Prognostic factors in victims of falls from height*

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Objective: **Falls from height cause significant mortality in the urban environment, but reliable prognostic factors have not been identified. Even the intuitive relation between the distance fallen and mortality rate has been questioned. Our objective was to determine factors predictive of increased mortality rate in victims of falls from height.**

Design: **Clinical observational study, retrospective for January 1998 to May 1999 and prospective from June 1999 to September 2000.**

Setting: **The study population was drawn from Seine-Saint-Denis, an urban region near Paris with 1.3 million inhabitants treated by a French out-of-hospital medical emergencies unit.**

Patients: **Patients were victims of falls from height >3 m, age >12 yrs. Study entry was performed on the scene by an emergency physician from the medical emergencies unit.**

Interventions: **None.**

Measurements and Main Results: **Studied data included age, gender, circumstances of fall, height of fall, nature of the impact surface (soft or hard), transient impact preceding final impact, and part of the body touching the ground first. The primary end point was mortality. The study included 287 patients, 116 (40%) during the retrospective phase and 171 (60%) during the prospective phase. Ninety-seven patients (34%) ultimately died. In multivariate analysis, age (mean, 41.6 ± 16.6 yrs in patients who died vs. 34.9 ± 14.9 in survivors; odds ratio, 1.05; $p < .0005$); height of fall (median, 5.0; 3.8–8.0 vs. 2.0; 1.2–3.0 floors; odds ratio, 1.24; $p < .0001$); nature of the impact surface (hard in 39% vs. soft in 22%; odds ratio, 2.7; $p < .05$); and head, anterior, and lateral body surfaces touching the ground first (with respectively mortality rates of 44%, odds ratio, 16.7, $p = .0001$; 57%, odds ratio, 10.6, $p < 0.005$; 32%, odds ratio, 11.1, $p < .001$) were independently correlated with the final mortality rate.**

Conclusions: **Patient age, height of fall, impact surface nature, and body part first touching the ground are independent prognostic factors in victims of falls from height. (Crit Care Med 2005; 33:1239–1242)**

Falls from height represent an important cause of morbidity and mortality in the urban environment. Despite the frequency of this mechanism of severe blunt injury, prognostic factors are not yet clearly identified. According to physical principles, several factors have long been suggested to be related to mortality after falls from height (1–3). Most of them, however, have never been specifically studied. Even the intuitive relation between the height of the fall and mortality rate has been recently called into question (4). Thus, we identified potential prognostic factors in victims of falls from height and studied their prognostic value in a clinical study.

METHODS

French Emergency Medical System. In France, out-of-hospital medical emergencies are managed by the Service d'Aide Médicale Urgente (SAMU) (5). The service employs a nationwide phone number to contact the regional emergency physician dispatcher of the SAMU, 24 hrs a day. In cases of a fall from height, the dispatcher is systematically notified by other health care providers, including fire department rescue services. In our region, seven ambulances carrying an emergency physician, nurse, and trained driver are stationed at various hospitals throughout the region and sent on site by the dispatcher. In cases of fall from height, an ambulance with an emergency physician is systematically sent to the scene, including cases where cardiac arrest is initially diagnosed by health care providers.

Inclusion Criteria and Study Protocol. The study population was drawn from Seine-Saint-Denis, an urban region near Paris with 1.3 million inhabitants. Patients were included after a fall from a height >3 m or one building floor. Patients <12 yrs of age were excluded. A retrospective study was conducted for the period from January 1998 to May 1999 (17 months). During this period, patients were identified, along with the circumstances of the call from the computerized SAMU database. Beginning in June 1999, the study was continued in a prospective manner as an observational study through September 2000 (16 months). Because patient care was not altered in any way, neither informed consent nor ethics committee approval for the study was required under French law.

The following data were obtained for all patients included in the study: the date of the fall, victim age, victim gender, circumstances of the fall (suicide attempt, accident, or escape attempt), height of the fall (one floor was considered to be equivalent to 3 m), the nature of the impact surface (soft or hard) as subjectively evaluated by the emergency physician on scene, any physical contact preceding the final impact (shrub, tree, balcony, glass roof, etc.), and the part of the body touching the ground first (head, lower extremities, ventral, dorsal, or lateral position). These latter data were obtained from the patient, if possible, or from witnesses, scene observation, and patient examination in the remaining cases. The duration of stay in the hospital and final outcome were recorded.

Statistical Analysis. Results are expressed as mean ± SD or median (25th, 75th percentiles). Quantitative data were compared by means of a two-tailed Student's *t*-test and qualitative data using the chi-square test. We considered $p \leq .05$ as significant. Univariate and multivariate analyses were performed using a logistic regression model (Statview 5.0, SAS Institute, Cary, NC). Odds ratios were calculated.

***See also p. 1426.**

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RESULTS

During the period of the study, 353,912 calls were managed in the Seine-Saint-Denis SAMU medical emergency dispatching center, and 43,987 ambulances staffed by an emergency physician were dispatched. Among these, 287 patient victims of from height were logged in the database and included in this study, 116 (40%) during the retrospective phase and 171 (60%) during the prospective phase. Ninety-seven patients (33.8%) ultimately died. The chronology of mortality is reported in Table 1.

Table 1. Chronology of mortality after falls from height

Location and Time of Death	Patients, No.	Mortality, %
Out-of-hospital mortality	68	70.0
Dead on arrival at scene	54	55.7
Dead on scene after care	9	9.2
Dead during transport	5	5.1
In-hospital mortality	29	30.0
Before 24 hrs	22	22.9
After 24 hrs	6	6.2
Total	97	100

One hundred and ninety-one were male (67%) and 95 were female (33%). Their mean age was 37.2 ± 15.8 yrs. Patients who died were significantly older than survivors (41.6 ± 16.6 vs. 34.9 ± 14.9 yrs; $p < .001$). Heights of falls are reported in Figure 1. The median height of fall, in floors, was significantly higher in the group of patients who died than in the group of surviving patients (5.0 [3.0, 8.0] vs. 2.0 [1.2, 3.0] $p < .0001$). Circumstances of falls, the nature of the impact surface, occurrence of transient impact before the final impact, and the part of the body touching the impact surface first and univariate analysis are respectively reported in Table 2.

The mortality rate significantly correlated with each of the studied criteria. Individual criteria significantly correlated with the mortality rate were used to perform multivariate analysis. Age (odds ratio [OR], 1.053; $p = .0003$), height of fall (OR, 1.0242; $p < .0001$), nature of the impact surface (OR, 2.662; $p < .05$), and the body part first touching the ground first (head [OR, 16.754; $p = .0001$]; anterior face [OR, 10.636; $p < .005$]; lateral surface [OR, 11.097; $p < .001$]) were independently correlated with the final mortality rate (Table 3).

DISCUSSION

Patient age, height of fall, circumstances of fall, and the body part first touching the ground are independent prognostic factors in victims of falls from height in our study. We report a very high mortality rate (34 %) that dramatically contrasts with previously published studies. Goodacre et al. (4), Scalea et al. (6), and Agalar et al. (7) reported mortality rates of 1.2%, 4.9%, and 9.1%, respectively, after falls from height in most recently published studies (8). In these studies, only those patients arriving at hospital were included. Out-of-hospital mortality was not taken into consideration. This is probably the reason why these authors failed to identify useful prognostic factors. In our study, out-of-hospital mortality comprised 70% of the total mortality, including 56% of the patients who died immediately on site, without resuscitation. Nine percent died after resuscitation attempts and 5% during transport.

Thus, we believe that inclusion of out-of-hospital deaths was the sole means that permitted a pertinent study of the prognostic factors in victims of falls from height. Importance of out-of-hospital mortality is illustrated by the relation between height of fall and mortality. According to physical principles, the velocity of impact (V), which is a major prognostic determinant, is calculated by the following formula:

$$v = \sqrt{2gh} \qquad [1]$$

where g is the force of gravity (9.8 $m \cdot sec^{-2}$) and h the vertical distance fallen in meters (1). Thus, the height of fall is anticipated to be a major prognostic factor. Goodacre et al. (4) failed to demonstrate this relation and concluded that "height fallen is a poor predictor of injury severity." In contrast, our results demonstrate a strong correlation between height of fall and mortality. Furthermore, Goodacre et al. reported a cutoff point at less than two floors in comparison with the three-floor cutoff point we identified. In our study, the median height of fall in patients who died (15 m, five floors) was also dramatically greater than that found in the study of Agalar et al. (7) (less than three floors). This is consistent with their lack of inclusion of patients who died immediately after a fall from height, which in our experience constitutes the majority of deaths.

Patient age, height of fall, nature of the impact surface, and body part first touching the ground are independent prognostic factors in victims of falls from height.

Despite the fact that falls are a classic mechanism of severe injury, the relation between height of fall and mortality has not been previously demonstrated. Additional factors, such as the nature of the impact surface or the position of the body at the time of the impact, have been advocated as prognostic factors after falls from height according to physical principles (4, 7, 9). These factors are poorly documented, however, and none of them has been previously demonstrated to be independently correlated with mortality rate.

Intuitively, the nature of the impact surface should be a prognostic factor after a fall from height. This is demonstrated in our study. In effect, the mechanical energy responsible for trauma after falls from height increases when potential energy decreases, that is, when deformability of the impact surface increases (1). In 1942, De Haven (10) reported eight cases of survival after falls from height. He reported a case of a fall from 96 m, with a 28 $m \cdot sec^{-1}$ velocity at contact, and deceleration estimated at 191 G on a beach with a 23-cm deformation. He postulated that the nature of the ground and the body orientation on impact were responsible for these unexpected survivals. In contrast, deceleration would exceed 700 G in case of impact on concrete with a 0.5-cm deformation. In fact, particularly soft impact surfaces such as snow, whose deformability is maximal, can be live saving. During the last world war, a USAF pilot who jumped from his plane at 7320 m altitude and landed in pine forest and snow is regarded as the survivor of the most extraordinary free fall ever reported. The nature of the impact surface is an independent prognostic factor after a fall from

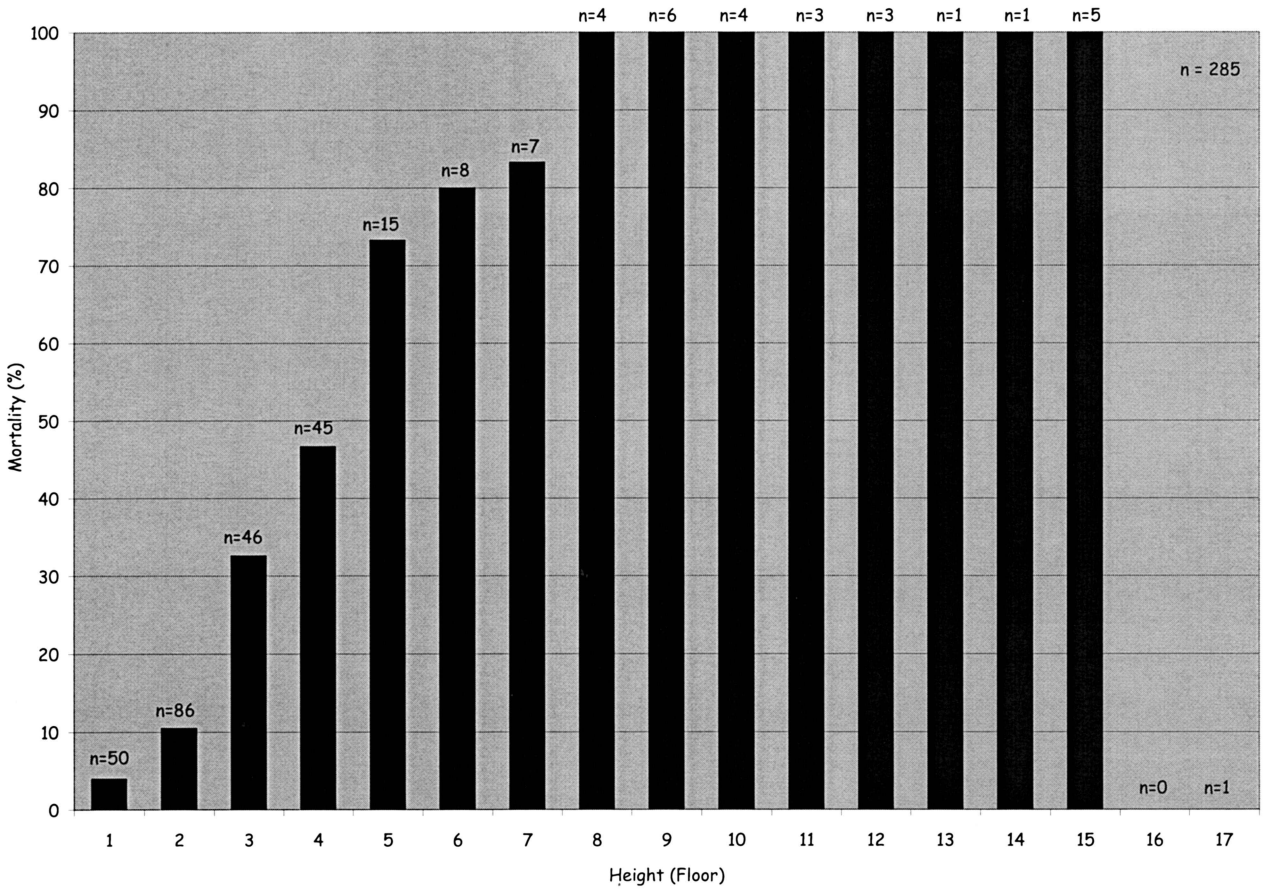

Figure 1. Height of fall and related mortality.

Table 2. Characteristics of fall from height and mortality

	Patients, No.	Survived, No.	Died, No.	Mortality Rate, %	*p*
Circumstances of fall					
Suicide attempt	123	67	56	45.5	.01
Accident	109	92	17	16.6	
Escape	28	25	3	10.7	
Unknown	27	9	18	66.7	
Nature of the impact surface					
Hard	208	127	81	38.9	<.01
Soft	74	58	16	21.6	
Unknown	5	5	0	0.0	
Preliminary impact before final impact					
Yes	46	39	7	15.2	<.01
No	240	151	89	37.1	
Unknown	1	0	1	100.0	
Part of the body touching the ground first					
Head	72	40	32	44.0	<.0001
Lower extremities	69	66	4	5.6	
Posterior	52	40	13	23.0	
Anterior	35	14	20	57.1	
Lateral	19	13	6	31.5	
Unknown	38	17	21	55.3	
Total	287	190	97	33.8	

height. It has previously been shown to prevent extremity injuries in cases of falls from standing height (11).

Falls from height into water constitute a unique circumstance of impact. Because of its deformability, the water surface allows an increase in deceleration time and reduces injuries. For example, in cases of impact of the feet on the water, deceleration force is around 6 G. In comparison, in cases of lateral impact, this force reaches 40 G (12).

On a solid impact surface, according to these physical principles, body orientation at the time of the impact was a theoretical prognostic factor, as it determines contact surface area. Potential energy decreases when this surface increases. Theoretically, landing on the feet (i.e., on a surface of <450 cm^2) should increase injury severity in comparison with ventral impact (i.e., on a larger surface). This is not exactly what is observed, however, as body position also determines nature of the lesions. Impact on the feet results in lower extremity trauma which is not life threatening in most cases. Such an impact, associated with appropriate maneuvers, has been demonstrated to decrease by a factor of 36 the deceleration in parachutists (10). In contrast, injuries after impact on the head are clearly life threatening. The role of body position in determining the nature

Table 3. Multivariate analysis: Criteria correlated with mortality rate

Criterion	*p*	Odds Ratio
Age	.0003	1.053 (1.024–1.083)
Height	<.0001	1.0242 (1.140–1.354)
Nature of the ground (hard)	<.05	2.662 (1.003–7.069)
Part of the body touching the ground first		
Head	.0001	16.754 (3.902–71.941)
Anterior surface	<.005	10.636 (2.210–51.186)
Lateral surface	<.001	11.097 (1.895–64.993)
Circumstances of fall		NS
Initial impact before final impact		NS

NS, not significant.

of the lesions is illustrated by an increased mortality rate after ventral impact. Mortality rate reached 57% in such circumstances, compared with 23% after dorsal impact in the current study. After ventral impact, thoracic organs are submitted to shearing and torsion forces, which are particularly pejorative. This is frequently observed in motor vehicle trauma (13). On the other hand, distribution of impact forces can be modified. As parachutists are instructed to land in a position optimal for absorbing forces, they can attenuate the deceleration forces by a factor of 36 (10). The importance of body orientation at the time of impact after a fall from height is clear in the case of children. Because of the head weight, they are particularly predisposed to cranial trauma. For this reason, we excluded study victims <12 yrs old. In adults, the relation between advanced age and mortality is well known in trauma and intensive care. The relation between age and trauma severity after falls from height has previously been demonstrated (4, 7, 8, 14).

Our study suffers from several limitations. Our use of numbers of floors to characterize the height of fall might have been a source of inaccuracy. Height in meters was not used, as it remains difficult to evaluate on a vertical axis. In our urban region, however, floor heights are more or less standard at 3 m. Other sources of bias include our subjective determination of impact surface deformability (hard or soft surface) and of other difficult to evaluate variables (circumstances of fall or part of the body touching the floor first). Objective criteria to characterize such variables are not likely achievable in a clinical study. The large number of patients included, particularly during the prospective period, compensates, in part, for these limitations.

Other factors, such as patient physical and mental conditions and tissue properties, have been suggested to be related to trauma severity and prognosis after falls from height (2, 8). Such variables remain difficult to analyze after the fall, as one third of victims of falls die. Furthermore, the role of muscle activity determined by reflexes, mental status, and physical conditions on the impact is probably minor in falls from significant height.

CONCLUSION

Patient age, height of fall, nature of the impact surface, and body part first touching the ground are independent prognostic factors in victims of falls from height. The mortality rate (34%) was dramatically high in this study performed by mobile intensive care unit physicians taking into account out-of-hospital mortality.

REFERENCES

1. Warner KG, Demling RH: The pathophysiology of free-fall injury. *Ann Emerg Med* 1986; 15:1088–1093
2. Snyder RG: Human tolerance of extreme impacts in free fall. *Aerospace Med* 1963; 34: 695–709
3. Seymour MTJ, Phillips JB: Free fall from twelve storeys with survival. *Br J Clin Practice* 1987; 41:802–803
4. Goodacre S, Than M, Goyder EC, et al: Can the distance fallen predict serious injury after a fall from a height? *J Trauma* 1999; 46:1055–1058
5. Nikkanen HE, Pouges C, Jacobs LM: Emergency medicine in France. *Ann Emerg Med* 1998; 31:116–120
6. Scalea T, Goldstein A, Phillips T, et al: An analysis of 161 falls from a height: The "jumper syndrome." *J Trauma* 1986; 26: 706–712
7. Agalar F, Cakmakci M, Sayek I: Factors effecting mortality in urban vertical free falls: Evaluation of 180 cases. *Int Surg* 1999; 84: 271–274
8. Rozycki GS, Maull KI: Injuries sustained by falls. *Arch Emerg Med* 1991; 8:245–252
9. Mathis RD, Levine SH, Phifer S: An analysis of accidental free falls from a height: The "spring break" syndrome. *J Trauma* 1993; 34:123–126
10. De Haven H: Mechanical analysis of survival in falls from height of fifty to one hundred and fifty feet. *War Med* 1942; 2:586–596
11. Robinovitch SN, Chiu J: Surface stiffness affects impact force during a fall on the outstretched hand. *J Orthop Res* 1998; 16: 309–313
12. Lukas G. Golden Gate Bridge. *J Trauma* 1981; 612–618
13. Baosong L, Zhengguo W, Huaguang L, et al: Relationship between the dynamic parameters and injury severity of chest subjected to impact. *J Trauma* 1996; 40:S71–S74
14. Knaus WA, Draper EA, Wagner DP, et al: Prognosis in acute organ system failure. *Ann Surg.* 1985; 202:685–693