THE EFFECT OF SHOCK WAVES CAUSED BY A PENETRATING PROJECTILE ON SIMULATED BLOOD-VESSEL SYSTEMS

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Abstract. This article contains an analysis of the effects of shock waves caused by penetration of a small calibre projectile through simulated human tissue and blood-vessel system. Results of experiments that have been carried out at the Military Academy in Brno are shown. A small calibre projectile was fired into a model of the part of the lower limb and the response of the blood-vessel system to a non-complicated injury has been evaluated.

INTRODUCTION

Literature concerning wound ballistics [1,2] shows relatively large amounts of information on the effects on both live tissue and their artificial substitutes. On the other hand, there is relatively little information about the non-direct effects of penetrating projectiles and fragments on the human blood-vessel system, especially when the projectile moves in close proximity to the large blood vessels without a direct hit. The aim of the work described in this paper was to investigate the terminal ballistic effects of small calibre ammunition using simulated human tissue and human blood vessel system, in particular, to:

- verify the suitability of the model and instrumentation for this type of investigation.
- assess the predictive capability of the model.

Secondary aims were to:

- evaluate the behaviour of the artificial tissue, mainly its ability to transfer energy associated with shock wave caused by the projectile penetration.
- measure the pressure extremes in the artery, and to use this data to predict the effect of the projectile on an artery in close proximity to the wound path.

The experiment was designed to simulate a non-complicated injury of the thigh, that is, when the projectile hits only the soft tissues, missing both the thighbone and the artery.

Tests were carried out using a 7.62 mm calibre test rifle and a 357 Magnum revolver.

PHYSICAL MODEL

A physical model of part of a thigh was designed, comprising a block of substitute tissue and an artificial artery. The following materials were used to simulate the behaviour of live tissue:

1. A 20%-gelatine solution (G-20).
2. A mixture of petroleum and paraffin waxes in the ratio 75%:25% (PP 75/25).
3. Plasticine-grey modelling material (PL).

The physical characteristics of these materials are shown in Table 1, and were obtained from tests carried out at the Military Academy in Brno, Weapon Systems Department according to [3] and [4].

Cylindrical samples of G-20 and PP 75/25, with a diameter of 15 cm and a height of 20 cm, were prepared by casting and allowing the material to solidify at room temperature. Any cavities arising during solidification of PP 75/25 were eliminated manually. The PL samples were made by ramming the material into a wooden mould, 15x15x20 cm. The samples made from PP 75/25 and PL were held at an ambient temperature of 21°C; sample G-20 was held at a temperature of 5°C, which is temperature advised for use of this material by the manufacturer.

		Substitute materials		
Characteristics	**Unit**	**PP 75/25**	**G–20**	**PL**
Density	kg/m^3	933	1100	1710
Creep index	-	0.643	0.605	0.866
Dyn. viscosity	10^{-3} Pa s	10.98	4.47	13.79
Specific. acoustic impedance	10^{-6}Pa m^{-1} s	-	1.73	-

Table 1. Characteristics of substitute materials.

The speed of sound was only available for the G-20 material and so the acoustic impedance could be found only for this material. The values of the acoustic impedance of pig tissue (1.79 10^{-6} Pa m^{-1} s) and the G-20 are in sufficient agreement.

The thigh artery was modelled by a thick-walled silicon duct of outer diameter, 2*R*, of 10 mm and wall thickness, *t*, of 2 mm, placed along the longitudinal axis of the sample.

None of the samples was designed with a thighbone. The entire hydraulic system, simulating the blood-vessel system, was filled with a replacement blood (colloid infuse detergent Gelafundin). A hydrostatic pressure was created, and the air removed from the system before firing.

HYDRAULIC MEASUREMENT AND RECORD OF PRESSURE IN BLOOD-VESSEL

The propagation speed of a pressure wave in a duct filled with water depends on the modulus of elasticity, *E*, of the duct material and on the radius to wall thickness ratio, *R*/*t*. The modulus of elasticity, *E*, for the duct material used was obtained from measurements performed in laboratories at the Military Academy in Brno (Department of Aircraft and Engines) and is 7 MPa for an *R*/*t* value of 2.5.

Figure 1 shows curves representing ducts of different *R*/*t* with a range of values of modulus of elasticity, *E*, for commonly used artificial duct materials. From this data the speed, *c*, of the pressure wave for the duct used is 40m/s, and corresponds to a duct with a very soft wall filled with incompressible liquid.