed by the Agriculture, Forestry, Fishing, and Hunting Industry (NAICS: 11) with a rate of 59.7 per 100 000 workers, and then the Wholesale Trade Industry (NAICS: 42) with a rate of 57.1 per 100 000 workers.

The 53 self-employed and a large percentage of the 111 farmers would be out of scope for the BLS employer survey.

3.6 | Michigan OSHA interventions

A total of 57 of the 77 (74%) workplaces inspected by MIOSHA where a nonfatal crushing injury had occurred, received 212 citations for violations of MIOSHA safety rules. A total of 45 of the 57 (78.9%) companies cited had not corrected the circumstances causing the crushing injury at the time of the inspection. Total penalties assessed were \$276 425, with the maximum penalty assessed in a single inspection of \$36 300.

Two brief case histories of examples of cases, one identified from hospital and one from ED records inspected that were inspected by MIOSHA follow:

3.6.1 | Case study 1

A 35-year-old male had a crushing injury to his right hand after his hand was caught in a pulley with a belt-weighted system. His hand was pulled and pitched through a narrow space of the machine. He also sustained full thickness burns to his fingertips, and elbow and wrist abrasions. The employee was hospitalized for 5 days due to his injuries. MIOSHA cited the company for two serious violations: "A point of operation guard or device as prescribed in a specific standard, or, in the absence of a specific standard, shall be designed and constructed, when required, to prevent the machine operator exposed to the hazard from having any part of his/her body in the hazardous area during the operating cycle"; and "The employer shall conduct a periodic inspection of the energy control procedure at least annually to ensure that the procedure and the requirements of this standard are being followed." The company had not corrected the hazard at the time of the inspection, which was performed 3 months after the injury.

3.6.2 | Case study 2

A 22-year-old male was treated in the Emergency Department for a crushing injury and lacerations to his left hand and wrist after a forklift fork fell directly onto his hand. The forklift, which weighed approximately 800 pounds, fell from a height of 12 feet. MIOSHA cited the company for five serious and one other-than-serious violations: 1) If the truck is equipped with front end attachments, the name plate shall be marked to show all of the following: (a) identification of the attachments; (b) The approximate weight of the truck and attachment; (c) The load capacity of the truck and attachment combination at maximum elevation of the load engaging means with load laterally centered; 2) An operator shall lift or transport only a load that is within the rated capacity of the truck; 3) An employer shall provide training to the employee before the employee's

assignment as an operator of a powered industrial truck. Instruction shall include all of the following: (a) Capacities of the equipment and attachments; (b) Purpose, use, and limitations of controls; (c) How to make daily checks; 4) Refresher training in relevant topics shall be provided to an operator under the following conditions: An operator has been involved in an accident or near-miss accident; 5) An operator shall safeguard other employees at all times; and 6) Each recordable injury or illness was not entered on the MIOSHA 300 log and/or an incident report (MIOSHA 300 or equivalent) within 7 calendar days of receiving information that a recordable injury or illness had occurred. The company had not corrected the hazard at the time of the inspection, which was performed 5 months after the injury.

3.7 | Trend data

Figure 3 shows the number and rate of work-related crushing injuries from 2013 to 2015 in the BLS and Michigan surveillance systems.

4 | DISCUSSION

Michigan has a multi-source surveillance system for work-related injuries and illnesses, whose primary sources are hospital medical records, emergency department medical records, poison control center reports, death certificates, individual health care practitioners' reports, and worker compensation data.²⁰⁻²² For crushing injuries, all but two of the reports were identified from hospital and ED medical records. For other conditions, typically a larger number of sources are useful for identifying the cases. Michigan's multi-source surveillance system identified 3131 individuals who sustained 3137 occupational crushing injuries between 2013 and 2015; four individuals sustained two unique crushing injuries in the same calendar year and two individuals had two unique crushing injuries in two different calendar years. Michigan's multisource surveillance system provided a larger

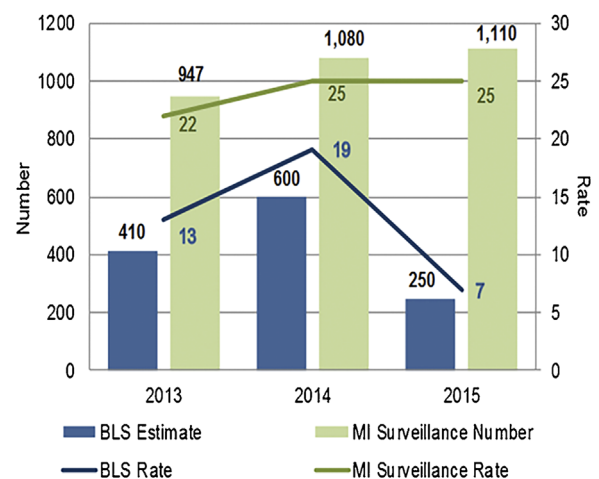


FIGURE 3 Number and rate per 100,000 workers of work-related crushing injuries comparing BLS and MI surveillance, Michigan 2013-2015

count of the number of work-related crushing injuries than the reporting system maintained by BLS, which was based on extrapolating from a survey of a statistical sample of employers. For years 2013 through 2015, the Michigan system identified two and half times more work-related crushing injuries than BLS (3137 vs 1260). Our finding that BLS underestimated the number of work-related crushing injuries by 59.8% is consistent with previous reports from Michigan that BLS underestimated the number of work-related amputations by 59%,²⁰ work-related burns by 69%,²¹ and work-related skull fractures by 54%.²² Similarly to identifying a much smaller number of crushing injuries, BLS' rates of crushing injuries per 100 000 full time equivalents were smaller (13 in 2013, 19 in 2014, and 7 in 2015) and showed a downward trend in comparison to the upward trend of the rates of crushing injuries identified in the Michigan system (22 in 2013, 25 in 2014, and 25 in 2015) (Figure 3).

The smaller number of crushing injuries estimated in the BLS' system can be partially explained by a number of limitations in the BLS data.^{25,26} First, BLS only collected information on the type of injury where the injury caused one or more days away from work (only 32% of all injuries employers reported to BLS). BLS did not collect the cause of the other 68% of injuries, including those that caused restricted work or job transfer. Other possible explanations for the BLS undercount may be that employers are not providing complete reporting due to not properly identifying employees' injuries as crushing injuries or BLS' statistical sampling procedure was not adequate. Moreover, employees may not inform their employers of workplace injuries in fear of retaliation (eg, disciplinary action, denial of promotion opportunities) from the employers or because of incentive programs rewarding low levels of reported injuries.²⁶ The Michigan multi-source surveillance system counted all work-related crushing injuries, including two fatalities treated in Michigan hospitals and emergency departments. The Michigan system is independent of employer reporting and employee reticence to inform their employer. The fact that BLS excluded self-employed, household employees, and farm workers who worked on farms with less than 11 employees was a minor factor in the difference, since those exclusions only explained 164 (53 self-employed individuals and 111 farmers were identified in the Michigan multi-source system) of the 1877 difference in counts between the two systems.

A factor that will cause small differences in the rates but not the number of cases in certain industries between the Michigan multi-source system and BLS system was that the denominator used in the Michigan multi-source system was the number of workers and BLS used full time equivalents. This difference would not explain the downward trend from 2013 to 2015 in the BLS numbers and rate as compared to the upward trend in the Michigan multi-source system (Figure 3).

Crushing injuries of upper extremities were the most common location both in the BLS data set (750 or 60%) and in the Michigan multi-source surveillance system (2287 or 72.9%). According to the BLS, most (31% or 390) of the crushing injuries occurred in workers in the 45-54 age group, followed by 310 (24.6%) in the 25-34 age group, whereas in Michigan's multi-source surveillance system, the 25-34 age

group had the most (820 or 26.3%) crushing injuries, followed by 648 (20.8%) in the 35-44 age group (Table 1).

Michigan's Workers' Compensation identified a larger number of work-related contusions/crushing injuries than BLS and the Michigan multi-source system because contusions, which are more common than crushing injuries, were given the same code as crushing injuries and those two natures of injuries cannot be separated in the Michigan Workers' Compensation database. Both the BLS's estimates and Michigan multi-source data differentiate crushing injuries from contusions. However, the Workers' Compensation data, similarly to the BLS statistics, identified a smaller number of work-related crushing injuries. Workers' Compensation database identified only 213 (6.8 %) of the 3137 work-related crushing injuries that were identified by the Michigan's multi-source surveillance system. There might be different reasons contributing to the workers' compensation undercount. First, WCA dataset included only crushing injuries that caused 7 or more consecutive days away from work, presumably the most severe cases. Second, WCA, similarly to the BLS, did not include self-employed, but again there were only 53 self-employed workers in the Michigan multi-source system. Third, differences in coding/miscoding issue were a reason for the WCA's undercount of crushing injuries. The reporting of crushing injuries from hospitals/EDs included crushing injuries that were either the primary or a secondary diagnosis. BLS and Workers compensation, which selects a single diagnosis (nature of injury) may have coded these injuries differently. This certainly appears to be the case for 511 work-related crushing injuries identified from the medical records that were not classified as crushing injuries in the WCA database. Since we could not match with cases in BLS, we cannot determine how frequently this occurred with respect to the BLS data. This coding difference, however, is probably not due to hospitals having multiple diagnoses because for 2015, the 1 year we have the data, all crushing injuries reported by the hospitals were the primary diagnosis. Finally, it is possible that not all companies reported injuries to workers' compensation insurance companies or the WCA but rather handled the injuries unofficially.²⁶ All these factors likely contribute to the WCA undercount.

A great advantage of Michigan multi-source surveillance system is not only being able to provide a more robust estimate of the true number of work-related crushing injuries, but also in identifying specific workplaces to perform follow back investigations. The receipt of the medical records in an ongoing timely manner along with the employer's name allowed Michigan to conduct Michigan OSHA enforcement inspections. Between 2013 and 2015, 77 workplaces were identified by the surveillance data and were inspected by MIOSHA. BLS data cannot be used for initiating enforcement inspections at specific companies but only for targeting industry sectors as the reports from individual employers are kept confidential. A total of 74% of the inspected Michigan companies were cited for violations of OSHA standards or serious hazards. A total of 79% of the cited companies, at the time of the inspection had not corrected the hazardous situation that caused the crushing injury even though the inspections occurred 3-6 months after the injury. A total of 96% of these companies were cited for at least one violation of MIOSHA rules

directly related to the crushing injury. The highest maximum penalty of \$36 300 in monetary penalties was assessed on a workplace in the Primary Metal Manufacturing industry. The Primary Metal Manufacturing industries had the most: work-related crushing injuries (694; 26.7%), companies cited (26; 45.6%), violations (109; 51.4%), and total penalties, \$154 750. We have found that referring injuries for inspections to OSHA has been equally productive for other conditions under surveillance, including work-related amputations, burns, and skull fractures.²⁰⁻²² Ideally additional inspections would be conducted but if the employer's name is missing from the medical record, the hazard is not sufficiently described to determine if it is ongoing hazard or the record is not received and reviewed in a timely manner than inspections would not be conducted.

In January 2015, Federal OSHA revised the recordkeeping and reporting rule of work-related injuries and illnesses. The revised rule preserved the current requirement of reporting all work-related fatalities and added the requirement to report all work-related inpatient hospitalizations, amputations, and loss of an eye within 24 h to OSHA.¹⁰ Michigan OSHA implemented the Federal reporting rule on September 1, 2015. Employers in Michigan are required to adhere to the new rule, including reporting all hospitalized crushing injuries. Our multi-source surveillance system identified 29 non self-employed work-related hospitalized injuries between September 1 and December 31, 2015. Only two of 29 (6.9%) employers complied with the new reporting rule and had reported hospitalized crushing injuries to MIOSHA. The matching of the 29 medical records with the MIOSHA's database of hospitalized injuries was done retrospectively. Since April 2017, matching has been done on a more timely basis, which allows for sharing information provided in the medical records with MIOSHA. Workplaces then may be contacted by MIOSHA to determine why a report was not made and potentially cite the employer for not making the report. OSHA, although it does not have data to do actual matching to check on non-reporting, has estimated on a national level that they are not receiving half of the required reports.²⁷

Although the Michigan surveillance system identified more crushing injuries than BLS or Michigan's WCA, and identified hospitalized injuries that had not been reported by employers to Michigan OSHA, there were still limitations of the system. First, the type of records submitted by the 134 hospital/EDs and the information in the medical records and/or WCA reports varied. Therefore, information on race and ethnicity, name of employer, even type of visit, and source of payment, was not complete. Second, if individuals who sustained a work-related crushing injury while working in Michigan were treated in an out-of-state hospital, in an urgent care or personal physician office, that injury would have been missed. Some hospitals may have under-reported cases or not classified them as work-related, and those also would have been missed. Third, workers' compensation did not distinguish in their data base between contusions and crushing injuries so we were not able to determine how many of the 6505 contusions/crushing injuries in the worker comp data base that did not match to the hospital/ED crushing injuries should be included in a surveillance system of crushing injuries. Ideally

we could have matched these 6505 worker compensation cases with all hospital/ED records but that was not feasible since it would have involved matching with over a 3.3 million hospital and 14.7 million ED records. Fourth, information on the costs of crushing injuries was not available from our reporting sources. The data available on the costs of crushing injuries, suggests that the average cost per hospital inpatient stay for a crushing injury or internal injury in 2005 was \$16 900.²⁸ However, this economic cost only represents inpatient work- and non-work related crushing injuries, and does not include emergency department and/or outpatient visits.

The use of multiple reporting sources has been very effective in providing a more accurate count and initiating investigations of crushing injuries. The NIOSH system of reviewing records from a national sample of emergency departments, the National Electronic Injury Surveillance System (NEISS) is somewhat analogous to the Michigan system as it is based on medical records.²⁹ NEISS is limited by being a sample and not a census, only ED records, and because the data cannot be used to initiate follow back workplace inspections. However, NEISS does provide information that is not dependent on employer reporting and therefore is an independent source of data.³⁰ Michigan currently has similar systems for work-related burns, amputations, farm injuries, hospitalizations, and skull fractures. The ultimate goal of all these surveillance systems is to recognize and prevent work-related injuries, and plan interventions to reduce the occurrence of workplace injuries.

AUTHORS' CONTRIBUTIONS

Joanna Kica participated in the collection, analysis and interpretation of the data, and in drafting the manuscript. Kenneth D. Rosenman was responsible for the design of the system for data collection, for assisting in the interpretation of data and for revising the manuscript for important intellectual content. Both authors provided the final approval of the manuscript and are accountable for all aspects of the manuscript in ensuring that questions related to the accuracy or integrity of any part of the manuscript are appropriately investigated and resolved.

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ETHICS APPROVAL AND INFORMED CONSENT

Human subjects' institutional review and approval was given by the Michigan State University Review Board. Informed consent was not applicable, as Michigan law requires this information to be reported to the state as part of the Public Health code. Michigan State University has been authorized as the bona fide agent of the state to collect and analyze this data.

DISCLOSURE (AUTHORS)

The authors declare no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

Steven B. Markowitz declares that he has no competing or conflicts of interest in the review and publication decision regarding this article.

DISCLAIMER

None.

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