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PRINCIPAL INVESTIGATOR: Edward Moshang
Geoffrey Ling, M.D., Ph.D.

CONTRACTING ORGANIZATION: EMTech Consultants, Incorporated
Towson, Maryland 21286

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Towson, Maryland 21286

email - emoshang@comcast.net

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13. ABSTRACT *(Maximum 200 Words)*

This report describes a method for modeling penetrating traumatic brain injury (PTBI) caused by gunshot using rats as the subjects. The method will be an improvement over previously used techniques in that it is minimally invasive, humane and based on a mathematical approach that is founded on known ballistic biophysics. This technique specifically avoids using a fired projectile. The proposed use of this animal model should improve the understanding of the pathophysiology of penetrating traumatic brain injury.

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Introduction

The objective of this study is to develop a method for modelling penetrating traumatic brain injury (PTBI) caused by gunshot using rats as the subjects. The method will be an improvement over previously used techniques in that it is minimally invasive, humane and based on a mathematical approach that is founded on known ballistic biophysics. This technique specifically avoids using a fired projectile. The proposed use of this animal model should improve the understanding of the pathophysiology of penetrating traumatic brain injury.

The initial objective is to develop a mathematical model for rats that describes the biophysics of wound formation following a ballistic injury. The bullet-size model will be the full metal jacket ammunition like the 7.62mm round and the 9mm which are most commonly used in the military. These equations can then be used generically to determine the dimensions of the salient features of ballistic injury, i.e. the size and shape of the permanent and temporary would cavities, rapidity of expansion and duration of inflation.

The second objective is to develop a device for minimal invasive recreation of the wound in rats. This device will be based on an air inflation technique. It will be built exactly to precise specifications based on the above mathematical model. This devise will be designed in accordance with all elements of the wound arising from a gunshot. The wound cavities assume the proper size, shape and for the appropriate duration.

The third objective will be to conduct in vivo validation study in rats to demonstrate that this model can recreate wounds similar to those caused by military gunshot. Histopathologic findings will be compared to the results from human gunshot victim autopsy reports and to the work of Carey et al (1989, 1990) using the now-abandoned fired projectile feline model.

Construction of the mathematical model

In the development of the mathematical model it is important to understand the flight characteristics of a projectile. The penetrating model consists of two distinct phases during its flight. These are the stable and the unstable phases of flight in a representative medium, like gelatin. The portion of a projectile's stable flight is a function of a number of variables, such as initial velocity, the shape of the projectile (drag characteristics), rotational velocity (spin stabilization) and the medium (μ) of travel. These are a few of the major parameters that come into play, and do not neglect the usual forces that act on the projectile such as gravity. Ammunition producers go through great pains to insure flight stability over very wide ranges of operation. Ballistic flight dynamics are well documented, Sellier and Kneubuehl's text (1994) as well as Bellamy and Zajtchuk's treatment in the Textbook of Military Medicine (chapter 4) both provide an excellent review of this subject. During stable flight energy transmitted (dissipated) into the medium is a minimum because the manufacturers have designed the projectile for maximally effective ranges and thereby minimizing the drag on the projectile. During unstable flight a maximal amount of energy is dissipated into its medium. This is the phase of flight we are focused on because it generates the large temporary cavity which causes the most damage. The key point underlying this study is that the center of pressure (CP) is not the same as the center of gravity (CG) of the projectile and as the projectile continues its path in the medium be it air, soap, gelatin or brain tissue it will eventually become unstable and tumble. The instability is due primary to drag forces on the projectile, along with the existence of a "yaw angle" (aerodynamically "angle of attack"). The combined effect of drag forces and small yaw angles eventually causes the CP to move, and in turn the projectile becomes unstable and tumbles.

During the tumbling action more energy will be dissipated into its surrounding medium. This will accentuate the production of a larger temporary cavity. The energy dissipated is modelled as an ellipsoid, where the major and minor axis governing its shape is related to the energy and associated velocity.

The model for describing the formation of the temporary cavity and its relation to the energy levels are described below, assuming the projectile remains intact after penetration. This assumption allows for the mass to remain a constant.

The energy available and amount of energy dissipate in its medium is characterized in figure 1.0, below where:

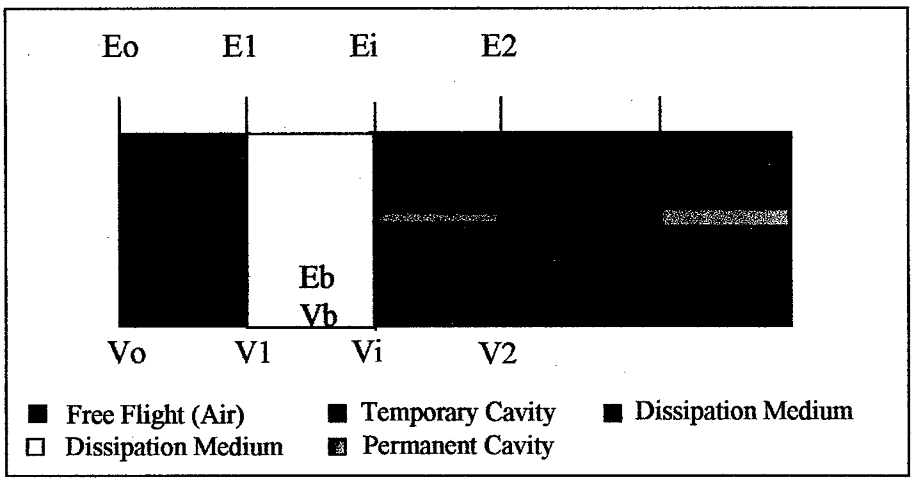


Figure 1.0 Energy Profile for Intact projectiles

- Eo is the muzzle energy, and Vo its associated muzzle velocity.
- Ea is the energy dissipated during free flight, which is a function of range to target and projectile design.
- E1 is the energy available at impact, and V1 is the associated velocity.
- Eb is energy dissipated on impact, and Vb the associated velocity.
- Ei is the initial impact energy available in the medium (μ) to form the temporary and permanent cavities.
- Ec is the energy dissipated in the medium (μ), while forming of the temporary cavity during its stable flight, and Vc is the associated velocity.
- E2 is the energy available in the medium to form the large temporary cavity during the unstable flight, and V2 is the associated velocity
- Ed is the energy dissipated in the medium (μ), while forming the temporary cavity during unstable flight or deformation of the projectile. Vd is the associated velocity.
- Er is the residual energy, and Vr is the associated velocity.

The muzzle energy and velocities of all ammunition projectiles are well documented and have been shown to vary considerably. However for the purposes of this study a set of Firing Tables are provided in Sellier and Kneubuehl text (pages 356 to373) and these data will be used as the basis of free flight performance (air). It measured data but represents typical manufactures' data. The projectiles under consideration are the 7.62 mm NATO round characterized by 9.5g mass, muzzle velocity of 830 m/s and the 9mm parabellum round of 8g mass and muzzle velocity of 350 m/s. The 7.62 x39mm AK-47 round of 8 g mass and muzzle velocity of 716 m/s was also investigated. These were selected since they are very common military rounds and widely used in all arenas, including the 9mm for civilian law enforcement. The performance of 7.62mm NATO round will be representative of supersonic projectiles and the 9mm parabellum will represent the transonic or low velocity projectiles. Note that the muzzle velocity of the 9mm round is transonic but within 20 meters from the muzzle its velocity has dropped sufficiently so that upon impact it maybe considered subsonic.

The equations describing the energy and associated velocity are all related back to the muzzle energy (Eo) and muzzle velocity (Vo), with the fundamental assumption that the mass of the projectile is constant. The projectile may tumble after entering the brain or may deform (hollow point) but as long as the projectile does not fragment the mass will be constant. E1 is the energy available at impact and V1 is its associated velocity after a period of free flight. The velocity at impact (V1) is derived by:

$$V1 = Vo - (Br) \times (\text{Range to Target from muzzle}) \qquad \text{(equation 1.0)}$$

where the constant (Br) is a derived constant, based on free flight data. This constant is a simple linear curve fit to manufacture's free flight data to permit ease of determining velocities at different ranges from the muzzle, but Br is different for each projectile because of the shape and construction of the projectile. Figure 1.2 illustrates the curves fit and Table 1.0 shows the error of the fit is less then 0.5% over the ranges of interest.

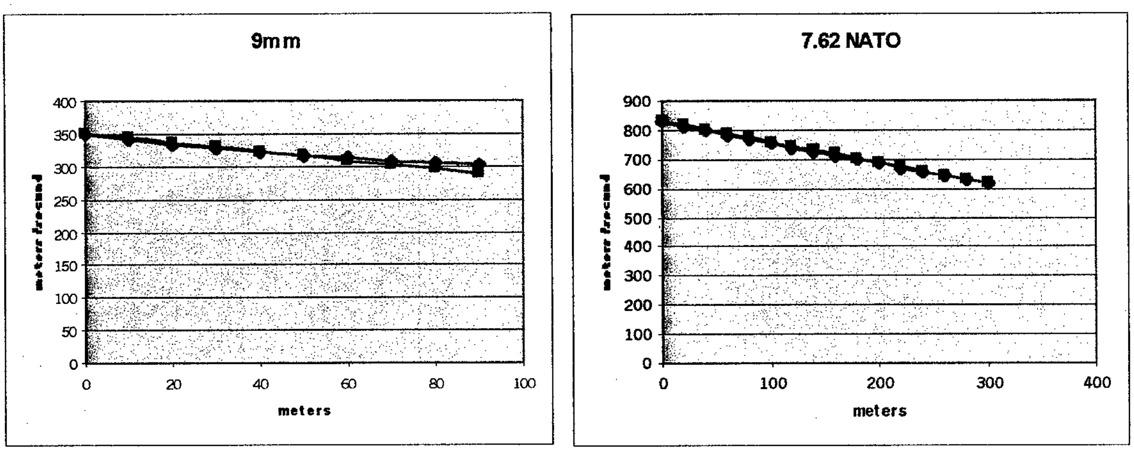


Figure 1.2 Extrapolated data for 9mm and 7.62 NATO Rounds

Range (Meters)	9mm Manufacture's Data (m/s)	9mm Extrapolated Data (m/s)	Range (Meters)	7.62mm Manufacture's Data (m/s)	7.62mm Extrapolated Data (m/s)
0	350	350	0	830	830
10	341	343	60	783	787
20	333	336	100	754	758
30	327	330	160	711	715
40	321	323	200	683	686
50	317	316	260	643	643
60	312	309	300	616	614

Table 1.0 Comparison of Extrapolated Data and Manufacture Data

It then follows that the available impact energy (E1) is:

$$E1 = (1/2)\, m\, V1^2 \qquad \text{(equation 2.0)}$$

where m is the mass of the projectile of interest and V1 is the result of equation 1.0, which depends on the range to target.

Since Ea is the energy dissipated during free flight, which is a function of range to target and projectile design, it follows;

$$Ea = Eo - E1. \qquad \text{(equation 3.0)}$$

Eb is energy dissipated on impact and depends on whether or not protective gear is used. Without protective gear, the penetration model developed by Sellier (ref a, pages 210-211) through the hair, scalp, skull, and into the brain changes the impact velocity by 110 m/s for the 9mm, or 48.4 joules of energy, which is approximately 10% of the available energy. Eb maybe represented as a percentage of E1 (the energy available at impact) and is computed as:

$$Eb = (X)E1, \qquad \text{(equation 4.0)}$$

where "X" is a number much less then 1.0, ($0 < X < 1.0$). However this parameter maybe modified if protective gear is used for the different types of projectiles. It follows that the associated magnitude of the velocity (Vb) is determined by:

$$Vb = (2Eb/m)^{1/2}. \qquad \text{(equation 5.0)}$$

Ei is the initial impact energy available in the medium (μ) to form the temporary and permanent cavities and is derived as follows:

$$Ei = E1 - Eb, \text{ and} \qquad \text{(equation 6.0)}$$

$$Vi = (2Ei/m)^{1/2} \text{ its associated velocity.} \qquad \text{(equation 7.0)}$$

During the stable flight portion in the medium, equation (1) is modified to estimate the magnitude of the velocity just prior to the unstable flight. The modified equation simply accounts for the differences in densities between air and 20% gelatine and the difference is a factor of 848:1 changing equation (1) to:

$$V2 = Vi - Br\,(848)(D1), \qquad \text{(equation 8.0)}$$

where D1 is now the distance travelled in the medium prior to becoming unstable, which is observed for the gelatin tests.
The computed energy at this velocity (E2) is :

$$E2 = \tfrac{1}{2}\, m\, (V2)^2 \qquad \text{(equation 9.0)}$$

E2, and V2 now represent the available energy and associated velocity to form the larger temporary cavity as the projectile tumbles. From the data presented by Bellamy and Zajtchuk (pages 130 – 131), projectiles typically dissipate 83% of the available energy in the formation of the larger temporary cavity when the flight becomes unstable.

Data also presented by Bellamy and Zajtchuk (page 134) also shows that there is a linear relationship between the maximum diameter of the temporary cavity and the impact velocity, similar to figure 1-3, below. This relationship shows the time to dissipate the available energy in the formation of the large temporary cavity is constant which is true if the medium is homogeneous like gelatin. Though the data shown by Bellamy and Zajtchuk is for soap, the behaviour in gelatin shows the same a linear relationship between maximum radius and velocity, but the specific time required to dissipate the energy is different. These results are from the mathematical model.

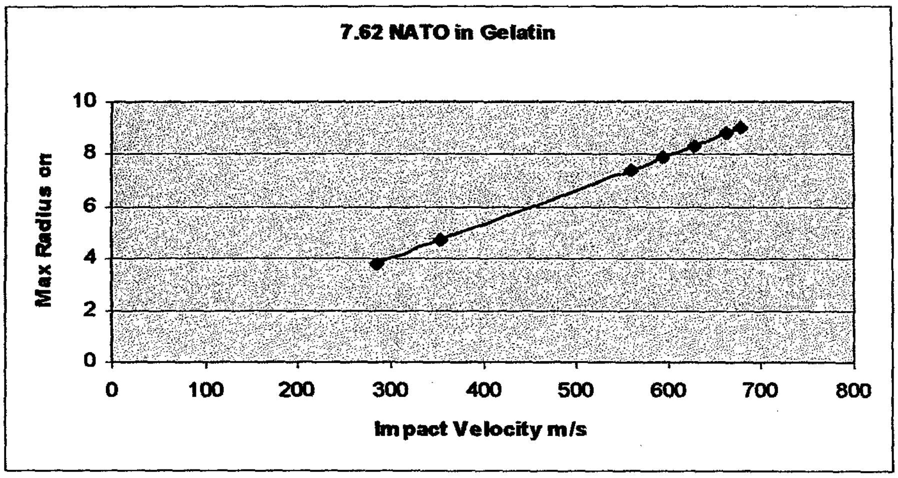


Figure 1-3 Maximum Radius vs. Velocity in Gelatin

Based on the gelatin data depicted below, figures 1-5 and 1-6, dynamic models are developed to depict the formation of the cavities after penetration. These data are obtained from U.S. Army Advanced Research Laboratories(ARL), in a series of reports by Bruchey et al (1979) Specifically, two models are required to capture the dynamics of the cavity formation. One represents the temporary cavity in stable flight after penetration and the other the large temporary cavity during the unstable flight. The size of the permanent cavity is strictly a function of the bullet selected. We have selected a typical 7.62 mm NATO round with a muzzle velocity of 830m /sec and muzzle energy of 3272 j. The 9mm characteristics are: muzzle velocity 350 m /sec; muzzle energy 490 j.

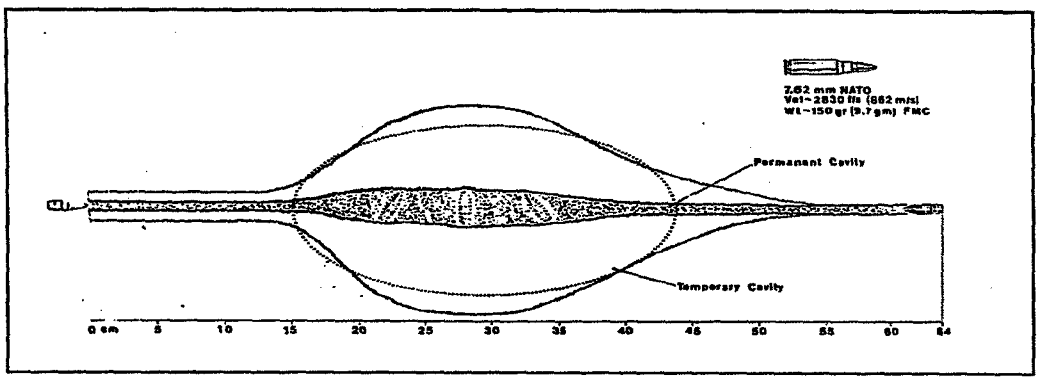
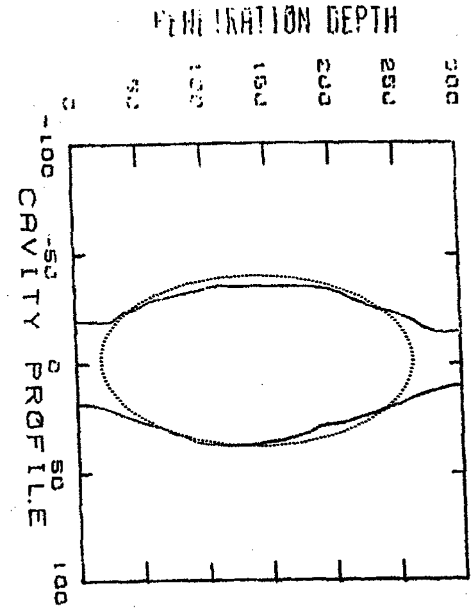


Figure 1-5 7.62 NATO in Gelatin



9mm, FMJ, 8gm, 371.25 (m/s)

Penetration Distance (mm)	Cavity Radius (mm)
0	19
18	19
46	25
65	29
102	36
149	35
177	33
205	29
233	23
251	19
299	12

Figure 1-6 9mm in Gelatin

Dashed outline in both cases shows the large temporary cavity may be approximated by an ellipse, or in three dimensions an ellipsoid, except for different values associated with the major and minor axes of both rounds.

Figure 1-7 depicts the volumes of interest, Volume of the permanent cavity (Vp), the temporary cavity during stable flight (Vts), and the temporary cavity due to unstable flight (Vt).

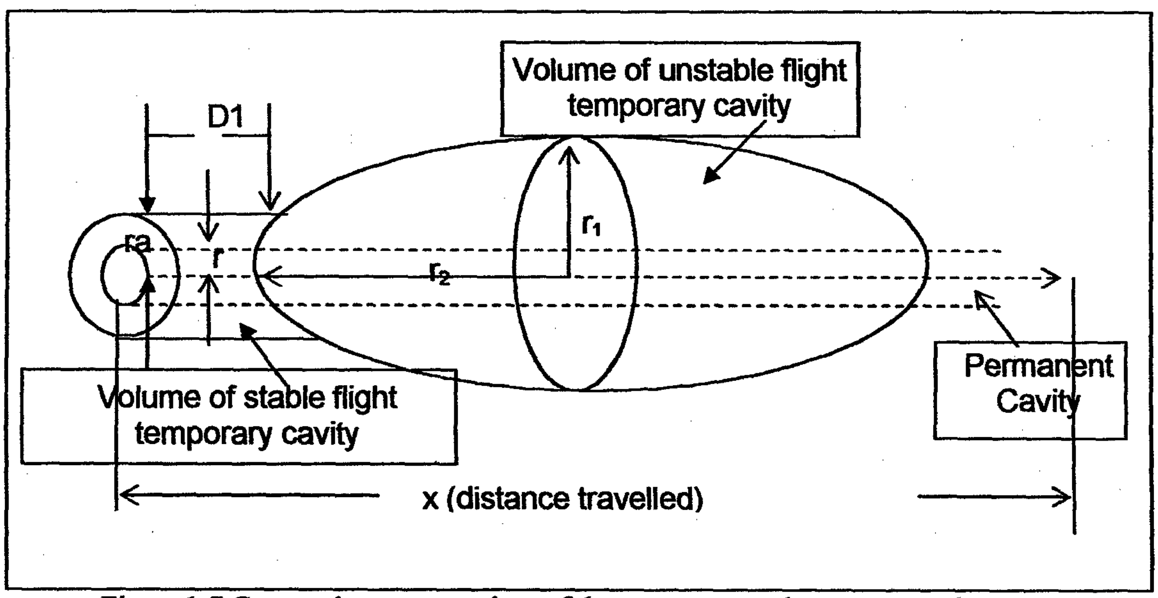


Figure 1-7 Geometric representations of the permanent and temporary volumes

Based on these observations, the calculations for energy and velocities as they relate to the geometric volumes are as follows:

The energy dissipated in forming the temporary cavity is (Ed),

$$Ed = K3 * E2. \qquad \text{(equation 10)}$$

and K3 is (0.83), representing factor for the dissipated energy.

The volume of the permanent cavity is expressed as:

$$Vp = \pi(r^2x), \qquad \text{(equation 11)}$$

where Vp is the volume of the permanent cavity, "r" is the radius of the projectile (½ its caliber) and "x" is the penetration distance t.

The volume of the temporary cavity during stable flight is expressed as:

$$Vts = \pi(ra^2D1), \qquad \text{(equation 12)}$$

where Vts is the volume of the cavity, "ra" is the cavity radius at penetration and D1 the penetration distance in the medium prior to going unstable.

The volume of the larger temporary cavity caused by the unstable flight is represented by:

$$Vt = (4\pi/3)r_2r_1^2, \qquad \text{(equation 13)}$$

where Vt is the volume of the temporary cavity, "r_2" is the major radius of the temporary cavity and "r_1" is the related minor axis where $r_1 = ka\ r_2$. The variables r_1, r_2 are related to velocity of the bullet within the cavity.

Both models equations (12) and (13) are combined to form the total dynamics of the temporary cavities . However it is noted that the amount of energy dissipated during stable flight is small in comparison to the energy dissipated unstable flight. The geometric representation of equation 13 is our main focus in the development of the mechanical model.

Since r_1, r_2 are related by, $r_1 = ka\ r_2$ and ka defines the shape of the ellipsoid. Based on the measured data of reference (c), ka for the 7.62 NATO round has a value of 0.61 and for the 9mm ka has a value of 0.43. Again, for different rounds there will be modifications to this parameter. It follows that r_1 and r_2 are related to the velocities; Vt1 and Vt2, by:

$$r_1 = Vt1(TM) \text{ and } r_2 = Vt2\ (TM), \qquad \text{(equations 14, 15)}$$

where TM is the dissipation time during unstable flight and $Vd^2 = Vt1^2 + Vt2^2$.

After the formation of the large temporary cavity, the remaining energy is dissipated in the medium by continuing in flight or comes to rest. The residual energy is Er = E2 – Ed. Er establishes whether on not sufficient energy remains to exit on the other side of the skull.

The combined volumes are the total volume of interest is represented by:

$$Vtotal = Vp + Vts + Vt.$$ (equation 16)

However, of major interest is the large temporary cavity (Vt). This is the focus of our investigations. Vt is compared to the size of the human brain and then scaled down by 672.5:1 for the rat's brain size and designated as Vt rat. The ratio of Vt to 1345 cm^3 is called the Reference Volume (Vref); this number should be much less then one (1) for survival probabilities to increase. In cases where Vref is equal to or greater then 1 (one), it simply means there is enough energy in forming the large temporary cavity to completely destroy the human brain. The value of 1345 cm^3 is representative of the volume of the human brain, as shown by Walker, A. and Shipman, P., 1996. The volume of the rat's brain is measure to be 2 cm^3, which establishes the 672.5 to 1 ratio for scaling purposes. The scaling is required to establish the diameter of the probe to be inserted simulating the permanent cavity produced by the projectile.

Developing A Minimal Invasive Device

The device for the insertion into the rat's brain is a probe whose diameter is the scaled diameter of the bullet of interest (9mm or 7.62). The probe contains air holes which are covered by Silex. When air is injected into the probe, by a pneumatic device, the Silex will expand and contract within 30 milliseconds simulating the expansion and contraction of the temporary cavity produced by the unstable flight portion of the projectile. Figure 2.1 illustrates the design of the probe and Figure 2.2 is a representative prototype to use for the In Vito studies. Figure 2.3 shows the Pneumatic device producing the air.

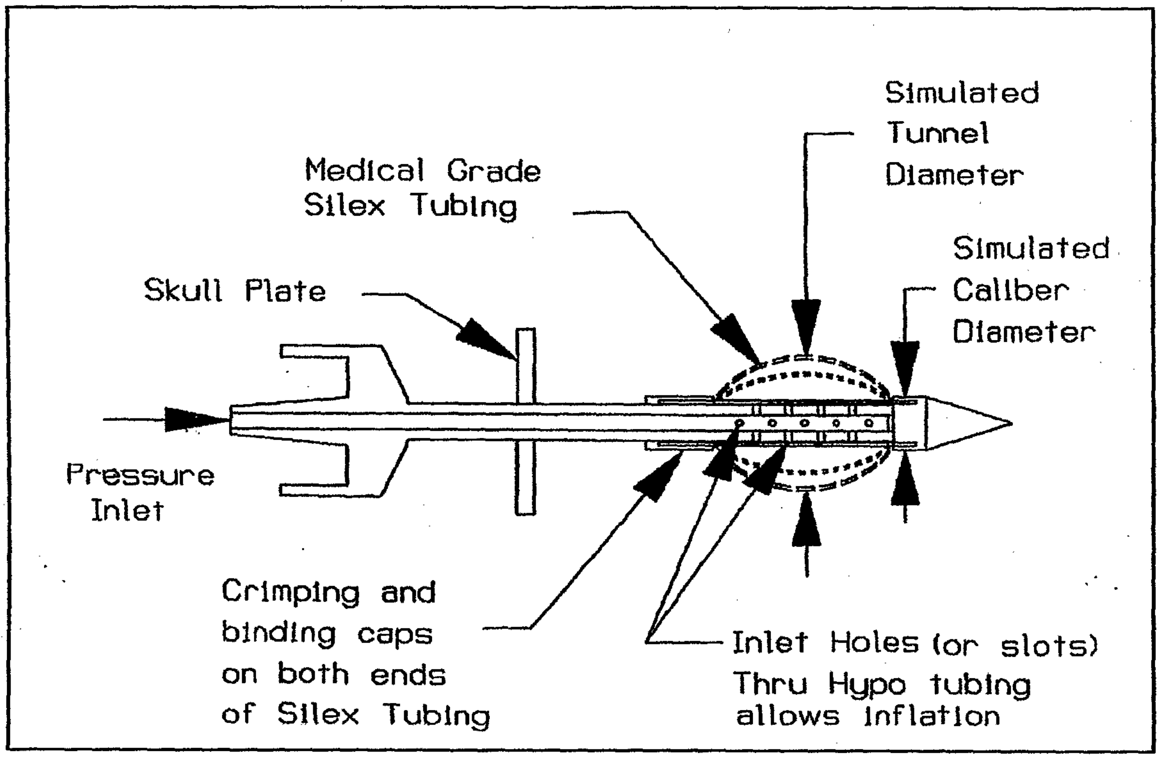


Figure 2.1 Illustrative Design of the Probe

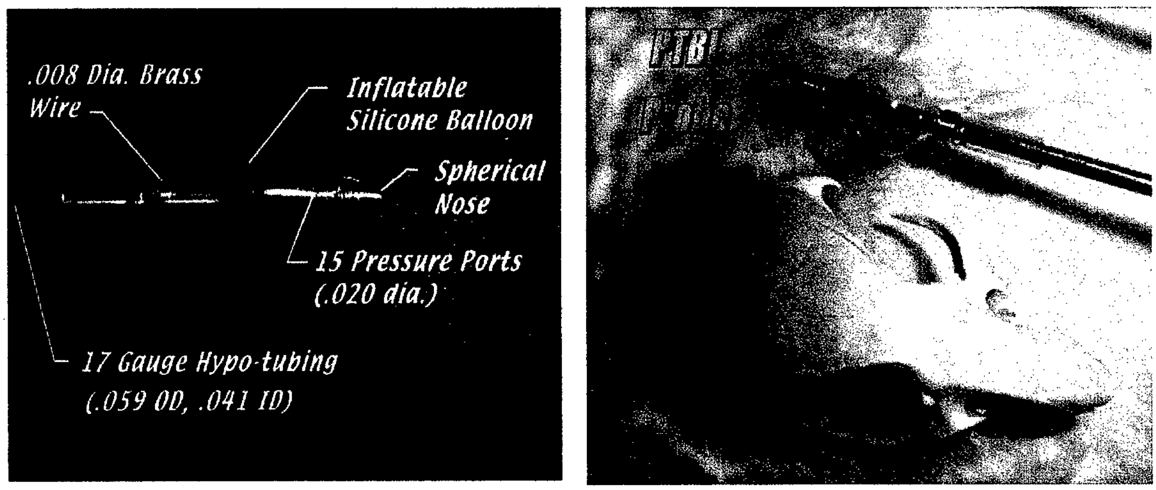


Figure 2.2 Prototype PTBI Probe

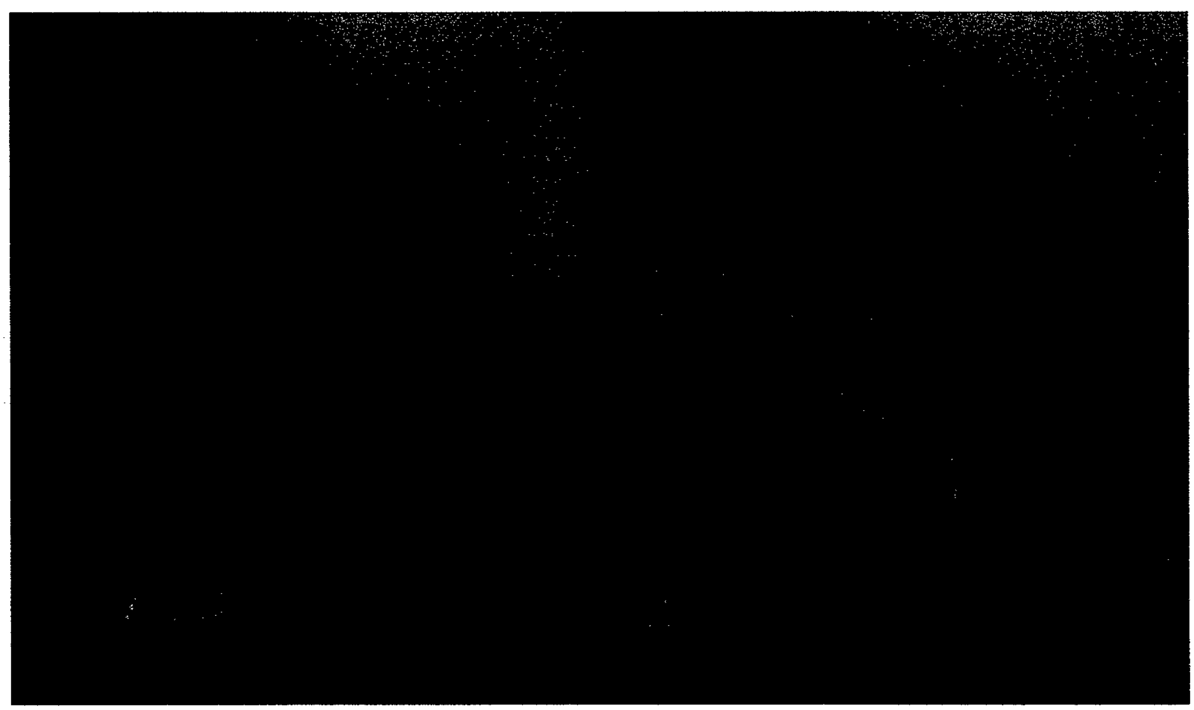


Figure 2.3 Pneumatic Device

The final probes are very near completion but must be calibrated prior to the initiation of the in vivo studies. Preliminary results are expected in September time frame to validate the mathematical and mechanical models.

Key Research Accomplishments

The mathematical model is complete and maybe used as intended, to predict the size and shape of the temporary cavities for different impact energies and velocities. This mathematical model is the first in the investigation of PTBI .

The mechanical model is being calibrated and will be ready of the in vivo studies within the next two months. The in vivo studies will serve to validate the mathematical / mechanical predictions.

Reportable Outcomes

Included are sample outcomes of the mathematical PTBI model. Based on these outcomes the mechanical probe was designed. Recognize that at this point in time the models have not been validated by in vivo tests.

Sample calculations for the 9mm predicting volume size and shape at various ranges:

9mm						
INPUTS						
mass (g)=	8	8	8	8	8	8
Muzzle velocity (m/s) (Vo)=	350	350	350	350	350	350
Muzzle energy(joules) (Eo)=	490	490	490	490	490	490
Range to target(m) (Rm)=	10	20	30	40	57	110
Coupling Coefficient Ka Ka=	0.43	0.43	0.43	0.43	0.43	0.43
Diameter (caliber) (cm) =	0.9	0.9	0.9	0.9	0.9	0.9
Vel/Range Coef . Br : Br=	0.68	0.68	0.68	0.68	0.68	0.68
Assumptions						
Energy Diss on Impact Eb (j) Eb=	48.4	48.4	48.4	48.4	48.4	48.4
Density of (gelatin/air) =	848	848	848	848	848	848
Dissipation into Temp Cav K3.=	0.83	0.83	0.83	0.83	0.83	0.83
*Dissipation time(sec) TM=	0.000365	0.000365	0.000365	0.000365	0.000365	0.000365
**Dissipation time(Sec) TM2=	0.000465	0.000456	0.000456	0.000456	0.000456	0.000456
Computing Energy & Velocities						
Energies						
Vel at range V1 (m/s) V1=	343.2	336.4	329.6	322.8	311.24	275.2
Energy at range (j) E1 =	471.14496	452.6598	434.5446	416.7994	387.4814	302.9402
Energy Diss in Free Flt EA (j) Ea=	18.85504	37.34016	55.45536	73.20064	102.5186	187.0598
Energy Diss on Impact Eb (j) Eb=	48.4	48.4	48.4	48.4	48.4	48.4
Energy Avail at medium Ei (j) Ei=	422.74496	404.2598	386.1446	368.3994	339.0814	254.5402
Energy Diss Stable Ec (j) Ec=	104.995834	102.5092	100.0166	97.51751	93.25288	79.79632
Energy avail for lg Cavity E2 (j) E2=	317.749126	301.7506	286.128	270.8818	245.8285	174.7438
Energy Dissin lg cavity Ed (j) Ed=	263.731774	250.453	237.4863	224.8319	204.0376	145.0374
Residual Er (joules) Er=	54.0173514	51.2976	48.64177	46.04991	41.79084	29.70645
Velocities						
Computing V i (m/s) Vi =	325.094202	317.9072	310.7027	303.4796	291.1535	252.2599
Computing V 2 (m/s) V2 =	281.846202	274.6592	267.4547	260.2316	247.9055	209.0119
Computing Vc (m/s) Vc=	162.015304	160.0853	158.127	156.139	152.6867	141.2412
Computing Vd (m/s) Vd=	256.77411	250.2264	243.6628	237.0822	225.8526	190.4189
Computing Vr (m/s) Vr =	116.208166	113.2449	110.2744	107.2962	102.214	86.1778

Dimensions-Low Speed

Computing Vt1(m/s)	Vt1=	101.432899	98.84637	96.25357	93.65406	89.21805	75.22074
Computing Vt2(m/s)	Vt2=	235.890463	229.8753	223.8455	217.8001	207.4838	174.932
Computing D1(cm)	D1=	7.53371161	7.29989	7.210591	7.119937	6.962512	6.440599
Computing R1(cm)	R1=	3.70230082	3.607893	3.513255	3.418373	3.256459	2.745557
Computing R2 (cm)	R2=	8.6100019	8.390448	8.170362	7.949705	7.57316	6.385016
Volume lg temp (cm3) Vt	**Vt=**	494.414923	457.5486	422.4795	389.166	336.4444	201.6359
Volume Stable Cavity Vca	Vca=	147.943262	143.3516	141.598	139.8178	136.7263	126.4773
Total Volumes Vt + Vca(cm3)=		642.358185	600.9002	564.0775	528.9838	473.1707	328.1132
Tot RAT Volume (cm3)	Vrat=	0.95517946	0.924462	0.867812	0.813821	0.727955	0.504789
Rat Vol from Vt/672.5(cm3)Vrat1=		0.73518948	0.68037	0.628222	0.578685	0.500289	0.29983
Compute Rat Rr2(cm)	Rr2=	0.68422858	0.666781	0.649291	0.631755	0.601832	0.507411
Compute Rat Rr1(cm)	Rr1=	0.29421829	0.286716	0.279195	0.271655	0.258788	0.218187
Ref Volume lg temp (Vt) / 1345=		0.36759474	0.340185	0.314111	0.289343	0.250145	0.149915
Reference Total Volume/1345		0.47758973	0.446766	0.419388	0.393296	0.3518	0.24395
Reference Volume =Vt/1345		0.36759474	0.340185	0.314111	0.289343	0.250145	0.149915
Reference Volume Rat		0.36759474	0.340185	0.314111	0.289343	0.250145	0.149915

Sample calculations for the 7.62 NATO predicting volume size and shape at various ranges:

7.62 NATO
INPUTS

mass (g)=	9.5	9.5	9.5	9.5	9.5	9.5
Muzzle velocity (m/s) (Vo)=	830	830	830	830	830	830
Muzzle energy(joules) (Eo)=	3272	3272	3272	3272	3272	3272
Range to target(m) (Rm)=	25	50	100	200	500	615
Coupling Coefficient Ka Ka=	0.61	0.61	0.61	0.61	0.61	0.61
Diameter (caliber) (cm) =	0.78	0.78	0.78	0.78	0.78	0.78
Vel/Range Coef . Br : Br=	0.72	0.72	0.72	0.72	0.72	0.72
Assumptions:						
Dissipation on Impact 0<X<1; X=	0.1	0.1	0.1	0.1	0.1	0.1
Density of (gelatin/air) =	848	848	848	848	848	848
Dissipation into Temp Cav K3.=	0.83	0.83	0.83	0.83	0.83	0.83
*Dissipation time(sec) TM=	0.00028	0.00028	0.00028	0.00028	0.00028	0.00028
**Dissipation time(Sec) TM2=	0.000406	0.000406	0.000406	0.000406	0.000406	0.000406
Computing Energy & Velocities						
Energies						
Vel at range V1 (m/s) V1=	812	794	758	686	470	387.2
Energy at range (j) E1 =	3131.884	2994.571	2729.179	2235.331	1049.275	712.1382
Energy Diss in Free Flt EA (j) Ea=	140.116	277.429	542.821	1036.669	2222.725	2559.862
Energy Diss on Impact Eb (j) Eb=	313.1884	299.4571	272.9179	223.5331	104.9275	71.21382
Energy Avail at medium Ei (j) Ei=	2818.696	2695.114	2456.2611	2011.798	944.3475	640.9244
Energy Diss Stable Ec (j) Ec=	630.3836	615.5264	585.811967	526.3832	348.0968	279.7536
Energy avail for lg Cavity E2 (j) E2=	2188.312	2079.588	1870.44913	1485.415	596.2507	361.1708
Energy Dissin lg cavity Ed (j) Ed=	1816.299	1726.058	1552.47278	1232.894	494.8881	299.7717
Residual Er (joules) Er=	372.013	353.5299	317.976353	252.5205	101.3626	61.39903

Velocities							
Computing V i (m/s)	Vi =	770.3308	753.2545	719.10194	650.7967	445.8812	367.3302
Computing V 2 (m/s)	V2 =	678.7468	661.6705	627.51794	559.2127	354.2972	275.7462
Computing Vc (m/s)	Vc=	364.297	359.9785	351.182054	332.8926	270.7093	242.684
Computing Vd (m/s)	Vd=	618.3678	602.8105	571.696051	509.4671	322.7801	251.2167
Computing Vr (m/s)	Vr =	279.8545	272.8138	258.732275	230.5693	146.0805	113.6931
Dimensions-Supersonic							
Computing Vt1(m/s)	Vt1=	322.0207	313.9191	297.715979	265.3097	168.0907	130.8234
Computing Vt2(m/s)	Vt2=	527.9028	514.6215	488.058983	434.9339	275.5585	214.4646
Computing D1(cm)	D1=	14.78682	14.61153	14.2579914	13.51211	10.98809	9.850542
Computing R1(cm)	R1=	9.01658	8.789736	8.33604742	7.42867	4.706539	3.663056
Computing R2 (cm)	R2=	14.78128	14.4094	13.6656515	12.17815	7.715638	6.005009
Volume lg temp(cm3) Vt	**Vt=**	5034.318	4663.828	3978.28243	2815.453	716.0118	337.5559
Volume Stable Cavity Vca	Vca=	290.3761	286.9338	279.991306	265.3441	215.7786	193.44
Total Volumes Vt + Vca(cm3)=		5324.694	4950.762	4258.27374	3080.798	931.7904	530.9959
Tot RAT Volume (cm3)	Vrat=	7.917761	7.361728	6.33200556	4.581112	1.385562	0.789585
Rat Vol from Vt/ 672.5(cm3)Vrat1=		7.485974	6.935061	5.91566161	4.186548	1.064701	0.501942
Compute Rat Rr2(cm)	Rr2=	1.872371	1.825264	1.73105213	1.542627	0.977353	0.760665
Compute Rat Rr1(cm)	Rr1=	1.142146	1.113411	1.0559418	0.941003	0.596186	0.464006
Reference Total Volume/1345		3.95888	3.680864	3.16600278	2.290556	0.692781	0.394792
Reference Volume =Vt/1345		3.742987	3.46753	2.95783081	2.093274	0.532351	0.250971
Reference Volume Rat		3.742987	3.46753	2.95783081	2.093274	0.532351	0.250971

Conclusions- The first and second objective of this study has been met and the third objective will be achieved. The results of this study will be a part of the final report. Due in June of 2003.

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US ARMY MEDICAL RESEARCH AND MATERIEL COMMAND
504 SCOTT STREET
FORT DETRICK, MD 21702-5012

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PHYLIS M. RINEHART
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