Forensic Science International 302 (2019) 109883

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

The pathological diagnosis of the height of fatal falls: A mathematical approach

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ARTICLE INFO

Article history:
Received 14 December 2018
Received in revised form 18 June 2019
Accepted 20 July 2019
Available online 29 July 2019

Keywords:
Height of fall
Autopsy
Injury severity
Mathematical model
Forensic sciences

ABSTRACT

The authors analyzed the injury pattern of 385 victims of fall from a height which underwent a complete autopsy, with the objective to investigate whether it was possible to construct a mathematical model to be used for height of the fall diagnosis. The cases were selected and enrolled according to a balanced stratification of the heights of the fall, allowing a subdivision into seven classes consisting of 55 subjects each: 6 m or less, 9 m, 12 m, 15 m, 18 m, 21 m, 24 m or more (maximum 36 m). For each case anthropologic and necroscopic data was collected and analyzed to obtain a standardized description of the injury pattern was obtained, dividing the body into 4 major anatomical areas (Head, Thorax, Abdomen, Skeleton), each of them further divided in 5 major organs. Every organ was finally divided into 5 objective degrees of injury. Statistical analysis was performed on all the available data using IBM SPSS Statistics 20, to test the performance of the "injury pattern assessment table" in the diagnosis of the height of the fall and to develop a related mathematical model. Our findings confirm that the height of the fall is significantly associated with age, weight of the body and the injury pattern. An Injury Pattern Assessment Table and two mathematical models which correlates the height of the fall with analyzed variables are presented.

1. Introduction

Death due to falls from heights is a common phenomenon worldwide, especially in urban setting, and can result from homicide, suicide or accident [1].

Dealing with fatal falls from a height, forensic pathologists are often asked to give a technical estimation of the height of the fall and such estimation is clearly an important element in the connected judicial investigation. In the Authors' professional routine it is not infrequent the absolute lack of non-technical clues concerning the height of the fatal fall: in such cases the only useful information may therefore come from the autoptic examination of the body. Despite an extensive descriptive literature about victims of fatal falls, pathological contributions specifically focused on the estimation of the height of the fall are not numerous. The available literature homogeneously suggests that the injury pattern of such victims is linked to the height of the fall and to the kinetic energy at impact [2–5]. Starting from previous contributions [6,7], the Authors' aim was to investigate if it is possible to create a reliable mathematical model for the pathological diagnosis of the height of fatal falls. As the first experimental step, the present work proposes an Injury Pattern Assessment Table, integrating skeletal and visceral data and ready to use in the routine autoptic practice.

2. Materials and methods

The Authors analyzed 385 victims of falls from a height which underwent a complete autopsy at the Institute of Forensic Medicine of Milan-Italy, from January 1st 2009 to December 31st 2015. Only cases with complete police reports (i.e. with known height of the fatal fall) and with reported single impact on solid surface, death on site and absence of hospital medical procedures were included in the study. No imaging techniques were used, according to the Authors' basic routine autoptic practice. The experimental cases were selected and enrolled according to abalanced stratification of the height of the fall: a subdivision into seven classes consisting of 55 subjects each was obtained (6 m or less, 9 m, 12 m, 15 m, 18 m, 21 m, 24 m or more - maximum

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http://dx.doi.org/10.1016/j.forsciint.2019.109883
0379-0738/

36 m -). The regular 3 m shift along the experimental classes of height was based on the well-known rule about the standard and mean heights for the floors in civil buildings. For each enrolled case, anthropologic and necroscopic data was also investigated (sex, age, weight, height of the subject, skeletal and visceral injury pattern distribution). The injury pattern was described for each case dividing the body into 4 major anatomical areas (Head, Thorax, Abdomen, Skeleton), each of them further divided in 5 organs; every organ was finally divided into 5 objective degrees of injury (Injury Pattern Assessment Table, Appendix 1). The proposed Injury Pattern Assessment Table was always completed real-time during the autoptic examination. All the autoptic procedures were performed by one of the Authors (MBC, AB, EF) or by a trained forensic pathologist co-working with one of the Authors (MCB, AB, SG, EF). The proposed scoring Table directly comes from the results of a previous series on suicidal fatal falls published by the Authors [7]. Statistical analysis was performed on all the available data using IBM SPSS Statistics 20 to test the performance of the Injury Pattern Assessment Table in the diagnosis of the height of the falls and to develop a connected mathematical model: after a model with three grades of lesions was created (0 = no lesions, 1 and 2 = minor lesions; 3 and 4 = severe lesions), a further useful dicotomic evaluation was obtained to simplify statistical analyses (no or minor lesions versus severe lesions).

3. Results

Specific information about sex, age, height of the subjects, weight of the subjects stratified for the height of the falls are summarized in Table 1.

Detailed results for all the autoptic variables, according to the proposed Injury Pattern Assessment Table are represented in Table 2.

As far as the analysis of the major anatomical areas is concerned, thoracic lesions are present in almost every case, with an average of 96.4% of all cases. An increase in the incidence of lesions for the Abdomen was noted, since it ranges from 58.2% in falls ≤6 m to 87.3% in those ≥12 m ($p < 0.01$). The axial skeleton has a 94.5% incidence of injury in falls ≤6 m and here there is always injury when the fall is ≥16 m. It is noticeable that head injuries are almost stable across the height classes (Fig. 1).

Further, evaluating the observed lesions in a craniocaudal sense, it is observed that the presence of lesions of the cranial vault and of the cranial base is attested around 55% for each class of height of the fall. Similarly, the presence of severe lesions occurs on average in 40.3% of the fall from any height.

Facial bones injuries have a very low incidence in ≤6 m falls (14.5% of cases with presence of any type of lesion) but their frequency increases proportionally to height (until a presence of injury in 52.7% cases for falls ≥24 m).

Cerebrum severe lesions are directly related with the height of the fall: the presence ranges from 12.7% in ≤6 m falls to 32.7% in ≥24 m falls. Cerebellum and brainstem are the head organs less injured and have lesions in 17.7% and 15.6% of cases, respectively. In both organs, the presence of severe lesions is directly proportional to the height of the fall: in both cases the presence of severe lesions rises from 1.8% to 3.6% in falls ≤6 m up to 29% in falls ≥24 m.

Lungs are often affected: the presence of lesions was registered in about 75% of cases ≤9 m, and in 98.2% cases ≥21 m. Severe lesions are present in more than 50% of cases ≥21 m.

Injuries of the trachea and major bronchi are infrequent (11.2% of all cases); however a direct correlation with the height of the fall has been noted.

Also heart injury pattern showed a direct correlation with the height of the fall: the presence of lesions is observed in 32.7% of falls ≤6 m and in 72.7% of cases ≥24 m. Severe lesions have an incidence of 5.5% in falls ≤6 m and of 34.5% in cases ≥24 m.

Thoracic aorta is characterized by a low incidence of lesions (21.8%) in falls ≤6 m, with a plateau of 50–60% incidence for cases falling ≥16 m.

Diaphragm is often intact (90% of all cases); however severe lesions have a certain progression according to the increasing height of the fall (from 1.8% to 25.4%).

Hepatic lesions are present in 50% of falls ≤9 m falls, while in higher falls only less than 25% of cases have no lesions (for cases ≥24 m 92.7% have lesions). The presence of hepatic severe lesions has then a clear correlation with the height of the fall with incidence of 12.7% in ≤6 m cases, of 43.6% in cases from 12 m and of 72.7% in falls ≥24 m.

About the spleen, falls ≤6 m seem to rarely result in injuries. In cases falling from 9 m to 18 m, less than 30% have lesions, but in the subgroup ≥21 m severe lesions are quite frequent (even if with a homogeneous distribution among no-lesions, minor lesions and severe lesions: 33% versus 34% versus 33%).

Injuries of the abdominal aorta are very infrequent: only 9.3% of all cases report an injury, mainly minor injuries.

Kidney injuries for falls ≤6 m and ≥24 m are present in, respectively, 9.1% and 36.4% of the cases. Severe kidney lesions are present in 16.3% of cases ≥21 m.

Concerning the mesentery, there is presence of lesions in less than 20% of cases ≤18 m, while for cases falling from 21 m such percentage increases until reaching a 45.5% in falls ≥24 m.

Table 1
General population data.

	Gender		Age at fall	Age's categories			Height (cm)	Weight (kg) [range]	BMI	Potential energy (J)
	F	M		16–35	36–59	60+				
<6 m	19 (	36	58.8	11	14	29	167.2	76.3	27.1	3.977
55 (14.3)	34.55)	(65.45)	(20–90)	(20)	(25.5)	(52.7)	± 8.8	[29.6–116.3]	±5	±1.261
7–9 m	28	27	61.2	6	14	35	163.9	66.1	24.9	5.817
55 (14.3)	(50.9)	(49.1)	(18–85)	(10.9)	(25.5)	(63.6)	± 11.6	[30–98]	±4.2	±1.280
10–12 m	24 (	31	55.2	11	19	25	167.6	72.5	25.6	8.531
55 (14.3)	43.64)	(56.36)	(21–94)	(20)	(34.5)	(45.5)	±11.2	[46–123.9]	±5.7	±2.435
13–15 m	22	33	54.1	6	24	25	167.5	72.3	25.8	10.610
55 (14.3)	(40)	(60)	(11–87)	(10.9)	(43.6)	(45.5)	± 8.7	[51.2–116]	±5.1	±1.898
16–18 m	34	21	54.4	13 (23.6)	17	25	164.5	67.9	24.8	11.981
55 (14.3)	(61.82)	(38.18)	(14–94)		(30.9)	(45.5)	± 10.1	[42–104.7]	±3.7	±2.485
19–21 m	19	36	53.8	13 (23.6)	19	23	167.3	69	24.5	14.190
55 (14.3)	(34.55)	(65.45)	(19–95)		(34.5)	(41.8)	± 9.9	[34–124]	±4.6	±3.561
22 + m	29	26	52.6	15 (27.3)	18	22	163.9	68	25.1	17.164
55 (14.3)	(52.73)	(47.27)	(13–95)		(32.7)	(40)	± 7.7	[49.7–141]	±6.7	±5.582
Total	175 (45.45)	210 (54.55)	55.7	75	125	184	165.9	70.2	25.4	10.466
385 (100)			(11–95)	(19.5)	(32.5)	(47.8)	± 9.9	[29.6–141]	±5.1	±5.178

Table 2
Resulted autoptic variables according to the proposed Injury Pattern Assessment Table.

	Height of the fall							
	<6 m 55 (14.3)	7–9 m 55 (14.3)	10–12 m 55 (14.3)	13–15 m 55 (14.3)	16–18 m 55 (14.3)	19–21 m 55 (14.3)	22+ m 55 (14.3)	Total 385 (100)
Head	34 (61.8)	38 (69.1)	39 (70.9)	36 (65.5)	34 (61.8)	39 (70.9)	39 (70.9)	259 (67.3)
Skull (vault + base) 0	24 (43.6)	25 (45.4)	27 (49.1)	26 (47.3)	24 (43.6)	24 (43.6)	25 (45.4)	175 (45.5)
Skull (vault + base) 1	5 (9.1)	6 (10.9)	2 (3.6)	7 (12.7)	1 (1.8)	3 (5.4)	4 (7.3)	28 (7.3)
Skull (vault + base) 2	4 (7.3)	5 (9.1)	4 (7.3)	2 (3.6)	5 (9.1)	4 (7.3)	3 (5.4)	27 (7)
Skull (vault + base) 3	14 (25.5)	5 (9.1)	8 (14.5)	7 (12.7)	10 (18.2)	5 (9.1)	8 (14.5)	57 (14.8)
Skull (vault + base) 4	8 (14.5)	14 (25.5)	14 (25.5)	13 (23.6)	15 (27.3)	19 (34.5)	15 (27.3)	98 (25.5)
Facial skeleton 0	47 (85.5)	35 (63.6)	37 (67.3)	33 (60)	34 (61.8)	31 (56.4)	26 (47.3)	243 (63.1)
Facial skeleton 1	5 (9.1)	5 (9.1)	6 (10.9)	5 (9.1)	5 (9.1)	14 (25.5)	6 (10.9)	46 (11.9)
Facial skeleton 2	1 (1.8)	5 (9.1)	4 (7.3)	4 (7.3)	3 (5.4)	3 (5.4)	5 (9.1)	25 (6.5)
Facial skeleton 3	1 (1.8)	5 (9.1)	4 (7.3)	2 (3.6)	2 (3.6)	1 (1.8)	4 (7.3)	19 (4.9)
Facial skeleton 4	1 (1.8)	5 (9.1)	4 (7.3)	11 (20)	11 (20)	6 (10.9)	14 (25.5)	52 (13.5)
Cerebrum 0	34 (61.8)	36 (65.5)	44 (80)	43 (78.2)	42 (76.4)	37 (67.3)	36 (65.5)	272 (70.6)
Cerebrum 1	10 (18.2)	7 (12.7)	–	1 (1.8)	3 (5.4)	1 (1.8)	1 (1.8)	23 (6)
Cerebrum 2	4 (7.3)	2 (3.6)	4 (7.3)	1 (1.8)	1 (1.8)	1 (1.8)	–	13 (3.4)
Cerebrum 3	3 (5.4)	3 (5.4)	1 (1.8)	1 (1.8)	–	2 (3.6)	3 (5.4)	13 (3.4)
Cerebrum 4	4 (7.3)	7 (12.7)	6 (10.9)	9 (16.4)	14 (25.5)	16 (29.1)	52 (13.5)	64 (16.6)
Cerebellum 0	53 (96.4)	49 (89.1)	49 (89.1)	43 (78.2)	44 (80)	41 (74.5)	38 (69.1)	317 (82.3)
Cerebellum 1	1 (1.8)	3 (5.4)	1 (1.8)	1 (1.8)	2 (3.6)	–	1 (1.8)	9 (2.3)
Cerebellum 2	–	–	1 (1.8)	3 (5.4)	–	–	–	4 (1)
Cerebellum 3	–	–	1 (1.8)	2 (3.6)	–	–	–	3 (0.8)
Cerebellum 4	1 (1.8)	3 (5.4)	3 (5.4)	6 (10.9)	9 (16.4)	14 (25.5)	16 (29.1)	52 (13.5)
Brainstem 0	49 (89.1)	48 (87.3)	54 (98.2)	47 (85.5)	42 (76.4)	46 (83.6)	39 (70.9)	325 (84.4)
Brainstem 1	4 (7.3)	3 (5.4)	–	–	1 (1.8)	–	–	8 (2.1)
Brainstem 2	–	1 (1.8)	–	1 (1.8)	–	–	–	2 (0.5)
Brainstem 3	–	–	–	–	1 (1.8)	–	3 (5.4)	4 (1)
Brainstem 4	2 (3.6)	3 (5.4)	1 (1.8)	7 (12.7)	11 (20)	9 (16.4)	13 (23.6)	46 (11.9)
Thorax	48 (87.3)	49 (89.1)	55 (100)	55 (100)	54 (98.2)	55 (100)	55 (100)	371 (96.4)
Lungs 0	15 (27.3)	13 (23.6)	4 (7.3)	3 (5.5)	4 (7.3)	1 (1.8)	1 (1.8)	41 (10.6)
Lungs 1	22 (40)	18 (32.7)	11 (20)	15 (27.3)	17 (30.9)	10 (18.2)	14 (25.5)	107 (27.8)
Lungs 2	9 (16.4)	17 (30.9)	15 (27.3)	23 (41.8)	22 (40)	8 (14.5)	9 (16.4)	103 (26.7)
Lungs 3	5 (9.1)	4 (7.3)	20 (36.4)	5 (9.1)	7 (12.7)	19 (34.5)	15 (27.3)	75 (19.5)
Lungs 4	4 (7.3)	3 (5.5)	5 (9.1)	9 (16.4)	5 (9.1)	17 (30.9)	16 (29.1)	59 (15.3)
Trachea/Bronchi 0	54 (98.2)	53 (96.4)	52 (94.5)	49 (89.1)	46 (83.6)	46 (83.6)	42 (76.4)	342 (88.8)
Trachea/Bronchi 1	–	–	–	–	3 (5.5)	1 (1.8)	2 (3.6)	6 (1.5)
Trachea/Bronchi 2	–	1 (1.8)	–	–	–	–	1 (1.8)	2 (0.5)
Trachea/Bronchi 3	–	1 (1.8)	3 (5.5)	4 (7.3)	6 (10.9)	6 (10.9)	5 (9.1)	25 (6.5)
Trachea/Bronchi 4	1 (1.8)	–	–	2 (3.6)	–	2 (3.6)	5 (9.1)	10 (2.6)
Heart 0	37 (67.3)	26 (47.3)	31 (56.4)	30 (54.5)	19 (34.5)	20 (36.4)	15 (27.3)	178 (46.2)
Heart 1	6 (10.9)	16 (29.1)	8 (14.5)	12 (21.8)	14 (25.5)	10 (18.2)	12 (21.8)	78 (20.3)
Heart 2	9 (16.4)	9 (16.4)	9 (16.4)	7 (12.7)	8 (14.5)	9 (16.4)	9 (16.4)	60 (15.6)
Heart 3	3 (5.5)	3 (5.5)	6 (10.9)	5 (9.1)	9 (16.4)	10 (18.2)	1 (1.8)	37 (9.6)
Heart 4	–	1 (1.8)	1 (1.8)	1 (1.8)	5 (9.1)	6 (10.9)	18 (32.7)	32 (8.3)
Thoracic Aorta 0	43 (78.2)	28 (50.9)	30 (54.5)	24 (43.6)	23 (41.8)	22 (40)	23 (41.8)	193 (50.1)
Thoracic Aorta 1	5 (9.1)	8 (14.5)	13 (23.6)	6 (10.9)	6 (10.9)	7 (12.7)	5 (9.1)	50 (13)
Thoracic Aorta 2	–	–	1 (1.8)	4 (7.3)	1 (1.8)	2 (3.6)	4 (7.3)	12 (3.1)
Thoracic Aorta 3	4 (7.3)	18 (32.7)	11 (20)	16 (29.1)	15 (27.3)	15 (27.3)	14 (25.5)	93 (24.1)
Thoracic Aorta 4	3 (5.5)	1 (1.8)	–	5 (9.1)	10 (18.2)	9 (16.4)	9 (16.4)	37 (9.6)
Diaphragm 0	52 (94.5)	50 (90.9)	51 (92.7)	48 (87.3)	43 (78.2)	39 (70.9)	34 (61.8)	317 (82.4)
Diaphragm 1	2 (3.6)	1 (1.8)	2 (3.6)	1 (1.8)	2 (3.6)	1 (1.8)	5 (9.1)	14 (3.6)
Diaphragm 2	–	1 (1.8)	1 (1.8)	1 (1.8)	1 (1.8)	4 (7.3)	2 (3.6)	10 (2.6)
Diaphragm 3	–	2 (3.6)	–	–	2 (3.6)	1 (1.8)	6 (10.9)	11 (2.8)
Diaphragm 4	1 (1.8)	1 (1.8)	1 (1.8)	5 (9.1)	7 (12.7)	10 (18.2)	8 (14.5)	33 (8.6)
Abdomen	32 (58.2)	37 (67.3)	48 (87.3)	49 (89.1)	50 (90.9)	53 (96.4)	53 (96.4)	322 (83.6)
Liver 0	29 (52.7)	27 (49.1)	13 (23.6)	18 (32.7)	9 (16.4)	7 (12.7)	4 (7.3)	107 (27.8)
Liver 1	8 (14.5)	4 (7.3)	3 (5.4)	4 (7.3)	6 (10.9)	–	6 (10.9)	31 (8)
Liver 2	11 (20)	12 (21.8)	15 (27.3)	8 (14.5)	14 (25.5)	10 (18.2)	5 (9.1)	75 (19.4)
Liver 3	2 (3.6)	5 (9.1)	3 (5.4)	2 (3.6)	4 (7.3)	6 (10.9)	5 (9.1)	27 (7)
Liver 4	5 (9.1)	7 (12.7)	21 (38.2)	23 (41.8)	22 (40)	32 (58.2)	35 (63.6)	145 (37.6)
Spleen 0	45 (81.8)	35 (63.6)	36 (65.5)	27 (49.1)	37 (67.3)	19 (34.5)	18 (32.7)	217 (56.4)
Spleen 1	6 (10.9)	4 (7.3)	3 (5.4)	6 (10.9)	6 (10.9)	4 (7.3)	5 (9.1)	34 (8.8)
Spleen 2	4 (7.3)	7 (12.7)	9 (16.4)	10 (18.2)	5 (9.1)	8 (14.5)	14 (25.5)	57 (14.8)
Spleen 3	–	3 (5.4)	1 (1.8)	4 (7.3)	–	4 (7.3)	3 (5.4)	15 (3.9)
Spleen 4	–	6 (10.9)	6 (10.9)	8 (14.5)	7 (12.7)	20 (36.4)	15 (27.3)	62 (16.1)
Abdominal Aorta 0	54 (98.2)	53 (96.4)	54 (98.2)	48 (87.3)	50 (90.9)	47 (85.4)	47 (85.4)	353 (91.7)
Abdominal Aorta 1	–	1 (1.8)	–	4 (7.3)	1 (1.8)	5 (9.1)	3 (5.4)	14 (3.6)
Abdominal Aorta 2	–	1 (1.8)	1 (1.8)	–	3 (5.4)	2 (3.6)	–	7 (1.8)
Abdominal Aorta 3	1 (1.8)	–	–	2 (3.6)	–	1 (1.8)	4 (7.3)	8 (2.1)
Abdominal Aorta 4	–	–	–	1 (1.8)	1 (1.8)	–	1 (1.8)	3 (0.8)
Kidneys 0	50 (90.9)	47 (85.4)	41 (74.5)	37 (67.3)	39 (70.9)	36 (65.5)	35 (63.6)	285 (74)
Kidneys 1	2 (3.6)	2 (3.6)	5 (9.1)	2 (3.6)	5 (9.1)	5 (9.1)	1 (1.8)	22 (5.7)
Kidneys 2	2 (3.6)	2 (3.6)	7 (12.7)	11 (20)	6 (10.9)	5 (9.1)	10 (18.2)	43 (11.2)
Kidneys 3	1 (1.8)	2 (3.6)	1 (1.8)	2 (3.6)	1 (1.8)	2 (3.6)	4 (7.3)	13 (3.4)
Kidneys 4	–	2 (3.6)	1 (1.8)	3 (5.4)	4 (7.3)	7 (12.7)	5 (9.1)	22 (5.7)

Table 2 (*Continued*)

	Height of the fall							
	<6 m 55 (14.3)	7–9 m 55 (14.3)	10–12 m 55 (14.3)	13–15 m 55 (14.3)	16–18 m 55 (14.3)	19–21 m 55 (14.3)	22+ m 55 (14.3)	Total 385 (100)
Mesentery 0	49 (89.1)	44 (80)	47 (85.4)	49 (89.1)	44 (80)	38 (69.1)	30 (54.5)	301 (78.2)
Mesentery 1	2 (3.6)	2 (3.6)	2 (3.6)	1 (1.8)	–	2 (3.6)	3 (5.4)	12 (3.1)
Mesentery 2	4 (7.3)	8 (14.5)	6 (10.9)	2 (3.6)	8 (14.5)	8 (14.5)	15 (27.3)	51 (13.2)
Mesentery 3	–	1 (1.8)	–	1 (1.8)	1 (1.8)	3 (5.4)	4 (7.3)	10 (2.6)
Mesentery 4	–	–	–	2 (3.6)	2 (3.6)	4 (7.3)	3 (5.4)	11 (2.8)
Skeleton	52 (94.5)	53 (96.4)	55 (100)	55 (100)	55 (100)	55 (100)	55 (100)	380 (98.7)
Cervical Spine 0	50 (90.9)	49 (89.1)	43 (78.2)	41 (74.5)	36 (65.5)	37 (72.5)	37 (72.5)	293 (76.1)
Cervical Spine 1	3 (5.4)	4 (7.3)	7 (12.7)	8 (14.5)	6 (10.9)	9 (16.4)	5 (9.1)	42 (10.9)
Cervical Spine 2	–	1 (1.8)	1 (1.8)	3 (5.4)	2 (3.6)	3 (5.4)	4 (7.3)	14 (3.6)
Cervical Spine 3	2 (3.6)	1 (1.8)	2 (3.6)	3 (5.4)	6 (10.9)	4 (7.3)	6 (10.9)	24 (6.2)
Cervical Spine 4	–	–	2 (3.6)	–	5 (9.1)	2 (3.6)	3 (5.4)	12 (3.1)
Thoracic Spine 0	46 (83.6)	35 (63.6)	38 (69.1)	33 (60)	31 (56.4)	28 (50.9)	29 (52.7)	240 (62.3)
Thoracic Spine 1	4 (7.3)	7 (12.7)	6 (10.9)	8 (14.5)	7 (12.7)	11 (20)	10 (18.2)	53 (13.8)
Thoracic Spine 2	2 (3.6)	5 (9.1)	5 (9.1)	4 (7.3)	3 (5.4)	2 (3.6)	4 (7.3)	25 (6.5)
Thoracic Spine 3	2 (3.6)	7 (12.7)	4 (7.3)	6 (10.9)	8 (14.5)	10 (18.2)	6 (10.9)	43 (11.2)
Thoracic Spine 4	1 (1.8)	1 (1.8)	2 (3.6)	4 (7.3)	6 (10.9)	4 (7.3)	6 (10.9)	24 (6.2)
Lumbar Spine 0	51 (92.7)	46 (83.6)	53 (96.4)	45 (81.8)	43 (78.2)	50 (90.9)	49 (89.1)	337 (87.5)
Lumbar Spine 1	3 (5.4)	6 (10.9)	–	6 (10.9)	6 (10.9)	2 (3.6)	3 (5.4)	26 (6.7)
Lumbar Spine 2	1 (1.8)	2 (3.6)	1 (1.8)	2 (3.6)	1 (1.8)	–	–	7 (1.8)
Lumbar Spine 3	–	1 (1.8)	1 (1.8)	–	4 (7.3)	3 (5.4)	2 (3.6)	11 (2.9)
Lumbar Spine 4	–	–	–	2 (3.6)	1 (1.8)	–	1 (1.8)	4 (1)
Pelvis 0	27 (49.1)	24 (43.6)	11 (20)	16 (29.1)	11 (20)	6 (10.9)	7 (12.7)	102 (26.5)
Pelvis 1	8 (14.5)	6 (10.9)	12 (21.8)	10 (18.2)	5 (9.1)	8 (14.5)	6 (10.9)	55 (14.3)
Pelvis 2	6 (10.9)	11 (20)	11 (20)	8 (14.5)	6 (10.9)	7 (12.7)	7 (12.7)	56 (14.5)
Pelvis 3	11 (20)	11 (20)	16 (29.1)	13 (23.6)	22 (40)	21 (38.2)	23 (41.8)	117 (30.4)
Pelvis 4	3 (5.4)	3 (5.4)	5 (9.1)	8 (14.5)	11 (20)	13 (23.6)	12 (21.8)	55 (14.3)
Complex Sternum/Clavicle/Ribs 0	7 (12.7)	4 (7.3)	2 (3.6)	2 (3.6)	2 (3.6)	2 (3.6)	1 (1.8)	20 (5.2)
Complex S.C.R. 1	6 (10.9)	5 (9.1)	3 (5.4)	5 (9.1)	2 (3.6)	–	2 (3.6)	23 (6)
Complex S.C.R. 2	4 (7.3)	5 (9.1)	1 (1.8)	–	5 (9.1)	–	–	15 (3.9)
Complex S.C.R. 3	16 (29.1)	7 (12.7)	10 (18.2)	5 (9.1)	6 (10.9)	2 (3.6)	6 (10.9)	52 (13.5)
Complex S.C.R. 4	22 (40)	34 (61.8)	39 (70.9)	43 (78.2)	40 (72.7)	51 (92.7)	46 (83.6)	275 (71.4)

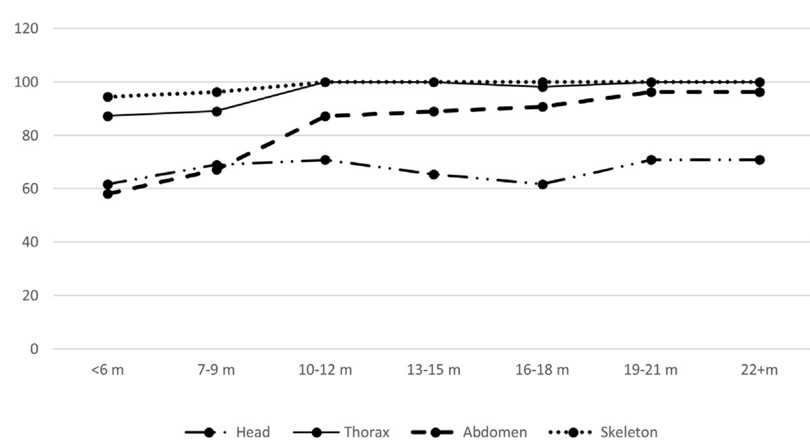

Fig. 1. Major anatomical areas involvement.

The cervical spine for cases falling ≤6 m has damage in 9.1% of cases. The thoracic part of the vertebral column is involved from 16.4% of cases ≤6 m to about 50% in falls ≥21 m. Of the three spinal tracts evaluated, the lumbar one is the less involved, also concerning the spinal cord involvement (the latter actually found in 3.9% of all the studied population).

The pelvic bone is injured in 51% of cases ≤6 m falls and this percentage reaches up to 89.1% for falls ≥21 m. While minor lesions are present with minimal discrepancies across all the height classes, severe lesions have a clear correlation with the height of the fall: their presence ranges from 25.5% in falls ≤6 m to 63.6% in falls ≥24 m.

As expected, the sternum-clavicle-ribs complex is almost invariably involved: the presence of fractures occurs in about 87% of falls ≤6 m, in 93% of falls from 9 m and in about 96% of cases for all the subsequent classes. Unilateral fractures are present in 18.2% of cases falling up to ≤9 m, while in the subsequent height classes they are generally present in less than 10% of cases. Bilateral fracture lesions are present in 69.1% of falls ≤6 m and they reach an incidence of 96.4% for cases ≥21 m.

Based on all the acquired data, a multiple linear regression was carried out. Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity, multicollinearity and homoscedasticity. In the proposed mathematical model, the height of the fall is the dependent variable (Y) studied through the numerous independent variables previously showed (Xn). The analysis used all the autopsy results as independent variables, translated into a dichotomous 0–1 score to represent the absence (0) versus the presence (1) of severe lesions to each organ. Among the independent variables, the age of the subject and the weight of the body were also analyzed, as previously done by Lau et al. regarding the age and accordingly also to the fact that the weight of the body affects the kinetic energy [6,7]. Based on all these findings, the following mathematical equation was obtained (Table 3 and Fig. 2):

$$\begin{aligned}Y(m) = {} & 15.630 - 0.097(\mathrm{Age}) - 0.038(\mathrm{weight}) \\ & + 0.170(X_{\mathrm{neurocranium}}) + 1.073(X_{\mathrm{facial\ skeleton}}) \\ & - 0.530(X_{\mathrm{cerebrum}}) + 0.604(X_{\mathrm{cerebellum}}) + 1.711(X_{\mathrm{brainstem}}) \\ & + 1.210(X_{\mathrm{lungs}}) + 1.492(X_{\mathrm{trachea/bronchi}}) + 0.674(X_{\mathrm{heart}}) \\ & + 1.613(X_{\mathrm{thoracic\ aorta}}) + 2.223(X_{\mathrm{diaphragm}}) + 2.789(X_{\mathrm{liver}}) \\ & + 1.306(X_{\mathrm{spleen}}) + 4.002(X_{\mathrm{abdominal\ aorta}}) + 0.302(X_{\mathrm{kidneys}}) \\ & + 2.490(X_{\mathrm{mesentery}}) + 1.086(X_{\mathrm{cervical\ spine}}) \\ & + 0.735(X_{\mathrm{thoracic\ spine}}) + 1.607(X_{\mathrm{lumbar\ spine}}) + 1.921(X_{\mathrm{pelvis}}) \\ & + 3.133(X_{\mathrm{s-c-c\ complex}})\end{aligned}$$

where age = age in years, $X=1$ if there is a severe lesion in the organ versus $X=0$ if there is not.

This equation accounts for approximately 42% of the variability observed, as indicated by the adjusted R^2 value. The standard error in the height prediction given by the regression line is 5.199 m.

A second multiple linear regression analysis was also carried out, using as independent variables the number of organs with high lesions in each major anatomical area (Table 4 and Fig. 3).

The mathematical equation (resulting in an adjusted R^2 value of 39.3% and in a standard error of 5.191 m) is

$$\begin{aligned}Y(m) = {} & 16.098 - 0.090(Age) - 0.036(weight) + 0.421(X_{\mathrm{head}}) \\ & + 1.465(X_{\mathrm{Thorax}}) + 1.974(X_{\mathrm{Abdomen}}) + 1.836(X_{\mathrm{Skeleton}})\end{aligned}$$

where X = the number of organs with severe lesion in that major anatomical area.

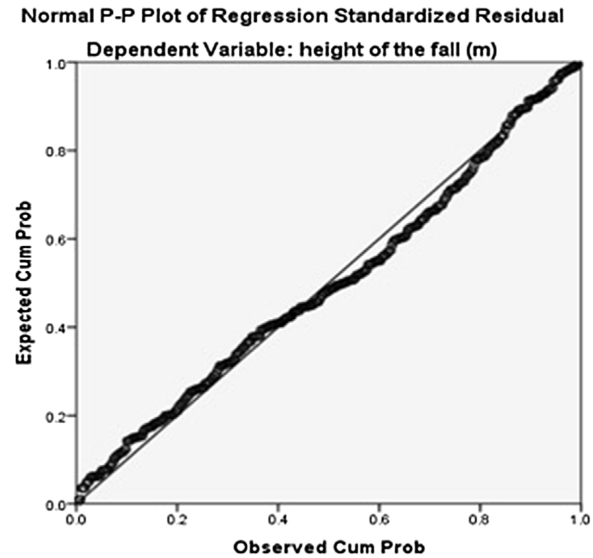

Fig. 2. P-P plot regarding first equation.

4. Discussion

The results of the present study confirms the previous finding of Lau et al. ascertaining the possibility to design a mathematical model to relate the height of the fall to the injury pattern.

Previously the height of the fall was linked with the Injury Severity Score (ISS), but the Authors believe that ISS (as a clinical tool) is prone to interpretative biases in the forensic field. The Authors believe that the forensic description of lesions using a guided Injury Pattern Assessment Table (like the one here proposed) can appreciably increase the inter-individual reproducibility of the autoptic evaluation of the victims of falls from a

Table 3
Multiple linear regression model (organs).

R	0.648
R Square	0.420
Adjusted *R* Square	0.381
Std. error of the estimate	5.199

Independent variables	Regression coefficient	Standard error	T-statistic	P value
Intercept (constant)	15.630	1.697	9.208	<0.0001
Age	− 0.097	0.015	−6.398	<0.0001
Weight	− 0.038	0.017	−2.212	0.028
Neurocranium	0.170	0.732	0.232	0.816
Facial skeleton	1.073	0.905	1.186	0.237
Cerebrum	− 0.530	1.049	−0.506	0.614
Cerebellum	0.604	1.242	0.486	0.627
Brainstem	1.711	1.194	1.433	0.153
Lungs	1.210	0.672	1.800	0.073
Trachea/bronchi	1.492	1.078	1.385	0.167
Heart	0.674	0.885	0.762	0.447
Thoracic aorta	1.613	0.656	2.458	0.015
Diaphragm	2.223	0.942	2.360	0.079
Liver	2.789	0.634	4.399	<0.0001
Spleen	1.306	0.777	1.679	0.094
Abdominal aorta	4.002	1.750	2.287	0.023
Kidneys	0.302	1.050	0.288	0.774
Mesentery	2.490	1.334	1.867	0.063
Cervical spine	1.086	1.023	1.062	0.289
Thoracic spine	0.735	0.796	0924	0.356
Lumbar spine	1.607	1.517	1.060	0.290
Pelvis	1.921	0.620	3.096	0.002
S-c-c complex	3.133	0.869	3.604	<0.0001

Table 4
Multiple linear regression model (anatomical areas).

R				0.627
R Square				0.393
Adjusted *R* Square				0.382
Std. error of the estimate				5.191
Independent variables	Regression coefficient	Standard error	T-statistic	P value
Intercept (constant)	16.098	1.592	10.109	<0.0001
Age	− 0.090	0.014	− 6.332	<0.0001
Weight	− 0.036	0.017	−2.155	0.032
Head	0.421	0.195	2.158	0.032
Thorax	1.465	0.283	5.177	<0.0001
Abdomen	1.974	0.338	5.836	<0.0001
Skeleton	1.836	0.344	5.344	<0.0001

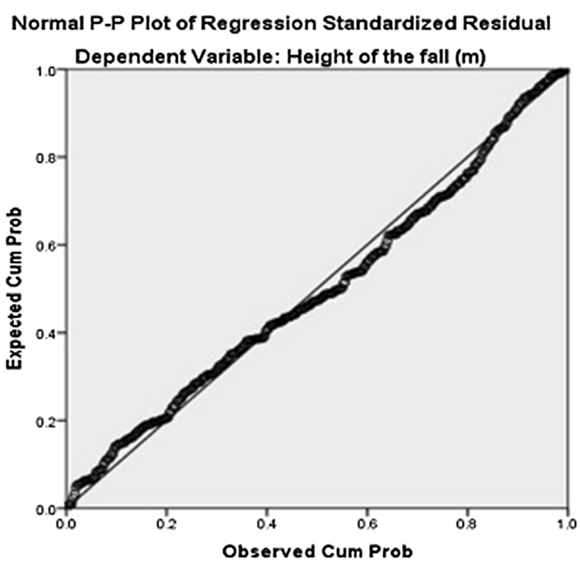

Fig. 3. P-P plot regarding second equation.

height. Furthermore, the proposed Injury Pattern Assessment Table can be used real-time during the judicial autopsy without the need for a significant additional time. Moreover, the same authors previously and retrospectively working on victims of falls from a height stated that prospective evaluations could have provided more precise mathematical models [6].

The multiple linear regression models here proposed have used the height of the fall as the dependent variable and have shown that the topographic trend for severe lesions can roughly diagnose about 40% of the variability of the height of the fall (Tables 3 and 4). The height of the fall is therefore significantly associated with the topographic trend for severe lesions.

As can be seen in Tables 3 and 4, subject's age and weight remove centimeters from the estimated height: this indicates that, with the increase of these variables, we can expect to find more severe injuries for lower heights in the comparison with younger or thinner subjects. Previous literature had already observed that the elderly are relatively vulnerable to extensive and severe injuries in falls from a height and in cases of vertical decelerations in general [6,7]. Moreover, there is a clear correlation between the injury severity and the kinetic energy at the impact, thus explaining the observed inverse correlation between the subject weight and the height of the fall and the fact that, for the same class of height, the resultant injury pattern tends to be more severe in thicker subjects [5,6]. Concerning this issues, the authors believe that more extensive considerations must await a data expansion, possibly in a multicenter context.

The final mathematical models have been tested on a sample composed of 15 consecutive cases of falls from a height that had occurred in our Institute (about a couple of cases for each floor). The results are shown in Table 5 and seem to be considered encouraging; in Fig. 4 a comparison between the proposed equations, the ISS and Lau's mathematical model is shown.

Back to methodological considerations, the Authors studied a wide population characterized by a good sex (54.5% males) and age stratification, unlike previous literature published on the same subject [4,7–29]. It is however obvious that victims of fall from a height have no unequivocal epidemiological features.

Table 5
Test sample comprising 15 consecutive cases with known heights of fall that occurred in our Institute.

Case	Estimated Height model 1 (m)	Estimated Height model 2 (m)	Actual Height (m)	ISS	Lau estimated HB (m)
1	6.42	7.53	6	25	1.54 (0–10)
2	9.06	10.22	6	33	1.12 (0–10)
3	7.25	8.31	6	29	1.52 (0–10)
4	10.05	9.2	9	27	1.71 (0–10)
5	11.37	10.1	9	38	1.82 (0–10)
6	14.23	15.32	12	66	5.85 (40–70)
7	17.7	17.31	12	75	2.82 (10–20)
8	13.92	13.43	15	48	2.70 (10–20)
9	15.92	15.03	15	75	3.20 (20–30)
10	18.09	16.98	18	34	2.75 (10–20)
11	18.72	17.69	18	48	2.93 (10–20)
12	19.76	20.52	21	75	3.71 (20–30)
13	23.95	22.26	21	41	3.70 (20–30)
14	21.16	20.76	24	75	5.42 (40–70)
15	27.04	25.39	36	75	6.45 (40–70)

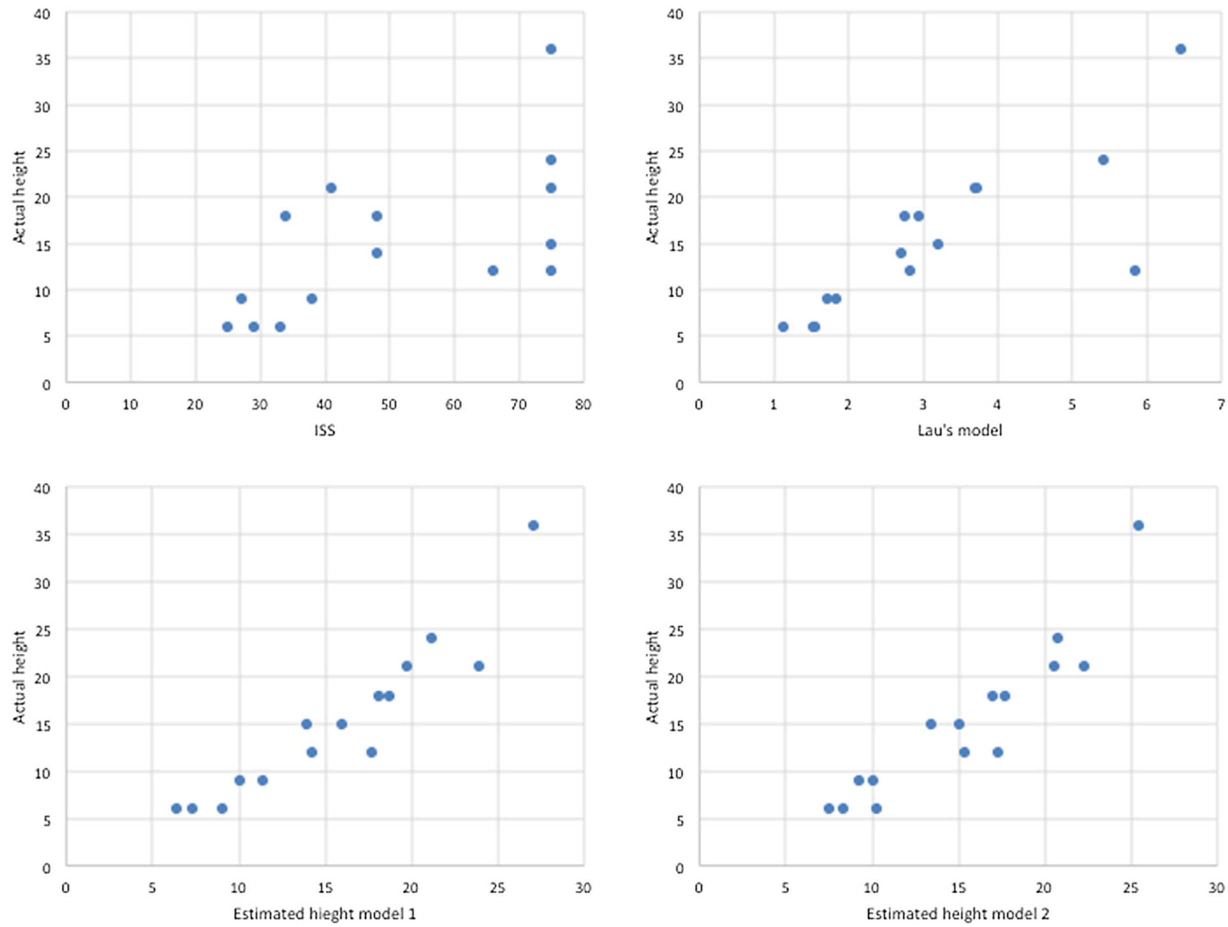

Fig. 4. Graphical comparison between ISS, Lau's mathematical model and author's models in relationships between the actual and estimated height in the sample tested.

About the global injury pattern in the analyzed population, the most frequently injured districts were the rib cage (94.8%), the lungs (89.4%), the pelvic bone (73.5%), the liver (72.2%) and the heart (53.8%). In a topographic perspective, the head was injured in 67.3% of cases, the chest in 96.4%, the abdomen in 83.6% and the skeleton in 98.7%. A detailed comparison with the results coming from the previous literature is shown in Table 6 [1,8,9,11,12,14,18–20,28,30–32].

Table 7 [1,3,7,10,12,14,16,19,20,22,23,28–31,33] is a focus about the skull: in the present study, the skull was injured in 54.5% of all cases.

The protective function of the skull to the brain seems to be confirmed: 54.5% of skeletal lesions vs. 29.4% of parenchymal lesions, these data being in full agreement only with a part of the available literature [7,19,20,30] and in substantial disagreement with other works conversely showing a higher incidence of cerebral lesions compared to those concerning the skull [14,33]. Previous works showing more cerebral injuries than skull injuries suffer possibly the enrollment bias determined by a very low mean height of the falls (3 to 6 m): such fall heights can be considered sufficient to create deceleration brain and meningeal injuries, but not sufficient to create skull fractures. Isolated meningeal haemorrages were not considered in the present study. The incidence of vault and base fractures of any grade in our study is not statistically influenced by the height of the fall, while the

Table 6
Frequence of major areas injuries in previous literature.

Authors, year.	Head	Thorax	Abdomen	Skeleton	Studied Heights
Gupta et al., 1982 [30]	79.3%	46%	23.8%	100%	0–90 ft
Hanzlick et al., 1990 [31]	–	100%	100%	–	18–141 m
Li et al., 1994 [8]	70%	66%	46%	–	8– 375 ft
Richter et al., 1996 [9]	26.7%	20.8%	5.9%	–	2–21 m
Goren, Subasi et al., 2003 [11]	91%	54%	37%	–	1–28 m
Teh et al., 2003 [12]	46%	–	–	–	4–100 ft
Türk e Tsokos, 2004 [1]	50%	–	–	–	3–57 m
Türk e Tsokos, 2004 [32]	42%	–	–	94%	3–57 m
Kohli, Banerjee, 2006 [14]	84.7%	–	15.9%	45.7%	3-> 15 m
Atanasijevic et al., 2009 [18]	–	66%	–	–	0–70 m
Behera et al., 2010 [19]	93.7%	10.9%	6.3%	–	2–48 ft
Thierauf et al., 2010 [20]	76.4%	91%	–	1.5–100 m	
Rocos et al., 2015 [28]	20%	24%	7.3%	–	Not specified

Table 7
Skull lesion in previous literature.

Authors, year.	Neurocranium	Facial skeleton	Cerebrum	Cerebellum	Brainstem	Studied Heights
Goonetilleke et al., 1980 [33]	59.5%	–	72%	–	–	2.5–170 ft
Gupta et al., 1982 [30]	80%	–	75.6%	–	–	0–90 ft
Hanzlick et al., 1990 [31]	77%	–	–	–	–	18–141 m
Cetin et al., 2001 [10]	25%	60%	–	–	–	64 m
Gill, 2001 [3]	66%	–	–	–	–	3–141 m
Teh et al., 2003 [12]	36.5%	21.5%	–	–	–	4–100 ft
Türk e Tsokos, 2004 [1]	50%	–	50%	–	–	3–57 m
Kohli, Banerjee, 2006 [14]	62.3%	–	75.5%	–	–	3-> 15 m
Venkatesh et al., 2007 [16]	65%	–	–	–	–	0.6–23 m
Behera et al., 2010 [19]	59.2%	34.5%	23.8%	–	–	2–48 ft
Thierauf et al., 2010 [20]	44.4%	70.7%	17.5%	–	–	1.5–100 m
Petaros et al., 2013 [22]	55%	–	–	–	–	4–30 m
Freeman et al., 2013 [23]	81.8%	–	–	–	–	1.5–101 m
Casali et al., 2014 [7]	40%	30%	37%	19%	3–84 m	
Rocos et al., 2015 [28]	19.5%	9.8%	–	–	–	Not specified
Obeid et al., 2016 [29]	58.6%	–	–	–	–	6–420 ft

incidence of high grade facial fractures does so (even if only in the comparison for falls lower and higher than 22 m) Similar skeletal results have been published in 2013 by Petaros et al. [22], where the frequency of the skull fractures was not statistically associated with the increase of height of the fall and the vast majority of the high falls victims presented frontal bone and facial skeleton fractures.

Regarding the thorax, pulmonary injury is known to be the most frequent. Its median incidence along all the available literature is 62% (Table 8) [1–3,7,10,14,18,19,29,30,32,33]. Also in the present study, pulmonary lesions are confirmed as a very common finding in falls from a height. Previous literature observed cardiac injuries in about 5–54% of cases, with the only study specifically addressing such a topic showing injuries in 54% of cases [32]: such a prevalence is very close to what the Authors observed (54% vs 53.8%), making heart injuries a quite reliable and sensitive mark for falls from a height.

The influence of the height of the fall on the injury pattern of the thorax is quite clear and the extent of the injuries is influenced by the height: both the absence of lesions (typical only in fall from a height ≤9 m) and the presence of 3 or more injured organs are strongly associated with the increase of height.

To the Authors' knowledge, this is the first study showing a significant increase in the incidence of abdominal injuries according to the increasing height of the fall (Table 9) [1,2,7,9,10,13,14,19,29,30,32,33]. However, a high prevalence of abdominal lesions has already been reported [8]. It was confirmed in the present study that the liver is the most injured among abdominal organs [1,2,10,14,19,33]. The kidneys are well protected by the surrounding adipose tissue: there is in fact a low global incidence of kidney injuries in our population. On the converse, mesenteric injuries (incidence at about 20% both in the present study and in the previous literature) are mainly the effect of its great mobility.

In our study, high grade injuries involving the liver, the spleen and the mesentery were correlated with the height of the fall. Abdominal aorta and kidneys are characterized by a significant increase for high grade lesions only for fall from a height >22 m. The height of the fall also affects the extent of abdominal injuries: the absence of high grade lesions is typical for falls ≤9 m, while the presence of at least 1–2 organs with high grade lesions is a common feature of higher falls.

A focus about the literature contributions about the skeletal injuries is shown in Table 10 [2,3,7,9–12,14,16,18,19,21–23,28–33]. In our study, the thoracic spine is the most commonly affected site (37.7%) while the lumbar spine is the least commonly affected: these data are confirmed within the previous literature, often treating the dorsal spine and the lumbar spine as one. The Authors analyzed the sternum, the clavicle and the ribs as a single skeletal site, this probably creating a higher global incidence of injuries in the comparison with previous works. Similar considerations should be proposed regarding the pelvic bone. Previous literature shows that a typical fracture (or a picture of some typical fractures) for the victims of falls from a height does not exist [22]. Venkatesh et al. [16] stated that multiple fractures affecting ribs, long bones and spine are very frequent in falls from a height and unusual in other cases of violent death. Gill [3] established that rib fractures are practically universal in cases of falls higher than the 3rd floor.

Table 8
Thorax lesion in previous literature.

Authors, year.	Lungs	Trachea and bronchi	Heart	Thoracic Aorta	Diaphragm	Studied Heights
Goonetilleke et al., 1980 [33]	30.8%	–	8.9%	7.5%	–	2.5–170 ft
Gupta et al., 1982 [30]	28.27%	–	4.76%	–	–	0–90 ft
Simonsen et al., 1983 [2]	40%	–	–	–	–	35–51 m
Cetin et al., 2001 [10]	75%	–	5%	5%	–	64 m
Gill, 2001 [3]	–	–	–	60%	–	3–141 m
Türk e Tsokos, 2004 [1]	62%	–	36%	15%	–	3–57 m
Türk e Tsokos, 2004 [32]	89%	–	54%	48%	–	3–57 m
Kohli, Banerjee, 2006 [14]	4.6%	–	0%	–	–	3-> 15 m
Atanasijevic et al., 2009 [18]	22.7%	–	16%	21%	–	0–70 m
Behera et al., 2010 [19]	5.2%	–	–	–	–	2–48 ft
Casali et al., 2014 [7]	76%	10%	53%	43%	11%	3–84 m
Obeid et al., 2016 [29]	64.6%	–	–	–	–	6–420 ft

Table 9
Abdomen lesion in previous literature.

Authors, year.	Liver	Spleen	Abdominal aorta	Kidneys	Mesentery	Studied Heights
Goonetilleke et al., 1980 [33]	10.9%	1.4%	0%	6.8%	5.5%	2.5–170 ft
Gupta et al., 1982 [30]	22.2%	3.17%	–	3.17%	–	0–90 ft
Simonsen et al., 1983 [2]	40%	10%	–	–	–	35–51 m
Richter et al., 1996 [9]	1%	1%	–	3%	–	2–21 m
Cetin et al., 2001 [10]	40%	30%	–	25%	–	64 m
Türk e Tsokos, 2004 [1]	52%	55%	–	–	24%	3–57 m
Türk e Tsokos, 2004 [32]	54%	–	24%	–	3–57 m	
Atanasijevic et al., 2005 [13]	21%	19%	–	–	–	0–70 m
Kohli, Banerjee, 2006 [14]	9.3%	4.6%	–	0%	–	3-> 15 m
Behera et al., 2010 [19]	4.6%	0.6%	–	–	–	2–48 ft
Casali et al., 2014 [7]	58%	46%	5%	28%	18%	3–84 m
Obeid et al., 2016 [29]	52.6%	32.8%	–	22.2%	–	6–420 ft

Table 10
Skeletal lesion in previous literature.

Authors, year.	Cervical spine	Thoracic spine	Lumbar spine	Complex sternum/clavicle/ribs	Pelvis	Studied Heights
Goonetilleke et al., 1980 [33]	9.6%	19.1%	4.1%	48%	23.9%	2.5–170 ft
Gupta et al., 1982 [30]	4.7%	30.15%	6.3%	0–90 ft		
Simonsen et al., 1983 [2]	20%	20%	-	70%	-	35–51 m
Hanzlick et al., 1990 [31]	50%	78.6%	100%	50%	18–141 m	
Richter et al., 1996 [9]	6.9%	33.9%	66.3%	70%	17.8%	2–21 m
Cetin et al., 2001 [10]	35%	75%	5%	64 m		
Gill, 2001 [3]	-	-	-	94.6%	60%	3–141 m
Goren, Subasi et al., 2003 [11]	9.9%	-	-	24.8%	15.3%	1–28 m
Teh et al., 2003 [12]	14%	8.7%	14%		12%	4–100 ft
Türk e Tsokos, 2004 [32]	-	-	-	76%		3–57 m
Kohli, Banerjee, 2006 [14]	10.6%	1.3%	0%	26.5%	6%	3-> 15 m
Venkatesh et al., 2007 [16]	11.2%	73.7%	8.7%	0.6–23 m		
Atanasijevic et al., 2009 [18]	-	7.1%	-	85.5%	-	0–70 m
Behera et al., 2010 [19]	5.7%	-	1.1%	2–48 ft		
Gulati et al., 2012 [21]	1.9%	11.8%	-	6.9%	0.6–12 m	
Petaros et al., 2013 [22]	40%	73%	28%	4–30 m		
Freeman et al., 2013 [23]	18.2%	-	-	-	-	1.5–101 m
Casali et al., 2014 [7]	22%	37%	10%	92%	35–50%	3–84 m
Rocos et al., 2015 [28]	12.2%	19.5%	34.1%	-	34.1%	Not specified
Obeid et al., 2016 [29]	12.2%	33.4%	75.2%	48%	6–420 ft	

Our study confirms that fall from a height (even falls $\leq$6 m) is characterized by at least 87.3% of rib fractures (bilateral in 69.1% of cases): therefore a fall from a height without rib fractures is infrequent, validating previous findings [7].

Only the cervical and the thoracic spine are characterized by an increase in the incidence of high grade lesions (that is injuries extended to spinal the cord) directly related to the height of the fall. It is noteworthy the protective effect of the cervical vertebrae, since, excluding falls from a height $\geq$18 m, there are at least twice as many pure bone lesions than lesions involving also the underlying cervical cord. In the thoracic part of the vertebral column the protective effect of the vertebrae seems less pronounced: there is, in fact, a smaller difference between the number of pure fractures without cord involvement and the number of the combined lesions (bone and cord).

The pelvic bone and the rib cage are instead characterized by an inverse correlation between incidence of low grade lesions and height of the fall. The frequency of high grade lesions in the pelvic bone is positively influenced by the height of the fall. The absence of lesions and the presence of 3 or more skeletal districts with high grade lesions are significantly related to the height of the fall.

In the present work it has to be underlined that the authors did not have information regarding the first impact site: however, in the forensic field, the site of first impact is actually often not known, as the forensic pathologist is usually asked to get information from the injury pattern presented, without having any further concrete information about the fall from a height. Finally, it must be stressed that the mathematical models here presented were created on a population with a fall from a height $\leq$ 36 meters: the concrete utility of such models in higher heights is not known.

5. Conclusions

Mathematical models appear useful in the investigation of fatal falls from a height, but only further researches including a wide experimental sample cases will allow to assess and confirm such a preliminary suggestion. Autoptic real-time grading scores must be further evaluated as standard diagnostic tools for the forensic pathologists worldwide. The proposed Injury Pattern Assessment Table is one of these autoptic real-time tools, hopefully ready to undergo multicentric independent tests prior to its possible improvement and standardization. The height of the fatal fall shows a significant correlation with both the topographic extension and the pathological severity of the injuries, thus allowing the creation of promising mathematical formulas for the diagnosis of the height of the fall moving from the autoptic injury pattern. Quali-quantitative forensic diagnosis on cases of fall from a height (and also of major blunt traumas) is a crucial topic still needing definite and decisive contributions coming from multicentric research.

Appendix A. Injury Pattern Assessment Table

Head	Skull (vault + base)	Not fracture lesions
		Single fracture line
		Multiple independent fracture lines
		Complex fracture patterns/ Depressed fracture
		Global deformity/Dispersion of bone fragments
	Facial skeleton (Nasal bones + zygomatic bones + upper maxillary nones + jaws)	Not fracture lesions
		Single fracture line
		Multiple independent fracture lines
		Complex fracture patterns/ Depressed fracture
		Global deformity/Dispersion of bone fragments
	Cerebrum	No lesions
		Contusive areolae, up to 1 cm in size
		Major homolateral contusive injuries (contusive areas >1 cm in size/diameter, parenchymal lacerations, parenchymal hematomas) with conservation of global surface anatomy
		Major bilateral contusive injuries (contusive areas >1 cm in size/diameter, parenchymal lacerations, parenchymal hematomas) with conservation of global surface anatomy
		Massive destruction and/or dispersion (also partial)
	Cerebellum	No lesions
		Contusive areolae, up to 1 cm in size
		Major homolateral contusive injuries (contusive areas >1 cm in size/diameter, parenchymal lacerations, parenchymal hematomas) with conservation of global surface anatomy
		Major bilateral contusive injuries (contusive areas >1 cm in size/diameter, parenchymal lacerations, parenchymal hematomas) with conservation of global surface anatomy
		Massive destruction and/or dispersion (also partial)
	Brainstem	No lesions
		Single or multiple contusive areolae, $\leq$0.3 cm in size/ diameter
		Single or multiple contusive areolae, >0.3 cm in size/ diameter of the minor lesion
		Single or multiple parenchymal lacerations with conservation of global surface anatomy
		Single or multiple transection/s or massive destruction dispersion (also partial)
Thorax	Lungs	No lesions
		Single or multiple monolateral or bilateral contusion/s
		Monolateral major contusive injuries (parenchymal lacerations, ribs penetration, hilar discontinuance/break) with conservation of global surface anatomy
		Major bilateral contusive injuries (parenchymal lacerations, impaled wounds, hilar discontinuance/break) with conservation of global surface anatomy
		Monolateral or bilateral massive destruction
	Trachea and Bronchi	No lesions
		Single contusive lesion
		Multiple contusive lesions
		Single laceration
		Multiple lacerations
	Heart	No lesions
		Single/multiple epicardial/ myocardial/endocardial contusions or single/multiple non full-thickness lacerations
		Single full-thickness laceration
		Multiple full-thickness lacerations with conservation of global surface anatomy
		Partial or total destruction (including atrial full-thickness lacerations with no conservation of global surface anatomy)
	Thoracic Aorta	No lesions
		Single non-full thickness laceration
		Multiple non-full thickness lacerations
		Single full thickness laceration
		Multiple full thickness lacerations
	Diaphragm	No lesions
		Single/multiple subcapsular blood infiltrations or single/ multiple non full thickness lacerations
		Single full thickness laceration
		Multiple full thickness lacerations
		Broad frenic breach with possible abdominal/thoracic herniations
Abdomen	Liver	No lesions
		Single/multiple subcapsular blood infiltration/s or single surface laceration (maximum depth 0.5 cm)
		Multiple superficial lacerations (main lesion with a maximum depth $\leq$0.5 cm)
		Single major parenchymal lesion (deep laceration, superficial laceration with depth >0.5 cm, cavitation) with conservation of global surface anatomy
		Multiple parenchymal lesions or partial/total destruction
	Spleen	No lesions
		Single/multiple subcapsular blood infiltration/s or single surface laceration (maximum depth 0.5 cm)
		Multiple superficial lacerations (main lesion with a maximum depth $\leq$0.5 cm)
		Single major parenchymal lesion (deep laceration, superficial laceration with depth >0.5 cm, cavitation) with conservation of global surface anatomy
		Multiple parenchymal lesions or partial/total destruction
	Abdominal Aorta	No lesions
		Single non-full thickness laceration
		Multiple non-full thickness lacerations
		Single full thickness laceration

		Multiple full thickness lacerations
	Kidneys	No lesions
		Single/multiple monolateral/ bilateral contusion/s
		Monolateral single/multiple full thickness lacerations
		Bilateral full thickness lacerations
		Partial/total destruction or autonomization (monolateral or bilateral)
	Mesentery	No lesions
		Single blood infiltration with maximum diameter $\leq$ 3 cm
		Multiple areas of blood infiltrations or single blood infiltration with maximum diameter > 3 cm
		Single laceration
		Multiple lacerations
Skeleton	Cervical spine	Not fracture lesions
		Single disk/somatic lesion with no spinal cord injury
		Multiple disk/somatic lesions with no spinal cord injury
		Single disk/somatic lesion with spinal cord injury
		Multiple disk/somatic lesions with spinal cord injuries
	Thoracic spine	Not fracture lesions
		Single disk/somatic lesion with no spinal cord injury
		Multiple disk/somatic lesions with no spinal cord injury
		Single disk/somatic lesion with spinal cord injury
		Multiple disk/somatic lesions with spinal cord injuries
	Lumbar spine	Not fracture lesions
		disk/somatic lesion with no spinal cord injury
		Multiple disk/somatic lesions with no spinal cord injury
		Single disk/somatic lesion with spinal cord injury
		Multiple disk/somatic lesions with spinal cord injuries
	Pelvis (including the sacrum)	Not fracture lesions
		Fracture(s) of a single element
		Fractures of multiple homolateral structures (N.B. 1: in case of co-presence of pubic and/or sacrum symphysis fractures and of single fracture of another bone structure, to the symphysis and/or sacrum is assigned the laterality of the concomitant lesion is assigned; N.B. 2: in case of co-presence of pubic and/or sacrum symphysis lesions and multiple omolateral lesions, the laterality of the concomitant lesion is assigned to the symphysis and/or sacrum.
		Bilateral fractures with up to 4 damaged elements
		Multiple bilateral fractures with > 4 damaged elements or complete collapse of the osteopelvic ring
	Complex sternum/clavicle/ribs (considering the single or multiple lesions of the same bone element as equivalent)	Not fracture lesions
		Monolateral fractures with up to 6 damaged bones elements (N.B. 1: In case of co-presence of the sternal lesion and of single/ multiple clavicular or ribs lesions, to the sternum is assigned the laterality of the concomitant lesion(s))
		Monolateral fracturs with > 6 damaged bones elements (N.B. 1)
		Bilateral fractures with the most involved bone hemicomplex with up to 6 damaged bones elements (N.B. 1)
		Bilateral fractures with the most involved bone hemicomplex with > 6 damaged bones elements (N.B. 1): in case of co-presence of the sternal lesion and of single/multiple clavicular or ribs lesions, to the sternum is assigned the laterality of the bone hemicomplex with more fractures)) or collapse of the bone complex, with evident deformity already observable during the external examination

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