

Work-Related Electrocutions Involving Portable Power Tools and Appliances

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Portable power tools and appliances can be identified as the source of injury in approximately 9% of occupational electrocutions. A search of fatality records for 1984 through 1986 in National Institute for Occupational Safety and Health (NIOSH) and Occupational Safety and Health Administration (OSHA) data bases identified 102 electrocutions involving portable appliances and tools that used 110-volt AC and 33 deaths involving welding equipment, which usually operates on 220-volt AC or higher. Of these 102 deaths, 51 occurred in the construction industry, 13 in services, 13 in manufacturing, and 25 in other industries. Plumbing contractors (Standard Industrial Classification [SIC] 1711) had the largest number of deaths (15) in construction. Powered hand-tools were involved in 58 deaths, with electric drills (23) and saws (13) the two largest classes. Proper provision of ground-fault circuit interrupter protection, particularly at temporary work sites, could have prevented most of the deaths from 110-volt AC. Engineering controls for preventing electrocution from portable arc-welding equipment should be evaluated.

Electrocution from powered hand tools is a recognized hazard in the workplace.¹ A case series of occupational fatalities investigated by medical examiners reported that 27 of 69 (39%) deaths from electrocution at work involved low voltage power tools.² A study done for the Consumer Product Safety Commission (CPSC) reported that for the years 1976 through 1983 one third of electrocutions involving power tools were work related.³ An analysis of 789 fatal electrical injuries investigated by the Occupational Safety and Health Administration (OSHA) in 1984 through 1986 estimated that at least 96 deaths (12%) involving 110-volt AC contact could have been prevented by proper use of ground-fault circuit interrupters (GFCI)⁴ but did not specify the number of deaths involving power tools. The National Institute for Occupational Safety and Health (NIOSH) has issued "Alerts" regarding the electrocution hazard associated with faulty electrical outlets and connectors supplying 110- or 220-volts AC for portable tools and appliances.^{5,6} The present study was done to combine information from surveillance sources of fatal workplace injury maintained by NIOSH with OSHA investigation data to obtain a more complete picture of the low-voltage AC electrocutions, particularly with respect to portable tools and appliances where GFCI are applicable.

Methods

Death certificate information for 1984 through 1986 concerning work-related electrocutions was obtained by searching the NIOSH National Traumatic Occupational Fatality (NTOF) data base. The NTOF data base, described before,⁷ consists of all US

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death certificates since 1980 where the "Injury at Work" box was marked "yes," the external cause of death was an injury (E800-E999), and the victim was 16 years of age or older. All 1308 NTOF cases for 1984 through 1986 with the external cause of death E925 (electrocution) were reviewed for mention of hand-tools, portable appliances, and extension cords.

The 789 fatality investigations for 1984 through 1986 in the OSHA Integrated Management Information Systems (IMIS) data base that involved electrical injury⁴ were reviewed, and the 254 deaths involving low-voltage AC were searched as described for NTOF. The OSHA data base excluded California, Michigan, and Washington state.

Case reports for 1984 through 1986 from the NIOSH Fatal Accident Circumstances and Epidemiology (FACE) program of electrocutions involving portable tools, appliances, and extension cords were reviewed. All reports from the three sources were then combined and matched by location of injury, date of injury, and other descriptive factors.

Results

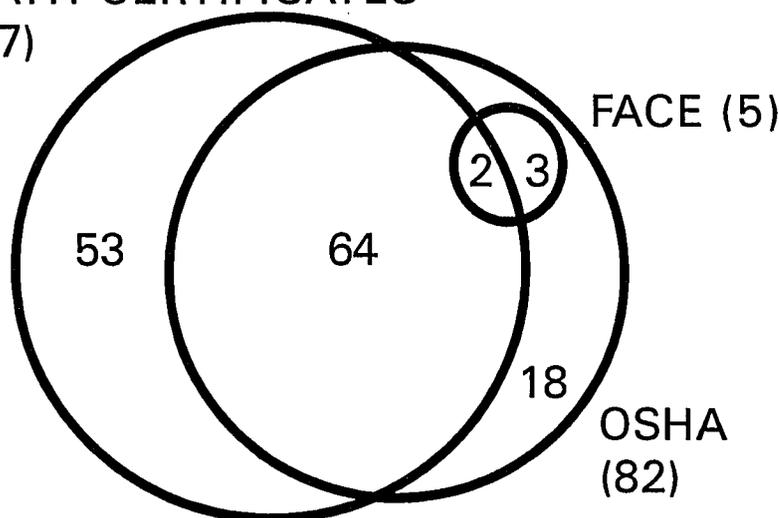
In the 3-year period there were 135 electrocution deaths involving hand tools, portable appliances, or extension cords (Table 1). All the deaths occurred in separate incidents and all the victims were men. Their mean age was 32.1 years. There were 117 deaths identified from death certificates, 82 from OSHA files, and five from FACE investigations (Fig. 1). The greatest number of deaths were in construction (56), followed by manufacturing (25) and services (18). Low-voltage

TABLE 1
Electrocutions Involving Power Tools, Appliances, and Extension Cords 1984 through 1986

	Welding Apparatus		Total
	110V AC	(220V AC or higher)	
1984	33	14	47
1985	31	13	44
1986	38	6	44
Total	102	33	135

DEATH CERTIFICATES

(117)



TOTAL = 135

Fig. 1. Distribution of work-related deaths in 1984 through 1986 involving tools, portable appliances, and power cords among the various data sources.

(110-volt) AC caused 102 deaths; 33 deaths involved welding apparatus operating from 220-volt to 440-volt AC. Of the 102 reports involving 110-volt AC, 58 specified a powered hand tool and 34 a portable electrical appliance. In 10 cases a faulty extension cord was the source of electrocution, and the type of tool or appliance was not specifically mentioned (Table 2). Thirty eight (28%) of the 135 reports mentioned the worker was standing in water or on a wet surface at the time of death, and in one case the worker was noted to be barefoot.

Powered Hand Tools

The types of tools and appliances identified are shown in Table 3. Of the 58 deaths involving powered hand tools, drills (23) and saws (13) were the two largest groups. The amount of detail in the reports varied considerably. For example, only 12 of the 58 reports mentioned the type of casing on the tool. Ten tools had a metal case that was the source of contact; two tools were double insulated and the point of contact was a damaged power cord.

Details concerning the power sup-

TABLE 2
Industry Division and Deaths from Portable Power Tools, Appliances, and Extension Cords 1984 through 1986

Industry	Powered Hand Tools	Other Portable Appliances	Extension Cords (No Appliance or Tool Specified)	Welding Apparatus	Total
Agriculture	2	3	1	2	8
Mining (oil and gas)	1	2	0	3	6
Construction	38	10	3	5	56
Manufacturing	6	6	1	12	25
Trans/utilities	1	3	0	2	6
Trade	2	7	1	2	12
Services	7	5	1	5	18
Other	1	1	0	2	4
Total	58	37	7	33	135

TABLE 3
Portable Power Tools and Appliances Identified in Low Voltage AC Work-Related Electrocutions, 1984 through 1986

Electric drills	23
Saws	13
Sewer augers and snakes	5
Buffers and sanders	5
Powered hand tool, unspecified	5
Other powered hand tools	7
Total powered hand tools	58
Portable pumps	8
Trouble lights	8
Steam jennies	4
Battery chargers	4
Floor fans	3
Other portable appliances	8
Total portable appliances	34
Faulty or worn extension cords, type of tool or appliance not mentioned	10
Total	102

ply to the hand tool were available in 25 of 58 cases (Table 4). Interruption of the ground path by removal of the ground pin from the power plug or by the use of a two-prong adapter or two-conductor extension cord was noted in 10 deaths. Frayed, worn, cut, or improperly spliced power cords were noted in nine deaths. Four deaths were because of outlets that were wired in reverse polarity, energizing the tool case. In one incident, a plumber who was using a portable saw soaked with water from a pipe leak

TABLE 4
Electrocutions Involving Powered Hand Tools 1984 through 1986 Defective Power Supply Conditions Noted

Frayed, worn, cut, or improperly spliced power cords	9
Interruption of ground path by use of two-conductor extension cord or by removal of ground pin from power plug	10
Outlets wired in reverse polarity	4
Defective outlet with broken ground contact	1
GFCI* failed to trip	1
Insufficient details reported	33
Total	58

* GFCI = ground-fault circuit interrupters.

was electrocuted when a portable GFCI failed to trip.

Plumbing contractors in SIC 1711 were involved in more hand-tool electrocutions (15) than were workers in any other construction trade.

Portable Appliances

Portable submersible pumps (eight deaths) and trouble lights (eight deaths) were the most frequently cited portable appliances (Table 3). In four of the eight deaths involving trouble lights, the worker touched the energized metal frame surrounding the bulb; in the other four deaths, a frayed or cut lamp cord was the source of electrical contact.

Welding Apparatus

There were 33 deaths involving portable arc-welding equipment. The primary circuit of 220- to 440-volt AC was identified as the source of electrocution in 10 deaths (Table 5). In all these, the frame of the welder was not grounded and became energized. Two of the 10 reports mentioned the power plug had been wired incorrectly. In another case, the power plug was damaged, allowing it to be inserted incorrectly into a 277-volt outlet. An ungrounded extension cord was used with another welder, a cut power cord energized the frame in another case, and five reports did not specifically mention how the case became energized.

In 13 deaths involving welding apparatus, there was insufficient information in the report to determine which circuit was involved. In 10 deaths the welding electrode or another part of the secondary circuit was the source of contact. Gloves were *not* worn in three of these ten cases; in

TABLE 5
Conduction Path in Electrocutions Involving Welding Apparatus 1984 through 1986

Primary circuit (220V-440V AC)	10
Secondary circuit	10
Not mentioned in report	13
Total	33

one case a welder was wearing wet cotton gloves and in another wet leather gloves. In the other five cases, the use of gloves was not reported.

In addition to the 33 deaths known to have occurred from welding apparatus, 10 death certificates were found that indicated a welder had been electrocuted at work but did not provide any further details and did not meet the criteria for inclusion in this study.

Firm Size

Information on the number of employees in each firm was available for only the 88 deaths investigated by OSHA. Thirty two (36%) of the 88 deaths were in firms with fewer than 11 employees.

Discussion

The cases reported should be viewed as a low estimate of the number of work-related electrocutions from portable tools and appliances that occurred in the 3-year period, 1984 through 1986. OSHA investigation reports identify only 30% and death certificates only 80 percent of all work-related deaths.⁸ In addition, details often are missing from reports that would allow classification of the type of electrocution or apparatus involved in the incident. For cases on death certificates, portable tools and appliances were involved in 9% of electrocutions (117/1308 deaths). However, only 72 percent of death certificates in the NTOF data base in which the underlying cause of death is electrocution contain sufficient details to identify the circumstances of injury. Although we matched data sources to increase case finding, the actual number of such deaths could be higher. The distribution of tools involved, with drills most commonly involved and then saws, was the same as seen outside the workplace in a 1975 through 1978 study done for the Consumer Product Safety Commission (CPSC).⁹

Power Hand Tools and Appliances

Electrocutions from 110-volt AC appliances and tools are less frequent

than are those from high-voltage power lines⁴ but deserve attention because they are preventable by proper maintenance of equipment, by grounding, and by the use of engineering controls such as GFCIs. Hand tools were involved in 58 of the 135 deaths, and many of the other deaths occurred while part of an appliance or an extension cord was being held in the worker's hand. Electric shock at 60Hz tends to make muscles contract. Because the flexor muscles of the human arm are more powerful than are the extensor muscles, a hand grasping an object at the time of shock may be unable to let go to release the object. This increases the time of shock and the chance it may be fatal. Depending on the current path and duration, a shock from AC voltage can kill either by causing ventricular fibrillation or by paralyzing muscles of the thorax and asphyxiating the victim. The use of plastic or other nonconductive materials in the grip areas of power tools and equipment would reduce this hazard.

Details were not available for every case to determine whether the tool or appliance developed a fault or whether the supply cord or outlet was defective. A substantial number of deaths from powered hand tools were due to worn or frayed power cords (Table 4) and to the improper use of two-prong adapters or ungrounded extension cords that caused the tool frame to be ungrounded.

Most of the 102 deaths from 110-volt AC tools and appliances could have been prevented with proper GFCI protection. A GFCI is a device

designed to open the power source circuit quickly when the difference in the supply and return currents exceeds 4 to 6 mA.¹⁰ This is less than the estimated 50 mA¹¹ to 100 mA² of 60 Hz current needed to cause ventricular fibrillation in man. The function of the GFCI is to detect phase-to-ground faults and to disconnect the power source before injury occurs.^{12,13} An example of a phase-to-ground electrocution hazard GFCI would remedy is that of a worker holding a power tool while standing in water or on a wet surface.

GFCI will not protect against phase-to-neutral faults, however. There was one death in the present study in which a GFCI failed to trip. It is not known whether the worker contacted both conductors, the phase-to-neutral fault condition the GFCI would not protect against. In a fatality involving a hand tool investigated by CPSC in which GFCI had failed to trip, the victim had contacted both conductors.³

Most of the powered hand-tool deaths in this study occurred in the construction industry at temporary work sites rather than at a plant. The nature of the construction industry requires that portable GFCI be used. The use of GFCI at construction sites is not required by OSHA regulations.¹⁴ OSHA requires that *either* a GFCI or an "assured equipment grounding conductor" program be used to protect employees. It is apparent from the data presented here that *neither* GFCIs *nor* assured grounding programs are effectively used at all work sites.

Welding Apparatus

A circuit for a typical arc welder is shown in Figure 2. Electrocutions from welding apparatus have been reported as rare.¹⁵ In a series of five electrocutions, all involved the secondary circuit, and no defects were found in the welding apparatus itself.¹⁵ Defective equipment was certainly involved in some incidents in the present study. The 10 electrocutions known to have occurred from the primary (220-volt to 440-volt) circuit of the welding apparatus were caused by the same factors as deaths involving power tools: use of ungrounded extension cords, and frayed or cut cords that touched the case and energized the frame of the welder. Special care should be taken when replacing power plugs and cords of welding apparatus to ensure that the ground wire is properly connected and that the notches on the power prongs are not worn off, allowing the plug to be inserted backward. OSHA addresses arc-welding safety requirements in detail.¹⁶

Prevention by Administrative and Engineering Controls

Prevention of electrical work injuries can be accomplished through the use of administrative and engineering controls. To be successful, administrative controls require a firm commitment from management and employees^{17,18} and should be incorporated into a written safety policy.^{19,20} The effectiveness of administrative controls is a function of how well they are implemented and enforced at the work site. Effective administrative controls attack the two main areas of human error responsible for power tool electrocutions: working with damaged or modified equipment, and failure to provide effective grounding.

An effective work-site grounding conductor program is an example of an administrative control, as is a scheduled preventive maintenance program. Older power tools with conductive metal cases once were associated with the majority of power tool electrical injuries.²¹ Many older tools

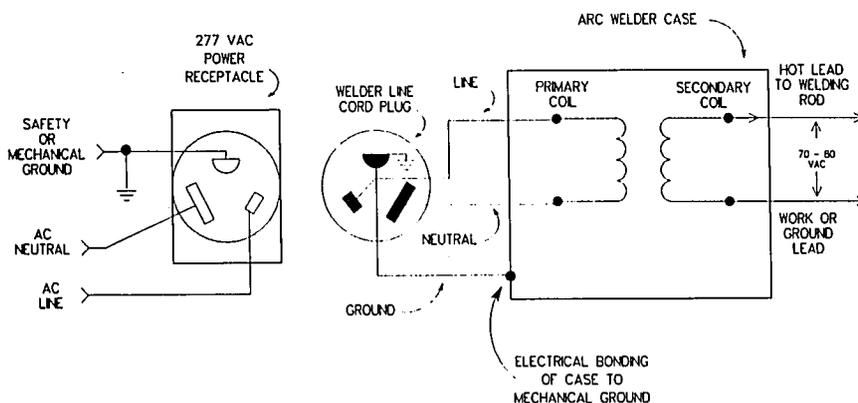


Fig. 2. Basic circuit diagram of an AC arc welder.

were still in use in 1984 through 1986, as evidenced by the 10 incidents noted in the present study. Newer tools were double insulated and provide good protection against electrical shock.²² Electrical injuries occurring while using double-insulated tools often involve the supply cord, and preventive maintenance should be directed at replacing frayed cords and those that have been spliced.

Extension cords used to supply power to portable tools need particular attention because the grounding pin (third prong) is often removed to accommodate a two-pronged receptacle. Use of two-conductor extension cords may encourage removal of the ground pin from the tool power cord. Extension cords used with portable electric tools and appliances must meet more stringent criteria.²³ However, inasmuch as the function of GFCIs is not dependent on the existence of a safety ground (or third prong), they would protect the worker in these instances.

Effective engineering controls would protect workers from electrocution in the event of a tool or appliance failure. The design objective for such devices should be to provide ground-fault protection and to ensure its availability as close to the worker as is practical. An ideal protective device would be inexpensive, not interfere with the work process, and be tamper resistant. Ideally, the GFCI should be an integral part of the tool or appliance to ensure its use and to physically locate the protection near the worker. Incorporating a GFCI into the plug end of a portable tool's power cord would be a useful engineering control to circumvent the problem of faulty power cords. Particularly for high-risk trades such as plumbing, where the work environment is often damp and the available electrical outlets may be in older buildings not meeting current wiring standards, the cost of the additional protection could be justified. The user would then be protected from shocks arising from cuts or abrasions to the power cord as well as faults within the tool itself. To be effective, a GFCI built into the tool cord would have to avoid the many

nuisance "trips" that plagued GFCIs in the 1960s when they were first introduced.⁹ An alternative engineering control would be the substitution of battery-powered tools for AC-powered tools.

Engineering controls to protect welders should be concerned with both the power source (primary circuit) and the working (secondary circuit) sides of the welding equipment. Ground-fault protection for the primary circuit would be similar to that for other equipment at the same voltage. However, for worker protection from secondary circuit-related injuries a different approach should be used. The ground or "work" side of the secondary circuit is connected to the item being welded, and the other secondary lead is connected to the work through the welding rod. A standard GFCI would not sense a fault because the supply and return currents are always the same. Methods to discriminate between normal welding current and actual fault current need to be evaluated for their applicability to the prevention of electrical injury among welders. The use of insulated work gloves would protect the welder's hands from contact with the secondary welding circuit. DC arc welders would not appear to present as much hazard from electrocutions involving the secondary circuit as do AC welders.

Conclusions

Fatal injuries from portable power tools and appliances continue to be a problem in the workplace despite the introduction of double-insulated tools and requirements for work-site GFCI or equipment grounding. The main risk is in the construction industry, particularly in plumbing, where the constantly changing work site exposes the worker to temporary wiring that may be substandard and to harsh conditions that damage tool power cords and plugs. Based on the data in the present study, at least 30 deaths from low-voltage electrocution involving portable appliances could be prevented each year through proper grounding or use of GFCI, and the

actual number of such electrocutions is probably greater. Electrocutions from arc-welding equipment claim at least 11 lives a year, although again, the actual number may be greater. Effective use of administrative and engineering controls could prevent these deaths.

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Religious Rationale for Health Promotion

... In the twentieth century there have been attempts by noted theologians to systematically articulate theological definitions of health. . . . In the writings of such thinkers the sacredness of the gift of life has been reaffirmed. More than that, health promotion in all areas—including the occupational area—is frequently stated as participating in and advancing God's process of salvation that begins in this life and culminates in the next.

In a culture as secular as America appears to be today, it would be both presumptuous and inaccurate to assert that the average physician, nurse, public health professional, or occupational health promotion specialist carries on their work in such a theological context. However, it is probably equally presumptuous and inaccurate to assert that the preservation and promotion of health by health professionals and laypeople alike has no connection with this religious tradition. For example, the Hippocratic tradition does not explain the modern physician's dedication to preserving life at all costs. Hippocrates advised his students to walk away from borderline and terminal patients since they usually die and that is not good for a physician's reputation. We do not walk away. We regard life as a sacred gift and spare little in trying to preserve it. That is our religious tradition. Much that passes for secular, humanistic altruism has as its wellspring the Judeo-Christian religious tradition.

In sum, in various forms the Judeo-Christian religious tradition continues to be one of the most powerful ideological rationales for health promotion in general, and for occupational health promotion specifically. The past two decades of American history have manifested a renewal of the behavioral connection between religion and health. The revival of evangelical Protestantism—some estimates indicate there are now over 40 million self-declared "born again Christians" in America—the Catholic charismatic movement, and one should also add, the small but growing interest in Oriental religions—all have combined to strengthen the religious rationale for health promotion in America.

—From "Ideological and Historical Rationales for Occupational Health Promotion: From Asclepius to Hygeia."
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