ORIGINAL ARTICLE

Cardiac monitoring of high-risk patients after an electrical injury: a prospective multicentre study

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Objective: To report our experience monitoring patients with previously identified theoretical risk factors of significant electrical injury.

Methods: Patients who presented to one of 21 emergency departments between October 2000 and November 2004 were eligible to be enrolled in a prospective observational cohort study if after an electric shock they had one of several risk factors (transthoracic current, tetany, loss of consciousness or voltage source ⩾1000 V) and therefore needed cardiac monitoring.

Results: Of the 134 patients enrolled, most were monitored because of transthoracic current (n = 60), transthoracic current and tetany (n = 39), tetany (n = 10), or voltage ⩾1000 V (n = 10). There were 15/134 (11%) patients with abnormal initial ECGs. No patient developed potentially lethal late arrhythmia during the 24 hours of cardiac monitoring.

Conclusion: Although only patients deemed at risk of late arrhythmias were monitored, none developed potentially lethal late arrhythmias. Asymptomatic patients with transthoracic current and/or tetany and a normal initial ECG do not require cardiac monitoring after an electrical injury with voltage <1000 V and no loss of consciousness.

Several theoretical factors that determine the severity of an electric shock have been highlighted.[1 2] These risk factors include magnitude of the energy delivered, resistance to current flow, type of current, duration of contact and current pathway.[1 2]

Over the years, many recommendations have been made as to which patients should be monitored. For the most part, these have been based on an initial ECG.[3–16] Most of these studies, however, have not reported the number of patients that presented with the identified theoretical risk factors. Thus, it is possible that most of these patients did not present with any of them. For example, in one study that did report risk factors, only 8/151 (5%) children had tetany and 6/151 (4%) transthoracic current.[12] This suggests that in most studies, the majority of patients did not have the identified risk factors. Thus, it is still unknown if these patients are clinically at risk for late arrhythmias even if they have a normal initial ECG.

The aim of this multicentre study was to report our experience in monitoring patients with transthoracic current, tetany, loss of consciousness, or voltage source ⩾1000 V after a significant electrical injury.[1 2]

METHODS

Study design

We performed a multicentre prospective observational study using a convenience sample of patients who had received an electric shock and presented with at least one predefined risk factor that indicated the need for cardiac monitoring. The study was approved by each hospital's institutional review board (IRB). In the case of primary care hospitals without an IRB, the study was approved by the chief medical officer with approval by the principal investigator's IRB. Parental consent was obtained for any children included in the study.

Study setting and population

In total, 21 emergency departments (EDs) (see Appendix online; available at http://emj.bmj.com/supplemental) over a wide geographical area, ranging from small community hospitals to tertiary care centres (including paediatric hospitals), with a median annual census of 37 000 (range 20 000 to 85 000), participated in enrolment in the period October 2000 to November 2004.

Patients were eligible to be included in the study if they had at least one of these risk factors: transthoracic current (suggested by sensation or burn marks from one upper extremity to the other or from one upper extremity to a lower extremity or the thoracic region, or by history), tetany >1 second, loss of consciousness of any length of time, or voltage source ⩾1000 V. Patients with documented arrhythmia could also have been included. The risk factors were those established by doctors from the local electricity company based on the medical literature,[1 2] but also on unpublished experience from all over the world. These guidelines, which help determine who requires cardiac monitoring after an electric shock, were already in use for at least 10 years in EDs in our area (38/44 (86%) in a pre-study survey) and in all participating centres. Thus, patients were essentially asymptomatic and ready for discharge if it were not for the concern of late arrhythmia. Exclusion criteria were: patients not giving consent, patients with an injury not caused by an electric shock and injuries due to lightning.

Study protocol

Once the ED doctor determined the eligibility and obtained consent, they completed a standardised form providing the investigators with details concerning the electric shock. The form contained the following items: age, sex, time of accident and assessment in the ED, cardiac history, scenario of the accident including voltage and source of the electricity, and the presence or not of the following factors: tetany, transthoracic current (suggested by sensation, burns marks or history), loss of consciousness, wetness on the extremities and burns.

Abbreviations: CPK, creatine phosphokinase; CPK-MB, creatine phosphokinase myoglobin; ED, emergency department; IRB, institutional review board

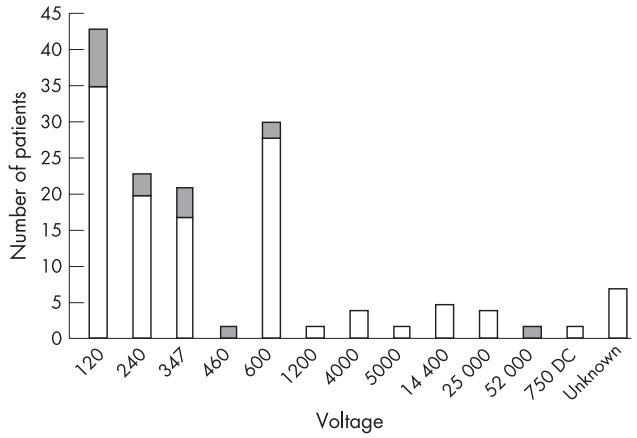

Figure 1 Voltage involved in the electric shock for the 134 patients enrolled in the study and results of initial ECG. White areas show the number of patients with a normal initial ECG, dark areas the number of patients with abnormal initial ECG. DC, direct current.

Creatine phosphokinase (CPK), creatine phosphokinase myoglobin (CPK-MB), or troponin results were recorded on the standardised form if these had been obtained.

Measurements

All participants had an initial ECG and another 24 hours later or before discharge, whichever occurred first. Copies of both ECGs were sent to the principal investigator. The ECG interpretation of the treating doctor was used and validated by the investigators. When available, previous ECGs were used to compare with the study ECG. No specific criteria exist for screening ECGs in patients with electrical injuries, therefore any abnormality was considered a positive finding. The treating doctors recorded the results of the 24-hour cardiac monitoring, which was carried out in the ED or intensive care unit by telemetry by direct observation with alarms. Any anomaly was reported. Measurements of CPK, CPK-MB or troponin were left to the discretion of each doctor.

Table 1 Reasons for which cardiac monitoring was performed in the 134 patients

	n (%)
One factor	
Voltage >1000 V	10 (7)
Unknown voltage	5 (4)
Tetany	10 (7)
Loss of consciousness	3 (2)
Transthoractic current (total)	60 (45)
Suggested by sensation	42 (31)
Suggested by burn marks	9 (7)
Suggested by history	9 (7)
Two factors	
Tetany and loss of consciousness	1 (1)
Transthoracic current and loss of consciousness	1 (1)
Suggested by sensation	1 (1)
Transthoracic current and tetany	39 (29)
Suggested by sensation	25 (19)
Suggested by burn marks	7 (5)
Suggested by history	7 (5)
Transthoracic current and voltage >1000 V	1 (1)
Suggested by history	1 (1)
Three factors	n (%)
Transthoracic current, tetany and voltage >1000 V	2 (1)
Suggested by sensation	1 (1)
Suggested by burn marks	1 (1)
Transthoracic current, tetany and loss of consciousness	2 (1)
Suggested by sensation	1 (1)
Suggested by history	1 (1)

Follow-up

Patients were called by a research nurse at least 1 month after the electric shock, and 1 year later to determine if they had any cardiac symptoms since their discharge from the ED. A standardised form was used by the research nurse and contained both open and specific questions: need for scheduled or unscheduled medical visit since discharge, any cardiac symptoms, and any palpitations, chest pain, angina, myocardial infarction or loss of consciousness.

Data analysis

All data were entered into an excel spreadsheet (Microsoft, Redmond, Washington, USA) by a research nurse. The entries were verified by the principal investigator. Missing data were completed by consulting the original charts of the patients obtained at the stated hospital. Results are reported as mean (SD) unless specified. The upper limits of the 95% confidence interval for the incidence of potentially lethal arrhythmia for each risk factor were calculated by the Wilson method (Confidence Interval Analysis software, V2.0). The difference in the prevalence of risk factors between patients with normal follow-up versus cardiac symptoms or new-onset cardiac symptoms at short term or 1-year follow-up was performed using χ^2 test or Fisher's exact test as appropriate (SPSS V13.0; SPSS Inc., Chicago, Illinois, USA). The difference in age between the patients who presented with cardiac symptoms at either the short term or the 1-year follow-up was evaluated by Student's t test (SPSS V13.0). In all cases, when significant, the difference and its 95% confidence interval is reported.

RESULTS

Over the 4-year period, 134 patients aged 29.8 (16.1) years (range 1 to 67), including 26 children, were enrolled. There were 88 work-related accidents. For the hospitals that were able to enrol patients, the median number of patients enrolled was 7 (range 1 to 27); 5 (24%) hospitals did not enrol any patient.

Figure 1 shows the voltage to which the patients were exposed, and table 1 shows the risk factors that indicated cardiac monitoring. Most of the patients had only one risk factor. In total, 22 patients (16%) had contact with the electrical source with an area of the body that was either moist or wet, 6 (4%) had a history of cardiac problems and 77 (57%) had burn marks. The size of the burns was estimated at a median of 1 cm^2 (n = 57, range 0.09 to 16). The burns were first degree in 32 patients, second degree in 28, third degree in 5, and unspecified in 12.

In total, 115 patients had normal initial and discharge ECGs. Of the 15 patients that had an abnormal or borderline initial ECG, 8 were unchanged at discharge. Four patients had abnormal or borderline initial ECGs (one incomplete right bundle branch, one T wave anomaly with possible anterior ischemia, and two sinus tachycardia) that normalised completely at discharge. There were four patients with normal initial ECGs but borderline discharge ECGs; all had sinus bradycardia (table 2).

Cardiac monitoring was performed for 20.2 (7.4) hours up to 23.8 (6.7) hours after electric shock. Except for the anomalies noted on the discharge ECGs, cardiac monitoring was normal in all but two patients: one patient developed a long PR (up to 240 ms) that lasted 12 hours and another had a P wave block with an atrial extrasystole. Based on the result of the cardiac monitoring, the upper limit of the 95% confidence interval for the occurrence of potentially lethal late arrhythmia for each risk

Table 2 Abnormal initial and discharge ECGs

Initial ECG	Discharge ECG
Abnormal or borderline	Abnormal or borderline
Decreased T wave in V1–3	Unchanged
T wave inversion in V1	Unchanged
T wave inversion in V4–6	Unchanged
Right bundle branch block	Unchanged*
First degree AV block	Unchanged
Nonspecific ST anomaly	Unchanged
T wave inversion in V2	Unchanged
Right bundle branch block	Unchanged
RSR′ in V2 with depressed ST in V3-5 (1 mm)	Non-specific ST anomaly
Incomplete right bundle branch block with sinus bradycardia (45 bpm)	Sinus arrhythmia with sinus bradycardia (53 bpm)
RSR′ in V1 (62 bpm)	RSR′ in V1 with sinus bradycardia (58 bpm)
Abnormal or borderline	Normal
Sinus tachycardia (109 bpm)	Normal (68 bpm)
T wave anomaly, possible anterior ischemia	Normal
Incomplete right bundle branch block	Normal
Sinus tachycardia (102 bpm)	Normal (60 bpm)
Normal	Borderline
Normal (62 bpm)	Sinus bradycardia (54 bpm)†
Normal (61 bpm)	Sinus bradycardia (54 bpm)
Normal (68 bpm)	Sinus bradycardia (50 bbm)
Sinus arrhythmia (72 bpm)	Sinus bradycardia (59 bpm)

AV, atrioventricular.
*Known for incomplete right bundle branch block previously; †known to be present previously.

factors were: voltage ⩾1000 V 22.8%, tetany 6.6%, loss of consciousness 35.4%, and transthoractic current 3.5%.

CPK was measured in 116 patients at a median of 2.5 hours after electric shock, and showed a median of 163 U/L (range 45 to 7110). In 84/92 (91%) patients, the initial CPK was the maximum CPK, and there were 22 patients with CPK >300 U/L. CPK-MB was measured in 39 patients, with a mean (SD) of 2.0 (1.6)% (median 2.0, range 0 to 6.2). There were seven patients with CPK-MB >3% and one >6%. Troponin T or I was measured in 86 patients at the same time as CPK measurement: all were at or below the limit of detection, including the seven patients with CPK-MB >3%.

At the short-term follow-up, carried out for 114 patients (85%), 11 (10%) reported new-onset cardiac symptoms: 6 patients complained of palpitations, 3 of chest pain, 1 of palpitations and chest pain, and 1 of palpitations with a single episode of syncope unrelated to the palpitations. One patient reported chest pain that had already been present before the electric shock. Only one of those patients had consulted a doctor prior to the follow-up, which was carried out at a mean (SD) of 71.8 (54.3) days (median 52). Patients with new-onset cardiac symptoms at the short-term follow-up were similar in age to those without: 28.8 (12.5) vs 30.1 (16.6) years (Δ = −1.3, 95% CI −14.9 to 12.4).

At the 1-year follow-up, carried out for 87 (65%) patients at a mean of 395 (28.2) days (median 391) after the electric shock, 10 (11%) patients had new-onset cardiac symptoms not present at the short term follow-up; 5 had palpitations and retrosternal pain, 2 had palpitations, 1 had a myocardial infarction (58-year-old man), 1 had angina, and 1 had chest pain. Furthermore, five patients who had cardiac symptoms at the short term follow-up still complained of symptoms at the 1-year follow-up; two had palpitations, two had palpitations and chest pain, and one had angina. Patients with new-onset cardiac symptoms since the short-term follow-up were similar in age to those without: 38.7 (13.4) vs 29.3 (17.4) years (Δ = 9.4, 95% CI −2.0 to 20.8).

There were no other cardiac symptoms at either the short-term or the 1-year follow-up for all risk factors evaluated (table 3).

DISCUSSION

It has been suggested that an electrical current may permanently damage the cardiac conduction tissue and predispose to late arrhythmia.[17] This is illustrated by a case series that reported three patients who developed late arrhythmias 8–12 hours after electrical injuries that did not require initial ED assessment (220 and 380 V alternating current, 3000 V direct current).[17]

Table 3 Prevalence of risk factors in patients with normal results, cardiac symptoms or new onset-cardiac symptoms at the short-term and 1-year follow-ups

Follow-up	Transthoracic current, n (%)	Tetany, n (%)	Loss of consciousness, n (%)	Voltage ⩾1000 V, n (%)
Short term*				
Normal	79/102 (77)	45/102 (44)	5/102 (5)	10/102 (10)
Cardiac symptoms	10/12 (83)	4/12 (33)	1/12 (8)	2/12 (17)
New-onset cardiac symptoms	9/11 (82)	3/11 (27)	1/11 (9)	1/11 (9)
1 year†				
Normal	53/72 (74)	30/72 (42)	2/72 (3)	10/72 (14)
Cardiac symptoms	13/15 (87)	7/15 (47)	1/15 (7)	1/15 (7)
New-onset cardiac symptoms	9/10 (90)	3/10 (30)	1/10 (10)	0/10 (0)

Cardiac symptoms were: *palpitations, retrosternal pain and angina; †palpitations, retrosternal pain, angina and myocardial infarction.

The incidence of late arrhythmias is not known but is certainly rare. In a review of 104 electrocutions over 15 years in a region of Australia, all victims died at the scene of the accident.[18] In another retrospective coroner's study in the province of Quebec, there was only 1 case of late arrhythmia out of 124 electrocutions over 6 years.[19] In a 6-year review of electrocutions from South Delhi, 150 of 153 people died at the scene and the other 3 died at the hospital; of those 3, two died of septicaemia and one of arrhythmia that was present on admission.[20] Thus, the challenge for clinicians is to identify which patients are at risk of late arrhythmias.

A review of the literature shows that a normal initial ECG suggests the absence of late arrhythmias, at least for low voltage injury.[3–13 15 16 19] There is less evidence for high voltage injury.[3 9 10 13] What about patients with identified theoretical factors that determine the severity of an electric shock, such as magnitude of the energy delivered, resistance to current flow, type of current, duration of contact and current pathway? Most of the previous studies that concluded a normal initial ECG did not take these factors into account. Our study attempted to clarify this.

In this study, patients had cardiac monitoring after an electrical injury if they had the following risk factors: transthoracic current, tetany, lost of consciousness, or a voltage source of 1000 V or more. Although only patients deemed ''at risk'' were monitored, no patient developed late potentially lethal arrhythmias. This reinforces the notion that late arrhythmias are exceptional.

Most of the patients monitored in our study had transthoracic current and/or tetany. These theoretical risk factors were not associated with abnormal cardiac monitoring. Considering this and the fact that, as discussed earlier, a normal ECG appears to predict absence of late arrhythmias, asymptomatic patients with transthoracic current and/or tetany in the future may be discharged if the initial ECG is normal and there are no other risk factors. An exception to this may be a patient with a severe burn at the entry point suggesting an injury with high current density. Because patients rarely have no symptoms after a shock with a voltage of ⩾1000 V (only 13 in our study), the monitoring of such patients makes sense until we have more data. This will not represent a large burden for the ED as these patients most often have burns that require admission. From the literature, it also appears that a normal ECG predicts the absence of late arrhythmias in those patients. However, a study of nine patients with high-voltage injuries investigated after discharge from the hospital showed that cardiac dysfunction is possible in initially asymptomatic patients.[21] Therefore, this must be considered a possibility until further studies with much larger numbers of patients given cardiac assessment after their high-voltage injuries can exclude it. Because loss of consciousness may be a sign of arrhythmias, any patients with this history require cardiac monitoring.

Almost 10% of patients had new onset cardiac symptoms at the short-term follow-up and an additional 10% by the 1-year follow-up. The extent of these symptoms is not known because most patients did not feel the need to seek medical advice. Although we might suspect that their injuries were minor because of that, the study by Guinard *et al* suggests that such patients should probably be investigated.[21] Thus, patients should be informed of this possibility at discharge and told to seek medical attention if cardiac symptoms occur within the first year after an electric shock.

Limitations

Despite the duration of the study and the number of participating EDs, the number of enrolled patients was small, especially the number of those receiving shocks ⩾1000 V. However, this study is the largest to date for patients monitored with transthoracic current, and possibly with tetany. These are risk factors identified by others.[1 2]

As no study has shown exactly what abnormalities on an ECG predict poor outcome, our a priori definition of abnormal ECG was large and included what most emergency doctors interpret as normal ECG, such as sinus bradycardia or tachycardia. Future studies should determine what constitutes a normal ECG after an electrical injury, as the existing criteria are based on the presence of a normal initial ECG.

No late arrhythmias were detected. This illustrates the difficulty of identifying who is at risk of late arrhythmias even if we only included patients deemed at risk according to the medical literature.

The study evaluated only those patients with certain risk factors who would have been given immediate discharge were it not for the concern of late arrhythmias after an electric shock. Patients injured by lightning were not included. Patients requiring admission for reasons other than cardiac monitoring, such as extensive burns or trauma were not enrolled, and neither were patients without risk factors Although this reduced the range of available patients, it also focused on a group of patients not previously studied—that is, those with previously identified risk factors such as transthoracic current or tetany.

Most patients had small burn marks suggestive of an injury with low current density. The effect of severe burns at the entry point, which could be associated with high current density, is not known. This could explain, why, on rare occasions, a patient may have myocardial damage after such an electrical injury. In our study, most patients who seemed to have injury with low density current did not have noticeable myocardial damage.

Future studies should focus on patients with shocks from a voltage >1000 V, and patients with burns from high current density at the entry point to determine if a normal initial ECG may still predict the absence of late arrhythmia in these patients. Because of the rarity of the event, it is unlikely that direct risk factors for the occurrence of late arrhythmia will be identified, thus we have to define the clinical situation in which we can predict the absence of late arrhythmia.

CONCLUSION

Even though only patients deemed at risk of late arrhythmias were monitored, none had potentially lethal late arrhythmias. Asymptomatic patients with transthoracic current or tetany and a normal initial ECG do not require cardiac monitoring after an electrical injury unless the source of the voltage is ⩾1000 V, or if they have loss of consciousness. The effect of burns after high current density is not known. Patients may develop cardiac symptoms after discharge from the ED. They should be advised to seek medical attention should that occur.

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The appendix can be viewed on the EMJ website at http://emj.bmj.com/supplemental.

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