Circumstances of Fatal Lockout/Tagout-Related Injuries in Manufacturing

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Background *Over the past few decades, hundreds of manufacturing workers have suffered fatal injuries while performing maintenance and servicing on machinery and equipment. Using lockout/tagout procedures could have prevented many of these deaths.*
Methods *A narrative text analysis of OSHA accident investigation report summaries was conducted to describe the circumstances of lockout/tagout-related fatalities occurring in the US manufacturing industry from 1984 to 1997.*
Results *The most common mechanisms of injury were being caught in or between parts of equipment, electrocution, and being struck by or against objects. Typical scenarios included cleaning a mixer or blender, cleaning a conveyor, and installing or disassembling electrical equipment. Lockout procedures were not even attempted in the majority (at least 58.8%) of fatal incidents reviewed.*
Conclusions *Lockout/tagout-related fatalities occur under a wide range of circumstances. Enhanced training and equipment designs that facilitate lockout and minimize worker contact with machine parts may prevent many lockout/tagout-related injuries.* Am. J. Ind. Med. 51:728–734, 2008. *© 2008 Wiley-Liss, Inc.*

KEY WORDS: injury; occupational safety; lockout/tagout; machine; manufacturing

INTRODUCTION

Of the approximately 5,700 workers fatally injured in the United States in 2005, just over 1,000 (18%) were injured by ‘‘contact with objects and equipment,’’ the second leading cause of occupational fatalities after ‘‘transportation incidents,’’ according to the Census of Fatal Occupational Injuries (CFOI) maintained by the Bureau of Labor Statistics [BLS; BLS, *2005 CFOI*]. Industrial equipment is a particularly large source of injury for workers in some occupations. Contact with objects and equipment caused 38% of occupational injury deaths among workers in production occupations and 27% among workers in installation, maintenance, and repair occupations in 2005. Installation, maintenance, and repair workers are at especially high risk of injury death, with an overall fatality rate of 7.6 per 100,000 workers, compared to a rate of 2.9 for production workers, and 4.0 for all workers [BLS, *Census of Fatal Occupational Injuries Charts*].

Workers who service industrial machinery and equipment face unique hazards due to their close contact with equipment, frequently working in dangerous zones

Abbreviations: BLS, Bureau of Labor Statistics; CFOI, Census of Fatal Occupational Injuries; IMIS, Integrated Management Information System; NIOSH, National Institute for Occupational Safety and Health; OSHA, Occupational Safety and Health Administration.

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beyond machine guards that protect workers during normal production operations. Consequently, special procedures are necessary to protect workers during maintenance and servicing. ''Lockout/tagout'' is the practice of shutting down and disconnecting power from machinery or equipment and placing locks and warning tags on energy-isolating devices to prevent activation of the machine or equipment during maintenance or servicing [OSHA, 2002].

By the early 1970's, private employers, trade associations, and safety organizations in the US were developing voluntary lockout/tagout guidelines [Grund, 1995]. In 1983, the National Institute for Occupational Safety and Health (NIOSH) published its *Guidelines for Controlling Hazardous Energy During Maintenance and Servicing*. The procedures outlined in these guidelines became mandatory in 1989 when the Occupational Safety and Health Administration (OSHA) promulgated The Control of Hazardous Energy (Lockout/Tagout) Standard (29 CFR 1910.147). The Lockout/Tagout Standard requires employers in certain industries to establish an energy control program for locking out equipment, employee training, and periodic inspections. The energy control procedures must include steps for shutting down machines; isolating, blocking, or dissipating hazardous energy; placing and removing lockout and tagout devices; and verifying that the hazardous energy has been controlled.

Despite such guidelines, lockout/tagout-related fatalities have continued to occur. In 1999, NIOSH issued an alert on this topic. They reviewed 152 lockout/tagout-related fatalities investigated under the NIOSH Fatality Assessment and Control Evaluation program from 1982 to 1997, and identified three primary contributing factors for these incidents: (1) failure to de-energize, block, or dissipate energy sources (82% of incidents); (2) failure to lockout and tagout energy isolation devices after de-energization (11%); and (3) failure to verify that equipment was de-energized before beginning work (7%).

Clearly, failing to take even the first step of de-energizing equipment is injuring many workers. Therefore, understanding more about the specific circumstances under which workers are unlikely to de-energize or lockout equipment is critical for preventing future fatalities. This article examines fatal lockout/tagout-related injuries to identify these specific circumstances. Based on these circumstances, we suggest possible avenues for prevention.

MATERIALS AND METHODS

Study Design

A narrative text analysis of accident investigation summaries was performed to examine the circumstances surrounding lockout/tagout-related fatalities. Narrative text often provides detailed information that is not available from coded data fields. Narrative data analysis therefore allows more in-depth examination of the specific circumstances of incidents and is particularly useful for identifying cases that are not classified by standardized coding schemes [Sorock et al., 1997], such as lockout/tagout-related incidents.

Data Source and Selection Criteria

Accident investigation report summaries for lockout/tagout-related incidents resulting in a fatality and occurring in the manufacturing industry in the 50 United States and Washington DC from 1984 to 1997 were obtained from OSHA's Integrated Management Information System (IMIS). Electronic reports are available from IMIS beginning with 1984, and 1997 is the last year for which a substantial number of reports were available at the time of this analysis. Incidents were obtained through the Accident Investigation Search tool on OSHA's Web site. Lockout/tagout-related incidents were identified by searching for the term ''lockout'' in the keyword field. Cases were limited to the manufacturing industry, where 74–82% of all lockout/tagout-related incidents are thought to occur [OSHA, *LOTO Preamble*]. Industry division was specified by using the two-digit Standard Industrial Classification codes for major groups 20 through 39 [OSHA, *SIC Division*]. These selection criteria yielded 592 unique incidents resulting in 624 fatalities. The Accident Report Detail (hereafter ''accident report'') for each incident meeting these criteria was reviewed.

Narrative Text Coding

The order in which the incidents were reviewed was randomized, and all incidents were coded without knowledge of the event date. Information obtained directly from standard fields in the accident reports included industry code; number of workers fatally injured; number of workers non-fatally injured; age, sex, and occupation of fatality victims; and nature of injury. All other information was coded from the narrative text (see Box I for an example).

Box I. Example of narrative text from an accident report.

At approximately 4:30 PM, Employee #1 was in a ribbon blender (mixer) in the act of cleaning it. He was caught in the revolving blades when a supervisor activated the mixer from a remote control panel. The supervisor assumed that a micro switch on the mixer was in the open position. He was not aware, nor in a position to observe, that Employee #1 was in the mixer. Causal and contributing factor was the lack of a positive lockout procedure for deenergizing the electrical circuit.

Variables coded from the text:
Activity: Cleaning.
Equipment Type: Mixer/blender.
Mechanism: Caught in.
Energy Control Status: No lockout attempt—definite.

A preliminary coding scheme was developed based on prior studies of occupational injury. As a starting point, the nine ‘‘key data elements’’ used by Lincoln et al. [2004] in their template for reconstructing injury events were adapted to fit the needs of this study. Other important circumstances of the injuries were captured with additional variables.

Incident characteristics of interest include: the activity engaged in at the time of the incident (e.g., unjamming); the type of equipment involved in the incident (e.g., conveyor); the mechanism of the fatal injury (e.g., ‘‘caught in’’); the nature of the injury leading to death (e.g., amputation); and the cause of the hazardous energy release, which we refer to as the ‘‘energy control status.’’ Each incident was classified into one of five energy control status groups: (1) lockout was definitely not attempted (explicitly stated in the text), (2) lockout was probably not attempted (text indicates that equipment was inadvertently activated or was intentionally activated without knowledge of the proximity of the victim to the equipment), (3) a lockout attempt failed due to human error, (4) energy control procedures were used but injury occurred due to a mechanical failure, and (5) the energy control status is unclear.

Coding of the ‘‘mechanism,’’ ‘‘activity,’’ and ‘‘energy control status’’ variables was initially based on the corresponding survey responses from the [1981] BLS report, *Injuries Related to Servicing Equipment*. Other codes were added as needed, based on the wording of the text. Definitions and coded values for each variable were formalized in a coding manual. All 592 accident reports were coded manually and the circumstances of each incident were recorded in a Microsoft Excel database (Microsoft Corporation, 2003).

Inter-Rater Reliability

After the coding scheme was finalized, a 10% subset of accident reports was selected randomly and coded by a second reviewer to assess the reliability of the coding scheme for the variables coded solely from the text. Inter-rater reliability was assessed using percent agreement and kappa statistics. The percent agreement for the variables used in this analysis ranged from 80.0% for ‘‘activity’’ and ‘‘energy control status’’ to 90.0% for ‘‘type of equipment.’’ The kappa statistics ranged from 0.59 for ‘‘energy control status’’ to 0.77 for ‘‘activity,’’ which is considered good to excellent agreement [Gordis, 2000].

Analysis

A descriptive analysis of the most common characteristics of the lockout/tagout-related incidents was conducted. Frequencies were calculated for victim and incident characteristics. Cross-tabulations of activity by equipment type, and occupation by activity were performed to identify common scenarios. Additionally, incidents occurring before and after the Lockout/Tagout Standard took effect were compared to determine whether the circumstances most commonly involved have changed over time. Statistical analyses were performed using the Stata statistical software package (Stata Corp., TX, Canada version 9.0 1984–2005). The scenario cross-tabulations were performed using Microsoft Excel (Microsoft Corporation, 2003).

Ethics Approval

This study was approved by the Johns Hopkins Bloomberg School of Public Health Committee on Human Research.

RESULTS

Victim Characteristics

The 592 lockout/tagout-related incidents reviewed resulted in a total of 624 fatalities. All but eight incidents involved a single fatality. The exceptions include one incident (a fire at a food processing plant precipitated by failure to de-energize a cooker) resulting in 25 fatalities, one incident resulting in three fatalities, and six incidents resulting in two fatalities each.

Age and sex

The age of individuals killed in lockout/tagout-related incidents ranged from 15 to 72 years, with a mean of 37 years (SD = 12.0 years). Most individuals killed in lockout/tagout-related incidents (58.0%) were between 25 and 44 years of age (Table I). Nearly all (95.4%) of the fatality victims were male.

Occupation

Maintenance and repair workers accounted for the largest proportion of lockout/tagout-related fatalities (17.2%). Interestingly, operators and production workers accounted for almost as many (16.7%). Notably, occupation was not available from the accident detail contained in IMIS for 44.4% of the fatalities. Excluding these victims with unknown occupations, maintenance and repair workers accounted for 30.8% of fatalities, and operators and production workers accounted for 30.0%.

Mechanism of injury

Individuals killed in lockout/tagout-related incidents most commonly were caught in or between parts of

TABLE I. Individual Characteristics of Lockout/Tagout-Related Fatality Victims

Individual characteristics	Number of fatalities N = 624	Percentage of fatalities[a]
Age group (years)		
15–24	99	15.9
25–34	187	30.0
35–44	175	28.0
45–54	94	15.1
55+	69	11.1
Sex		
Male	595	95.4
Female	29	4.7
Occupation		
Maintenance and repair workers	107	17.2
Operators and production workers	104	16.7
Electricians and electrical workers	73	11.7
Other workers	63	10.1
Not reported	277	44.4

[a]Percentages may not sum to 100 due to rounding.

TABLE II. Injury Characteristics of Fatal Lockout/Tagout-Related Injuries

Injury characteristics	Number of fatalities (N = 624)	Percentage of fatalities
Mechanism of injury		
Caught in/between	325	52.1
Electric current	165	26.4
Struck by/against	67	10.7
Chemical substance	30	4.8
Temperature extremes	21	3.4
Fall	10	1.6
Suffocation	3	0.5
Unknown/not specified	3	0.5
Nature of injury		
Fracture or crushing injury[a]	183	29.3
Electric shock	164	26.3
Asphyxia	73	11.7
Amputation	37	5.9
Cut/laceration	31	5.0
Other	96	15.4
Unknown/not specified	40	6.4

[a]Includes 107 cases with "fracture" in the nature of injury field and 76 cases with "other" in the nature of injury field and "crushed" indicated in text.

equipment (52.1% of fatalities). Substantial numbers were electrocuted (26.4%), or struck by or against objects such as machinery, parts, or tools (10.7%). Smaller numbers died from other causes (Table II).

Nature of injury

Fractures or crushing injuries were the most common fatal injuries suffered in lockout/tagout-related incidents, occurring in 183 cases, or 29.3% of fatalities (Table II). In 107 of these cases, ''fracture'' was listed in the nature of injury field on the accident report. In 76 cases, the nature of injury field in the accident report was coded as ''other,'' but the text indicated that the victim was ''crushed'' by equipment. Fractures and crushing injuries were grouped together because it was often difficult to distinguish between the two types of injuries from the text. Electrocution was the second most common type of fatal injury, occurring in 164 cases (26.3% of fatalities).

Sensitivity Analysis

Removing the 25 fatalities associated with the plant fire incident does not substantially change the results, other than the following: males increase from 95.4% to 98.2% of victims; the mechanism ''chemical substance'' drops from 4.8% to 0.8% of victims; and asphyxia as the nature of injury drops from 11.7% to 8.0% of cases.

Incident Circumstances

Energy control status

All of the incidents included in this study involved a failure to control hazardous energy, but one aim was to determine exactly how or why energy was released in each case. In 348 incidents (58.8%), it was clear from the text that lockout was definitely not attempted at all. Lockout attempts failed due to human error in only 31 incidents (5.2%), and only seven incidents (1.2%) occurred despite energy control procedures being used (Table III).

TABLE III. Use of Energy Control Procedures During Lockout/Tagout-Related Fatal Incidents

Energy control status	Number of incidents (N = 592)	Percentage of incidents
No lockout attempt—definite	348	58.8
No lockout attempt—probable	55	9.3
Lockout attempt failed (human error)	31	5.2
Incident despite energy control procedures (mechanical failure)	7	1.2
Unknown/unable to determine	151	25.5

Activity involved

Repairing and cleaning were the activities most frequently involved in the lockout/tagout-related incidents reviewed (Table IV). Other common activities were installing or disassembling equipment; unjamming materials or equipment; and troubleshooting, testing, or inspecting equipment.

Some activities are closely related (e.g., troubleshooting and repairing). Classification of these types of activities was based on decision rules established in the coding manual, and captures the stage of the activity most immediately involved in the incident. Classifying such activities into separate categories is important because one stage (troubleshooting) may require equipment to be energized, whereas another stage (repairing) might not.

Type of equipment involved

A wide range of equipment was cited in the narratives—over 40 different types of machines, systems, or equipment parts were specifically mentioned in more than one accident report. Despite such a diverse list, some patterns are evident. Conveyors were the single type of equipment most frequently involved, being cited in 62 incidents (10.5% of the total). The general category ''electrical equipment'' by itself accounts for 59 incidents (10.0%), but if grouped with ''lighting fixtures'' and ''panelboards/control panels,'' together they become the largest group, accounting for 88 incidents (14.9%). Mixers or blenders were also commonly involved, being cited in 43 incidents (7.3%).

Injury scenarios

The most common activity-equipment scenarios were cleaning a mixer or blender (26 incidents), cleaning a conveyor (23 incidents), and installing or disassembling electrical equipment (18 incidents). Collectively, these scenarios account for 11.3% of all incidents.

The most common occupation-activity scenarios were maintenance and repair workers repairing equipment (31 incidents), electricians and electrical workers installing or disassembling equipment (23 incidents), and operators and production workers unjamming materials (22 incidents). Collectively, these scenarios account for 12.8% of all incidents.

TABLE IV. Activity Involved in Fatal Lockout/Tagout-Related Incidents

Activity	Number of incidents (N = 592)	Percentage of incidents
Repairing	107	18.1
Cleaning	100	16.9
Installing/disassembling	74	12.5
Unjamming	66	11.2
Troubleshooting/testing/inspecting	61	10.3
Routine maintenance (e.g., oiling)	37	6.3
Adjusting	32	5.4
Operating equipment	19	3.2
Other	61	10.3
Unknown/not specified	35	5.9

Change over time

The circumstances of lockout/tagout-related fatalities were remarkably similar before and after January 1990, when the Lockout/Tagout Standard took effect. Excluding the plant fire incident, age and sex of fatality victims, and nature and mechanism of injury were not significantly different before and after 1990. Occupation was significantly less likely to be ''not reported'' after 1990, but the distribution of fatalities among occupation groups remained very similar. The distribution of incidents among types of activities and among energy control status categories was also very similar before and after 1990. Lockout was definitely not attempted in 59.6% of incidents before 1990, compared to 57.2% of incidents after 1990.

DISCUSSION

Narrative text analysis of OSHA accident investigation report summaries allowed us to identify the specific circumstances surrounding lockout/tagout-related fatalities. The accident reports available from IMIS are a good source of information about age and sex of fatality victims, mechanism of injury, equipment involved, and activity involved. Unfortunately, these report summaries did not consistently provide information about the occupation of the fatality victims or the energy control procedures used. While the victim's occupation is likely contained in the original OSHA investigation reports, it is important that OSHA make such information available in the report summaries as well, since the summaries are more accessible than the full investigation reports. Information about energy control procedures used is clearly not as standardized as occupation, but an effort to include as much detail as possible about the incident circumstances would make these summaries more useful to researchers and safety professionals.

Individuals killed in lockout/tagout-related incidents followed a younger distribution than those killed by all traumatic injuries in manufacturing during a similar time period [Marsh and Layne, 2001]. Inexperience may be a factor in some of these incidents. Additional training for less experienced workers could be explored as a possible strategy for prevention of some lockout/tagout-related fatalities.

Work activities and types of equipment involved in the lockout/tagout-related fatalities varied widely. Typical activity-equipment scenarios included cleaning a mixer or blender, cleaning a conveyor, and installing or disassembling electrical equipment, which together accounted for 11.3% of incidents. However, no single scenario was associated with the majority of lockout/tagout-related fatalities. Therefore, prevention efforts must target a variety of situations.

Risk of injury may be elevated when workers perform unusual activities. Lacking information about workers' exposure to certain activities, this study could not test this assumption. However, the most common occupation-activity scenarios (maintenance and repair workers repairing equipment, electricians and electrical workers installing or disassembling equipment, and operators and production workers unjamming materials) indicate that workers tend to be injured while performing their usual activities. Integrating lockout/tagout training with training for specific job tasks may therefore improve appropriate use of these safety procedures. Additionally, a higher level of training may benefit some production workers. Under the Lockout/Tagout Standard, many production workers would be considered ''affected employees'' who are required to receive instruction only about the ''purpose and use'' of lockout/tagout. The finding that production workers account for about the same proportion of lockout/tagout-related fatalities as maintenance workers suggests that certain production workers should be classified as ''authorized employees'' who are trained also to recognize hazardous energy sources and to use various means of energy isolation and control.

Lockout procedures were not attempted in the majority (at least 58.8%) of fatal incidents reviewed. There were very few incidents in which a lockout attempt was made or other energy control measures were in place and a fatality still occurred due to human error or mechanical failure. This small proportion suggests that lockout/tagout procedures, when properly used, do indeed prevent fatalities.

Several strategies have been proposed to increase the use of lockout/tagout [Kelley, 2001]. Employers can place lockout stations containing locks and tags closer to equipment lockout points to make lockout as convenient as possible. Similarly, equipment can be designed for easy lockout, with energy isolation devices clearly labeled. Consensus standards such as the National Fire Protection Association's NFPA 79: Electrical Standard for Industrial Machinery provide guidance for designing such power disconnects, and machinery manufacturers and employers should consult them [NFPA, 2006]. Worker exposure to hazardous energy can be reduced by designing equipment in such a way that some routine maintenance tasks can be performed either using remote systems or without removing machine guards, so that workers do not need to come into contact with machine parts [Kelley, 2001]. Machines that are designed, constructed, and maintained to need minimal repair would also reduce worker exposure.

Limitations

A concern with many studies using OSHA's IMIS data is the completeness of fatalities captured by this database because OSHA does not investigate incidents occurring under the jurisdiction of other government agencies, such as homicides, motor vehicle crashes, or mining incidents [Suruda, 1992]. However, most lockout/tagout-related incidents would fall under OSHA's jurisdiction, and Stanbury and Goldoft [1990] found that only 7% of all cases under OSHA's jurisdiction were not investigated. Our results would be biased only if the lockout/tagout-related incidents included in IMIS are systematically different from those that are not included.

A larger limitation of the IMIS data is the inconsistency across cases in the amount of detail reported. Accident investigations are completed by many different investigators, and narrative descriptions are open-ended, so the level of detail varies widely. While this inconsistency prevents us from drawing conclusions about some incident circumstances, narrative text provides information that is not available from other data sources.

In this study, information about exposure to various circumstances (e.g., time spent performing certain activities or time spent working on various types of equipment) was not available, so this analysis did not allow us to draw conclusions about the relative *risks* of certain factors. Nor could this analysis determine whether the *rate* of lockout/tagout-related fatalities has changed since 1990, when the Lockout/Tagout Standard took effect, although clearly these incidents continue to occur [Bulzacchelli et al., 2007].

Conclusions

Despite the publication of voluntary guidelines for controlling hazardous energy, and the Lockout/Tagout Standard which made hazardous energy control procedures mandatory, hundreds of workers over the past few decades have suffered fatal injuries while performing maintenance and servicing on machinery and equipment. Following lockout/tagout procedures could have prevented many of these deaths. Between 1984 and 1997, at least 348 fatalities resulted from incidents in which lockout was *not even attempted*.

Enhanced OSHA enforcement of the Lockout/Tagout Standard may improve compliance. Designing equipment to minimize worker contact with moving parts is a promising strategy as it does not rely on individual workers to follow safety procedures every time maintenance is performed. However, some close contact with machinery will probably always be necessary. Therefore, future research should focus on understanding barriers to following lockout/tagout procedures and finding ways to increase appropriate usage of these procedures.

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