Jurisprudencija, 2005, t. 66(58); 18–23

CONCISE BIOMECHANICS OF EXTREME DYNAMIC LOADING ON ORGANISM

Prof. Habil. Dr. Jiří Straus
Dr. Viktor Porada

Department odf Criminalistics
Police Academy CR, Prague, Czech Republic
Lhotecká 559/7, 143 01 PRAHA 4
Phone +00420974828030
E-mail: straus@polac.cz

Keywords: biomechanics, criminalistics, strange dynamical situations, injuries.

Summary

The forensic application of biomechanics deals with the decoding of relevant criminalistic information originating in the vestige of penal action reflecting the functional and dynamic characteristic of the offender's or some other person's organism. The possibilities of application in accordance with the acquired experiences and literary research might be introduced as followingly:

The assessment of the biomechanical content of the selected criminalistic vestiges; the up-to-now mostly analyzed is the biomechanical content of the trasological phenomena, partly even graphological print.

The extreme mechanical loading of organism, e.g. hitting by fist, stick or by some other object.

The biomechanical estimation of falls from height most often out of the house window. It happens very frequently that the aggressor attack with the intention to kill and he throws the victim out of the window; during the investigation he defends himself by stating that the victim fell out by some unhappy chance.

Among the very frequent injuries, we meet in criminological practice, are the head injuries caused by a blunt object. These blunt head injuries are significant partly for their exposed position and partly because nearly each time the attacked body part comprises a vital organ.

The most realistic variant of the mathematical model would certainly be appropriate to compare the results with empirical data. These possibilities are rather very limited as the corresponding data concerning the mechanical qualities of skull and brain substance are not available and the standards describing the brain injury are not known.

The experimentally reached results enlarge the contemporary basis of knowledge in biomechanics, criminalistics and forensic medicine.

1. Introduction

The forensic application of biomechanics deals with the decoding of relevant criminalistic information originating in the vestige of penal action reflecting the functional and dynamic characteristic of the offender's or some other person's organism. The possibilities of application in accordance with the acquired experiences and literary research might be introduced followingly:

– The assessment of the biomechanical content of the selected criminalistic vestiges; the up-to-now mostly analyzed is the biomechanical content of the trasological phenomena, partly even graphological print. Among these biomechanical applications might be classified even the mechanical behavior of the offender, his energetic output connected with the criminal act and his potential performance of movement viewing his abilities and limits of movement.

– The extreme mechanical loading of organism, e.g. hitting by fist, stick or by some other object. Most frequently the attack is directed on the head of the victim. Analyzing these facts one must state whether the attacked person died instantly or survived and theoretically might have been rescued. It is important to determine and quantify the limit for possible survival after this cerebral mechanical loading of the victim's head structures.

– The biomechanical estimation of falls from height most often out of the house window. It happens very frequently that the aggressor attack with the intention to kill and he throws the victim out of the window; during the investigation he defends himself by stating that the victim fell out by some unhappy chance. The biomechanical analysis may elucidate the fact of the involuntarily falling down or that there was an impulse and then that the victim was thrown out.

In this contribution we would like to concentrate on the extreme mechanical load of the victim's head and on the tolerance of man's organism. Under the extreme dynamic situations is to be understood the toleration and resistance to the supercritical quantities of force, acceleration and pressure causing the injury of the organism, which might or could not be survived. Here we speak about lethal injuries. The limits of toleration being rather broad and individual the kinematic and dynamic analysis seems necessary together with the individual casuistic excess [1].

Among the very frequent injuries, we meet in criminological practice, are the head injuries caused by a blunt object. These blunt head injuries are significant partly for their exposed position and partly because nearly each time the attacked body part comprises a vital organ.

2. Balance of Mechanical Energy at External Head Impact

On analyzing the head injury it is necessary to respect the reality that the skull fracture need not be accompanied by a serious brain injury, on the contrary even mortal injury might exist without cranial fractures. Nearly all head injuries are accompanied by brain leisures.

At the arbitrary interaction force contact of a blunt object and man's head three phases may be distinguished from the mechanical point of view:

– external dynamics – the motion of the object or head before the contact or hit,

– proper hit – contact between the object and head, the transport of forces, energy of deformation,

– the following phase – the motion of head or object after the hit (contact).

The attracting object is far stiffer or resistant than the attacked head of the victim. The attacking object moves with a certain kinetic energy, which is absorbed either by the soft tissue deformation or osseous cranial deformation, further the neck soft tissue may be deformed and finally a part of the kinetic energy cause the movement of the head.

The energy balance of the mechanical interaction may be expressed as follows:

$$E_P = \Delta E + E_{Po} + E_H \text{, where} \qquad (1)$$

E_P – kinetic energy of the moving object,

ΔE– energy consumed by the soft tissue of the head or by the deformation of the skull,

E_{Po} – potential energy consumed by the tissue deformation of the neck,

E_H – kinetic energy of head following the hit.

With regard to the fact that the hardness of the object exceeds the hardness of the man head tissued some part of the kinetic energy will be absorbed by the soft tissue deformation of the head or the skull fracture. The energy loss ΔE may be expressed[1] (acc. to Jablonskij, 1977) as:

$$\Delta E = \left(1 - k^2\right) \frac{m_1 m_2}{2\left(m_1 + m_2\right)} \left(v_1 + v_2\right)^2 \text{, where} \qquad (2)$$

ΔE – loss of energy by head tissued deformation,

[1] Jablonskij, A.A.: Kurs teoretičeskoj mechaniky, č. 2, 1977.

k – recovery coefficient,
m_1 – mass of the moving object,
m_2 – mass of the attacked head,
v_1 – velocity of the object closely after the hit,
v_2 – velocity of the head before the hit.

Provided the head will be motionless at the mechanical interaction, i.e. $v_2 = 0$, then the upper equation may be arranged as follows:

$$\Delta E = \left(1 - k^2\right)\frac{m_2}{\left(m_1 + m_2\right)} E_P \text{, where} \qquad (3)$$

E_P means the kinetic energy of the moving object. The absorbed deformation energy influencing the soft head tissues may be determined by the latter equation.

This energy depends on four factors:

- kinetic energy of the attacking object (E_P)
- mass of the attacking object (m_1)
- mass of the man's head (m_2)
- coefficient of recovery (k)

In assessing real casuistic the deformation energy may be calculated on basis of sufficient number of input variables. For the mass of head one may assess the relation according Zaciorskij-Selujanov[1] (1978) by simplified expression:

$$m_2 = 1{,}296 + 0{,}0171\, m_T + 0{,}0143\, v_T \ , \qquad (4)$$

where m_2 – is the mass of the head [kg],
m_T– is the whole body mass [kg],
v_T – height [cm] of the human being.

We may calculate the mass of the head more precisely as suggested by Karas-Otįhal[2] (1991) following the linear regression function for the calculation of any arbitrary body segment (i = 1, 2…) using the common formula

$$m_i = B_o + B_1 x_1 + B_2 x_2 \qquad (5)$$

All needed coefficients for the arbitrary height and body mass are introduced by the mentioned authors for the precise calculation of the head mass.

The recovery coefficient (k) characterizes the visco-elastic properties of the hitting object and human head. For the nonelastic hit (coefficient equals 0) consisting of one phase only, there exists no rebound of the object but only deformation. Such kind of mechanical interaction between the head and blunt object does not come on. Coincidentally, such mechanical situation between the perfect tough and elastic body when k equals 1, does not come forth either. The hit is characterized by the coefficient (k) from an open internal (0,1).

The recovery coefficient (k) may be expressed by the velocity relation of the hitting object and head before the stroke and after it:

$$k = \frac{u_2 - u_1}{v_1 - v_2} \ , \qquad (6)$$

where u_2 – is the head velocity after the strike,
u_1 – is the head velocity till the strike,
v_1 – is the object velocity till the strike,
v_2 – is the object velocity after the strike.

All the mentioned coefficients were experimentally verified by Korsakov[1] (1991) on corpses using the recording by high-speed camera. His experimental results demonstrated that the velocity of

[1] Zaciorskij, V. M.- Selujanov, V.: Biomechanics of sports Techniques. Moscow: KFKS, 1978.
[2] Karas,V. - Otáhal,S. Základy biomechaniky pohybového aparátu člověka. Praha: FTVS UK, 1991.

the hitting object after the stroke was practically equal zero, the minimal back- or sidemovement was damped by holding, thus the formula could be simplified to

$$k = \frac{u}{v} \tag{7}$$

where *u* – is the head velocity after the strike,
v – means the object velocity after the strike.

3. Experimental Data for Different Head Injuries

Mogutov's[2] experiments [6] examined the strength of the strike and the subsequent characteristics of injury in corpses in 76 experiments distributed into three groups according to the spherical radius of the hitting device (3, 6 and 8 cm).

The analysis of the mentioned head injury enabled to formulate four basic groups characterized by the quantity and volume of injury. According to the analysis of the mechanical loading of cadaverous skulls we introduce a survey in tables that follow.

The first group is represented by the stab injury, the second by crater shaped wound geometrically copying the spherical object, the skull does not crack (break) only depression arises.

Diameter of the spherical object [cm]	Strength of strike [N]	Bone thickness [cm]
3	9 986	0,68
6	6 605	0,63
8	12 691	0,68
Medium value	9 761	0,66

The second group of

Diameter of the spherical object [cm]	Strength of strike [N]	Bone thickness [cm]
3	7 457	0,53
6	7 183	0,51
8	8 389	0,57
Medium value	7 677	0,54

The third group creates a crater with radial infractions and the forth group with craters with transversal and radial infections

Diameter of the spherical object [cm]	Strength of strike [N]	Bone thickness [cm]
3	6 889	0,44
6	6 664	0,42
8	7 330	0,40
Medium value	6 961	0,42

The fourth group

Diameter of the spherical object [cm]	Strength of strike [N]	Bone thickness [cm]
3	7 428	0,45
6	7 311	0,44
8	6 978	0,37
Medium value	7 239	0,42

(For given purpose chosen by Mogutov, 1984)

[1] Korsakov, S. A.: Sudĕbno-medicinskije aspekty biomechaniky udarnovo vzajmodějstvija tupovo tverdovo predmeta i golovy čelovĕka. Sudĕbno-medicinskaja ekspertiza. XXXIV, 1991, 3.

[2] Mogutov, S. V.: Sudebno-medicinskaja ocenka povreždĕnij kostĕj čerepa sferičeskimi predmetami. Sudebno-medicinskaja expertiza, Moskva, XXVII, 1984, 2.

The second and third group of injury are characterized by the crater with dimensions, diameter and length may be precisely measured. These data are introduced in further table.

Diameter of the spherical object [cm]	Second group of injury Max. [cm]	Second group of injury Min. [cm]	Third group of injury Max. [cm]	Third group of injury Min. [cm]
3	2,2	1,8	2,5	2,3
6	2,6	2,5	3,4	3,0
8	3,0	2,8	3,8	3,4

4. Discussion of Results and Conclusion

The experimental data are necessary to the assessment of the biomechanical model of the tolerance of organism to the dynamical loading. The validity of this model depends on the variability of data acquired.

The most realistic variant of the mathematical model would certainly be appropriate to compare the results with empirical data. These possibilities are rather very limited as the corresponding data concerning the mechanical qualities of skull and brain substance are not available and the standards describing the brain injury are not known. Up to now the best expression of the critical values is under "Wayne State Curve" described by Hiding–Wenner (1973). The mentioned curve describes the situation of a direct hit (stroke) of the head against a flat blunt object, and vice versa. The mentioned curve may be expressed as the time integral of an algebraic function, of the acceleration *a*(*t*), i.e.:

$$GSI = \int_0^t a^{2,5}(\tau)\, d\tau \,, \tag{8}$$

where the quantity *GSI* represents the skull loading stands for the acceleration.

The quantity *GSI* signalizes, from the empiric point of view, that any overcoming of its critical value ($GSI \geq 1000$) give rise to a very dangerous blunt impact. The load value of such head injury is represented by the function of acceleration. Some empirical data for short pulsatory intervals (2–5 ms) were obtained from experiments with corpses in which the skull fracture was taken as criterion of tolerance. For longer pulsatory intervals (approximately more than 40 ms) the data from volunteers tests were used in which case the light degree of brain commotions or unconsciousness served as criteria. The average pulsatory intervals were based on experiments with animals (dogs and apes).

The intracranial pressure following the strike changes along the ateroposterior axis at the impulse duration till 2 ms. At lower values (t = 0,1 ms) has the pressure directly under the loading point a positive value, the interference does not reach the posterior part of the skull. At the strike by a blunt and solid object on the skull the pressure spreads in the interior and after certain time the pressure wave returns from the posterior wall and this pressure is denominated as negative pressure. This negative pressure reaches its highest values for t = 0,8 ms. The highest negative pressure is on the posterior wall of the skull – of which fact follows, that the brain mass could be easily damaged by the tension or compression and the region on the contralateral part of the skull towards the loading point demonstrates higher degree of damage than the region of the stroke.

The type of the stroke in Wayne State Curve (8) does not always correspond to the model and physical reaction (unconsciousness, commotion) is not precisely understood. No criteria exist to clarify the brain injury. The time interval of loading seems to approximate most precisely the criterion of brain injury. The negative pressure value in brain tissue depending on the intensity and duration of loading would sufficiently describe the process. Important data were obtained at loading tests carried out on fresh dead bodies after the autopsy in the range of frequencies 1–350 Hz (Hicling-Wenner, 1973). In order to calculate the influence of pressure in duration of some milliseconds it is necessary to know the loading function in the frequency interval from 0 to 2200 Hz. The time limit of load duration is 0,0022 s which load corresponds to the stroke action.

The experimentally reached results enlarge the contemporary basis of knowledge in biomechanics, criminalistics and forensic medicine.

♦ ♦ ♦

REFERENCES

1. **Hicling, R.–Wenner, M. L.** Mathematical model of a head subjected to an axisymmetric impact. J. Biomechanics, 1973. Vol. 6. N. 2.
2. **Jablonskij, A. A.** Kurs teoretičeskoj mechaniky. Č. 2. 1977.
3. **Karas, V. - Otáhal, S.** Základy biomechaniky pohybového aparátu člověka. – Praha: FTVS UK, 1991.
4. **Korsakov, S. A.** Sudĕbno-medicinskije aspekty biomechaniky udarnovo vzajmodĕjstvija tupovo tverdovo predmeta i golovy čelovĕka. Sudĕbno-medicinskaja ekspertiza. XXXIV, 1991, 3.
5. **Mogutov, S. V.** Sudebno-medicinskaja ocenka povreždĕnij kostĕj čerepa sferičeskimi predmetami. Sudebno-medicinskaja expertiza. – Moskva, XXVII, 1984, 2.
6. **Straus, J.** Tolerance organismu člověka na některé extremní dynamické situace. Bezpečnostní teorie a praxe. 1, 1998.
7. **Zaciorskij, V. M. - Selujanov, V.** Biomechanics of sports Techniques. – Moscow: KFKS, 1978.

♦ ♦ ♦

Biomechanika teismo ekspertizėje

Prof. habil. dr. Jiři Straus
Dr. Viktor Porada
Čekijos policijos akademijos Kriminalistikos katedra, Čekijos Respublika

Pagrindinės sąvokos: *biomechanika, kriminalistika, nepaprastos dinamiškos situacijos, sužalojimai.*

SANTRAUKA

Biomechanika, taikoma teismo ekspertizėje, nagrinėja svarbios kriminalistinės informacijos, atsiradusios padarius baudžiamąją veiką ir atspindinčios funkcines bei dinamines nusikaltėlio ar kito asmens organizmo savybes, iššifravimą. Biomechaninių tyrimų galimybės apima kriminalistinių pėdsakų biomechaninio turinio įvertinimą, pavyzdžiui, apytikrį smūgio kumščiu, lazda ar kitu daiktu, jėgos kritimų iš aukščio biomechaninį apskaičiavimą ir pan.

Šiame eksperimentiniame darbe nagrinėjamos nepaprastos dinamiškos situacijos (extreme dynamic situations), sukeliančios organizmo sužalojimus, kurie gali būti ir mirtini. Buku daiktu padaryti galvos sužalojimai, kurių susidarymo mechanizmą tiria kriminalistika, yra dažniausi.

Gauti rezultatai išplėtė jau turimas žinias biomechanikoje, kriminalistikoje bei teismo medicinoje.