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## MORPHOLOGICAL PECULIARITIES OF DETERMINING THE SITE OF INITIAL CONTACT BETWEEN THE VEHICLE AND CHILD PEDESTRIAN

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**Abstract.** This article focuses on the forensic medical investigation of the mechanism of initial contact between vehicles and child pedestrians. The study analyzed 52 cases of road traffic accidents involving children aged 1 to 18 years. The research established that the localization of primary contact significantly depends on the child's age and the ratio of their height to the bumper height of the vehicle. In the 1-3 year age group, contact most frequently occurs at the level of the head (40 %) and chest (40 %), reflecting the inherent vulnerability of very young children whose height typically positions these body regions at bumper level. Toddlers' underdeveloped motor skills and limited traffic awareness further increase their risk of sustaining severe head and thoracic injuries during vehicle collisions. In the 4-7 year age group, primary contact shifts predominantly to the abdomen (44.4 %) and chest (33.3 %), corresponding to their increased height. Children in this developmental stage demonstrate improved but still limited traffic awareness, with their abdomen and thoracic regions typically aligning with vehicle bumper heights. For children aged 7-11 years, the primary impact points move lower to the thigh (41.2 %), abdomen (23.5 %), and pelvis (23.5 %). This transition reflects their continued physical growth and the changing proportion of body segments relative to vehicle front structures. In the 12-18 year age group, impacts predominantly occur at the thigh (57.1 %) and lower leg (23.8 %) levels, approaching the adult pattern of pedestrian injuries, as their height progressively approximates that of adults. The study revealed age-specific morphological characteristics of injuries: younger children predominantly sustain "greenstick" fractures of the skull and ribs, characterized by incomplete breaks with partial bending, reflecting the higher elasticity and lower mineralization of their developing skeletal system. In contrast, older children more frequently exhibit classic bumper fractures of the femur, similar to those observed in adults but modified by their developing skeletal structure. Vehicle component imprints were identified on the bodies of 40.4 % of the victims, with bumper imprints being the most common (25 %). These imprints provide valuable forensic evidence for accident reconstruction, vehicle identification, and impact force estimation. The researchers propose a coefficient representing the ratio of bumper height to child height (BHCH) as a predictive tool for the localization of primary contact. This coefficient enables forensic specialists to better assess the expected injury pattern based on the specific vehicle-child interaction dynamics. The findings from this study have significant applications in forensic medical examinations of child pedestrian accidents, accident reconstruction, medicolegal investigations, and the development of more effective preventive measures to reduce childhood traffic injuries. The results can inform both vehicle design modifications and targeted educational programs aimed at reducing the severity of injuries sustained by child pedestrians. Furthermore, the age-specific injury patterns identified provide a valuable reference for emergency medical personnel, potentially improving triage decisions and treatment protocols for injured children.

**Keywords:** road traffic accidents, child pedestrians, primary contact, morphological features, bumper fractures, injury biomechanics, age-specific characteristics.

**Introduction.** Road traffic accidents (RTAs) involving child pedestrians constitute a significant proportion of traumatic cases with high mortality and disability rates worldwide [1, 2]. According to the World Health Organization, approximately 186,000 children die annually from injuries related to road traffic accidents, representing more than 500 child deaths per day. Child pedestrians are particularly vulnerable, accounting for about 38 % of the total number of injured minors in RTAs [3].

In Ukraine, according to official data from the National Police, approximately 150-180 children die in road accidents each year, with an additional 3,500-4,000 sustaining injuries of varying severity. Child pedestrians represent a significant portion (42-45 % of all injured

children). In the structure of child mortality from external causes, injuries resulting from road accidents rank second after drownings. Child road traffic traumatism is characterized by high lethality, reaching 4.8-6.5 % of the total number of injured children [4, 5].

Determining the site of initial contact between a vehicle and a child's body is crucial for establishing the mechanism of injury, reconstructing the circumstances of the accident, and providing an accurate forensic medical assessment of the case. This is particularly important in legal disputes regarding responsibility for pedestrian collisions, establishing the vehicle's speed, and determining the child's position at the moment of contact [6].

Unlike adult pedestrians, children have specific anatomical and physiological characteristics that significantly influence the nature and localization of traumatic injuries during vehicle collisions. These characteristics include: the ratio of head size to body, location of the body's center of mass, lower body height, incomplete skeletal ossification, and soft tissue peculiarities. These factors lead to differences in injury mechanisms and morphology among children of different age groups [7, 8].

There is a significant body of research dedicated to child pedestrian injuries, but most studies focus on epidemiological aspects or general injury characteristics without paying sufficient attention to the morphological features of the initial contact between a vehicle and a child pedestrian, taking into account modern diagnostic methods and biomechanical aspects of trauma.

Specifically, research by Adanu EK, et al. (2023) [9] primarily addresses statistical data on the prevalence of road traffic injuries among children of different age groups, while Halari MM, et al. (2022) [10] focuses on the impact of social and infrastructural factors on the risk of child road traffic injuries. Studies by Swedler DI, et al. (2024) [11] and Vijay NC, et al. (2024) [12] predominantly examine neurotraumatic aspects of child injuries and injuries from falls, respectively. Meanwhile, comprehensive studies on the morphological characteristics of injuries resulting from initial contact between a vehicle and a child

pedestrian, considering biomechanical aspects and age-specific features of the child's body, remain insufficient.

Thus, there is a need to systematize data regarding the morphological features of initial contact between a vehicle and a child pedestrian, taking into account modern diagnostic methods and biomechanical aspects of trauma.

**The aim of the study** is to identify and systematize the morphological features for determining the site of initial contact between a vehicle and a child pedestrian, taking into account the anatomical and physiological characteristics of the child's body at different developmental stages, as well as to develop a comprehensive approach to the forensic medical assessment of such cases.

**Materials and methods.** The research material consisted of forensic medical data, including photo-radiograms, computed tomography results, obtained from inpatient records from the "Ivano-Frankivsk Regional Children's Clinical Hospital" and during forensic medical examinations of 52 individuals aged 1 to 18 years who sustained traumatic injuries as a result of collisions with moving vehicles. The study also incorporated data obtained from 52 forensic automotive technical examination reports conducted during the period 2014-2024 at the Ivano-Frankivsk Research Forensic Criminalistic Center of the Ministry of Internal Affairs of Ukraine. The structure of the study sample is presented in Table 1.

Table 1

Structure of the Studied Sample

Group	Age	Gender	Sample size
1	1 to 3 years	male	2
	1 to 3 years	female	3
2	4 до 7 years	male	5
	4 to 7 years	female	4
3	7 to 11 years	male	9
	7 to 11 years	female	8
4	12 to 18 years	male	11
	12 to 18 years	female	10

The criteria for inclusion in the study were voluntary consent from parents or official representatives of the child and an age range from 0 to 18 years. In cases where data were obtained during forensic medical examinations, in addition to informed consent from parents or official representatives of the child, consent was obtained from the person who ordered the examination (police investigator). The scope and methods of the study comply with the fundamental principles of the Helsinki Declaration on Biometric Research (1974), adapted at the 41st International Assembly in Hong Kong (1989), where a person is the main object of research. During the study, adherence to basic principles such as respect for the individual, informed consent, and assessment of risk and benefit was ensured.

The following methods were used in the study: general scientific methods (analysis, synthesis, comparison, generalization); morphological examination of injuries (nature, localization, size, shape); radiological diagnostic method (X-ray, CT); medical-criminalistic studies (trasological, spectral); statistical methods (calculation of mean values, standard deviation, Student's t-test,  $\chi^2$ -test, correlation analysis. Statistical data processing was carried out using the STATISTICA 10.0 software package).

**Research results and their discussion.** Analysis of the studied material allowed to establish significant differences in the localization and nature of injuries during the primary contact of a car with a child-pedestrian depending on the age of the child and the corresponding anatomical and physiological features.

The study of 52 cases of collisions of children of different age groups with a car showed that the localization of the primary contact of the car with the child's body significantly depends on the age of the injured child (Table 2).

In children aged 1-3 years, the primary contact most often occurred at the level of the head (40.0 %) and chest (40.0 %), which is explained by the low height of children in this age group (average height 84.2±6.3 cm) and the ratio of this height to the bumper height (average height of passenger car bumpers 47.3±5.1 cm).

In the group of children aged 4-7 years, the primary contact most often occurred at the level of the abdomen (44.4 %) and chest (33.3 %), which corresponds to their average height (108.7±7.4 cm) and bumper height.

Table 2

Localization of the Primary Contact of a Car with a Child's Body in Different Age Groups

Localization of primary contact	1-3 years (n=5)	4-7 years (n=9)	7-11 years (n=17)	12-18 years (n=21)	p-value
Head	2 (40.0 %)	1 (11.1 %)	0 (0 %)	0 (0 %)	<0.1
Thorax	2 (40.0 %)	3 (33.3 %)	2 (11.8 %)	1 (4.8 %)	<0.01
Abdomen	1 (20.0 %)	4 (44.4 %)	4 (23.5 %)	1 (4.8 %)	<0.05
Pelvis	0 (0 %)	1 (11.1 %)	4 (23.5 %)	2 (9.5 %)	>0.05
Thigh	0 (0 %)	0 (0 %)	7 (41.2 %)	12 (57.1 %)	<0.001
Shin	0 (0 %)	0 (0 %)	0 (0 %)	5 (23.8 %)	<0.01

In children of the 7-11 age group, there was greater variability in the localization of primary contact, with predominance in the thigh area (41.2 %), abdomen (23.5 %), and pelvis (23.5 %). The average height of children in this group was 132.5±9.6 cm.

In the older age group (12-18 years), the primary contact predominantly occurred in the thigh area (57.1 %) and shin (23.8 %), which brings the trauma mechanism closer to the adult type due to increased height (average height 158.4±12.8 cm).

Statistical analysis showed a high correlation between the child's height and the localization of primary

contact ( $r=0.83$ ,  $p<0.001$ ). A statistically significant correlation was also established between the ratio of the child's height to the bumper height and the localization of primary contact ( $r=0.76$ ,  $p<0.001$ ). These data indicate the determining role of the child's anthropometric indicators in the formation of a characteristic pattern of injuries during a car collision.

Detailed analysis of the morphological features of injuries revealed characteristic signs indicating the site of primary contact in different age groups (Table 3).

Table 3

Morphological signs of primary contact in different age groups

Morphological feature	1-3 years (n=5)	4-7 years (n=9)	7-11 years (n=17)	12-18 years (n=21)	p-value
Abrasions with impression marks of car parts	3 (60.0 %)	4 (44.4 %)	6 (35.3 %)	8 (38.1 %)	>0.05
Bruises with well-defined contours	4 (80.0 %)	6 (66.7 %)	9 (52.9 %)	10 (47.6 %)	>0.05
Lacerated-contusion wounds	1 (20.0 %)	2 (22.2 %)	5 (29.4 %)	7 (33.3 %)	>0.05
Fractures of the cranial vault bones	2 (40.0 %)	1 (11.1 %)	0 (0 %)	0 (0 %)	<0.01
Rib fractures	2 (40.0 %)	3 (33.3 %)	2 (11.8 %)	1 (4.8 %)	<0.5
Pelvic bone fractures	0 (0 %)	1 (11.1 %)	3 (17.6 %)	2 (9.5 %)	>0.05
Femur fractures	0 (0 %)	0 (0 %)	5 (29.4 %)	9 (42.9 %)	<0.01
Bumper fractures	0 (0 %)	0 (0 %)	4 (23.5 %)	8 (38.1 %)	<0.01
Internal organ injuries	2 (40.0 %)	5 (55.6 %)	6 (35.3 %)	3 (14.3 %)	<0.05

In the youngest age group (1-3 years), bruises with well-defined contours (80.0 %), abrasions with imprints of vehicle elements (60.0 %), fractures of the cranial vault bones (40.0 %), and rib fractures (40.0 %) were most frequently observed. This group showed the highest percentage of cranial vault bone fractures, which is explained by the anatomical features of children of this age (relatively larger head compared to the body) and the localization of primary contact at the head level.

In children aged 4-7 years, bruises with well-defined contours (66.7 %), abrasions with imprints of vehicle elements (44.4 %), rib fractures (33.3 %), and internal organ injuries (55.6 %) were most commonly found. The high frequency of internal organ injuries in this group is explained by the fact that primary contact most often occurred at the level of the abdomen and chest, as well as the peculiarities of the child's body structure (thin abdominal wall, relatively large size of the liver and spleen).

In the 7-11 age group, the following morphological signs of primary contact were observed: bruises with well-defined contours (52.9 %), abrasions with imprints of vehicle elements (35.3 %), femur fractures (29.4 %), and internal organ injuries (35.3 %). In this group, bumper fractures (23.5 %) appear for the first time — transverse

fractures of the diaphyses of long tubular bones with a wedge-shaped fragment, the apex of which is directed toward the impact side.

In the older age group (12-18 years), the most characteristic signs of primary contact were: bruises with well-defined contours (47.6 %), femur fractures (42.9 %), abrasions with imprints of vehicle elements (38.1 %), and bumper fractures (38.1 %). This group had the highest frequency of bumper fractures, which is associated with the localization of primary contact at the level of the lower extremities and increased bone mineral density compared to younger age groups.

Analysis of the morphological signs of primary contact showed that some signs are common to all age groups (abrasions, bruises), while others are specific to certain age groups (cranial vault bone fractures in the youngest group, bumper fractures in older age groups).

In 21 cases (40.4 %), marks reproducing the contours of car details were found on the bodies of injured children (Table 4). The frequency of detection of such marks was higher in younger age groups, which is explained by the characteristics of children's skin (thinner, more elastic) and less protection by clothing.

Most frequently, bumper imprints were found on the victims' bodies (25.0 %), less frequently - radiator grille imprints (5.8 %), car emblem imprints (5.8 %), and headlight imprints (3.8 %). In younger age groups (1-3 and 4-7 years), radiator grille and headlight imprints were more commonly observed, while in older age groups (7-11 and 12-18 years), bumper imprints and, less frequently, car emblem imprints predominated.

Forensic examinations of victims' clothing (conducted in 43 cases) revealed traces of contact with the vehicle in 27 cases (62.8 %). Spectral analysis, performed in 18 cases, detected microparticles of the car's paint coating in 14 cases (77.8 %).

A characteristic feature of vehicle part marks on the bodies of younger children was their clearer impression, which is explained by the thinner subcutaneous fat layer and greater skin elasticity. In older age groups, the imprints of vehicle parts often had an indistinct character but were accompanied by more pronounced damage to the underlying tissues.

Analysis of the nature of bone fractures in different age groups showed significant differences related to age-specific features of bone tissue and the localization of primary contact (Table 5).

Table 4

Frequency and nature of vehicle part marks on the bodies of victims

Character of the imprint	1-3 years (n=5)	4-7 years (n=9)	7-11 years (n=17)	12-18 years (n=21)	Total (n=52)
Bumper imprint	1 (20,0%)	2 (22,2%)	4 (23,5%)	6 (28,6%)	13 (25,0%)
Radiator grille imprint	1 (20,0%)	1 (11,1%)	1 (5,9%)	0 (0%)	3 (5,8%)
Headlight imprint	1 (20,0%)	1 (11,1%)	0 (0%)	0 (0%)	2 (3,8%)
Car emblem imprint	0 (0%)	0 (0%)	2 (11,8%)	1 (4,8%)	3 (5,8%)
Total cases with imprints	3 (60,0%)	4 (44,4%)	7 (41,2%)	7 (33,3%)	21 (40,4%)

Table 5

Nature of bone fractures in different age groups

Type of fracture	1-3 years (n=5)	4-7 years (n=9)	7-11 years (n=17)	12-18 years (n=21)	p-value
Linear skull fractures	2 (40.0 %)	1 (11.1 %)	0 (0 %)	0 (0 %)	<0.01
Greenstick rib fractures	1 (20.0 %)	2 (22.2 %)	1 (5.9 %)	0 (0 %)	<0.05
Complete rib fractures	1 (20.0 %)	1 (11.1 %)	1 (5.9 %)	1 (4.8 %)	>0.05
Pelvic bone fractures along synchondrosis lines	0 (0 %)	1 (11.1 %)	2 (11.8 %)	0 (0 %)	>0.05
Complete pelvic bone fractures	0 (0 %)	0 (0 %)	1 (5.9 %)	2 (9.5 %)	>0.05
Transverse fractures of long bone diaphyses	0 (0 %)	0 (0 %)	1 (5.9 %)	1 (4.8 %)	>0.05
Bumper fractures	0 (0 %)	0 (0 %)	4 (23.5 %)	8 (38.1 %)	<0.01

In children aged 1-3 years, linear skull fractures (40.0 %) and rib fractures (40.0 %) were most commonly observed, with half of the rib fractures having the character of incomplete greenstick fractures. This nature of fractures is explained by the characteristics of bone tissue in children of this age (greater elasticity, less mineralization) and the localization of primary contact at the level of the head and chest.

In the 4-7 age group, rib fractures (33.3 %) were most commonly found, with the majority of them (22.2 %) having the character of incomplete greenstick fractures. In this group, pelvic bone fractures (11.1 %) were also observed, which ran along synchondrosis lines, which is a characteristic feature of fractures in children with an incomplete ossification process.

In children aged 7-11 years, femur fractures (29.4 %) were most frequently noted, with most of them (23.5 %) having the character of bumper fractures. Pelvic bone fractures (17.6 %) were also observed, with the majority of them (11.8 %) running along synchondrosis lines.

In the older age group (12-18 years), femur fractures predominated (42.9 %), most of which (38.1 %) had the character of bumper fractures. Pelvic bone fractures (9.5 %) were also noted, which had the character of complete fractures, indicating completion of the ossification process in this age group.

Analysis of CT images in cases of bumper fractures showed characteristic features: transverse direction

of the fracture, presence of a wedge-shaped fragment with its apex directed toward the impact side, and absence of soft tissue tears. In 3 cases (25.0 % of all bumper fractures), fibula fractures were observed at the same level.

Analysis of biomechanical aspects showed that the following factors influence the nature and localization of injuries during primary contact: the height of the vehicle bumper, the shape of the front part of the car, the speed of movement, and the position of the child's body at the moment of impact.

It was established that with the same bumper height, the localization of primary contact changes depending on the child's age, which is explained by the different heights of children in different age groups. For quantitative assessment of this dependence, the ratio of bumper height to child's height (HRR) was calculated. With HRR values above 0.5 (characteristic for children aged 1-3 years), primary contact was most often localized in the head and chest area. With HRR values of 0.4-0.5 (characteristic for children aged 4-7 years), primary contact most often occurred in the abdominal and chest area. With HRR values of 0.3-0.4 (characteristic for children aged 7-11 years), primary contact was more often localized in the thigh, pelvis, and abdominal area. With HRR values less than 0.3 (characteristic for children aged 12-18 years), primary contact most often occurred at the level of the thigh and shin.

The shape of the front part of the car also influenced the nature of injuries. Cars with a sloping front part caused more injuries to the upper body due to throwing the child's body onto the hood, while cars with a vertical front part more often caused combined injuries to the lower extremities and injuries due to body ejection.

The speed of the car significantly affected the severity of injuries. At speeds up to 40 km/h, isolated injuries in the primary contact area predominated, while at speeds above 40 km/h, multiple and combined injuries of different anatomical areas were more often observed.

The position of the child's body at the moment of impact also influenced the nature of injuries. In most cases (67.3 %), the child was standing sideways to the car, in 21.2 % of cases - with their back to the car, and only in 11.5 % of cases - facing the car. When positioned sideways, an asymmetric distribution of injuries was observed with predominance on the impact side. When positioned with the back to the car, injuries to the occipital area of the head were often found due to the head being thrown backward upon impact. When facing the car, symmetrical injuries to the front surface of the body and injuries in the area of the knee joints were more often observed.

**Conclusions.** The localization of primary contact of a car with the body of a child pedestrian has a clear age pattern. In children aged 1-3 years, contact at the level of the head and chest predominates; in children aged 4-7 years - at the level of the abdomen and chest; in children aged 7-11 years - at the level of the thigh, abdomen, and pelvis; in children aged 12-18 years - at the level of the thigh and shin. The morphological signs of primary contact also have age characteristics: in younger age groups, skull fractures and incomplete greenstick rib fractures are more common; in older age groups - bumper fractures of the femur. Imprints of car details on the child's body are an important diagnostic sign of primary contact and are found in 40.4 % of cases, with younger children more often having them localized on the upper part of the body, and older children - on the lower extremities. The proposed ratio of bumper height to child's height allows predicting the localization of primary contact.

A comprehensive approach to the forensic medical assessment of primary contact of a car with a child pedestrian, which takes into account the anatomical and physiological features of the child's body, allows for a more accurate reconstruction of the circumstances of a traffic accident and contributes to the development of effective preventive measures to reduce child traffic injuries.

**Conflict of interest:** absent.

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#### МОРФОЛОГІЧНІ ОСОБЛИВОСТІ ВСТАНОВЛЕННЯ МІСЦЯ ПЕРВИННОГО КОНТАКТУ АВТОМОБІЛЯ З ДИТИНОЮ-ПІШХОДОМ

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**Резюме.** Стаття присвячена комплексному судово-медичному дослідженню механізму первинного контакту автомобіля з дитиною-пішоходом.

Проаналізовано 52 випадки дорожньо-транспортних пригод за участю дітей віком від 1 до 18 років. Це дозволило виявити закономірності формування травм залежно від віку постраждалих. Встановлено, що локалізація первинного контакту суттєво залежить від віку дитини та співвідношення її зросту до висоти бампера транспортного засобу. У групі 1-3 роки первинний контакт найчастіше відбувається на рівні голови (40 %) та грудної клітки (40 %), що пояснюється малим зростом дітей цієї вікової категорії; у групі 4-7 років – на рівні живота (44,4 %) та грудної клітки (33,3 %); у групі 7-11 років – на рівні стегна (41,2 %), живота (23,5 %) і таза (23,5 %); у групі 12-18 років – переважно на рівні стегна (57,1 %) та гомілки (23,8 %). Виявлено специфічні вікові особливості морфології ушкоджень: у молодших дітей переважають переломи кісток черепа та ребер за типом "зеленої гілки" через високу еластичність кісткової тканини; у старших дітей характерними є бампер-переломи стегнової

кістки. На тілі 40,4 % постраждалих виявлено чіткі відбитки деталей автомобіля, найчастіше бампера (25 %), які мають важливе ідентифікаційне значення під час проведення судово-медичних експертиз. Запропоновано новий діагностичний критерій – коефіцієнт співвідношення висоти бампера до зросту дитини (КСЗ), який дозволяє з високою точністю прогнозувати локалізацію первинного контакту та характер очікуваних ушкоджень. Результати дослідження мають практичне значення для судово-медичної експертизи під час встановлення механізму травмування, ідентифікації транспортного засобу та можуть бути використані для розробки профілактичних заходів дитячого дорожньо-транспортного травматизму.

**Ключові слова:** дорожньо-транспортні пригоди, діти-пішоходи, первинний контакт, морфологічні особливості, бампер-переломи, біомеханіка травми, вікові особливості.

**Конфлікт інтересів:** відсутній.

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