STRUCTURE AND MECHANOGENESIS OF LONG BONE FRACTURES IN LOWER EXTREMITIES DUE TO FALL
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Background. The study of the structure and mechanogenesis of falls is necessary to elucidate causal relationships in criminal catatrauma. Purpose of the study was to analyze the structure of mechanical injury resulting in fractures of the long bones of the lower extremities, and the mechanisms of their formation in victims as a result of a fall, according to the primary forensic examination. Material and methods. The study was carried out based on 130 reports of primary forensic examinations of victims with fractures of the femur and / or shin bones due to mechanical injury for the period February – June 2018. All victims were divided into 4 groups: group 1 included individuals sustaining mechanical injury; group 2 involved individuals sustaining injuries in car accidents; group 3 included patients with traumas from the fall, and group 4 included individuals with gunshot fractures. The methodology of the study was based on applying retrospective analysis, descriptive statistics. Results. In cases of catatrauma, the proportion of fractures of the lower extremities makes up 52%, while the proportions of fractures of the upper limbs, ribs and pelvic bones constitute 16% each; in case of car accident the fractures of low legs make up 82.1%, while the fractures of the upper limbs, ribs and pelvic bones constitute 7.8%; 2.4% and 7.7% each, respectively. There are two types of catatrauma included found out in this study: 1) household falls from the own body height (n = 4), and 2) falls from the height not exceeding 3 m (n = 9). The catatrauma mechanisms included the following: 1) active free uncoordinated fall from the own body height with the phase of primary collision with some isolated primary direct injuries; 2) passive free direct predominantly uncoordinated fall from a height of up to 3 m resulting in multiple combined injuries in the phase of primary collision (n = 4), and in the phases of primary and secondary collision of the body (n = 3). Conclusions. In the structure of mechanical injuries of the long bones in the lower extremities according to the initial forensic medical examination, falls from various heights rank the second position among the most frequent criminal injury (10%) after road traffic injuries (89.2%). Falls from own body height and from the height of up to 3 m were free, straight, and mostly uncoordinated, resulted in mainly primary direct injuries as the fractures of the long bones of the upper and lower limbs, ribs, pelvis, brain concussion, chest bruises and abdominal traumas.

Key words: mechanical injuries, lower extremities, fall, mechanogenesis; falls structure; forensic examination.

Introduction
Falls are one of the most common causes of mechanical injury. In the non-industry sector, about 37.3 million unintended non-fatal falls and 646 thousand fatal falls occur annually in the world [1]. In Ukraine, falls are the most common cause of unintentional accidents (57.8% in 2017 [2]; 58.4% in 2018 [3]; 50% for the first half of 2019 [4]) with a fairly low level of deaths (0.12% in 2017 [2] and the first half of 2019 [4]; 0.13% in 2018 [3]).

In industrial sector, falls are also one of the main causes of non-lethal and fatal accidents. For instance, in the USA in 2017, as a result of a fall, slipping or stumbling, 227,760 non-fatal accidents and 887 fatal accidents were registered (17.2% of the total 5147 deaths on industry sector), in 2018 the data increased up to 240160 non-fatal accidents, while 791 fatal accidents slightly reduced (15.1% of 5250 deaths in industry sector) [5]. The level of injuries due to falls varied significantly in different industries: in the USA in 2017 in the industrial sector, 21.4% of such accidents were recorded, while in the construction industry this made up 38.8% [6]. In Ukraine, the fall of the victim during movement is also the main cause of industrial injuries [7].

Studies of unintentional falls are mainly focused on studying the structure and causes of this type of mechanical injury. In criminal injuries and in cases of insurance investigations, the emphasis is typically made on clarifying the mechanogenesis of injuries, their severity, and establishing a causal relationship between a certain type of injury and circumstances that caused it. At the same time, the analysis of the structure of mechanical injuries can be of a certain diagnostic value in establishing the mechanism of damage and, even at the stage of the initial forensic medical examination, a certain prognostic value for determining the outcome of an injury.

The purpose of this study was to analyze the structure of mechanical injury resulting in fractures of the long bones of the lower extremities, and the mechanisms of their formation in victims as a result of a fall, according to the primary forensic examination.

Material and methods
The study material included 130 reports of primary forensic examinations of victims with fractures of the femur and / or shin bones due to mechanical injury. In all the cases, an expert assessment of the structure and causes of the injury was carried out based on applying retrospective analysis, descriptive statistics. Results. In cases of catatrauma, the proportion of fractures of the lower extremities makes up 52%, while the proportions of fractures of the upper limbs, ribs and pelvic bones constitute 16% each; in case of car accident the fractures of low legs make up 82.1%, while the fractures of the upper limbs, ribs and pelvic bones constitute 7.8%; 2.4% and 7.7% each, respectively. There are two types of catatrauma included found out in this study: 1) household falls from the own body height (n = 4), and 2) falls from the height not exceeding 3 m (n = 9). The catatrauma mechanisms included the following: 1) active free uncoordinated fall from the own body height with the phase of primary collision with some isolated primary direct injuries; 2) passive free direct predominantly uncoordinated fall from a height of up to 3 m resulting in multiple combined injuries in the phase of primary collision (n = 4), and in the phases of primary and secondary collision of the body (n = 3). Conclusions. In the structure of mechanical injuries of the long bones in the lower extremities according to the initial forensic medical examination, falls from various heights rank the second position among the most frequent criminal injury (10%) after road traffic injuries (89.2%). Falls from own body height and from the height of up to 3 m were free, straight, and mostly uncoordinated, resulted in mainly primary direct injuries as the fractures of the long bones of the upper and lower limbs, ribs, pelvis, brain concussion, chest bruises and abdominal traumas.

Key words: mechanical injuries, lower extremities, fall, mechanogenesis; falls structure; forensic examination.

This paper is a fragment of research project "Forensic substantiation of morpho-clinical criteria for expert assessment of bodily injuries, determination of limitation period and cause of death" by the M. S. Bokarius Department of Forensic Medicine, Medical Law, National Medical University, state registration number 011SU000229.

DOI 10.31718/2077-1096.20.3.179
UDK 616.718
Sokol V.K.
(KRBFME) for a period, which did not exceed a month since an injury sustained. Reports of primary forensic medical examinations were selected by random sampling for the period February – June 2018. Inclusion criteria were the following: mechanical traumas to the lower extremities, resulting in isolated fractures of the femur or shin bones; non-lethal multiple traumas with fractures of the long bones of the lower extremities as a leading injury.

Exclusion criteria were non-lethal polytraumas, in which fractures of the long bones of the lower extremities were as concomitant damage; fractures of long bones of the lower extremities, in which a forensic medical examination was carried out in terms exceeding 1 month; and fractures resulting from non-mechanical impact; fatal polytrauma.

The average age of the victims was 47.1 ± 26.6 years (10-81 years). All victims were divided into: group 1 sustaining mechanical injury; also, in accordance with the mechanism and circumstances of the injury, into group 2 involving car accident injury; group 3 including injuries from the fall; and group 4, having gunshot fracture.

When classifying injuries into isolated fractures, multiple and combined injuries, we did not take into account injuries of the integumentary system (abrasions, superficial bruised wounds, subcutaneous hematomas), qualified as minor bodily injuries (according to the "Rules of forensic identification of the severity of injuries" approved by the Order of the Ministry of Health of Ukraine No. 6, 01/17/1995). In multiple injuries of the musculoskeletal system (MSS), in addition to fractures of the long bones of the lower extremities, fractures of the bones and dislocations of the joints of the upper limbs, fractures of the pelvic bones without damaging the internal organs, were revealed. In case of combined trauma, a mild / moderate brain concussion, life-threatening concussions of the chest and abdomen, non-penetrating fractures of the ribs were observed.

The methodology of the study included: 1) retrospective analysis in order to investigate structure, mechanism, type, nature of the mechanical injury of the lower extremities from the falls; 2) descriptive statistics.

**Results and Discussion**

The analysis of the results revealed that during the initial forensic medical examination of the patients with fractures of long bones in the lower extremities, car injury (89.2%) and falls from various heights (10%) were the main types of mechanical injury. A case of an open gunshot fracture of the femur due to an unintended shot as a hunting accident can be considered as extremely rare, making up 0.8% of all cases.

The individuals from the general group 1, as well as from the group 2 ("Car accident injury") were aged 10 – 81 years; the majority of them were people of working age (31-60 years old; 74.6%). Group 3 ("Fall") included victims aged 27–65 years; the largest number of falls (77%) was recorded in 27-40 years (figure 1).

![Figure 1. Age distribution of victims with mechanical injury, according to primary forensic examinations.](image)

Group 3 included: 1) the cases of off-the-job falls from the own body height (n = 4) and 2) falls from the height not exceeding 3 m (n = 9). This group also included cases of falls from the roofs of domestic buildings (n = 6), scaffolding in building (n = 2), from a tree in daily life (n = 1). All the falls were free (directly to the surface) and straight (without accompanying objects). 1 case of a fall from a height of ~ 2.5 m was coordinated because of the body grouping at the moment of impact with the surface of the asphalt pavement; for all other victims, falls were considered as uncoordinated. Falls from the own body height were active, because occurred due to accelerating force (hand push). Accordingly, the remaining cases of falling (from a height of up to 3 m) were classified as passive.

By the nature of the injuries, in group 1 ("Me-
Mechanical injury") and group 2 ("Car accident injury"), polytrauma prevailed (85.3% and 87.9%, respectively) with predominantly combined injuries (66.8% and 71.6%, respectively). When falling (group 3), there was a tendency to an even distribution of victims with various types of injuries. Isolated fractures of the femur (n = 3) and tibia (n = 1) were obtained due to an active fall from the own body height. Polytrauma mainly with diaphyseal fractures of the femur and/or lower leg bones was due to a passive fall from a height of 1.5 – 3 meters (9 observations) (table 1).

| Groups | Injury mechanism | Number of observations | Isolated fracture | Multiple injury | Concomitant injury |
|--------|------------------|------------------------|-------------------|----------------|-------------------|
|        |                  | Abs. % | Abs. % | Abs. % | Abs. % | Abs. % |
| 1      | Mechanical injury | 130    | 100    | 19     | 14.7   | 24     | 18.5   | 87     | 66.8   |
| 2      | Car injury       | 116    | 100    | 14     | 12.1   | 19     | 16.4   | 83     | 71.6   |
| 3      | Fall             | 13     | 100    | 4      | -      | 5      | -      | 4      | -      |
| 4      | Gunshot fracture | 1      | 100    | 1      | -      | -      | -      | -      | -      |

The structure of bone fractures of the musculoskeletal system in victims of mechanical trauma is presented in table 2. From table 2, it is seen that the lower extremities are the most traumatic segment of MSS: the proportion of fractures of this location, in total, reaches 78.4% in group 1, 82.1% in group 2, and 52% in group 3. Most often, bones of the lower leg are affected by fractures - 47.4%; 52.3% and 16% respectively. Fractures of the femur formed in almost a third of the victims in each of these groups. In victims of falls, a more uniform nature of injuries to the trunk and lower extremities is traced in comparison with other groups. This is due to the position of the human body at the time of the injury. In the event of a car accident, at the moment of collision, the pedestrian is usually in an upright position, the driver and passengers are in a sitting position; lower limbs and pelvis are the regions of primary strike. When falling from a height, primary strike was on the lateral surface of the victim’s body with damage to the upper and lower extremities, chest and pelvis.

| Fracture localization | Mechanical injury (n = 130) | Car accident injury (n = 116) | Fall (n = 13) | Gunshot fracture (n = 1) |
|-----------------------|-------------------------------|-------------------------------|--------------|-------------------------|
|                       | Group 1                       | Group 2                       | Group 3      | Group 4                 |
| Shoulder              | 9; 46%                        | 7; 42%                        | 2; 8%        | -                       |
| Forearm               | 8; 41%                        | 4; 24%                        | 1; 4%        | -                       |
| Hand                  | 4; 21%                        | 2; 12%                        | 1; 4%        | -                       |
| Ribs                  | 6; 31%                        | 4; 24%                        | 4; 16%       | -                       |
| Pelvis                | 15; 77%                       | 13; 77%                       | 4; 16%       | -                       |
| Hip                   | 56; 28.9%                     | 48; 28.6%                     | 7; 28%       | 1                       |
| Shin                  | 92; 47.4%                     | 88; 52.3%                     | 4; 16%       | -                       |
| Foot                  | 4; 21%                        | 2; 12%                        | 2; 8%        | -                       |
| Total                 | 194; 100%                     | 168; 100%                     | 25; 100%     | 1                       |

On the whole, in the general group 1, in 130 injured there were 194 injured segments revealed; in group "car accidents injuries", in 116 injured (group 2), 168 segments were injured; in group "falls", in 13 injured, there were 25 broken segments (Table 2). Considering that some MSS segments have more than one bone (forearm, lower leg, pelvis, etc.), in group 1, 283 fractures formed in 130 victims; in group 2 – 254 fractures per 116 injured; in group 3 – 28 fractures per 13 victims. In car injuries, mostly there were two and three fractures; in victims of a fall, the presence of one as well as two fractures was noted with the same frequency (fig. 2). On average, there were 2 fractures per victim.
Falls occurred from the own body height (n = 4) and from a height of up to 3 m (n = 9). This type of damage has 2 mechanisms. In the first one, an active free uncoordinated fall from a one’s own body height was observed after a hand push, which gave acceleration to the victim’s body. Due to the relatively small force of the push, the fall on a solid flat surface (wooden floor) was just the initial collision phase resulting in primary direct injuries as isolated fractures of the bones of the knee joint when falling onto the knees (n = 3) and an isolated fracture of the proximal femur when falling onto lateral surface of the trunk (n = 1).

In the second mechanism, resulting from the fall from the height up to 3 m (7 cases), a direct free passive uncoordinated fall occurred on a flat deformable surface, soft ground (n = 4), and snow (n = 3). In the remaining 2 cases, the fall onto a flat hard surface (asphalt) was coordinated (n = 1) and uncoordinated (n = 1). All the victims had the landing process influenced by factors that made it possible to mitigate the impact force of the body: a relatively soft impact surface (n = 7), thick winter clothes (n = 3), loose outerwear that “parachuted” (n = 3), body grouping at the moment of collision (n = 1). In 7 victims, when they fell on the lateral surface of the trunk, only a primary collision occurred with the formation of: 1) primary direct injuries at the site of the primary interaction of the body and the surface of the collision (n = 1). Among the primary direct injuries, fractures of the proximal humeral (n = 2), radius (n = 1) and femoral (n = 4) bones, femoral diaphysis (n = 3), lower leg bones (n = 4), and pelvis (n = 4) and ribs (n = 4), brain concussion (n = 3), bruises of the chest (n = 4) and abdomen (n = 3). Secondary injuries were: fractures of the fifth metacarpal bone (n = 1), the middle phalanx of the third finger of the hand (n = 1), and the inner ankle (n = 1). Since falls resulted from the small height, at the moment of a sudden stop of the human body (i.e., at the moment of impact of the body with the surface), the amount of kinetic energy generated was not sufficient to cause primary indirect damage to the bone tissue that usually occurs in areas of the body that are distant from the place of primary hit, as a result of general concussion of the body.

In Ukraine, in the structure of non-occupational unintentional injury, the proportion of falls from various heights reaches 50 – 57.8%; traffic accidents make up 2 – 2.5% [3-5]. The data obtained represent the opposite pattern: 89.2% of cases of road traffic injuries and 10% resulted from the falls. These differences are due to the fact that the Department of Emergency Service of Ukraine registers all accidents regardless of the circumstances of their sustaining [3-5], while the results of our study include only criminal injuries.

Falls from various heights are one of the most common causes of admission to orthopedic and traumatological medical settings [8] and are the most common cause of death in the domestic buildings [9-13], with two of the three fatal falls occurring in job buildings with the number of employees less than 10 [9]; 60% of accidents are in companies where the number of employees does not exceed 49 [10]. The places with highest traumatic incidence rate are the building and roofing industries, in which the frequency of fatal falls reaches 80% [11]. In almost half of the cases (45.6%), occupational injury from falling occurs at the height of 3 – 6.1 meters; 16.7% of cases were at the height of 0 - 3 meters; 18.4% of cases were at the height of 6.1 - 9.0 meters, 19.3% of cases of injuries were sustained from the fall higher than 9.1 meters [12]. Most often, workers fell from scaffolding (33%), stairs (24%), and stepladders (21%) [12], from roofs (26.3%), and robotic loaders (8.8%) [13]. The bone fracture was found as the commonest type of injury (57%);
the most frequent localizations were spine, head, chest [14].

Domestic accidents are quite common among children and older people. In children (0 – 19 years old), unintentional falls are the main cause of non-fatal traumas [15]. Among the people over 65 years old, falls make up 28-35% of injuries, and their number rises to 32-42% for people over 70 [16].

Independent prognostic factors for the non-fatal outcomes of a fall are the patient's age, height of the fall, features of the surface of the impact, and localization of the primary impact on the human body. Reliably higher probability to survive after falling is among young victims (p <0.005), who fall from a height up to 6 m (p <.0001) to a soft deformable surface (p <0.05) [17].

The process of damage formation during a fall does not fully comply with the laws of physics, since the tissues of the human body are elastic, have different elasticity properties, resistance, and some parts of the body are able to move, which significantly reduces the force of impact [18]. Falls onto the lateral surface of the body are distinguished by a smaller amount of damage due to the greater inertial stability of the human body, which manifests itself in the lateral direction with respect to the vertical. In addition, the impact force is distributed in these cases over a larger area. Such injuries may resemble traffic injuries or injuries from body compression by blunt objects [19].

The nature of the damage when falling from a height depends, in particular, on the impact energy, which increases with the height of the fall and person's body weight [12].

Forensic medical assessment of criminal cases of falling from various heights, carried out for the period 2007 – 2011 by Alam S.P. et al. [20], revealed predominantly non-fatal falling trauma (n = 885; 86%). Falls onto the knee, ankle and back made up about half of the non-fatal incidence [20]. A specific sign of a fall on the knee area, in a free and uncoordinated fall, is the presence of “stamped sores” and skin wounds from impacts on a hard surface [21].

Conclusions

1. In the structure of mechanical damage to the long bones of the lower extremities according to the initial forensic medical examination, falls from various heights have been found out as the second most frequent criminal injuries (n = 13; 10%) following road traffic injuries (n = 116; 89,2%).

2. Falls from the own body height (n = 4) and from the height of up to 3 m (n = 9) can be described as free, straight, and mostly uncoordinated (n = 12), with the formation of mainly primary direct injuries as the fractures of the long bones of the upper limbs (n = 3) and lower limbs (n = 11), ribs (n = 4), pelvis (n = 4), brain concussion (n = 3), chest concussion (n = 4) and abdomen traumas (n = 3).

Prospects for further research

In-depth investigation of the frequency and nature of cases, which were not clarified during the primary forensic medical expert examination of victims as a result of the fall, as well as the causes to not draw corresponding conclusions by the forensic medical experts seem to be promising.

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Reферат

СТРУКТУРА І МЕХАНІЗМ УТВОРЕННЯ ПЕРЕЛОМІВ ДОВГИХ КІСТОК НИЖНІХ КІНЦІВЮК У РАЗІ ПАДІННЯ. Сокол В.К.

Ключові слова: механічна травма нижніх кінцівок; падіння; механізм падіння; структура падіння; судово-медична експертиза.

Обґрунтування. Дослідження структури і механогенеза падіння необхідне для з’ясування причинно-наслідкових зв’язків у разі кримінальної кататравми. Мета - вивчити структуру механічної травми, яка спричинила переломи довгих кісток нижніх кінцівок, і механізми їх утворення у пострадавших в результаті падіння за даними первинної судово-медичної експертизи. Матеріал і методи. Матеріал дослідження - 130 актів первинних судово-медичних експертиз потерпілих з переломами стегнової кістки та / або кісток гомілки внаслідок механічної травми за період лютого - червня 2018 року. Всі постраждали були об’єднані в групу 1 «Механічна травма»; також були виділені групи: 2 - автомобільна травма; 3 - падіння; 4 - вогневий перелом. Методи дослідження: ретроспективний аналіз, описова статистика. Результати. При кататравмі питома вага переломів нижніх кінцівок склала 52%, верхніх кінцівок, ребер і тазу - по 16%; у разі автотравми - 82,1%; 7,8%; 2,4% і 7,7% випадків відповідно. Структура кататравми включала: 1) побутові падіння з висоти власного росту (n = 4) і 2) падіння з висоти до 3 м (n = 9). Механізми кататравми: 1) активні вільні некоординовані падіння з висоти власного зросту з фазою первинного зіткнення з утворенням ізольованих первинних прямих пошкоджень; 2) прямі вільні пасивні переважно некоординовані падіння з висоти до 3 м з утворенням множинних або поєднаних пошкоджень в фазу первинного зіткнення (n = 4) і в фази первинного і вторинного зіткнення тіла з поверхнею (n = 3). Висновки. У структурі механічних пошкоджень довгих кісток нижніх кінцівок за даними первинної судово-медичної експертизи падіння з різної висоти є другою за частотою кримінальною травмою (10%) після дорожно-транспортної травми (89,2%). Падіння з висоти власного зросту і з висоти до 3 м супроводжувалися утворенням в основному первинних прямих пошкоджень у вигляді переломів довгих кісток верхніх і нижніх кінцівок, ребер, таза, струсу головного мозку, забитих місць грудної клітини і живота.

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