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MECHANICAL INJURY OF THE HEAD CAUSED BY EXTERIOR FORCE

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Dušan Mikičić, Vlado Savanović

Faculty of Electrical Engineering, Belgrade
Bulevar Revolucije 73, 11000 Beograd, Yugoslavia.
E-mail: mikicic@buef31.etf.bg.ac.yu
Military Medical Academy, Department for Neurology, Belgrade

Abstract. *Mechanical injuries of the head are certainly the most dangerous, so that the detailed theoretical study of this with all aspects is important, because it has practical application. Every head injury, even the mildest one, can lead to multiple mechanical, cognitive and emotional disturbance. Each strike in the live organism (particular in the head) causes at first: the pressure jump in the skin, in the bone with (or without) fractures and in soft (or liquid) tissue. Sometimes, the leaking of the liquid through the openings (eyes, ears, nose, throat, anus,...) with (or without) blood can be occured. After each strike, the pressure pulsation in live cells the* $p(t) = p_0 (1 + a_1 e^{-qt} \sin kt)$, p_0*=100kPa. The following (second) extreme - minimum represent already the vacuum pressure. Then the air penetration into the microstructure of the live cells occurs. Live cells composing a microstructure of the brain function normally at atmospheric pressure* p_o*=100kPa. Their function is jeopardized if the pressure varies for more than 50%. This paper confirms that in vacuum conditions dangerous deformations of the biomechanical microstructure of the brain can occur, which can jeopardize the normal work of cells. In more difficult conditions lead to their permanent damages. The structure of the brain is particularly sensitive to the vacuum pressure* $(0<p<80)$*kPa. So great pressure variations occur in traffic accidents, in dangerous sports (box, football, skiing), the fall from big altitude, etc. The consequence of such pressure variations is pass the air in the brain, through 24 a little circular holes on the head bone (nerve cerebrales). In such a way microballons are created which, apart from mechanical damages of the tissue, have cavitational effect too. Due to the later condensation of microballons, the surrounding cells lose the oxygen, stop functioning, or entirely expire.*

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INTRODUCTION

American scientists H.J. Proctor, M.D., F.A.C.S., G.W. Palladino,M.S. and D. Fillipo, M.S. have made experiments with animals in order to find out the endurance of the soft tissue at the increased pressure. The results of such an experiment are presented in paper [1], where the endurance of the soft tissue of the cat' marrow mass under the increased pressure is found. Some brain functions stopped at the pressure $p = 200$ kPa, and the pressure $p = 300$ kPa jeopardized the life. A similar experiment can be performed for other organs, too, in order to find out the quantitative endurance due to the pressure variation. The experiments with man is avoided, due to a great risk and possible permanent damages of live cells. However, man in his life is exposed to great pressure variations $p = (10 \div 1000)$ kPa, so that through the analysis of his organs functioning in such conditions the relevant conclusions can be drawn. The mountain climbers at the height $h = 5.5$ km live in vacuum conditions $p = 50$ kPa which is 50% less than the atmospheric pressure. It is similar for $h = 15$km, $p = 12$kPa, at temperature $t = -50$°C. The divers diving to the depth of 100m, endure the pressure $p = 1100$ kPa which is 11 times greater than the atmospheric pressure. The new world record is depth 130 m, with pressure $p = p_0 + 1300$ kPa = 1400 kPa, (Italian divers without protection apparatus). The head bone of man (skull) can endurance and more pressure, bat the problem is biomechanical structure of the brain. So great pressure variations occur in traffic accidents, in dangerous sports (box, football, skiing),the fall from big altitude, etc. What are the consequences of such pressure variations?

Nowadays there is a precise and detail recording of all microstructural changes in the soft tissue-by means of a scanner. These changes are reflected in the creation of microballons of diameter (1-100) μm, which are in more serious cases even of bigger diameter. Such damages were found in the brain of a boxer who had practiced box for a long time. The exterior manifestations are: more difficult speaking, uncertain walk, etc. In more serious cases the microballons destroy capillaries, hematomes appear-with smaller or bigger blood salients. Similar phenomena can be found on the liver, or some other organs, which are exposed to big pressure variations. This paper analyzes the influence of great accelerations (occurring at the collision of man and other bodies) on the pulsation of the pressure in our skin, skull and in brains.

REVIEW OF THE WORK

In this paper we are presenting simplify biomechanical method for assessment the pressure jump Δp and mechanical stress σ in live cells. Let as consider here soft stroke in the back of the head by force P (fig. 1).

The head rotation is made

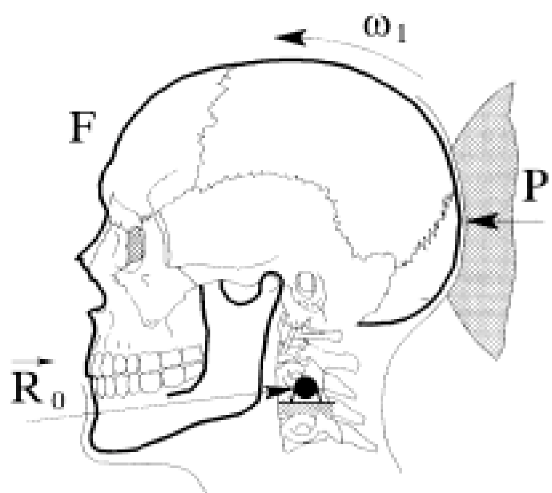

Fig 1. The Soft collision balls in the head

around a horizontal axis O_x, passing through the fourth thoracic vertebra of the spine.

$\vec{R}_0$ is the reaction of the joint, the same as the striking force. Due to this force we can anticipate mechanical damage in this joint and the adjacent joint. The impact of the force P (rubber ball with mass m_2) is transfered from the skin trough the skull and later through liquar in brain. The law of the conservation of the total angular momentum about axis O_x [5] we obtain for $\omega_1(0)=0$

$$\omega_1(\tau)[J_{ox} + m_2 a^2] = a m_2 v_2(0)(1+k) \tag{1}$$

t = 0, begining of the strike. Then, the contact area is A(0) = 0, (between ball on head).
t = 0.5τ, is a half of the strike. Then the contact area is $A(\tau/2) = b^2\pi$, $P = P_{max}$. Finally, for t = τ (the end of strike), A(τ) = 0, again.
$J_{ox} = J_{cx} + m_1 h^2 = 2/5 m_1 R_1^2 + m_1 h^2$, is axial moments of inertia of the head;
h is the distance between center C_1 of head, mass m_1 and joint O;
a is distance between horizontal velocity $v_2(0)$ and joint O;
$0 \leq k \leq 1$ – is coefficient of strike.
The moment of the strike pulse in this case $\omega_1(0)=0$ is:

$$0.5\, P \cdot a \cdot \tau = J_{ox}\omega(\tau) \tag{2}$$

The head and the ball we are present in the form of two balls with mass m_1(head) and m_2(ball). E_1 and E_2 are Young's modulus of elasticity, R_1 and R_2 are geometrical radius of the head and the ball.

According to [4] two centers C_1 and C_2 change the distance after elastic deformation with force P for Δ

$$\Delta = 0.83\left[P^2 \frac{R_1 + R_2}{R_1 R_2}(X_1 + X_2)^2\right]^{\frac{1}{3}} \leq 0.5 R_i \tag{3}$$

$$X_1 = (1-\mu_1)^2/E_1, \quad X_2 = (1-\mu_2^2)/E_2, \quad \mu \text{ - Poisson's ratio}$$

Then we can determine the endurance τ of the strike: $\tau = 4\Delta/v_2(0)$
The radius b of contact area $A(\tau/2)=b^2\pi$ we can determine with [4]

$$b = 0.91\left[P \frac{R_1 R_2}{R_1 + R_2}(X_1 + X_2)\right]^{\frac{1}{3}} \tag{4}$$

By four equations (1), (2), (3), (4) we obtain

$$P^5\left[\frac{R_1 + R_2}{R_1 R_2}(X_1 + X_2)^2\right] = 0.22\left[\frac{m_2(1+k)}{J_{ox} + m_2 a^2} J_{ox}\right]^3 v_2^{\,6}(0) \tag{5}$$

In the case $R_1 = 0.1$ m, $R_2 = 0.05$ m, $m_1 = 5$ kg, $m_2 = 0.5$ kg, $E_1 = 10^9$ Pa, $E_2 = 10^7$ Pa, k = 0.5, a = h = 0.1 m, $\mu_1 = 0.4$, $\mu_2 = 0.45$ (these are real biomechanical parameters for man and homogeneous rubber ball), we obtain:

$P = 210 v_2^{1.2}$, $\quad \Delta = 4.8 \cdot 10^{-5} P^{2/3}$, $\quad b = 1.26 \cdot 10^{-3} P^{1/3}$, $\quad \tau = 4\Delta\Delta/_2(0)$, table 1.

Table 1

$v_2(0)$ [m/s]	0	1.0	2.0	5.0	10.0	15.0	20.0
P [N]	0	210.0	482.0	1450.0	3328.0	5414.0	7646.0
$10^3\Delta$ [m]	0	1.7	3.0	6.0	10.7	15.0	19.0
10^3b [m]	0	7.5	10.0	14.0	19.0	22.0	25.0
Δp_s [MPa]	0	1.8	2.3	3.5	4.4	5.3	5.8
$\omega_l(\tau)$ [s^{-1}]	0	1.0	2.0	5.0	10.0	15.0	20.0
$v_1(\tau)$ [m/s]	0	0.1	0.2	0.5	1.0	1.5	2.0
ΔP_b [kPa]	0				80.0		

$$\Delta p_s = 1.5\frac{P}{b^2\pi} = \sigma_{c\,max} \qquad \text{(in the center of contact area } A=b^2\pi) \tag{6}$$

The skin of man can endurance $\Delta p_s \le 5$MPa. The head bone (skull) can endurance a surface pressure $\Delta p_s \le 100$MPa, but the problem is deflection and stability of the skull. At this instant the structure of the entire brain is exposed to an increased pressure Δp_b that is calculated by means of the first and second formula Zukovski [3]

$$\Delta p_b = \begin{cases} \rho C_e v_1(\tau), & \textit{for} \quad 0 \le \tau \le t_1 = 2D_1/C_e \\ \rho C_e v_1(t) t_1/\tau, & \text{for} \quad \tau \ge t_1 \end{cases} \tag{7}$$

$$C_e = \left[\frac{\varepsilon/\rho}{1+\dfrac{\varepsilon D}{E\cdot\sigma}}\right]^{1/2} \tag{8}$$

Biomechanics parameters in (7) and (8) have a following significance:

$\rho = 10^3$ kg/m^3 is density of the fluid (brain)

$v_1(\tau) = a\omega_l(\tau)$ is the jump of the speed of the brain center

$t_1 = \frac{2L}{C_e} = \frac{0.34}{580}s = 5.86\cdot10^{-4}s$ is the time needed for the compression wave to pass the path $2L = 4(R_1 - \delta_1) = 0.34$m

$\delta_1 = 0.015$ m, the mean thicness of skull, skin and muskule jointly.

$\varepsilon = 2\cdot10^9$ Pa is the module of the compressibility of the brain.

$E = 10^{10}$ Pa is the mean value of module of elasticity for skull [2].

D = 0.12 m the mean diameter of the brain.

$\delta = 0.005$ m the mean thicness of the skull.

For example $v_2(0) = 10$ m/s, $\omega_l(\tau) = 10$ rad/s

$$\tau = 4\frac{\Delta}{v_2(0)} = 4\frac{10.7\cdot10^{-3}m}{10\frac{m}{s}} = 4.3\cdot10^{-3}s = 4.3ms. \qquad v_1(\tau)=a\cdot\omega_l(\tau)=1m/s$$

$$\Delta p_b = \rho C_e v_1(\tau)\frac{t_1}{\tau} = 10^3\cdot580\cdot\frac{5.86\cdot10^{-4}}{4.3\cdot10^{-3}}Pa = 0.8\cdot10^5 Pa = 80\,kPa$$

Then the pressure pulsation in the brain begins $p(t) = p_0(1 + a_1e^{-qt}\sin kt)$, $p_{max} = p_0 + \Delta p_b = 180kPa$

$p_{min} = p_0 - 0.3\Delta p_b = 76kPa$ (vacuum pressure).

CONCLUSION

After each strike in the head we have the pressure jump Δp_s on the skin (6), and in the skull (table 1), and in the brain Δp_b (7). In more cases the the skin and skull are not jeapordized with the pressure jump Δp_s. However the brain is jeopordized, becouse the pressure pulsation causes the penetration of the air into the skull (absorption). In such a way microballons are created wich, apart from mechanical damages of the tissue have cavitational effect too. Due to the later condensation of microballons, the surrouding cells lose the oxigen and stop function. The main result of the present paper is the quantitative nonlinear functional link (5) between force P, velocity $v_2(0)$ and 11 biomechanical parameters R_1, R_2, m_1, m_2, E_1, E_2, μ_1, μ_2, k, a, h. Beside that, due to pulsation the pressure in the brain, the air penetrate in the skull through 24 a little circular hole (nerve cerebrales). This theory is concured with practical records, since the microballons are found in the brain in area: frontal, basal and medical parts, temporal cortex, diencephalon and upper parts of the marrow stern (fig.2)

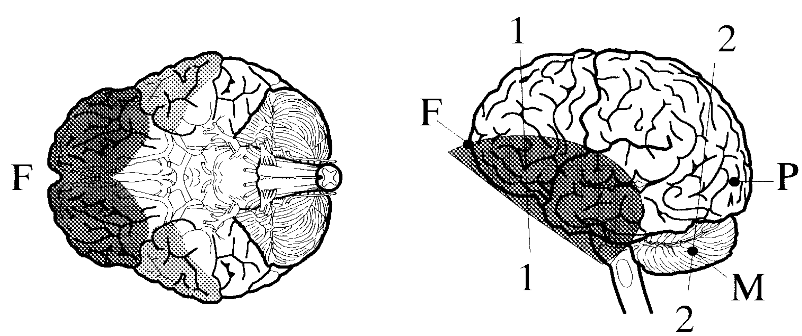

Fig 2. Typical distribution of contusion damages on the brain

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MEHANIČKA POVREDA GLAVE IZAZVANA SPOLJAŠNJOM SILOM

Dušan Mikičić, Vlado Savanović

Mehaničke povrede glave su obično najopasnije, tako da je njihova detaljna teorijska studija u svakom pogledu značajna, zbog njene praktične primene. Svaka povreda glave, čak i najlakša, može voditi višestrukim mehaničkim kognitivnim i emocionalnim poremećajima. Svaki udar na živi organizam (posebno na glavu) uzrokuje pre svega: skok pritiska na koži, na kostima sa (ili bez) preloma, i na mekom (ili tečnom) tkivu. Ponekad se može javiti curenje tečnosti kroz otvore (oči, uši, nos, grlo, anus...) sa (ili bez) pojave krvi. Posle svakog udara, pulsiranje pritiska u živim ćelijama $p(t)=P_0(1+a_1e^{-qt}\sin KT)$, $P_0=100$ *kPa. Sledeći (drugi = ekstrem – minimum, predstavlja već pritisak vakuuma. Zatim se javlja prodor vazduha u mikro-strukturu živih ćelija. Žive ćelije koje čine mikrostrukturu mozga funkcionišu normalno na atmosferskom pritisku* $P_0 = 100$ *kPa. Njihova funkcija je izložena opasnosti ako pritisak varira više od 50%. Ovaj rad potvrđuje da se u uslovima vakuuma mogu javiti opasne deformacije biomehaničke mikrostrukture mozga, što može dovesti u opasnost normalni rad ćelija. U težim uslovima to vodi njihovom trajnom oštećenju. Struktura mozga je posebno osetljiva na pritisak vakuuma (0;p;80) kPa. Tako, velike varijacije pritiska javljaju se u saobraćajnim udesima, opasnim sportovima (boks, fudbal, skijanje), pri padu sa velikih visina, itd. Posledica takvih varijacija pritiska je prodor vazduha u mozak kroz 24 mala kružna otvora na kosti glave (moždani nerv). Na taj način stvaraju se mikrobaloni, koji pored mehaničkih oštećenja na tkivu, imaju takođe karitacione efekte. Prouzrokovano kasnijim zgušnjavanjem mikrobalona, okolne ćelije gube kiseonik, zaustavljaju rad, ili potpuno odumiru.*