Deaths from Electric Shock in 1962 and 1963

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During this century the number of deaths from electric shock has risen from 8 in 1901 to 154 in 1963 (Registrar-General, 1902-1964), and there is no indication that we have seen the end of this increase. That is not to say there has been a deterioration in electrical safety. When the number of deaths in each year is related to the amount of electricity supplied it will be seen (Table I) that the number of fatalities per million kilowatt hours consumed has steadily fallen. Nevertheless, the steady rise in fatalities merits serious attention.

TABLE I.—Incidence of Death, Consumption of Electricity, and Ratio of Deaths to Electricity Consumed (1901-62)

Quinquennia	Average No. of Deaths Per Annum	Average Consumption of Electricity Per Annum (Million kW hrs.)	Average Rates of Deaths to Consumption of Electricity Deaths $\times$ 1,000 Million kW hrs.
(1901-04)	11.25	—	—
1905-09	22.0	—	—
1910-14	27.4	—	—
1915-19	31.8	—	—
1920-24	26.0	4,000	6.5
1925-29	47.2	6,900	6.8
1930-34	61.8	10,300	6.0
1935-39	82.6	18,000	4.5
1940-44	88.2	28,000	3.1
1945-49	80.2	36,000	2.25
1950-54	113	50,000	2.2
1955-59	128	74,000	1.7
(1960-62)	130.3	103,000	1.3

In their classical experiments Prevost and Batelli (1899) showed that ventricular fibrillation is a cause of death in electrical accidents when the current passes through the thorax. On the other hand, it has been generally held for many years that electric shock in some way causes respiratory arrest, persisting after the contact has been broken, so that the correct treatment of a victim should be artificial respiration. However, the evidence advanced to support this belief has recently been critically reviewed by Lee and Zoledziowski (1964), who also reported experimental work which suggests that medium-voltage shocks passed between the upper limbs do not cause respiratory arrest in small animals. Similar observations have been made in dogs by Strumza (personal communication). Shocks passing through the respiratory centre may cause prolonged arrest of respiration (MacLachlan, 1930; Morikawa and Steichen, 1960), but such a pathway may be uncommon in electrical accidents.

As there is no published information on the current pathway and supply voltage in fatal electrical accidents in this country it was decided to investigate these factors in the accidents which could be traced.

Method

The 12 area boards of the electricity supply industry keep records of all fatalities known to them (Electricity Supply Regulations, 1937). These records for 1962 and 1963 were examined and particulars of every accident noted. If a death occurs on premises subject to the Factories Act a full investigation is carried out by the factory inspectorate. With the co-operation of Dr. R. Morley, a medical inspector of factories, the same particulars were obtained for electrical fatalities in factories over the same period.

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Similar information on cases not included in either of the above groups was obtained from other sources, such as the Electricity Council, British Railways, the National Coal Board, etc.

Finally, from a list of deaths supplied by the Registrar-General of fatal electrical accidents in 1963, it was possible to determine how many of the fatalities in that year had in fact been traced.

Results

In the two years under review 112 and 154 deaths were registered in which electricity was mentioned as a cause. Full details were obtained in 99 (88%) and 132 (85%) cases respectively. There was no reason to suspect that the remainder would differ substantially in any respect from the majority. Particulars of the numbers obtained in the two years are given in the Appendix.

Voltage

From the power stations electricity is distributed by the grid system at high voltage (275,000 and 132,000 volts). These overhead lines are virtually inaccessible except to highly trained men working under stringent regulations, and fatalities on them are therefore very uncommon (one in the two years under consideration). Regionally, distribution is at 33,000 volts and at 11,000 volts. These lines, to judge from the fatality figures (Table II), seem to be more accessible or more attractive to climbers and more liable to be touched by the jibs of mobile cranes. Finally, to the majority of consumers electricity is delivered over the 415-volt network.

TABLE II.—Fatalities Grouped According to Voltage

Voltage:	< 250 V*	415 V	6.6 kV	11 kV	19 kV	33 kV	Other†	Unknown	Total
1962	92	1	19	0	2	0	17	1	132
1963	74	1	10	0	1	0	11	2	99
Total	166	2	29	0	3	0	28	3	231

* All fatalities in this group occurred between 200 and 250 volts.

† The "other voltages" are those used industrially and by British Railways.

All these systems are three-phase supply. This means that the alternating current is supplied along three conductors, in each of which it is out of phase (that is, out of step) to a fixed extent (120 degrees) with the other two. The current may be returned by a "neutral" conductor which is at (or very close to) earth potential. From the present point of view the important feature of this arrangement is that the phase voltage between any two of the phase wires is the same, but the voltage between any one phase wire and neutral (or earth) is the phase voltage divided by $\sqrt{3}$. This can be illustrated by reference to the ordinary domestic supply. The supply cable generally carries the three phases, with a voltage of 415 between any two of them, and a neutral conductor. (Incidentally, "earth" return is often carried in the armoured sheath of the cable.) For the vast majority of domestic premises connexion is made with the supply cable on to one phase and the neutral; thus the voltage between these conductors is $\frac{415}{\sqrt{3}}$ —that is, 240. An

earth wire is generally carried in at the same time. This is illustrated in Fig. 1 (the earth wire is omitted for clarity).

FIG. 1.—Voltage in three-phase supply. V is the voltage between any two-phase conductors. The voltage between any one-phase conductor and neutral (or earth) is $\frac{V}{\sqrt{3}}$.

It will be seen that, as might be expected, phase-to-phase accidents (415 V, 11 kV, 33 kV) are very rare. There were only two, and both were at 415 volts; one was to an electrician and the other was a suicide.

Medium-voltage (250 V or Less) Fatalities

The age distribution of medium-voltage fatalities is given in Table III. Although the male fatalities have the expected distribution, being highest during the period of the working life, the figures for females show a rise in the older age-groups. This is more pronounced when the number of deaths in the age-groups is related to population of those age-groups, as shown in the lower part of the Table. About half of the deaths of women over 60 were due to the use of metal scissors in the investigation of connectors of electric irons and kettles. Such deaths may indicate one hazard of old persons living by themselves, or they may reflect a generation which was brought up without instruction in the correct use and the potential hazards of domestic electrical appliances.

TABLE III.—Age Distribution of Fatalities at Voltage Less than 250 V

	Age:	0—	10—	20—	30—	40—	50—	60—	70—	80—	Unknown	Total
Nos.	M	11	23	24	16	16	8	7	5	1	6	117
	F	3	7	6	2	5	7	7	6	4	2	49
Per 10 ⁷ at risk	M	30	65	82	52	51	30	35	50	34	—	—
	F	9	18	21	7	16	25	27	36	65	—	—

Current Pathway

As already described, knowledge of current pathway through the body is important when considering the mechanism of death. From the accounts of the accidents which were found in the records it was possible to determine the current pathway in the great majority of accidents and to fit them into the groups shown in Tables IV and V. For the 166 medium-voltage fatalities the current pathways are shown in Table IV.

TABLE IV.—Current Pathway in Medium-voltage Fatal Accidents in 1962–3

Pathway	1962	1963	Total
Arm to other limb	62	66	128
Head to trunk or limb ..	3	2	5
Bath	6	14	20
Other	2	5	7
Unknown	1	5	6
	74	92	166

The pathways grouped together as upper limb to another limb—that is, with the current passing through the thorax and not directly through the respiratory centre—represent 128 (77%) of this group of fatalities. It is interesting to note that most of the remainder—20 (12%)—are deaths due to electrocu-

tion in the bath, nearly all caused by taking some faulty electric appliance (seven with electric fires, five with radios or record-players)—into the bathroom. In this group also the current possibly passes through the thorax and is unlikely to pass through the respiratory centre.

Accidents at More Than 250 V

There were 65 fatalities at voltages greater than 250 (Table II); of these, 29 were at 6,600 volts—that is, accidents on a main distribution line with the current flowing to earth through the victim. Of these 29 fatal accidents 25 occurred on overhead distribution lines; 12 through a crane jib touching the line, usually at the same time as a slinger was working at the hook. The usual current pathway in such accidents is from an upper limb to the feet (Fig. 2).

FIG. 2.—Usual current pathway (hand to feet) in overhead-line accidents with cranes.

An analysis of the current pathway in all the 65 accidents at more than 250 volts (Table V) shows that 48 (74%) were from an upper limb to the lower limb. All 65 accidents involved males.

TABLE V.—Current Pathway in Fatal Accidents in 1962–3 at More than 250 Volts

Pathway	1962	1963	Total
Arm to other limb	17	31	48
Head to trunk or limb ..	5	2	7
Other	1	4	5
Unknown	2	3	5
	25	40	65

Death from Ventricular Fibrillation

In the earlier part of this paper it was pointed out that there are grounds for believing that a medium-voltage shock passing from an upper limb to another limb is very unlikely to cause primary arrest of respiration. In this study it has been seen that the majority of these deaths occur at medium voltage—most of them when the current passes through the thorax. Such deaths are likely to be due to ventricular fibrillation (Lee, 1964).

When the cerebral circulation is arrested unconsciousness may ensue within 10 to 15 seconds (Robson, 1964). This is in keeping with the experimental work of Roberts (1954), who found, in dogs, that about 30 seconds may elapse before consciousness is lost after the onset of ventricular fibrillation due to electric shock. It is known also that, after arrest of the cerebral circulation, respiration does not immediately stop but may persist for about one minute (Robson, 1964). Again this is in keeping with experimental findings (Ettinger, 1933, 1935; Lee and Zoledziowski, 1964). The two observations would

explain the suggestion that the victim of a fatal electric shock may remain conscious and continue to breathe for a short time after receiving the shock (Jones, 1895 ; Oliver and Bolam, 1898). In this connexion the following case histories are instructive.

An 18-year-old youth wearing hobnailed boots was seeing to a 240-volt A.C. overhead light-fitting in a cattle shed. A colleague heard him call out and immediately went in. The youth was standing up with his hands above his head holding the lamp-fitting and said that he had been electrocuted. His colleague switched off, whereupon the youth fell down and did not speak again.

This was clearly a medium-voltage shock from upper limb to lower limb, and it almost certainly killed by ventricular fibrillation. The fact that the victim spoke after receiving the shock indicates that loss of consciousness was not immediate and that breathing continued for a short while.

The following case illustrates that a shock at a much higher voltage but following the same pathway through the body (upper limb to lower limb) does not immediately arrest respiration.

A youth aged 18 was one of a gang manhandling a steel pole near to a 33,000-volt overhead line—that is, 19,000 volts to earth. The steel pole touched an overhead line. He was seen to fall, and remained lying on the ground. A colleague sat him up, and because he appeared to have difficulty in breathing the colleague massaged him. Suddenly he seemed to stop breathing. His colleague then “breathed into his mouth” until the ambulance arrived—but to no avail.

Discussion

The management of victims of electric shock, together with a critical review of the use of artificial respiration, has been considered elsewhere (Lee, 1964). What is the medical contribution to preventive measures ?

To produce ventricular fibrillation a current must pass through the heart for a certain time. The necessary period of time varies with strength of the current. These parameters of time and current have been studied in dogs within the time range 8 msec. to 5 seconds by Kouwenhoven *et al.* (1959). The results, together with earlier investigations by Ferris *et al.* (1936) in sheep, have been analysed by Dalziel (1960). He suggests that, for man, a current of “i” milliamps should be interrupted within “t” seconds for fibrillation to be prevented, when i and t are related by the formula

i = 165 / sqrt(t)

This formula is known to be valid only within the times of 8 msec. to 5 seconds.

Dalziel (1962) described the use of the low-voltage earth-leak circuit-breaker operating within the limits demanded by this formula as a device to prevent ventricular fibrillation in electric shock. A number of these devices are now coming on to the market in different European countries.

A simplified scheme of operation is illustrated in Fig. 3. Under normal conditions the current flows between live and neutral and so through the primary coils A and B. Thus the magnetic fluxes induced in the ring-shaped core balance one another. Should someone touch the live side some current would pass through his body to earth. Coil A will then carry this current as well as the load current which passes through the appliance, but coil B will still only carry the load current from the appliance. As the two coils A and B are not carrying the same current the magnetic fluxes induced in the ring-shaped core will not balance and a current will be induced in the secondary coil C. This induced current is made to operate the relay A, which immediately switches off the current within the time limits of the above formula. So far no attempt has

been made to test these earth-leak circuit-breakers in animal investigations.

FIG. 3.—Earth-leak circuit-breaker. For explanation see text. Reproduced, by permission, from *Medical News* of 8 January 1965.

From the above description it will be seen that the circuit-breaker is operated by a current passing or leaking through the victim to earth (an “earth-leak” circuit-breaker). It is only in these circumstances that the device might prevent death from ventricular fibrillation. It is important to know, therefore, in what number of fatal medium-voltage accidents the current passes from limb to limb through the victim to earth. Out of the 166 medium-voltage accidents the path of the return current from the victim was studied in 62 taken at random. The results are given in Table VI.

TABLE VI.—Return Pathway in Medium-voltage Accidents in 1962–3

Return path: No. . .	Earth 55	Neutral 4	Other Phase 0	Unknown 3
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Thus if it is accepted that ventricular fibrillation is the mechanism of death in limb-to-limb medium-voltage accidents, then in at least 88% (55 out of 62) an earth-leak circuit-breaker might have saved the victim (presuming that, in practice, the device would fulfil the theoretical predictions). If this percentage is applied to the totals of medium-voltage limb-to-limb fatalities for the years 1962 and 1963 (Table IV) it may be postulated that 55 victims in 1962 and 58 victims in 1963 might have been saved. As noted under the heading of results, 99 out of 112 fatalities were traced for 1962 and 132 out of 154 for 1963. Thus the total number of victims in each year who might have been saved by these devices would be about 68. To these it would be reasonable to add the bath fatalities, giving a final total of about 80 persons in each of the years 1962 and 1963. It should be stressed that this would presuppose the universal installation and correct adjustment and maintenance of such devices.

Summary

About 140 deaths a year occur from electrical accidents, and the number is steadily increasing. It has been possible to study details of the majority of deaths from electric shock which occurred in 1962 and 1963 by referring to the investigations carried out by electrical engineers of various authorities. Rather more than 70% of these deaths occurred at medium voltage (200–250 volts), and in 128 (77%) of this group the current passed through the thorax and not directly through the head. In a further 20 cases death occurred in the bath ; again the current pathway is probably through the thorax.

Recent evidence indicates that when the current pathway includes the thorax (and does not pass directly through the head), death is most likely to be due to ventricular fibrillation, without immediate arrest of respiration. In fact, consciousness and respiration may not cease immediately ventricular fibrillation starts. This explains reports of persons talking and even moving about for a brief period after receiving a fatal shock.

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The parameters of time and current required to produce ventricular fibrillation have been studied and "earth-leak circuit-breakers" (whose mode of action is described) have been designed to operate within these limits. It was found that in at least 55 out of 62 accidents in which this aspect was studied the return pathway was to earth. If these figures are applied to the whole series it is estimated that about 60 to 70 lives a year might have been saved by the universal installation of these devices (presuming that they fulfilled the theoretical predictions) if they were correctly maintained and adjusted.

This study was made possible by the helpful co-operation of the engineers of the 12 area boards of the Electricity Council and the engineers of the other bodies mentioned. I am indebted to Miss I. Dingwall Fordyce for advice in presenting the data.

Appendix

In 1963 there were 154 deaths registered the cause of which mentioned electricity. Twelve of these were excluded, as seven of the deaths occurred in 1962 but were not registered until 1963, four victims clearly died from burns, and one died from an explosion. On the other hand, from the sources listed above, nine cases of death from electric shock were not on the Registrar-General's list. This gave a total population of 151, out of which it had been possible to obtain details in 132 cases (87.5%) (Table VII).

TABLE VII.—Fatal Electrical Accidents in 1963

Deaths registered, mentioning electricity	154
Excluded (7 in 1962; burns 4; explosion 1)	12
	142
Cases found in survey, not on Registrar-General's list	9
Total population	151
No details available	19
Population surveyed	132

For 1962 the procedure was slightly different. Particulars of 99 electrical fatalities, excluding burns, were collected from the same sources (the 12 area boards, Factory Inspectorate, National Coal Board, and British Railways). The number of deaths registered as accidents caused by electric current in 1962 was 112 (Registrar-General, 1963). Thus details were obtained in 88% of cases, a proportion very comparable with the proportion for 1963. It is therefore thought justifiable to consider the two years together. Another indication that the sample of records traced for 1962 was representative, for age at least, comes from a comparison of its age distribution with the age distribution of cases recorded by the Registrar-General (Table VIII).

TABLE VIII.—Age Distribution of Electrical Fatalities in 1962

	0—	5—	15—	45—	65+	Unknown	All Ages
From Registrar-General	6	16	60	24	6	—	112
% of total	5	14	54	21	5	—	100
Cases traced	5	12	54	19	6	3	99

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Vocal Cord Paralysis and Voice Changes in Patients with Surgical Hypoparathyroidism

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Vocal cord paralysis and hypoparathyroidism are both well-recognized sequelae of thyroid surgery. Several reported series (Riddell, 1956; Wade, 1960; Blomstedt and Rydmark, 1960; Blackburn and Salmon, 1961) have indicated the prevalence of each complication following different types of thyroid operations. There is, however, little published material concerning their coexistence in the same subject. This paper described the results of indirect laryngoscopy in a group of patients suffering from chronic post-operative hypoparathyroidism.

Patients and Methods

The group designated "hypoparathyroid" consisted of one man and 25 women aged 29–70 years at the time of examination. In all of them one or more thyroid operations had been performed for various indications, at times ranging from six months to 29 years before this study. They had been referred

by a number of physicians and surgeons because of our interest in hypoparathyroidism, and in each patient a serum calcium of 8.5 mg./100 ml. or below had been demonstrated on at least one occasion by the method in use at the time of diagnosis (Clark and Collip, 1925; Fales, 1953; Technicon Corporation, 1960). Patients were not classified as hypoparathyroid unless at the time of their hypocalcaemia their blood urea nitrogen was 24 mg./100 ml. or less, they had no symptoms of malabsorption, and their serum specific gravity was such that serum calcium, when corrected for serum specific gravity (Dent, 1962), did not exceed 8.5 mg./100 ml. Patients in whom serum specific gravity had not been estimated at the time of hypocalcaemia were not included unless their serum calcium was 8 mg./100 ml. or

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