Forensic Science International 255 (2015) 112–117

Contents lists available at ScienceDirect

Forensic Science International

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

Biomechanical analysis of biphasic distribution of skull injury in falls from height

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ARTICLE INFO

Article history:
Available online 19 June 2015

Keywords:
Skull fracture
Fall from height
Biphasic
Simulation
MADYMO

ABSTRACT

Fall from height is one of the most common ways of suicide in Korea. Skull fractures are typically accompanied with these cases, but several autopsy cases show absence of skull fracture even with serious body injuries including sternal and vertebral fracture. The mechanism of this pattern of injury can be explained by impact of facial part on chest or abdomen when the back of the body touches the ground first. We tried to figure out the relevance of this pattern of injury to the height of fall using a computer simulation tool (MADYMO 7.5). For this experiment, a condition of initial pose was limited to leaning forward. The simulation showed that when the body rotated forward, the body parts which got injured by the ground depended on the height of fall. For relatively lower height, head got injured, but as the height was set higher, the point of first impact area changed to the back, hip and then legs. When the body struck first around hip area on supine position, the impact made forceful flexion of lumbar, thoracic and cervical vertebrae, leading to folding the body in two, which resulted in collision between the part of face and the anterior part of body. Through the current investigation, it was explained that the biphasic distribution of the number of head injury cases versus the height distribution was attributed to the forward rotation of the body during the fall.

1. Introduction

When human body is impacted by the collision of fall from height, wide range of injuries including skull fractures are observed. Usually, it is assumed that the affected skull damages, organ damages and fractures are more extensive as the height of fall is higher. However, several cases of fall from height showed absence of skull fracture even with serious body injuries including sternal and vertebral fractures and various soft and skeletal injuries on their back. By careful autopsy examination, this pattern of injuries could be explained by hyper-flexed vertebral folding and impact of facial part on chest or abdomen when their back side of body touched the ground first. Based on this observation, we postulated that this phenomena could be a factor of explaining somewhat mysterious 'biphasic distribution of skull injury' with regard to the falling height or impacting energy [1,2]. Thus, the fall from height cases without skull fracture were further reviewed and the biomechanical simulations for the simple situation of fall from various heights were carried out with a multi-body dynamic simulation software, MADYMO 7.5.

2. Material and methods

Twelve falls from height autopsy cases showing absence of skull fracture with serious injuries at their back were reviewed. The cases were collected from the autopsy data of National Forensic Service in South Korea within the recent 5 years (2010–2014).

As an effort to systematically understand the injuries on human body by falls from height, widely used multi-body dynamic simulation software called, MADYMO 7.5 was adopted in the current study. For a human body model, a typical pedestrian body model was used provided by MADYMO 7.5 program. This pedestrian body model consisted of 75 ellipsoids and the height and weight of the simulated body was 174 cm and 75 kg, respectively. Posture before the fall was assumed to be straight up and forward falling as an initial investigation since it seemed rather common while actual situations before the fall might vary widely depending on the occasions case by case.

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http://dx.doi.org/10.1016/j.forsciint.2015.06.009
0379-0738/

Table 1
Distribution of injuries in falling from height autopsy cases showing no skull fracture.

Cases	Height	Back impaction	Vertebral fracture site: cervical (C), thoracic (T), lumbar (L)	Chest injuries: sternal fracture (SFx), multiple anterior rib fracture (ARFx), bruise on sternal area (B)	Chin area injuries: abrasion (A) bruise (B), mandibular fracture (MFx)	Scalp injuries: abrasion (A), subgaleal hemorrhage (SGH) Site: occipital (O), parietal (P)	Cerebral injuries: focal subarachnoid hemorrhage (SAH)
1	10 m	+	T11	–	–	A (O)	–
2	∼10 m	+	C3,4, T7,8, L2,3	ARFx, B	A	SGH (O)	–
3	10 m	+	T7	B	B	SGH (P)	–
4	10 m	+	C1, T12, L1	SFx, B	B	SGH (O)	SAH
5	12.5 m	+	T6,9, L1	ARFx	–	–	–
6	∼20 m	+	C3,4, L1-4	SFx, B	B	SGH (P)	SAH
7	20 m	+	C1, T4,7,12	SFx, B	A, B, MFx	–	SAH
8	22.5 m	+	C4,5	ARFx, B	B	–	SAH
9	22.5 m	+	C7	ARFx	–	–	SAH
10	30 m	+	L1	ARFx	–	A (O)	–
11	32.5 m	+	C6, T4	ARFx, B	A	–	SAH
12	32.5 m	+	C2,3, T1, T3	SFx, B	–	SGH (O)	SAH
Notes		100% (12/12)	C: 58.3% (7/12) T: 75% (9/12) L: 1.7% (5/12)	91.7% (11/12)	58.3% (7/12)	58.3% (7/12)	58.3% (7/12)

3. Results

3.1. Autopsy results

Total of 12 autopsy cases of FFH where no head injuries were analyzed. In Table 1, in all cases, the damages on the posterior of the body including back, waist, buttock and posterior thigh were noticed by compressed abrasions and soft tissue injuries.

Also, all cases showed vertebral fractures. Most common hyper-flexion fractures were found around thoracic area. Multiple posterior rib fractures including thoracic vertebral fracture site were also found in most of cases. Eleven cases revealed sternal (4 cases) or multiple anterior rib fractures (6 cases) or bruise (1 case). Among these cases, 7 cases (Case 2, 3, 4, 6, 7, 8 and 11) disclosed chin area injuries including abrasions, bruises and mandibular fracture as shown in Fig. 1 and the remaining 5 cases showed no evidence of chin area injury.

Typically patterned intradermal hemorrhages caused by clothes on the chin area and on the chest were noticed correspondingly in two cases as shown in Figs. 2 and 3. All cases showed the absence of skull fracture but the evidence of head injuries including small abrasion, contusion on scalp or focal subarachnoid hemorrhage on cerebral hemisphere. Based on all these observation and investigation, it was determined that the correlation was strong between the phenomena where the damages around the back area, vertebral hyper-flexion fractures, and the damages around the mandible and the anterior part of chest were noticed and the phenomena where the skull fractures were NOT found. For the reviewed cases, falling height range is 10–32.5 m. The one floor was transformed as 2.5 m because exact falling height were not measured in all cases by a ruler.

3.2. Computer simulation results

First simulation result of human body dynamics for the case of fall from 1 m height is illustrated in Fig. 4. In the current simulation of human body dynamics during the fall, arbitrary action and/or reaction by the human was completely ignored due to the computer simulation capability and the arbitrary nature of the human actions and/or reactions. As shown in Fig. 4, overall body shapes changes starting from the straight up position to the folded around waist line naturally and at the end, the top of the head of the human body model hits the ground first. For the case of forward falls, rotational motion of the human body model occurs consistently over various height situations.

As illustrated in Fig. 5(a), for the case of fall from 2 m height, the back of the head (occiput) contacts the ground first and for the case of fall from 6 m height (Fig. 5(b)), the occipital region

(a) (b)

Fig. 1. (a) Abrasion and bruise on chin area (ellipsoid) and bruise on sternal area (rectangle). (b) The deceased's neck was able to be flexed so the chin area could approach to the sternal bruise area (case 7).