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HYDRODYNAMICS OF WOUND BALLISTICS

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ABSTRACT
Simulation of a human body from 20% gelatin & 80% water mixture is examined from wound ballistics point of view. Parameters such as incapacitation energy & temporary to permanent cavity size & tools of hydrodynamics' have been employed to arrive at a model of human body similar to the one adopted by NATO(North Atlantic Treaty Alliance). Calculations using equations of motion yield a value for the time in which a temporary cavity reaches its maximum size i.e., 339 µs & settle down to permanent cavity in case of 4 different bullets i.e. 5.45, 5.56, 7.62,10 mm sizes. The obtained results are in excellent agreement with the body model of a right circular cylinder of 15 cm height & 10 cm diameter. An effort is made here in this work to present a sound theoretical bases to parameters commonly used in wound ballistics from field experience discussed by Coats & Beyer.

Keywords: Gelatine, gunshot, hydrodynamic model, oscillation time, temporary cavity and permanent cavity, Wound Ballistic.

INTRODUCTION
Firearm injuries caused in military conflicts are of great social & humanitarian concern. Firearms are needed for protection of the nation & enforcement of law and order. All this make it even more important to understand Wound Ballistic processes in order to minimize injuries & suffering & to maximize the prospect of recovery.

Wound Ballistics subject though existing since ages. It's development as a subject was published in the form of a book after World War II.A book on this subject was written by Col Coats and Major Beyer and was printed in 1962 **(2)** .It is taken as a Bible for all purposes in the subject of "Wound Ballistics". Recently a book on the subject by Karl.G.Sellier in 1994 **(3)**. Wound Ballistics deals with the formation of wound on interaction of a moving projectile with human body. We are generally concerned with open wounds, which are easily seen with the naked eye. But Wound Ballistic deals with wounds created by gunshots, which are usually created inside the body and hardly seen by naked eye. In 1980 at UNO conference had prohibited firing even the dead human body. As tissues of animals under anesthesic do not behave like human flesh it is no good to fire them for creating wounds. Also it is prohibited in International Agreement under Hague Conference 1899 not to subject animals for firing trials after deep anesthesia. Their tissues may not resemble with the human tissues. Gelatin almost behaves like human flesh. 20% by wt of wheat flour dissolved in 80% by wt of water at 60- 65^{0}C is used for preparing gelatin. It is kept in a fridge for one day i.e. 24 hours at 10^{0}C 15 x10 cm^3 right circular cylinder is taken as simulant to human flesh. A proposed NATO standard for gelatin model **(1)** 15 x 15 x15 cm^3 was challenged by Fackler **(6)**. He suggested dimensions for model of gelatin to be taken as 15 x 10 cm^3 as right circular solid cylinder that we have adopted for our present work.

In Indian army usually 7.62 mm rifle is used. When a projectile hit the human body it punctures the human skin & enters the human body. Projectile goes on dissipating its energy (KE) till it remains inside human body. Pressure is developed & tissues expand to that extent that it could rebuff the energy release & temporary cavity is formed. This temporary cavity oscillates and settles down in the form of permanent cavity. If energy release is sudden & enormous human muscles cannot stand the rate of release of energy and the skin ruptures from various places. An excellent work review exists in literature **(4)** we consider the case when energy release is just sufficient to tolerate the expansion and contraction 26 times before settling down in form of permanent cavity. If inner surface of the temporary and permanent cavity is taken as spherical shell shown in figure (1) and the space in between these two spheres is $4/3\ \pi C^3$. Where there is no external or internal pressure.

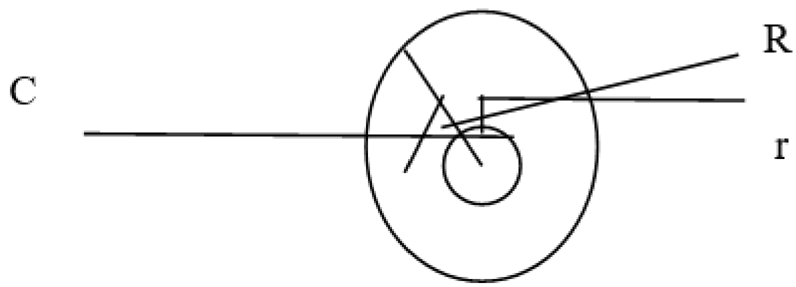

Figure (1)

The energy lost by the bullet within the body imparts momentum to the tissue elements, so that they rapidly move away from the bullet path and act like "Secondary missiles". Once set in motion, the inertia of the fluid particles continues. A large cavity follows the bullet path in conical form for a very short duration. This conical formed cavity is generally called "Temporary cavity" or "explosive cavity". Temporary cavity oscillates for a number of times & settles down in the form of"permanent cavity". Here attempt is made to calculate the time taken by temporary cavity to reach its maximum and settle down to permanent cavity when various bullets are used. Further research with ***steel spheres has demonstrated that some 400 µs after impact, a temporary cavity some 26 times the volume of the permanent cavity reaches its greatest diameter perpendicular to the path.***

MATH

If Let at any time t, p is the pressure and v be the velocity at distance r from the centre.

We know that the equation of the motion for a spherical shell of radius $r^1$is concurrent coordinate & velocity v^1 is: -

$$\frac{\partial v'}{\partial t} + v'\frac{\partial v'}{\partial r'} = \frac{-1}{\ell}\frac{\partial p}{\partial r'} \qquad (1)$$

Equation of continuity for spherical shell in polar coordinates, ρ is constant

$$\frac{1}{(r^1)^2} * \frac{\partial(\rho v^1 (r^1)^2)}{\partial r^1} = 0$$

$$\frac{\partial(\rho v^1 (r^1)^2)}{\partial r^1} = 0$$

$$v^1(r^1)^2 = F(t) = v(r)^2 \qquad (2)$$

$$v^1(r^1)^2 = F(t)$$

$$F^1(t) = (r^1)^2 * \frac{\partial(v^1)}{\partial t}$$

Put in equation (1)

$$\frac{F^1(t)}{(r^1)^2} + v^1\frac{\partial}{\partial r^1} = \left(\frac{-1}{\rho}\right)\frac{\partial(p)}{\partial r^1} \qquad (3)$$

Where

$$F^1(t) = \frac{\partial F}{\partial t}$$

Integrate eq (3) w.r.t. r^1

$$\frac{-F^1(t)}{r^1}+\frac{(v^1)^2}{2}=\left(\frac{-p}{\rho}\right)+c \tag{4}$$

where c is constant, .when r' is large enough, $v^1=0$, p = π_p (say) .Because F' (t) is very small, so r' insufficient large and taken as r' $\longrightarrow \infty$

put in (4) and we get $C = \pi_p / \rho$.

Put in (4) , we get

$$\frac{-F^1(t)}{r^1}+\frac{(v^1)^2}{2}=\left(\frac{\pi_p-p}{\rho}\right)$$

On the surface of the cavity.

r' = r, v' = v, p = 0. i.e. when Inside pressure = Outside pressure.

$$\frac{-F^1(t)}{r}+\frac{(v)^2}{2}=\left(\frac{\pi_p}{\rho}\right) \tag{5}$$

$$F(t)=vr^2$$

$$F^1(t)=\frac{\partial(vr^2)}{\partial t}=\frac{\partial(vr^2)}{\partial r}\frac{\partial(r)}{\partial t}=v*\frac{\partial(vr^2)}{\partial r}$$

Where $v=\frac{\partial(r)}{\partial t}$, Put in equation (5) .

$$\left(\frac{-1}{r}\right)*v*\frac{\partial(vr^2)}{\partial r}+\frac{(v)^2}{2}=\left(\frac{\pi_p}{\rho}\right)$$

$$\left(\frac{-v}{r}\right)*\left(2vr+r^2*\frac{\partial(v)}{\partial r}\right)+\frac{(v)^2}{2}=\left(\frac{\pi_p}{\rho}\right)$$

$$(-vr)*\left(\frac{\partial v}{\partial r}\right)-\frac{3(v)^2}{2}=\left(\frac{\pi_p}{\rho}\right)$$

$$v*\left(\frac{\partial v}{\partial r}\right)+\frac{3(v)^2}{2r}=\left(\frac{-\pi_p}{\rho r}\right)$$

$$\left(\frac{1}{2}\right)*\left(\frac{\partial v^2}{\partial r}\right)+\frac{3(v)^2}{2r}=\left(\frac{-\pi_p}{\rho r}\right)$$

Multiply by r^3 on both sides

$$\left(\frac{1}{2}\right)r^3*\left(\frac{\partial v^2}{\partial r}\right)+\frac{3r^3(v)^2}{2r}=\left(\frac{-r^3\,\pi_p}{\rho r}\right)$$

$$r^3*\left(\frac{\partial v^2}{\partial r}\right)+3r^2(v)^2=\left(\frac{-2r^2\,\pi_p}{\rho}\right)$$

$$\frac{\partial(r^3v^2)}{\partial r}=\left(\frac{-2r^2\,\pi_p}{\rho}\right)$$

Integrate w.r.t. "r"

$$r^3v^2 = \left(\frac{2r^3\,\pi_p}{3\rho}\right) + \; d \quad (\qquad (6)$$

[Just before expansion/ dissipation of energy]

Initial when r=a, v=0

$$\left(\frac{2a^3\,\pi_p}{3\rho}\right) = \; d$$

put in (6)

$$r^3v^2 = \frac{2r^3\,\pi_p}{3\rho} + \; \frac{2a^3\,\pi_p}{3\rho}$$

$$r^3v^2 = \frac{2\,\pi_p}{3\rho} * (r^3 - a^3)$$

$$v^2 = \frac{2\,\pi_p}{3\rho} * \left(\frac{r^3 - a^3}{r^3}\right)$$

$$v^2 = \frac{2\,\pi_p}{3\rho} * \left(\frac{r^3 - a^3}{r^3}\right)$$

$$v = \sqrt{\left[\frac{2\,\pi_p}{3\rho} * \left(\frac{r^3 - a^3}{r^3}\right)\right]}$$

As t >, r< 0, v < 0

$$\frac{\partial r}{\partial t} = \sqrt{\left[\frac{-2\,\pi_p}{3\rho} * \left(\frac{r^3 - a^3}{r^3}\right)\right]}$$

$$\frac{\partial r}{\partial t} = \sqrt{\left[\frac{-2\,\pi_p}{3\rho}\right]} * \sqrt{\left(\frac{r^3 - a^3}{r^3}\right)}$$

$$\sqrt{\left(\frac{r^3}{r^3 - a^3}\right)}\partial r = \left[\sqrt{\left[\frac{-2\,\pi_p}{3\rho}\right]}\right]\partial t$$

Integrate both sides as t;0 -→t , r ;a→0

$$-\int_a^0 \sqrt{\left(\frac{r^3}{r^3 - a^3}\right)}\partial r = \left[\sqrt{\left[\frac{2\,\pi_p}{3\rho}\right]}\right]t$$

Put $r^3 = a^3 \sin^2 Ø$, $3 r^2\, dr = a^3\, 2\sin Ø \cos Ø\, dØ$,Ø ; π/2→0

$dr = 2a/3\ \sin^{-1/3} Ø \cos Ø\, dØ$

$$\sqrt{2}\,\pi_p/3\rho\,.t = 2a/3 \int_0^{\pi/2} \sin^{2/3} Ø\, dØ$$

$$.t = \sqrt{2}\ \rho/3\ \pi_p \quad a \int_0^{\pi/2} \sin^{2/3}\text{Ø}\, d\text{Ø} \tag{7}$$

$\sqrt{2}/3 = 0.8165$, $\rho = 1.06$ (sellier), $\sqrt{\rho} = 1.0296$, $\pi_p = 101.3 * 10^3$ pa, $\sqrt{\pi_{p}} = 318.2766$

Case I:

a = 2.725/26 = 0.1048. [temporary cavity is 26 times the permanent cavity , 2.725 mm is radius of the bullet/ projectile.]

$$\int_0^{\pi/2} \sin^{2/3}\text{Ø}\, d\text{Ø} = 0.6667$$

t = 0.0003691 s = 369.1µs , 1 second $=10^6$ µs

t = 369 µs.

Case II:

a = 2.78/26 = 0.1069. [temporary cavity is 26 times the permanent cavity , 2.78 mm is radius of the bullet/ projectile.]

$$\int_0^{\pi/2} \sin^{2/3}\text{Ø}\, d\text{Ø} = 0.6667$$

t = 0.0003765 s = 376.5µs , 1 second $=10^6$ µs

t = 377 µs.

Case III:

a = 3.81/26 = 0.1465. [temporary cavity is 26 times the permanent cavity , 3.81 mm is radius of the bullet/ projectile.]

$$\int_0^{\pi/2} \sin^{2/3}\text{Ø}\, d\text{Ø} = 0.6667$$

t = 0.0005161 s = 516.1µs , 1 second $=10^6$ µs

t = 516 µs.

Case IV:

a = 5/26 = 0.1923. [temporary cavity is 26 times the permanent cavity , 5 mm is radius of the bullet/ projectile.]

$$\int_0^{\pi/2} \sin^{2/3}\text{Ø}\, d\text{Ø} = 0.6667$$

t = 0.0003387 s = 338.7µs , 1 second $=10^6$ µs

t = 339 µs.

UNITS

Wt(Weight), Cm(Centimeter), Mm(Millimeter), KE(Kinetic Energy), r(Radius of inner Spherical Surface), ρ(Density of gravitating flied), R(Outer Spherical Surface radius), V(Rupture Velocity). S(Seconds), µS(micro seconds), Pa(Pascal, Unit of atmosphere pressure.

CONCLUSION

This rigorous treatment using equations of motion of fluid mechanics yields the time taken by temporary cavity to reach its maximum is 339µs, which is close to, that stated by Major Beyer & Coats (2) as 400µs. This difference is not very significant because when models are framed in place of actual an agreement even within a factor of 2 is considered favorable (5) .Instead of the actual human body a simulant has been used for this theoretical work which cannot exactly match with the function of muscles in living humans .Therefore the gelatin model used is very close to reality if not perfect substitute for human body .Moreover this10- 20 % variation could also be there from person to person if it was permitted to fire on living humans .Thus we conclude that treatment carried out here using Hydro dynamical equations of motion and gelatin model for the body are in very good agreement and useful for further work on Wound Ballistics using different missiles , varying their speeds and parameters such as density , temperature and pressure etc. These calculations are in progress and shall be reported in a subsequent paper

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