J Accid Emerg Med 1999;**16**:186–188

Early prediction of neurological outcome after falls in children: metabolic and clinical markers

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Abstract

Falls are the foremost reason for non-fatal injuries and are second only to motor vehicle accidents in causing accidental death. The purpose of this study was to identify the clinical and metabolic predictors of the outcome of head injury caused by falls from a height.

Medical records of 61 children who had been admitted to the paediatric intensive care unit from 1990 to 1993 after falling from a height were reviewed retrospectively. Outcomes were categorised as good, moderate, severe, and poor. Glasgow coma scores, pupillary responses, brain oedema, and midline shift are significantly associated with poor outcome ($p<0.05$). Metabolic markers associated with poor outcome included hyperglycaemia and hypokalaemia. Children with a poor outcome had, at admission, significantly higher glucose concentrations compared with children with good outcomes (mean (SD): 20.0 (7.1) *v* 9.31 (4.0) mmol/l, $p<0.01$), and lower potassium concentrations compared with children with good, moderate, and severe outcomes (mean (SD): 2.8 (0.4) *v* 3.7 (0.4) mmol/l, $p<0.001$, 3.5 (0.3) mmol/l, $p<0.01$, and 3.41 (0.3) mmol/l, $p<0.05$, respectively).

These findings allow for an early allocation of effort and resources to children injured from such falls.

(*J Accid Emerg Med* 1999;**16**:186–188)

Keywords: falls; hyperglycaemia; outcome; trauma

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Accepted 11 January 1999

Falls are a common reason for emergency room visits by children. They are the fourth leading cause of trauma deaths[1] and are second only to motor vehicle crashes for causing accidental deaths.[2] Recent work suggests that children's mortality after trauma fluctuates somewhat from year to year, but the overall rate remains unacceptably high.[3] Yet, despite advances in emergency medicine and in critical care, the morbidity and mortality of falls from a height in the paediatric age group have not decreased.[1 2]

There has been increasing interest in the early identification of the prognosis of these patients in order to allow physicians to decide on the optimal allocation of the limited resources at their disposal. Early identification of predictive signs may affect therapeutic interventions and determine the indications for aggressive therapeutic measures. Therefore, this study attempts to identify clinical and metabolic markers of the outcome of children and infants who have fallen from a height and who were admitted to the paediatric intensive care unit.

Patients and methods

The medical records of 61 patients who were admitted to the paediatric intensive care unit at the Chaim Sheba Medical Center after falls from a height of at least 1 metre (m), during the period from 1990 to 1993, were reviewed retrospectively. Inclusion criteria for the study group were age between 2 months and 16 years and admission within two hours of having suffered a fall from a height of at least 1 m. We excluded patients who died before arrival at hospital and patients having a significant background illness. Upon arrival at the trauma centre, patients were evaluated by a team that included a senior paediatric and surgical resident. The primary injury in all patients was to the brain and therefore the initial Glasgow coma score (GCS) was determined at that time. The values for blood glucose, electrolytes, and arterial blood gases that were collected within minutes of arrival in the emergency room, as part of routine trauma laboratory tests, were used in this study.

The following information was gathered from each patient's record: age, height of fall, the GCS at admission and at 24 and 72 hours, pupillary response, blood pressure, heart rate, laboratory data, and computed tomography findings.

Patient survival and functional outcome were classified by a modified Glasgow outcome scale,[4] which classifies neurological disability according to four categories. Patients with "good" recovery were considered to be able to resume a normal life, even if they had minor neurological and psychological deficits. Those with "moderate" disability were still capable of functioning independently, while patients with "severe" disability were those left restricted in daily functionality, and depend on others for the daily life activities. The "poor" outcome category was of children who did not survive the accident. This classification was performed on discharge, and did not attempt to consider long term consequences.

Statistical analysis of the data was accomplished using Pearson's χ^2 and Yates's corrected χ^2.

Results

Sixty one patients with closed head injuries resulting from falls have met the inclusion criteria for the study group. There were 42 males and 19 females, and their median age was 6.0

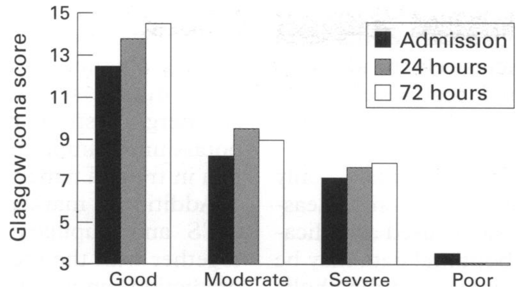

Figure 1 Mean Glasgow coma score of outcome groups at admission, 24 hours, and 72 hours.

Table 1 Incidence of different brain lesions detected by computed tomography

Observation	*No (%)*
Linear skull fracture ± normal scan	41 (67.0)
Depressed skull fracture	5 (8.2)
Midline deviation	6 (9.8)
Brain oedema	18 (29.5)
Intraventricular haemorrhage	5 (8.2)
Intracranial haemorrhage	3 (4.9)
Subarachnoid haemorrhage	7 (11.5)
Epidural haemorrhage	16 (26.2)
Brain infarct	1 (1.6)

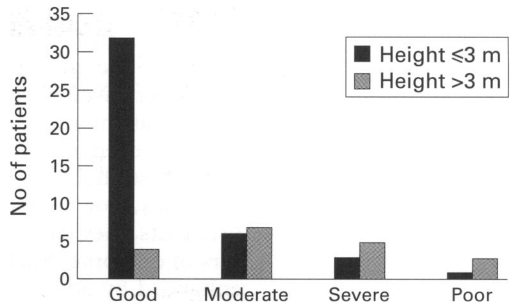

Figure 2 Height of fall and outcome.

Table 3 Significance of the differences within various factors, at admission, in relation to the outcome

Factor	*Probability*
Height of fall	<0.001
Glasgow coma score	<0.001
Pupillary response	<0.0001
Systolic blood pressure	NS
Midline shift	<0.05
Seizures	NS
pH	<0.01
Carbon dioxide pressure	NS
Oxygen pressure	NS
Hypokalaemia	<0.001
Hyperglycaemia	<0.001

years (range 1–15 years). Most (68.9%) fell from a height of 1–3 m, while the remainder fell from a height exceeding 3 m. Thirty six patients (59.0 %) were graded as having had a good outcome, 13 (21.3%) had a moderate outcome, eight (13.1%) had a severe outcome, and four patients' outcome was poor (6.6%).

The GCSs of these four categories at admission, 24 hours, and 72 hours are depicted in fig 1. The mean scores for the groups, at any time points, decreased with the severity of classification. The admission scores were found to have significant prognostic value: patients in the good outcome group had a mean score of 12.48 compared with 8.17, 7.13 and 3.50, respectively, in the moderate, severe, and poor groups. The GCSs of the good outcome group were significantly higher ($p<0.001$), at all times, than those of the other groups.

In 11.5% of the patients only one pupil was responsive, and in 6.6% both pupils were unresponsive. Three patients had no admission record of pupillary response. The majority (91.7%) of the good outcome group had equal and responsive pupils ($p<0.0001$). Of the various pathologies found on computed tomography of the head, brain oedema and midline deviation were correlated with progressively worse outcomes ($p<0.05$). Table 1 summarises the computed tomography findings of the head in the injured children.

The laboratory parameters examined included blood glucose, serum potassium, arterial pH, and clotting factors.

Table 2 Admission blood glucose and potassium concentrations and outcome

	Outcome category			
	Good	*Moderate*	*Severe*	*Poor*
No of patients	36	13	8	4
Mean (SD) glucose (mmol/l)*	9.31 (4.0)	13.8 (8.4)	12.3 (6.7)	20.0 (7.1)
Mean (SD) potassium (mmol/l)**	3.7 (0.4)	3.5 (0.3)	3.4 (0.3)	2.8 (0.4)

*$p<0.01$ and **$p<0.001$ for the difference between good and poor outcome.

The mean blood glucose concentrations on admission are listed in table 2. Patients with poor outcome had significantly higher admission glucose concentrations compared with patients with good outcome ($p<0.01$).

The mean blood potassium concentrations decreased progressively as outcome worsened (table 2). Patients with poor prognosis had significantly lower potassium than patients in the other groups ($p<0.0001$, $p<0.001$, $p<0.01$, compared with good, severe, and poor outcomes, respectively).

As one would expect, severity of injury was found to increase with increasing height of the fall. Whereas 88.9% of the good outcome group fell from 1–3 m, 75% of the poor outcome group fell from heights exceeding 3 m ($p<0.001$, fig 2). Further analysis also revealed a strong correlation between height of fall and brain oedema: 47.4% of the patients who fell from heights exceeding 3 m had brain oedema compared with 21.4% who fell from less ($p=0.05$). None of the patients who fell from less than 3 m had intraventricular haemorrhage, in contrast to 26.3% of the individuals who fell from more than 3 m ($p=0.001$).

The predictive values of variables that were examined are summarised in table 3. While height of fall, GCS, pupillary response, admission hyperglycaemia and hypokalaemia differed significantly among the outcome groups, age, seizures, blood pressure, 24 hour glucose, arterial blood gases, and brain infarct had no statistically significant correlation with the outcome.

Discussion

As was already noted by Hall and coworkers the severity of injury, and thus mortality, from a free fall is dependent primarily on the distance fallen.[1] The higher the fall, the greater is the impact of the body upon the ground.

Furthermore, it must be taken into account that bodies in free fall from great heights seem to strike the ground exclusively head first.[5] Moreover, Weiler reported that severe head injury was the main cause of death after a free fall from even less than 5 m.[6]

Because heights of fall are usually only estimates, not corroborated by on-site measurements, they cannot be safely used as indicators of outcome. Such suboptimal data may be enhanced by additional clinical and metabolic markers, for assessing the prognosis of the patients who have fallen from a height.

In this study of children who suffered head injury after falls, we have demonstrated that hyperglycaemia and hypokalaemia at admission are useful indicators of the severity of injury. The correlation of hyperglycaemia with the severity of outcome is consistent with previous studies.[7 8] Studies, in animal models, of focal ischaemia have demonstrated that increased neurological deficits and larger brain infarcts correlated with hyperglycaemia.[7 9] In adults with traumatic brain injury raised serum glucose has been shown to correlate significantly with decreased levels of consciousness and with poor prognosis.[7]

The results of the present study disagree with those of Parish and Webb, who found that the level of hyperglycaemia in children with severe head trauma could not be associated with any indicator of outcome.[10]

Although the mechanism of hyperglycaemia is not clear, it seems that the abundant supply of glucose during ischaemia enhances anaerobic metabolism and consequently accumulation of lactate and protons. The intracellular acidosis caused by these ischaemic conditions triggers lipolysis, release of cytotoxic fatty acids and glutamate, and may result in the destruction of neurons.[7] Therefore, our study adds to recent evidence that justifies those advocating aggressive treatment of hyperglycaemia in children who have fallen from heights, provided that precautions are taken to prevent the equally detrimental hypoglycaemia.

Hypokalaemia is found in many life threatening situations, such as cardiopulmonary bypass, burns, severe infections and severe multiple trauma, and may have prognostic significance.[11] Substantial hypokalaemia was seen in patients with severe isolated head trauma,[12] and it was linearly correlated with the severity of trauma and with the eventual mortality.[11] The central mechanism of potassium homoeostasis is the ATP dependent sodium-potassium pump that can be regulated via the β_2 adrenergic receptors.[12] The discharge of large amounts of catecholamines that takes place during severe trauma may induce β_2 adrenergic stimulation of the sodium-potassium pump, thus mediating hypokalaemia in trauma patients.[12]

Additional markers of prognosis were the GCS and pupillary responses. When taken together with the metabolic markers, outcome prediction can be established with some degree of certainty. Yet, in view of the inherent unpredictability of a patient's clinical course, the prediction of outcome in a patient after a fall remains dubious. Indeed, most clinicians with experience in the management of trauma victims develop their own criteria for predicting outcome. However, early identification of patients at risk may aid the physician in decisions pertaining to the admission of patients to intensive care units, transfer of patients to tertiary centres, and early initiation of monitoring.

In this study we have demonstrated that besides the widely used guides of severity of injury, hyperglycaemia and hypokalaemia were associated with a poor outcome. Additional randomised studies are needed to determine whether management of hyperglycaemia and hypokalaemia after head injury could improve the outcome.

Conflict of interest: none.

Funding: none.

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