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G.A. Huseynova
Azerbaijan Medical University, Baku, Azerbaijan

BIOMECHANICAL ASPECTS OF INTRACRANIAL INJURIES CAUSED BY FALLS FROM THE HEIGHT OF “OWN HEIGHT” ONTO THE SURFACE

e-mail: huseyngulshen800@gmail.com

The main purpose of the study was to analyze the biomechanical conditions of intracranial injuries caused by a fall from “own height”. The study was based on the analysis of forensic medical examination materials, examination data, and a preliminary investigation of 190 people falling to the surface from their “own height”. The victims were divided into 6 age groups (<20, 20–29, 30–29, 40–49, 50–59, and ≥60). Intracranial trauma was identified in 97 individuals (51.1 %). It was found that both isolated and combined intracranial trauma was registered predominantly in the age group ≥60. The analysis of the obtained results shows that in all falls onto the surface, the brain, its membranes, and blood vessels are damaged. Thus, the study of biomechanical conditions leading to damage to intracranial structures will significantly increase the objectivity of forensic experts' conclusions about the mechanisms and circumstances of craniocerebral injuries resulting from falls “own height”.

Key words: fall from height, cranial fracture, intracranial injury, mortality.

Г.А. Гусейнова

БІОМЕХАНІЧНІ АСПЕКТИ ВНУТРІШНЬОЧЕРЕПНИХ ПОШКОДЖЕНЬ, ВИКЛИКАНИХ ПАДІННЯМ З ВИСОТИ «ВЛАСНОГО ЗРОСТУ» НА ПОВЕРХНЮ

Основною метою дослідження був аналіз біомеханічних умов внутрішньочерепних ушкоджень, спричинених падінням з висоти «власного зросту». Дослідження проводилося на підставі аналізу матеріалів судово-медичної експертизи, даних огляду та попереднього розслідування 190 осіб, які впали на поверхню з висоти «власного зросту». Постраждалі були розділені на 6 вікових груп (<20, 20–29, 30–29, 40–49, 50–59 і ≥60). Внутрішньочерепну травму виявлено у 97 осіб (51,1 %). Встановлено, що як ізольована, так і поєднана внутрішньочерепна травма реєструвалася переважно у віковій групі ≥60 років. Аналіз отриманих результатів показує, що при всіх падіннях на поверхню ушкоджується головний мозок, його оболонки та судини. Таким чином, вивчення біомеханічних умов, що призводять до пошкодження внутрішньочерепних структур, дозволить суттєво підвищити об'єктивність висновків судово-медичних експертів щодо механізмів та обставин черепно-мозкових травм, отриманих внаслідок падінь з висоти «власного зросту».

Ключові слова: падіння з висоти, перелом черепа, внутрішньочерепна травма, летальність.

Craniocerebral injuries are a critical public health issue and a socio-economic problem worldwide [6, 10]. These injuries are one of the most important aspects of forensic medical examination, as they occupy the leading place among mechanical injuries.

In recent decades, there has been a steady increase in natural disasters, technological accidents, transportation incidents, and military conflicts worldwide, which are accompanied by mass traumatic injuries, particularly to the brain. Skull and brain injuries account for more than a third of all injuries, and according to WHO data, they increase by at least 2 % annually [3].

Since the occurrence of craniocerebral trauma can be a consequence of especially dangerous crimes against human life and health, the high social significance of determining the mechanism and origin of identified craniocerebral injuries is undeniable. This is especially important in craniocerebral injuries caused by “spontaneous” falls, as well as in cases where the victim is pushed to the surface as a result of extraneous intervention (acceleration) or a push. According to some authors, craniocerebral injuries account for 30.5–77.6 % of fatal injuries [4].

The mechanism of craniocerebral injuries is quite diverse, but, according to forensic medical examination data, in peacetime they more often occur as a result of impact with blunt hard objects (39.6 %) and as a result of impact of a moving head against a stationary obstacle, including when a person falls on a surface from a height of his "own height" (26.4 %) [9].

From this point of view, forensic examination of bodily injuries caused by a person falling on a surface from his "own height" should be on a clear and scientific basis to answer several questions of great importance for investigative authorities. These include clarification of the mechanism of occurrence of the detected injury, especially the presence of external interference (push, blow, etc.), determination of the force of impact, the nature of the impact surface, etc.

When falling on the surface, in addition to damage to the bones of the skull and soft covering tissues of the head, there are also intracranial injuries characteristic of this mechanism of injury.

Epidural, subdural, and subarachnoid hemorrhages, erosive defects of the pia mater in the affected area, hemorrhages and smearing of the cerebral cortex and white matter of the brain, intraventricular hemorrhages and bleeding, and subependymal ventricular hemorrhages observed in craniocerebral injuries caused by a fall on the surface. These injuries are not caused by a blow to the head of an immobile person. For such an injury to occur, the head must be mobile [11].

Analysis of literature data shows that damage to intracranial structures, the formation of injuries, and their main characteristics are almost completely unstudied. In practice, it is of great interest to determine the mechanism of damage to intracranial structures - the brain and cerebral meninges. When deciding on the mechanism and circumstances of the formation of craniocerebral injuries, a forensic expert takes into account certain parameters: age, weight, and height of the victim; bone thickness in the place of application of impact force (in the zone of force); and the nature of bone damage, as well as the characteristics of the hardness of the impact surface and the kinetics of head energy. From this point of view, in modern times there is a great need to study the main features and mechanisms of damage formation in craniocerebral injuries [7].

The purpose of the study was to investigate the biomechanical properties responsible for damage to intracranial structures as a result of a fall onto a surface from a height of "own height".

Materials and methods. The main objects of the study were forensic examinations of living individuals and corpses, primarily reliable information provided by law enforcement agencies and forensic experts regarding the circumstances under which bodily injuries occurred. In all cases, a detailed analysis of the causes of injuries was conducted in collaboration with law enforcement agencies in Baku. A total of 190 victims aged from 1 to 85 years falling onto a surface from a height of "own height" were investigated. The victims were divided into <20, 20–29, 30–39, 40–49, 50–59, and ≥60 age groups. Cases of fatal and non-fatal injuries in Baku city for 2006–2023 were selected for the study. Suspicious cases (where it was impossible to determine the circumstances of the injuries based on witness statements or other information) were excluded from further analysis.

During the study, a statistical analysis of retrospective data, including the gender, age, weight, height of victims, the location of the injury, the direction and cause of the fall, and the outcomes of the injuries, was conducted. The comparison of the obtained quality indicators was carried out with the Pearson's $\chi2$-test in the SPSS-26 statistical package.

Results of the study and their discussion. Craniocerebral injury was detected in 97 (51.1 %) of those who fell on the surface (190 persons (141 males, 49 females)). When analyzing the frequency and outcome of 97 people in the age group <20 (1–19) years, isolated trauma was recorded in 6 people and combined trauma from falls on the surface was recorded in 7 people. In the age group 20–29 years, 12 people who fell on the surface had a combined and 5 people had an isolated intracranial injury. The least number of falls occurred in the age group of 30–39 years old. Thus, of those who fell to the surface, 2 people had isolated intracranial trauma and 5 people had combined craniocerebral trauma. Craniocerebral trauma occurred in 18 people aged 40–49 years when they fell to the surface. Of these, 7 people had isolated intracranial trauma and 11 people had combined craniocerebral trauma. The third place by frequency of craniocerebral injuries is occupied by the age group of 50–59 years old (17 people). Thus, 12 of those who fell on the surface had a combined craniocerebral injury, and 5 had isolated intracranial trauma. Both isolated and combined intracranial injuries were registered predominantly in the age group ≥ 60 years (28 people). Thus, 10 of those who fell on the surface in this age group had combined craniocerebral trauma, and 9 had isolated intracranial trauma (Table 1).

Table 1

Distribution of intracranial injuries in falls on surfaces by age groups, direction, and outcomes of falls

Distribution of intracranial injuries in falls on surfaces by age groups				
No.	Age group	Isolated intracranial injury	Combined injury (intracranial injury + skull fractures)	χ2; P
1	<20	6 (19.4 %)	7 (10.6 %)	χ2=3.701; p=0.593
2	20–29	2 (6.5 %)	12 (18.2 %)	
3	30–39	2 (6.5 %)	5 (7.6 %)	
4	40–49	7 (22.6 %)	11 (16.7 %)	
5	50–59	5 (16.1 %)	12 (18.2 %)	
6	≥60 (60–85)	9 (29.0 %)	19 (28.8 %)	

Distribution intracranial injuries depending on the direction of fall				
Type of trauma	Forward falls	Backward falls	Lateral falls	χ2; P
Isolated intracranial injury	14 (45.2 %)	8 (25.8 %)	9 (29.0 %)	χ2=2.104; p=0.349
Combined injury (intracranial injury + skull fractures)	20 (30.3 %)	20 (30.3 %)	26 (39.4 %)	

Distribution of outcomes of craniocerebral injuries			
Result of injury	Isolated intracranial injury	Combined injury (intracranial injury + skull fractures)	χ2; P
Fatal (died)	28 (90.3 %)	64 (97.0 %)	χ2=1.906; p=0.167
Non-fatal (survivor)	3 (9.7 %)	2 (3.0 %)	

This is probably due to the fact that the range of this group (60–85 years) is wider than other groups. The analysis of the results shows that in all falls on the surface the membranes and brain matter were damaged.

Analysis of the study materials shows that craniocerebral trauma occurred as a result of a fall forward in 35.1 % of cases, a fall backward in 28.9 % of cases, and a fall sideways (right and left) in 36.1 % of cases. It is seen that falling on the side is more common in patients with craniocerebral injury than other directions.

Death occurred in 104 (54.7 %) of the fallen (190 people). 86 (45.3 %) people have survived. 88.5 % of deaths (92 persons) were due to craniocerebral injuries. The lethality for isolated and combined intracranial injuries was 28 (90.3 %) and 64 (97.0 %), respectively. With isolated craniocerebral injury, 3 (9.7 %) persons survived, and with combined injury, 2 (3.0 %) persons survived. Overall, death was recorded in 92 (94.8 %) individuals with craniocerebral injury. Only 5 victims (5.2 %) survived. Among the deceased, 22 (23.9 %) were women and 70 (75.1 %) were men (Table 2).

Table 2

Distribution of intracranial injuries in falls on surfaces by gender, location and cause of falls

Distribution of injuries by gender of the victims			
Gender of the victims	Isolated intracranial injury	Combined injury (intracranial injury + skull fractures)	χ2; P
Man	23 (74.2 %)	52 (78.8 %)	χ2=0.254; p = 0.614
Woman	8 (25.8 %)	14 (21.2 %)	
Distribution of injuries depending on the location of the fall			
Place of fall	Isolated intracranial injury	Combined injury (intracranial injury + skull fractures)	χ2; P
Workplace	2 (6.5 %)	10 (15.2 %)	χ2=2.844 p=0.241
Street	16 (51.6 %)	38 (57.6 %)	
Home	13 (41.9 %)	18 (27.3 %)	
Distribution of injuries depending on the cause of the fall			
Cause of fall	Isolated intracranial injury	Combined injury (intracranial injury + skull fractures)	χ2; P
Spontaneous	26 (83.9 %)	50 (75.8 %)	χ2=0.819 p=0.366
With accelertion	5 (16.1 %)	16 (24.2 %)	

77.3 % (75 people) of persons with craniocerebral trauma were men, and 22.7 % (22 people) were women. 55.7 % of injuries (54 people) occurred on the street, 32.0 % (31 people) at home and 12.4 % (12 people) at work.

76 people (78.4 %) who sustained traumatic craniocerebral injuries fell spontaneously without external intervention, while 21 people (21.6 %) did so as a result of external intervention (acceleration).

External interventions were identified in 4 individuals who fell forward, 3 individuals who fell backward, and 14 individuals who fell sideways. No external intervention was detected in 76 individuals.

The role of body mass index (BMI) in the occurrence of cranio-cerebral injuries was also investigated. It was found that 26 (26.8 %) of the fallers had a normal body weight, 60 (61.9 %) were overweight, and 11 (11.3 %) suffered from obesity. Among the injured individuals with obesity, 9 fell spontaneously – without external intervention – while 2 fell as a result of acceleration – external intervention. The direction of the falls was forward for 3 individuals, backward for 3 individuals, and sideways (to the right and left) for 5 individuals, with all cases resulting in death. 61.9 % (60 individuals) of those who sustained traumatic brain injuries were overweight. This shows that there is a direct correlation between excess weight and obesity and the outcome of the injury.

Craniocerebral injuries differ sharply from other injuries by their high polymorphism. According to the literature, we have established that the severity and outcome of a traumatic brain injury, both isolated and combined, are affected by the age, gender, height, and weight of the victim, the location of the injury, the shape of the surface with which the head comes into contact at the moment of the fall, the cause and direction of the fall, the kinetic energy of the head at the moment of the fall, and other factors [9, 11].

In the study, the majority (77.3 %) of the persons with craniocerebral injuries were males. In general, men are more traumatized than women. This is confirmed by the data of other authors [5, 11, 12].

Contrary to the findings of some authors [14], craniocerebral injuries are more common in the ≥60 (60–85) age group (28.9 %). This is also due to the fact that elderly people, especially those over 60 years of age, fall due to loss of balancing ability [13]. The least number of craniocerebral injuries is observed in the age group of 30–39 years. Thus, the number of those who fell in this group amounted to only 15 people. Of these, 7 persons (46.8 %) sustained intracranial injuries. From the <20 age group, a total of 22 persons fell, and 13 of them (59.1 %) sustained craniocerebral injuries. Taking into account that the number of victims in the <20 age group is smaller than in other groups and 59.1 % (13 people) of those who fell suffered intracranial trauma, it can be concluded that craniocerebral trauma occurs most often in this age group. This is related to the more active lifestyle of people belonging to this age group [2]. Although the total number of people who fell in the 20–29 age group was the largest – 44 people the number of those who received intracranial trauma was 14 people (31.8 %). 18 people in the 40–49 age group (18.6 %), and 17 people in the 50–59 age group (17.5 %) received intracranial trauma. The number of people with intracranial trauma in these age groups is almost the same.

According to some authors, most victims are people aged 50 to 60 years [1]. However, in contrast, our study showed that the majority of individuals with intracranial injury are aged ≥60 years. It has also been established that even relatively mild injuries in older individuals within this age group can lead to fatal outcomes [7]. Thus, all individuals who sustained an intracranial injury in this age group (28 people – 100 %) died. Of these, 9 individuals (32.1 %) died from isolated injuries, while 19 individuals (67.9 %) died as a result of combined cranio-cerebral trauma.

78.4 % of falls with intracranial injury were spontaneous, while 21.6 % occurred as a result of external intervention, which is consistent with data from other authors [7, 12, 13].

Regarding the place where the injuries occurred, contrary to some literature data, in our observations most of the intracranial injuries occurred in the street (55.7 %) and in the home (32.0 %), least of all in the workplace (12.4 %) [7].

We encountered some inconsistencies in the literature data regarding the direction of fall. Thus, of those who fell from their own height, 78 (44.1 %) fell forward, 51 (26.8 %) fell backward, and 61 (32.1 %) fell sideways. However, intracranial injury was found in 34 people who fell forward (35.1 %), 28 people who fell backward (28.9 %) and 35 people who fell sideways (36.1 %). Among those who fell forward and backward, the number of victims with intracranial trauma was very close, 34 and 35, respectively [9]. This refutes the opinion of some authors that intracranial injuries occur more often as a result of forward falls [8].

Mortality analysis shows that 92 (94.8 %) of those who received intracranial trauma died; only 5 (5.2 %) survived. Among those who died, 70 (76.1 %) were males and 22 (23.9 %) were females. 30.4 % of the deceased had isolated intracranial injuries, and 69.6 % had combined injuries (intracranial injuries + skull fractures). All survivors were males. Of them, 3 persons had isolated, and 2 persons had combined craniocerebral trauma. The analysis of the causes of death of those who died from craniocerebral trauma shows that the majority of the deceased (69.57 %) suffered from combined trauma and had subdural and subarachnoid hematomas and crushing of the brain (contusion) tissue.

The role of body mass index (BMI) in the occurrence of intracranial injuries was also investigated. It was found that 26 (26.8 %) of the fallers had a normal body weight, 60 (61.9 %) were overweight, and

11 (11.3 %) suffered from obesity. The prevalence of overweight individuals among craniocerebral trauma victims indicates a direct correlation between overweight and obesity and the outcome of the injury.

Finally, we also examined the effect of height on the severity of injuries. It was discovered that as height increases, the probability of sustaining an injury also rises. Only 2 individuals (180 cm and 162 cm, respectively) did not have skull fractures. However, both had recorded intracranial injuries.

Thus, the age, sex, height, and body weight of the victim, the place where the injury occurred, the nature of craniocerebral injuries, the features of the surface with which the head comes into contact at the time of the fall, and the kinetic energy of the head at the time of the fall are the main factors that determine the severity and outcome of the injury (death and recovery).

Conclusion

These results are of great clinical importance in all fields of medicine, both for first aiders (emergency workers) and physicians providing qualified medical care. Based on this result, physicians will be able to make a more accurate and comprehensive assessment of casualties of different ages. In particular, even minimal damage to intracranial structures in elderly and old people should be paid close attention to, the condition of victims should be in the constant focus of attention of all medical personnel, and appropriate therapeutic measures should be taken to prevent fatal outcomes.

Thus, studying the biomechanical conditions that lead to injuries of intracranial structures will significantly enhance the objectivity of forensic experts' conclusions regarding the mechanisms and circumstances surrounding craniocerebral injuries resulting from a fall from “own height.”

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