Forensic Science International
93 (1998) 33–44

Fatal falls from a height: The use of mathematical models to estimate the height of fall from the injuries sustained

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Received 22 September 1997; received in revised form 5 January 1998; accepted 17 January 1998

Abstract

The authors undertook a review of fatal falls from a height, that occurred in 1991–92 in Singapore, with the objective of constructing mathematical models relating the height of fall to the injuries sustained. The 603 cases studied showed a mean age of 41.4 years with a male to female ratio of approximately 2:1. A sub-sample of 416 (69%) of these subjects had fallen from known heights (mean, 26.9 m; range, 3–69.6 m) and were studied in further detail. Bivariate analysis of this group showed that their injury severity score (ISS) was significantly correlated with the height of fall (H) and age ($P<0.01$; $r=0.412$ and 0.187, respectively). As the ISS is not strictly a continuous variable and varied markedly with H, it was categorised into bands (ISSB) before being subjected to further analysis. Regression modelling to adjust for mutual confounding showed that both height of fall and age were significant independent determinants of the ISSB ($P<0.0001$). A model with H as the dependent variable was then constructed to relate the height of fall to ISSB and other statistically significant indicators of the extent and the severity of the injuries sustained. A second model with bands of height (HB) as the dependent variable was similarly constructed to assess the effect of banding both height and ISS. Our findings suggested that the height of fall was significantly associated with age, ISS and the extent of injury (mostly AIS≥3), and confirmed the usefulness of these models for investigative purposes. Statistical models could be designed and used to assess any apparent discrepancy between injury severity as determined at autopsy and the suspected/alleged height of fall. © 1998 Elsevier Science Ireland Ltd.

Keywords: Height of fall; Necropsies; Injury severity; Statistical modelling

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PII S0379-0738(98)00027-9

1. Introduction

Singapore is a highly urbanised, newly industrialised island-republic, where over 80% of its population of 3.6 million reside in high-rise apartments. Geographically, this tropical city-state enjoys a constantly hot climate, virtually undisturbed by strong winds or other naturally occurring, major meteorological upheavals. If it may be assumed that fatal falls from a height are by no means uncommon in urbanised areas, then it would be difficult to explain the relative paucity of published scientific literature on the pathology of trauma associated with these tragic events. When one of the authors carried out a MEDLINE search, it was found that, while literally several thousand papers on the non-forensic aspects of this subject had been published since 1968, relatively few pertained to the resulting patterns of injury [1–7]. Furthermore, these and a number of other major forensic references [8–12] generally did not describe these injuries in any great detail, nor did they systematically address the relation between injury severity and the height of fall.

Thus, the authors conducted a systematic review of 603 consecutive cases of fatal falls from a height that had occurred over a 2-year period (1991 to 1992) and for which medico-legal autopsies were conducted at the Institute of Science and Forensic Medicine, which undertakes all forensic casework for the island-republic. The primary objective of this project was to establish the patterns of injury arising from vertical deceleration, wherein it was found that almost all subjects had some manner of thoracic injury, while some 80% had head and/or abdominal injuries and slightly over half and a third had pelvic girdle and vertebral injuries, respectively. Interestingly, almost 50% showed a combination of head, thoracic and abdominal injuries, with severe or disruptive head injuries being found in approximately a third, and lacerations and ruptures of the heart and of the thoracic aorta in almost half, of all victims [13]. The present study constitutes an extension of that project and attempts to correlate the severity of the injuries sustained with the height of fall and other factors; the specific objective being to construct mathematical models estimating the height of fall from the extent and severity of the injuries sustained, which could then aid the forensic investigation of such cases and serve as the basis for assessing any discrepancy between an alleged height of fall and the autopsy findings.

2. Materials and methods

Data was systematically retrieved from 603 coroner’s autopsies, which had been conducted between 1 January 1991 and 31 December 1992, on fatal falls from a height. The minimum height of fall taken for our study was 3 m ($\approx$10 ft), this being the approximate height of the first floor of most apartments, the actual heights of which, varied from 2.7 to 3.6 m. The corresponding autopsy findings and the relevant police reports and hospital clinical records (where available) were reviewed, in order to determine the sex, age and racial distribution of the entire sample and, where possible, the height of fall. For each case, the body-mass index (BMI) (as an approximate measure of nutritional status) and the ISS [14] were calculated.

The ISS is the sum of the squares of the three highest values of the abbreviated injury scale (AIS) (ranging from 1 to 6) out of a total of six body regions; the maximum score being 75 (see Appendix A). Since the ISS was primarily an indicator of injury severity in relation to mortality, rather than of the full extent and severity of injury per se, it was deemed necessary to further specify injuries, corresponding to AIS≥3 (representing serious to lethal injury), of the heart (ruptured or perforated myocardium/lacerated heart valves, AIS≥4; abbreviated to HEART); the thoracic aorta (laceration/rupture/avulsion, AIS≥4; TA); the principal airways (perforation/rupture/avulsion, AIS≥4; AIRWAYS); the lungs (laceration/rupture, AIS≥4; LUNGS); the liver, spleen and kidneys (laceration/rupture/avulsion, AIS≥3; LIVER, SPLEEN, KIDNEYS); the gastrointestinal tract (perforation/transection, AIS≥3; GIT), together with the cranium/brain (severe calvarial/basal fractures and/or cerebral extrusion, AIS≥4; BRAIN). As additional indicators of the extent of injury, the presence of fractures of the pelvic girdle (AIS≥3; PELVIS) and injuries of vertebral column/spinal cord (AIS≥2) were also taken into account. This empirical selection was based on the consistent observation, at the ISFM, that the extent to which these organs were damaged generally reflected the magnitude of the height of fall. Other injuries, such as rib and limb fractures were not included, as the collective experience at this department has shown that significant damage to the thoracic cage, as well as the presence of extensive fractures of the upper and lower limbs are generally associated with even more severe visceral injury, as are serious injuries of other internal organs, not listed above, such as lacerations of the adrenal glands, rupture of the urinary bladder and vascular injuries apart from the aortic and cardiac disruption. For each case, an attempt was made to determine the probable anatomical site of primary impact on the ground, as accurately as possible, from the distribution of the most severe and/or extensive external and internal injuries, with due consideration for the pattern of the injuries in their entirety.

Of the 603 cases, 416 (69.0%) in which the height of fall (H) could be determined or inferred with reasonable accuracy from the police reports were identified for further data analysis. The majority (90.9%) of this group had fallen from public apartments which generally have standardised floor heights lying within a narrow range. Thus, the height of fall in each of these cases could be determined from information supplied by the national housing authority. The other cases (9.1%) involved industrial accidents wherein the heights from which the subjects had fallen were known or measured.

In the statistical analyses, the Student's t-test was used to compare sex-specific differences in the mean height of fall and the ISS, and Pearson's correlation to explore the relations between the ISS and variables such as H, age, sex, and BMI. To adjust for mutual confounding, significant variables were then subjected to multivariate analysis using linear regression modelling. As the ISS was not strictly a continuous variable and wide variations in the ISS, in relation to the height of fall, were observed at the outset, both these variables were also categorised into bands. This resulted in 7 height bands (HB) at intervals of 10 m, and 6 ISS bands (ISSB), comprising 2 bands for the extreme values (<14 and 66–75) and 4 bands of equal intervals for the remaining scores (16–59). A mathematical model with ISSB as the dependent variable was constructed. Subsequently, two mathematical models with height of fall as the dependent variable, were examined. In the first model, H was made the dependent variable to relate the height of fall to statistically significant indicators of the extent and the severity of the injuries sustained. In the second model, *H* was substituted with HB to assess the effect of banding the height of fall. Stepwise selection was used to achieve the best fit for the models. The final model was then tested on a sample comprising the first 20 consecutive cases of falls from known heights that had occurred in 1993. A difference of ±5 m (corresponding to 1–2 floors of public apartments) between the actual and the upper or lower limits of the estimated heights was considered to be a reasonable margin of error.

3. Results

3.1. Descriptive findings

The entire sample of 603 subjects showed a marked male predominance (65.2%) (Table 1). The majority were Chinese (81.3%), with the remainder comprising Indians

Table 1
Comparison of demographic parameters, injury severity score (ISS) and primary site of impact in whole sample of 603 fatal falls from a height and subsample of 416 with known heights of fall in Singapore, 1991–92

	Whole sample (%) $n=603$	Subsample with known heights of fall (%) $n=416$
Sex:		
Male	393(65.2)	254(61.1)
Female	210(34.8)	162(38.9)
Age:		
Mean	41.4	43.3
Median	35	37
Range	3–95	3–95
Race:		
Chinese	490(81.3)	346(83.2)
Indian	53(8.8)	34(8.2)
Malay	32(5.3)	22(5.3)
Others	28(4.6)	14(3.4)
Injury severity score:		
ISS≥16	594(98.5)	411(99.2)
ISS=75	303(50.2)	214(52.1)
Primary site of impact:		
Head/face	67(11.1)	49(11.8)
Feet/lower limbs	367(60.9)	246(59.1)
Hands/upper limbs	34(5.6)	24(5.8)
Upper and lower limbs	15(2.5)	14(3.4)
Front of body	29(4.8)	17(4.1)
Back of body	37(6.1)	26(6.3)
Side of body	24(4.0)	16(3.8)
Extensive/multiple sites	30(5.0)	24(5.8)

(8.8%), Malays (5.3%), and other minority ethnic groups (4.6%). Their age distribution comprised 6.9% under 19 years, 51.6%, 20–39 years, 18.4%, 40–59 years, 17.1%, 60–79 years, 5.5%, 80–99 years, and 0.5%, unknown. The mean and median ages were 41.4 and 35 years, respectively. Most (92.4%) of the subjects had landed on concrete surfaces or structures. A total of 594 subjects (98.5%) had an ISS≤16, while half (50.2%) had an ISS=75. The distribution of the probable anatomical sites of primary impact is shown in Table 1; the most common being primary feet or lower limb impact.

The subsample of 416 cases, wherein the height of fall was known, was very similar to the whole sample in terms of demographic composition, ISS and site of primary impact (Table 1). Of these, 384 (92.3%) had landed on concrete surfaces. Within this group, the mean height of fall and the range were 26.9 m and 3.0–69.6 m, respectively; the majority (80.3%) having fallen from heights of 10–40 m, while 7.7% and 12% fell from <10 m and from 40–70 m, respectively. When the distributions of ISSB and HB were compared, a clustering of cases within the highest ISSB even at relatively low heights of 10–20 m was observed (Table 2).

Overall, the mean height of fall among males (25.4 m) was lower than that for females (29.4 m). This difference was found to be significant (P=0.003; 95% CI, −1.38 to −6.60). The mean ISS was also lower in males (57.9) [nearest admissible values, 57, 59] compared to females (62.0) [59, 66], and this difference was marginally significant (P=0.058; 95% CI, −0.41 to −7.67). Bivariate analysis using Pearson's correlation showed that ISS correlated with H (r=0.412; P<0.01) and age (r=0.187; P<0.01). However, there was no significant correlation of ISS with BMI.

Multivariate analysis, using linear regression modelling with injury severity as the dependent variable, showed that height of fall and age could only account for approximately 22% of the variability observed, as indicated by the value of the coefficient of multiple determination, R^2 (Table 3). Adjustment for mutual confounding showed that neither sex nor the site of primary impact were significant determinants of the injury severity. However, the R^2 value was shown to increase markedly when mathematical models with the height of fall as the dependent variable were constructed (Table 4). H was significantly associated with age, ISSB, and serious head, cardiac, thoracic aortic, renal, liver and splenic injuries corresponding to AIS≥3, as well as to the presence of pelvic fractures and spinal injuries, and these accounted for some 45% of

Table 2
Correlation between height of fall[a] (m) and injury severity score (ISS) in 416 cases of fatal falls from a height in Singapore, 1991–92

	Height 3–<10	Height 10–<20	Height 20–<30	Height 30–<40	Height 40–<50	Height 50–<60	Height 60–<70
ISS≤14	1(3.2)	1(1.1)	2(1.4)	1(0.9)	0	0	0
ISS 16–26	9(28.2)	8(9.1)	3(2.2)	0	0	0	0
ISS 27–36	7(21.9)	12(13.6)	8(5.8)	0	0	0	0
ISS 38–48	5(15.6)	18(20.5)	34(24.5)	17(15.9)	1(4.5)	1(6.3)	0
ISS 50–59	6(18.8)	10(11.4)	28(20.1)	11(10.3)	3(13.6)	1(6.3)	2(16.7)
ISS 66–75	4(12.5)	39(44.3)	64(46.0)	78(72.9)	18	14(87.5)	10(83.3)
Total	32(100)	88(100)	139(100)	107(100)	22(100)	16(100)	12(100)

[a]The height categories correspond approximately to the following floor levels of public apartments: 1–3, 4–6, 7–10, 11–14, 15–17, 18–21, 22–25. Percentages given in parentheses.

Table 3
Multivariate analysis using multiple linear regression to adjust for mutual confounding between independent variables with ISSB as the dependent variable

Independent variables	Regression coefficient	Standard error	t-Statistic	P value
Intercept	3.378	0.177	19.116	
Height	0.042	0.004	9.992	<0.0001
Age	0.012	0.003	4.641	<0.0001

Excluded variables: sex and primary impact.
Sample size = 416.
$R^2 = 0.217$.

its variability in H. The findings were quite consistent when we ran a second model using HB as the dependent variable with the other significant factors as independent variables, wherein a similar R^2 was obtained (Table 5).

Based on these findings, a mathematical equation for the final model relating HB to age, ISSB and the injuries sustained, was constructed as follows:

$$HB = k - k_a A + k_i I + k_b B + k_c C + k_l L + k_p P + k_r R + k_s S + k_t T + k_v V$$

where A = age in years: I = ISSB; B = brain extrusion/lacerations (1 for AIS ≥ 4, 0 for AIS < 4); C = myocardial/valvular ruptures/lacerations (1 for AIS ≥ 3, 0 for AIS < 3); L = liver ruptures/lacerations (1 for AIS ≥ 3, 0 for AIS < 3); P = pelvic girdle fractures (1 for AIS ≥ 3, 0 for AIS < 3); R = renal ruptures/lacerations (1 for AIS ≥ 3, 0 for AIS < 3); S = splenic ruptures/lacerations (1 for AIS ≥ 3, 0 for AIS < 3); T = thoracic aortic laceration/rupture/transection (1 for AIS ≥ 4, 0 for AIS < 4); V = vertebral/spinal cord injuries (1 for present, 0 for absent); and k = 1.88 (95% CI, 1.42–2.34); k_a = 0.01 (0.008–0.02); k_i = 0.10 (0.00–1.97), k_b = 2.59 (0.50–4.65), k_c = 0.30 (0.07–5.43), k_l = 0.77 (0.54–1.00), k_p = 0.28 (0.08–0.49), k_r = 0.31 (0.07–0.54), k_s = 0.30 (0.08–0.52),

Table 4
Multivariate analysis using multiple linear regression to adjust for mutual confounding between independent variables with height of fall (H) as the dependent variable

Independent variables	Regression coefficient	Standard error	t-Statistic	P value
Intercept	12.509	2.264	5.525	
Age	−0.117	0.025	−4.668	<0.0001
ISSB	1.188	0.489	2.428	0.016
BRAIN	3.527	1.090	3.235	0.001
PELVIS	2.915	1.058	2.755	0.006
SPINE	4.197	1.041	4.032	<O.0001
HEART	3.837	1.197	3.204	0.001
LIVER	8.132	1.156	7.032	<0.0001
KIDNEYS	3.031	1.207	2.510	0.012
SPLEEN	3.284	1.113	2.949	0.003

Excluded variables: Sex, AIRWAYS, LUNGS, TA and GITSample size = 416.
$R^2 = 0.459$.

Table 5
Multivariate analysis using multiple linear regression to adjust for mutual confounding between independent variables with height of fall (HB) as the dependent variable

Independent variables	Regression coefficient	Standard error	*t*-Statistic	*P* value
Intercept	1.883	0.233	8.076	
Age	−0.013	0.003	−5.103	<0.0001
ISSB	0.098	0.051	1.928	0.055
BRAIN	0.354	0.108	3.283	0.001
PELVIS	0.284	0.105	2.706	0.007
SPINE	0.400	0.103	3.875	<0.0001
HEART	0.304	0.121	2.510	0.012.
TA	0.151	0.067	2.236	0.026
LIVER	0.769	0.115	6.711	<0.0001
KIDNEYS	0.307	0.120	2.567	0.011
SPLEEN	0.301	0.111	2.719	0.007

Excluded variables: Sex, AIRWAYS, LUNGS, GITSample size = 416.
$R^2 = 0.466$.

$k_t = 0.15$ (0.02–0.28), $k_v = 0.40$ (0.20–0.60) (Table 5). In this model, HB values <1 = height <10 m; 2 = 10–20 m; 3 = 20–30 m; 4 = 30–40 m and ≥5 = 40–70 m.

The application of this model to the test sample of 20 consecutive cases of fatal falls from known heights, that occurred in 1993, yielded the results shown in Table 6. The actual height fell within the probable estimated height brackets in the majority of cases

Table 6
Test sample comprising the first 20 consecutive cases, with known heights of fall, that occurred in 1993

Sex	*A*	*B*	*P*	*V*	*C*	*T*	*R*	*L*	*S*	ISS (ISSB)	Calculated HB (Nearest HB)	Estimated Height (m)	Actual Height (m)
F	77	0	1	1	1	1	1	1	1	75(6)	4.22(4)	30–40	31
F	79	1	1	1	0	1	0	1	1	75(6)	3.94(4)	30–40	27
F	21	0	1	0	0	0	1	1	0	34(3)	3.33(3)	20–30	28
M	35	1	1	0	0	1	1	1	1	57(5)	4.19(4)	30–40	23
M	26	0	1	0	1	1	0	1	0	43(4)	3.52(4)	30–40	34
F	49	0	1	1	1	1	0	1	1	75(6)	4.19(4)	30–40	34
F	74	1	1	0	1	1	0	1	0	75(6)	3.59(4)	30–40	20
M	83	1	1	1	1	1	0	1	1	75(6)	4.20(4)	30–40	26
M	37	1	0	0	0	0	0	0	0	21(2)	1.36(1)	<10	6
F	30	1	1	0	0	0	1	1	1	48(4)	3.99(4)	30–40	31
F	26	0	1	1	0	0	1	1	0	57(5)	3.88(4)	30–40	31
M	46	0	1	0	0	1	0	1	0	34(3)	2.92(3)	20–30	15
M	22	1	0	0	1	0	1	1	1	75(6)	4.29(4)	30–40	31
M	22	0	0	1	0	0	0	0	0	26(2)	2.26(2)	10–20	12
F	35	1	0	1	1	1	1	1	1	75(6)	4.71(5)	40–70	31
F	76	1	1	0	1	0	0	0	0	50(5)	2.55(3)	20–30	34
F	72	1	1	0	0	1	0	1	0	75(6)	3.31(3)	20–30	20
F	67	1	1	1	1	1	1	1	1	75(5)	4.67(5)	40–70	56
M	28	1	1	0	0	1	1	1	1	75(6)	4.64(5)	40–70	48
F	15	0	0	1	1	1	1	1	1	66(6)	4.56(5)	40–70	45

(14/20), while in four cases, the variation between the actual heights and the upper/lower limits of the calculated heights was within ±5 m, with an apparent tendency towards over-estimation.

4. Discussion

The results of this study indicate that it is feasible to construct mathematical models relating the height of fall to the severity and the extent of the injuries sustained. Thus, and perhaps not unexpectedly, the ISS was found to correlate with the height of fall and, only weakly, with age; the latter being consistent with the observation that the elderly (who comprised over a fifth of the entire sample) are relatively vulnerable to extensive and severe injuries from vertical deceleration, for a given height of fall.

Despite this positive correlation, however, there was marked clustering of cases at the upper extreme, even at relatively low heights of up to 30 m. This, together with the fact that >50% of cases were assigned the maximum ISS of 75, significantly limited its usefulness as an indicator of the height of fall.

Furthermore, it became clear at the outset, that there was much variability in the injury severity scores, in relation to the height of fall; this being borne out by multiple linear regression. This could be explained by the fact that the ISS (as with most existing injury scoring systems) is essentially an index of injury severity in relation to the risk of mortality, rather than of the total extent and severity of trauma, per se. Thus, a subject who had fallen through a height of 10 m, with primary feet impact, could have sustained complete traumatic transection of the thoracic aorta, with haemorrhage into the pleural cavities (AIS 6), but little else by way of serious injury; while another, similar, subject could have fallen through 20 m and had sustained multiple head, thoracic and abdominal injuries, with each of these three body region being assigned an AIS value of 5. In both instances, the ISS would be 75 although the latter subject would have fallen through a height twice that of the former. Incidentally, it was observed that females were apparently prone to fall from greater heights than their male counterparts. Bearing in mind that fatal falls involving women in this study were largely suicidal in nature, and assuming that there is no reason to believe that women generally live on higher floors than men, it would seem that the former are somewhat more determined to take their own lives when they have decided to do so. Interestingly, primary impact was found not to correlate with ISS, which is counterintuitive, given the likely causal relation between thoracic aortic rupture and transection and primary feet impact, wherein the predilection of the distal part of the aortic arch to rupture is attributed to the fact that the descending aorta is firmly adherent to the vertebral column, while much of the aortic arch and the heart are relatively mobile, with the result that the latter continue their descent momentarily after primary impact [13]. It should be noted, however, that the determination of the anatomical site of primary impact is by no means a straight forward matter. in contrast to the relative ease with which it was ascertained in an earlier study [1].

These limitations were compounded by the fact that the ISS, being derived from the AIS (which is essentially based on an ordinal scale), is not strictly a continuous variable.

In order to address this wide variability of the ISS in relation to the height of fall, multiple linear regression analysis, first with the raw ISS and height values and, subsequently, with the ISS and height bands, was deemed necessary.

Although the final statistical model proposed appears to be practicable, at least to some extent, it must be conceded that its applicability is largely restricted to a height of 70 m, with the best results being obtained for a range of 10–40 m, which covers some 80%, of the entire sample, and that, in their present form, they lack the statistical power required to discriminate between heights of fall ranging from 40 to 70 m or more. Also, the significant variables considered here only account for <50% of the variability in the calculated height of fall; this should prompt a further search for other possible variables and the analysis of a larger sample comprising, perhaps 800 to 1000 cases, with a separate model for each range of height, e.g. <10 m, 10–40 m, 40–70 m, and so on. Further, it is by no means easy to explain the exclusion of certain variables, by means of multiple linear regression, from the final model. While sex is obviously not an independent determinant of the height of fall and traumatic perforation of the gastrointestinal tract occurs rarely (and usually in conjunction with other, far more severe, visceral injuries), it is not known precisely why severe pulmonary and tracheobronchial injuries are found to be not statistically significant. One can only surmise that it could be because these injuries are usually accompanied by equally, or more severe and extensive, cardiovascular injuries, or that their effects are in some way subsumed by the ISS. Nevertheless, it is submitted that, within the limits imposed by the nature of their construction, these, and similar models, may be useful in the investigation of deaths resulting from falls from a height.

Initially, it was surprising and, somewhat disappointing, that in the final model, the ISSB was only marginally significant. Upon reflection, however, this result may simply imply that the height of fall is better correlated with the extent of serious injury (mostly AIS≥3) in the various body regions, than with the injury score per se, an observation which appears to be consistent with the autopsy findings of the approximately 300 cases of fatal falls from a height that occur annually in Singapore. A concise summary of some of the more prominent injuries, commonly encountered, in relation to the height of fall, is provided in Table 7.

Table 7
Distribution of injuries[1](%)[2] in relation to known height of fall ($n=416$)

HEIGHT BANDS (m)	3–<10	10–<20	20–<30	30–<40	40–<70
HEAD	9	27	34	47	68
THORACIC AORTA	12.5	34	56	68	76
HEART	9	36	47	64	68
LUNGS	22	36	55	67	82
LIVER	6	24	62	85	92
KIDNEYS	3	15	19	35.5	54
SPLEEN	12.5	23	38	58	82
PELVIC FRACTURES	25	34	64	69	72
SPINAL INJURIES	19	31	32	48	56

[1]Mostly corresponding to AIS≥3, with the exception of spinal injuries (AIS≥2).
[2]Incidence of injuries are given in overlapping frequencies.

A similar approach could be adopted by various jurisdictions where fatal falls from a height are common and a constitute an appreciable portion of the forensic caseload. In this respect, it would be pertinent to consider various possibly significant variables that are peculiar to each region. For example, the statistically significant, albeit weak, negative correlation of the height bands with age, seen in both of the present models (that suggests that the elderly tend to fall from lower heights compared to their younger counterparts), may or may not be demonstrable in other models. On the other hand, it is conceivable that climatic conditions, which did not feature in the current models, may be significant in regions buffeted by strong winds, while air resistance might be a valid consideration in situations where falls from extremely great heights exceeding, say, 100 m, are common.

In any case, such an endeavour would provide an objective means of assessing the discrepancy between the assumed height of fall and the injury severity; possibly enabling the height of fall to be estimated with increasing accuracy and assisting in the investigation of suspicious deaths or homicides, as well as in the subsequent reconstruction of the events leading to death.

The authors are of the view that further research in this area is warranted. Apart from multiple linear regression modelling, possible nonlinear relations between the height of fall and indicators of injury severity could be explored. This could be supplemented by more precise methods of establishing primary ground impact and of excluding impact with intermediate structures. As shown in this study, the ISS, of itself, is of limited usefulness, which could be explained by the fact that it approximates to an closed interval scale and is not strictly a continuous variable. Thus, there would appear to be a need for a more precise method of injury scoring suitable for the purpose at hand. Certainly, studies based on a ‘‘prospective’’, rather than a purely retrospective, design (in which the injuries are assessed and graded, by consensus, by a team of trained observers, during, or shortly after, the respective autopsies), might provide more precise mathematical models, each for a given range of heights.

Acknowledgements

The authors are grateful to the Housing Development Board of Singapore for providing them with information on the design of public apartments. They would also like to thank Professor T.C. Chao (Director, Institute of Science and Forensic Medicine) and Dr K.T. Goh (Director, Institute of Environmental Epidemiology) for their support and encouragement in the course of this study.

Appendix A

Derivation of ISS from AIS

The ISS was originally designed as a numerical method of comparing the severity of injuries in vehicular accidents. It is derived from the AIS, which is a numerical system which classifies individual injuries by body regions, based on a 6-point ordinal scale, as follows:

1 Minor
2 Moderate
3 Serious
4 Severe (life-threatening)
5 Critical (survival uncertain)
6 Unsurvivable (with current treatment)

The AIS is, in turn, derived from autopsy and operative findings; values of AIS≥3 correlate well with the probability of death. In summary, the ISS is the sum of the squares of the three highest AIS values, obtained from three out of six body regions, as follows:

Head and Neck
Face
Thorax
Abdomen (abdominal and pelvic organs)
Pelvic girdle and extremities
External Injuries

Subjects with ISS≥16 bear a mortality risk of ≥10%, while the maximum ISS of 75 is incompatible with life; also AIS=6 in any one body region corresponds to ISS=75. Due to its manner of computation, certain values are inadmissible, e.g. 7, 15, 37, 49, 67–74.

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