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Frequency and Severity of Injuries in Correlation with the Height of Fall

ABSTRACT: The main aim of this study was to examine the correlation between the height of fall and the frequency, extensiveness, and type of injuries of certain body regions and organs. The specific objective was to determine characteristic injuries of the analyzed body regions in relation to the certain height of fall. The study included 660 cases of fatal falls from height (469 males and 191 females). Results support the hypothesis that the frequency and extent of the injured body regions and organs are related to the fall height. Head injuries are characteristic of the falls from heights up to 7 m and beyond 30 m. Brain injuries in high falls from heights beyond 30 m show an absence of contre coup contusions and macroscopically evident intracranial bleeding. The extensiveness of chest injuries is significantly statistically associated with fall height. In cases of high falls, the frequency of abdominal injuries is not significantly statistically related to the height of fall. Liver injuries are the most common abdominal injury and the critical height of fall at which the liver injury occurs is 15 m. Injuries of liver and spleen are concomitant in high falls from heights beyond 24 m, irrespective of the manner of impact. The height of fall over 15 m appears to be a reasonable boundary height beyond which the injuries of two or three body regions are generally associated.

KEYWORDS: forensic pathology, autopsy, fall from height, injury, blunt trauma, biomechanics

The frequency, type and extensiveness of injuries in falls from height are determined by body weight and velocity (which influence kinetic energy), nature of the surface impacted, duration and intensity of the impact force, body orientation in the moment of impact, as well as the elasticity and viscosity of the tissue of the contact body region (1–3).

The height of fall is a major determining factor of injury because the velocity of impact is intrinsically related to the distance of the fall to the point of a terminal velocity (3). At the moment of impact, a falling body undergoes deceleration and the amount of kinetic energy transferred to the ground reacts with an equal amount against the body (4). Injuries result from the resorption of the lost energy (5). However, one can estimate the effect of deceleration by comparing it with the impact of a free falling weight where deceleration is expressed in multiples of "*g*" (so called "gravities" or "g-forces"). This calculation, which gives the "apparent weight" of human viscera at the moment of impact, shows that the forces in play are considerable (6).

Numerous studies have analyzed the physics that explain the mechanism of injury in falls from height (1–3,7). However, there are few studies in the available literature about forensic aspects of correlation between the height of fall and consequent injuries (4,5,8–10). Therefore, the aim of this study is to analyze the correlation between the height of fall and the frequency, extensiveness and type of injuries of certain body regions and organs. It also aims to determine characteristic injuries of the analyzed body regions in relation to the certain height of fall.

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Material and Methods

The authors present a retrospective study of 660 individuals who sustained fatal injuries as a result of falls from height on solid surfaces, including falls from standing height (stopping distance less than 0.05 mm). Falls down stairs not included. All the autopsies were carried out in the Institute of Forensic Medicine in Belgrade during the 20-year period from 1981 to 2000. Injuries were classified according to the type, body region, and absolute level of descent (in meters). The frequency of injuries of soft tissues and bones of various body regions (head, chest and abdomen) were analyzed. The severity of injuries was calculated according to the Abbreviated Injury Scale, from 1990. The fall heights have been estimated from available history and police reports. We have assumed the value to each floor of building to be from 3 to 3.7 m. The greatest height was 70 m.

Since the results suggested a correlation between the fall height and consequent injuries, factor analysis was applied. According to Scheirer-Ray-Hare two-way ANOVA analysis was used in complete uneven blocks due to disagreement with a normal distribution density, and the heterogeneous facts (11,12). According to the basic model of fall heterogeneous frequencies were defined: factor A—height of fall, factor B—injuries of organ systems or organs. The level of significance was 0.05.

Results

The sample included 660 cases—469 males (71%) and 191 females (29%). The average age of the examined individuals was 44.66 years (SD = 6.62). The correlation between the age of deceased and fall heights is presented in Table 1. The majority of cases were suicidal jumps—370 (56%), while accidental falls were presumed in 290 cases (44%).

Head injuries were found in 476 fatal falls (72% out of 660 cases in total). The percentage of cases with and without head injuries in

TABLE 1—*The age of victims related to the height of fall (percentage).*

	Height of Fall (meters)											
Age (years)	<1 $N=98$	1–3 $N=137$	4–7 $N=66$	8–11 $N=71$	12–15 $N=105$	16–19 $N=34$	20–23 $N=30$	24–29 $N=27$	30–35 $N=46$	36–40 $N=17$	40–50 $N=12$	>50 $N=17$
<20	4	3	6	4	3	6	. . .	7	5	12	8	23
20–30	3	3	11	8	22	15	13	22	22	12	34	41
31–40	11	10	18	15	17	31	17	23	15	59	8	12
41–50	22	22	21	16	16	15	30	11	17	12	25	12
51–60	17	24	19	28	11	12	23	11	9	. . .	25	6
61–70	22	22	12	14	17	12	10	19	17	5	. . .	6
71–80	16	10	9	11	7	9	7	7	11	. . .	. . .	. . .
81–90	5	6	4	3	7	. . .	. . .	. . .	4	. . .	. . .	. . .

N = Absolute number of cases in ecah group.

TABLE 2—*The absolute number of skull and brain injuries related to the height of fall.*

		Height of Fall (meters)											
	Type of Injury	<1	1–3	4–7	8–11	12–15	16–19	20–23	24–29	30–35	36–40	41–50	>50
Skull fracture	linear	80	60	19	12	16	6	4	2	. . .	. . .	. . .	. . .
	multifragmental	15	66	32	39	34	13	10	10	24	12	9	13
Brain damage	contusion	80	60	9	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	laceration	. . .	. . .	. . .	25	28	12	9	7	22	11	7	11
	contra coup contusion	54	81	30	19	16	6	3	2	1	. . .	. . .	. . .
	laceration & contusion	14	63	39	23	18	6	4	2	. . .	. . .	. . .	. . .
	brain stem injury	1	3	3	3	4	1	1	3	2	1	2	2
Intracranial bleeding	epidural	4	1	1	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	subdural	28	20	14	8	14	1	2	1	. . .	. . .	. . .	. . .
	intracerebral	1	6	. . .	4	. . .	1	. . .	. . .	. . .	. . .	. . .	. . .
	combination		3	2	4	4	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Total	with head injury	95	126	51	51	50	19	14	12	24	12	9	13
	without head injury	3	11	15	20	55	15	16	15	22	5	3	4
	Total	98	137	66	71	105	34	30	27	46	17	12	17

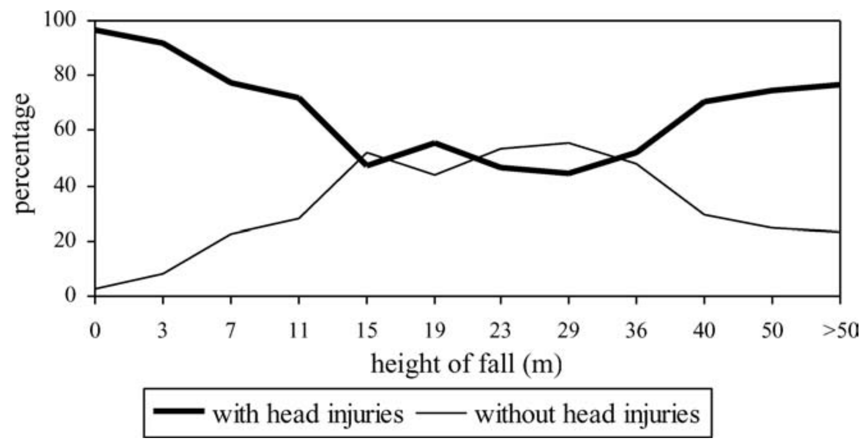

FIG. 1—*Percentage of cases with and without head injuries related to the height of fall.*

relation to the height of fall are presented in Fig. 1. In the group of falls from standing height, craniocerebral injuries were dominant, since these injuries were diagnosed in 95 out of all 98 cases, mostly in the form of cerebral contusions, linear skull fractures and subdural hemorrhage (Table 2). In this group, injuries of other body regions were rarely found, mostly as rib fractures. The gradual decrease of frequency of head injuries was noticed in the groups of falls from heights between standing position and 15 m, while the number of individuals with and without head injuries is the same in the group of falls from heights between 15 m and 30 m. In falls from heights beyond 30 m, the increase in frequency of head injuries was noticed to correspond to the rise of fall height. The statistical analysis shows that the rise of fall height is not associated with statistically significant increase of frequency of head injuries (for factor B—df = 1, $f = 347.314$, $p = 0.00$; for factor A—df = 11, $f = 30.599$, $p = 0.00$; for factor AB—df = 23, $f = 29.735$, $p = 0.00$).

The frequency of skull fractures and brain injuries in relation to the heights of falls are presented in Table 2. In falls from heights between 1 m and 7 m, the frequencies of linear and multifragmental fractures are almost equal (43% vs. 48%). The rise of fall height results in the increase of frequency of mutifragmental fractures. The statistical analysis of frequencies of brain and brain steam injuries regarding the height of fall, shows that type of brain injury

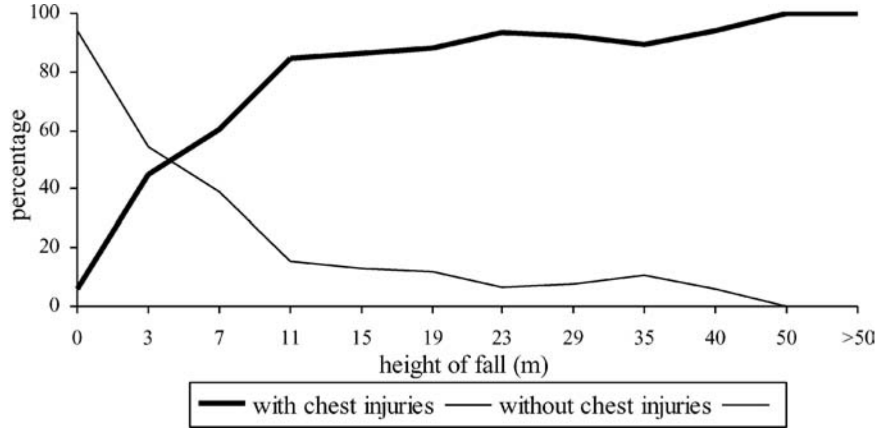

FIG. 2—*Percentage of cases with and without chest injuries related to the height of fall.*

TABLE 3—*The absolute number of chest injuries related to the height of fall.*

		Height of Fall (meters)											
	Type of Injury	<1	1–3	4–7	8–11	12–15	16–19	20–23	24–29	30–35	36–40	41–50	>50
Rib fractures	unilateral	6	39	24	11	38	10	9	4	14	6	3	4
	bilateral	1	22	16	49	53	20	19	21	27	10	9	13
Injured organ	lung	1	1	8	23	45	13	25	19	25	9	8	10
	heart	...	...	2	9	9	4	6	...	7	...	3	4
	aorta	1	4	4	7	20	5	7	4	8	8	4	1
	heart and aorta	...	...	1	5	10	7	4	7	11	6	4	8
Hemothorax	unilateral	...	...	5	15	11	2	3	4	1	1	1	...
	bilateral	1	4	8	15	38	12	11	6	8	4	5	7
Pneumothorax	unilateral	...	2	5	7	8	8	1	4	7	3	1	1
	bilateral	...	2	...	9	9	6	5	4	5	3	2	4
Total	with chest injury	6	62	40	60	91	30	28	25	41	16	12	17
	without chest injury	92	75	26	11	14	4	2	2	5	1	...	...
	Total	98	137	66	71	105	34	30	27	46	17	12	17

correlates with the rise of the height of fall (for factor B—df $= 3$, $f = 82.387$, $p = 0.00$; for factor A—df $= 21$, $f = 40.236$, $p = 0.00$; for factor AB—df $= 31$, $f = 35.230$, $p = 0.00$).

The frequencies of cases with and without chest injuries in view of the heights of falls are presented in Fig. 2. The statistical analysis shows that the rise of height of fall is significantly statistically associated with higher frequency of chest injuries (for factor B—df $= 1$, $f = 415.399$, $p = 0.00$; for factor A—df $= 9$, $f = 59.333$, $p = 0.00$; for factor AB—df $= 19$, $f = 49.968$, $p = 0.00$). The frequencies of rib fractures, injuries of chest organs and large blood vessels are presented in Table 3. A rupture of the aorta is most commonly located in the arch (82%). Ruptures of the aortic arch are found only in falls from the heights beyond 4 m. In 35% of all cases with injured aorta, the rupture of aortic arch is concomitant with fracture of the thoracic part of spine (Th 3/4). All ruptures of the lower parts of thoracic aorta are associated with fractures of the spine at the level of the aortic rupture. The heart ruptures are most commonly located on the atrial posterior wall (70%), while ruptures of ventricular wall are found in falls from heights beyond 7 m.

The frequencies of cases with and without abdominal injuries related to the heights of falls are presented in Fig. 3. The statistical analysis shows that the rise of height of fall is not significantly associated with increase of frequency of abdominal injuries (for factor B—df $= 1$, $f = 50.698$, $p = 0.00$; for factor A—df $= 11$, $f = 116.903$, $p = 0.00$; for factor AB—df $= 23$, $f = 58.116$, $p = 0.00$). The frequencies of injuries of abdominal organs and large blood vessels are presented in Table 4. The liver injuries were found in 21% of all cases, and the liver was the most commonly injured abdominal organ (91% out of all cases with abdominal trauma). In all cases with liver injuries, the right lobe was affected either solely or associated with injury of the other parts of the organ. Splenic ruptures were diagnosed in 19% of all cases, while concomitant injuries of spleen and liver were found in falls from heights beyond 24 m.

Discussion

The results of this study show that patterns and extent of injury are in correlation with fall height. The analysis reveal that cases could be classified into groups with and without head injuries depending on the height of falls. Gupta et al. (4) state that a high incidence of head injuries is found in falls from heights below 12 m. Our results show that the frequency of head injuries is the highest in falls from heights below 7 m and over 30 m. A possible explanation for this observation could be found in the body orientation at the moment of primary impact.

The greatest damage is related to the orientation of the body at the point of impact. The orientation of the body is determined by the fall height. In falls from heights up to 7 m and above 30 m primary head impact is the most frequent. In falls from heights over 30 m, associated with greater forces, the increased frequency of head injuries may be the result of primary impact, expected secondary head impact, and transmission of force.

TABLE 4—*The absolute number of abdominal injuries related to the height of fall.*

Type of Injury			Height of Fall (meters)											
			<1	1–3	4–7	8–11	12–15	16–19	20–23	24–29	30–35	36–40	41–50	>50
Injured organ	liver	rupture	1	3	11	15	59	17	11	20	28	...	...	...
		destruction	...	...	...	4	6	10	9	4	8	16	10	16
	spleen	rupture	1	1	3	2	28	10	6	14	8	4	3	6
		destruction	...	...	...	3	3	1	4	5	9	4	4	5
	stomach, intestines		...	...	...	9	12	7	4	10	5	3	4	5
	kidney		...	...	5	6	19	10	3	7	11	5	6	7
	diaphragm		...	...	...	3	1	1	...	2	3	1	1	2
	Hemoperitoneum		2	4	2	5	10	2	3	5	3	1	1	1
Total	with abdominal injury		2	4	14	22	68	27	21	24	36	16	10	16
	without abdominal injury		96	133	52	49	37	7	9	3	10	1	2	1
	Total		98	137	66	71	105	34	30	27	46	17	12	17

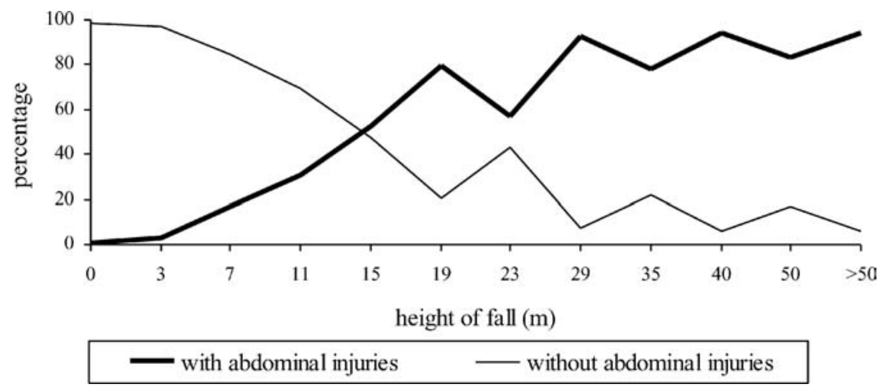

FIG. 3—*Percentage of cases with and without abdominal injuries related to the height of fall.*

The type of skull bone fractures statistically significantly correlates with the height of fall ($p > 0.05$). Heights beyond 7 m are associated with higher frequency of multifragmental fractures. In general, these fractures are depressed on a wide surface part of the head that impacted the ground. Most falls from height involve impact on flat ground. Depressed comminuted fractures are caused by some localized and projecting traumatic agent on the struck surface (4). A high frequency of multifragmental fractures in falls from heights beyond 30 m is thought to be the result of bouncing of the body following the primary impact. Often bony fragments cause external injuries (mostly skin lacerations), on the side of the head opposite to the spot of impact.

Combinations of lacerations and contusions of the brain are seen in low falls. In falls from heights beyond 30 m, the brain laceration without contusion is the only type of brain injury. These latter injuries are produced by a more severe level of violence and "jarring" (4). It has been reported that force effect that lasts 7.5 ms on average causes a fatal brain injury.

Contre coup contusions of the cerebral cortex are not found in falls from heights beyond 30 m. In very high falls, duration of force is very short, resulting in instant extensive damage to the brain in the site of impact (13) and instantaneous death—there is not enough time for intracranial bleeding to develop. At the other hand, contre coup contusions were found in falls between 7 m and 30 m because impact force is significantly lower than in heights above 30 m, and secondary head impact is rather frequent.

Thoracic injuries are in relation to fall height. The number of ribs fractured provides an index as to the relative force of the injury (14). The percentage of cases with fractured ribs is significantly statistically related to the height of fall ($p > 0.05$). It increases linearly in falls from heights beyond 3 m. Rib fractures are present in all falls from heights beyond 40 m. Despite the association of thoracic injury with fall height, the extensiveness of rib fractures is not connected. This is primarily due to the anatomic features of ribs, but also to the nature of the surface at the point of impact. The upper ribs have a small radius of curvature due to their circular shape, and they are protected by overlying muscles and scapula (5); fractures of the upper ribs (R1–R3) are associated with extreme force (15). The pattern of rib fractures may be useful to ascertain the nature of the impact.

The frequency of lung injuries increase in falls from heights beyond 3 m, but they are not significantly statistically related to the height of fall ($p < 0.05$). In falls from heights up to 12 m, the localization of lung lacerations corresponded to the location of the broken ends of the fractured ribs. In falls from heights over 12 m, rupture from the pneumostatic pressure caused by a sudden chest compression is also an important causative factor of lung lesions (4).

The frequency of aortic and heart ruptures is not significantly statistically related to the height of fall ($p < 0.05$). These ruptures are caused by caudorostral extension, deceleration, antero-posterior compression, hyper-extension, torsion, "hydraulic ram effect," penetration by broken bone ends, etc. The simultaneous effect of the above mentioned mechanisms generally increases with the rise of the height of fall. In the deceleration injuries, tears of the ascending part or arch of the aorta result from downward pull of the heart (4). Ruptures of the posterior atrial walls, being the thinnest area of the heart, are due to vertical deceleration, hyperextension or caudorostral extension, and increase of intracardial pressure caused by compression (antero-posterior "hydraulic ram effect)." Ruptures of anterior atrial walls are most commonly caused by broken ends of fractured ribs and sternum, thus, the probability of their occurrence is higher in high falls.

The frequency of hemothorax was not significantly statistically related to the height of fall ($p < 0.05$). Only the passive post-mortem haemorrhage from ruptured organs can be found in the pleural cavity in the case of high falls.

The frequency of abdominal injuries is not statistically significantly related to the height of fall ($p < 0{,}05$); however, in falls from heights beyond 15 m, the number of cases without abdominal injuries decreases, and the number of those with these injuries increases. This finding is primarily related to the liver injuries, predominantly rupture of the right liver lobe. A high frequency of liver injuries as compared to the other abdominal organs is determined by its mass and consistency. The majority of liver injuries are associated with a severe level of violence, caused by forces of compression (4). Rib fractures also contribute to the high frequency of liver injuries. On the other hand, splenic lacerations can be found in falls from all heights. The lesser mass of the spleen makes it less susceptible to pure decelerative forces. In low falls they are associated with fractures of lower ribs. This suggests a primary left side of body impact. In high falls, vascular hydrostatic pressure causes ruptures of this report that organ due to the compression forces. Gupta et al. similarly reportthat these injuries, found in falls from heights beyond 12 m, are caused by severe degree of violence produced by forces of compression (4). Also, traction forces may tear the spleen from its pedicle. Liver and spleen injuries were always associated in falls from heights beyond 24 m. In these high falls, when the force is sufficiently intensive to produce spleen injury, the liver, due to its mass, is also injured regardless of the nature of impact.

The frequency of hemoperitoneum is not related to the number and severity of injuries of abdominal organs, despite the fact that they usually produce considerable bleeding. The frequency and quantity of blood in the abdomen decreases in high falls from heights beyond 15 m. In all falls from heights beyond 40 m, the quantity of blood found in the abdominal cavity is less than 300 mL, and is located only around the injured organ. When the height of fall is great, death is instantaneous, so there is no time for significant intraabdominal bleeding to develop.

Injuries of the kidneys are not common. This can be explained by their anatomical position in a relatively well-protected retroperitoneal part of the body. Renal injuries are caused by direct force, and often associated with injuries of the pelvic bones. Kidney injuries are not related to fall height.

The results of our investigation reveal that the frequency and extent of injuries of various body regions and organs may be related to the height of fall. Head injuries are characteristic of falls from heights below 7 m and beyond 30 m. Frequency and extent of the thoracic injuries are strongly correlated with the height of fall. Frequency and extent of abdominal injuries are not associated with height of fall, while the frequency of liver injuries best represents the frequency of abdominal injuries. The height of fall over 15 m appears to be a reasonable border height over which the injuries of two or three body regions are generally associated.

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