THE APPLICATION OF COMPUTED TOMOGRAPHY IN WOUND BALLISTICS RESEARCH

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Abstract
In wound ballistics research there is a relationship between the data that characterize a bullet and the injury resulted after shooting when it perforates the human body. The bullet path in the human body following skin perforation as well as the damaging effect cannot always be predictable as they depend on various factors such as the bullet’s characteristics (velocity, distance, type of firearm and so on) and the tissue types that the bullet passes through. The purpose of this presentation is to highlight the contribution of Computed Tomography (CT) in wound ballistics research. Using CT technology and studying virtual “slices” of specific areas on scanned human bodies, allows the evaluation of density and thickness of the skin, the subcutaneous tissue, the muscles, the vital organs and the bones. Density data taken from Hounsfield units can be converted in g/ml by using the appropriate software. By evaluating the results of this study, the anatomy of the human body utilizing ballistic gel will be reproduced in order to simulate the path that a bullet follows. The biophysical analysis in wound ballistics provides another application of CT technology, which is commonly used for diagnostic and therapeutic purposes in various medical disciplines.

INTRODUCTION
The majority of firearms follow a similar way of operation which is consisted in a particular process for any type of them. After pulling the trigger an explosion takes place while the primer of the ammunition is hit, a chemical reaction creates expanded gases through which the bullet is detached and moves in the internal of the guns’ barrel accelerating to exit from the muzzle. Then it follows a linear and simultaneously a rotational motion against the external conditions of the environment. This movement depends on various factors such as the muzzle velocity, the caliber, the mass, its geometrical characteristics (tip, heel and ogive shape) and the type of the used firearm.

Besides, according the bullets’ trajectory, the injury resulted when a bullet perforates the human body depends on the distance, the angle of impact and the part of the body through which it enters. The bullet path in the human body after its skin perforation cannot always be predictable. The extent of injury depends on various factors such as the type of the firearm and its ammunition, its angular momentum, the shape, the caliber, etc. In addition, the trajectory has an effect on the path that the bullet will follow inside the human body in combination with the muscles and the vital organs that could be hit.

When a bullet hits the human body, it creates an entrance wound on the point of impact, the shape of which depends mainly on the angle of incidence and the distance of shooting.

Human body simulation
Experimental shootings on materials similar to human body are necessary to be performed. Specifically, the ballistic soap and the ballistic gel, which can be produced under concrete conditions, enable us to write down the path that a bullet follows as a simulation in a human body. Nevertheless, it is important to recognize that the best of measurements is an estimate and has some uncertainty associated with it. Based on numerous test shots into tissue stimulants, an uncertainty of ±5° to ±10° for wound paths is not unrealistic[1]. We can also notice the temporary and the permanent cavity that are caused by the energy deposited when the bullet passes through. It is very important to record the influence on human body that different types of bullets have. The scope through the CT technology is initially the calculation of density in different areas of the human body; We can then produce the ballistic gel for more accurate simulation.

The “Ballistic gelatine” is a protein produced by submitting collagen to an irreversible process that renders it water-soluble. It is usually made of skin or bone. The raw materials and the manufacturing process influence its characteristics like molecular weight, isoelectric point, transmittance, viscosity and gel strength. The last two parameters are of particular relevance to the use of gelatin for modeling. Gelatin is obtained by treatment with acid or alkali, followed by extraction using hot water. Gelatin is amphoteric; it reacts to an electrical field like a cation in
an acidic solution and like an anion in an alkaline solution. At a particular pH value, the reaction of the solution is neutral. This is known as the isoelectric point. The pH value of the isoelectric point depends highly on the treatment to which the collagen has been subjected. Treatment with alkali produces a Type B gelatin, with an isoelectric point somewhere between pH 4.7 and 5.4. The gel strength of the gelatin (which is of importance for its strength) is measured in Bloom[5].

The "Ballistic soap" that can be used for wound ballistics experiments is glycerine soap (moulded, transparent soap). It can be produced by mixing the constituent fats and oils with care, it is possible to maintain consistency over periods of many years, which is an important prerequisite for accuracy. It is possible to modify the density and softness of soap by varying its components. This allows us to achieve the penetration depth required for a particular calibration shot. It is therefore perfectly possible to standardize ballistic soap.

Depending on its composition, the density of new soap (1 to 3 weeks old) lies between 1060 and 1100 kg/m³ at room temperature. Soap has a very low limit of elasticity (0.5 N/mm²), which is an indicator of its plastic behavior. The deformation of soap due to the passage of a bullet is almost entirely plastic, and the wound channel only collapses very slightly. This gives us a direct image of the temporary cavity, on which we can readily take measurements[2]. Using the CT technology the thickness of layers in several areas of the human body can be calculated so as to simulate the wound channels.

**PROPOSED METHODOLOGY**

The aim is to highlight the contribution of Computed Tomography in wound ballistics research. Using CT technology and studying virtual “slices” of specific areas on scanned human bodies allows the evaluation of density and thickness of the skin, the subcutaneous tissue, the muscles, the vital organs and the bones. Density data taken from Hounsfield units can be converted in g/ml by using the appropriate software.

Data are collected by using DICOM images from people of different age, sex and weight that underwent CT examinations on a Philips Brilliance 64-slice CT scanner installed at the 2nd Department of Radiology in University General Hospital ATTIKON (Athens, Greece); similar ones are mentioned by Dr. Les Folio as they had been used for many radiology exams[3]. Data are rewritten following the rules imposed by the Bioethics Commission of the School of Medicine. Cross section slices have been collected from many areas of scanned human bodies (from patients who have been hospitalized in “ATTIKON” for various reasons), through the “Evorad RIS-PACS 3.0.0. build 170” (Evolving information technology for Radiology) software for visual images. Measurements are still taken for the thickness of the layers and for their density. In order to achieve satisfying statistical analysis results, following the biostatistics standards, the aim is to manage collecting data from 300 individuals - patients (males and females). The population sample should consist of two groups: the first includes individuals from twenty to fifty (20-50) years old and a second one includes individuals from fifty one and over (51+) years old.

An additional important parameter should be the weight, which means that each one of these two groups includes 3 weight categories: underweight (30–60 kgrs), normal weight (61–90 kgrs) and overweight ones (91+).

The areas from the human body have been chosen in order to cover almost the whole body surface, except the head (brain) and the area under the knees. This happens because there are no sufficient data from whole body examinations where total area of the patients’ body (from the top head to the toes) is scanned. Besides, for the sake of wound ballistics research, the human body’s figure has been “separated” in five parts according to the morphology, the muscles’ mass division, the shape and the bones’ form, as following: head - brain, arms - forearms, thorax - chest, abdomen and foot.

The cross section slices that have been chosen for taking measurements should have been marked keeping the same reference point for each computed tomography which is being examined as a new sample. For this purpose these slices cover the following areas: a) shoulder girdle, b) lungs and heart, c) liver, spleen and stomach, d) kidneys, intestine and pancreas, e) pelvis and forearms, f) middle of thigh.[4]

**Measurements**

For each cross section slice measurements for the density and the thickness from all the layers are taken, in particular measurements conducted in the skin, the subcutaneous tissue, muscles, vessels and the vital organs included in these slices (e.g. lungs, heart, liver, stomach, etc.). The region of interest (ROI) covers a surface of 50 - 55mm², except the skin where it is not possible the ROI to be more than 20mm², because of its oblong shape (Fig. 1 & 2). Furthermore, the choice of the ROI could be a potential source of error as it is nearly impossible to eliminate the human error factor in selecting the ROI [5]. Moreover, standardizing the ROI could be difficult because of the anatomical differences among organs. Density is recorded in Hounsfield units and the standard deviation (SD) is also received for each measurement.
Figures 1 & 2: Measurements of density from cross section slices: lungs-heart area (left), forearm (right).

Each pixel is assigned a numerical value (CT number), that is compared to the attenuation value of water and displayed on a scale of arbitrary units named Hounsfield units (HU). This scale assigns water as an attenuation value (HU) of zero. For a range of CT numbers in 2000 HU wide, each numeral value represents a shade of grey with +1000 (white) and –1000 (black) at either end of the spectrum (although modern scanners have a greater range of HU up to 4000).

The thickness is written down in cm (Fig. 3 & 4). All the values are collected in tables separately for each area of the human body and their recording follows the age group where the tomography correlates. Each age group includes the three categories of weight. The next step is to convert the Hounsfield units to units of density (gr/cm³), before calculating the average values for each area and layer.

Figures 3 & 4: Measurements of thickness from cross section slices: arm (left), lungs – heart area (right).

Preliminary results

To convert the HU units to units of mass density (gr/cm³) the Matlab code ‘hounsfield2density’ is used⁶, ⁷, (process which is in progress). In the following table there are indicative measurements of the density from the area of thorax.

| MEASUREMENTS OF DENSITY IN LAYERS OF HUMAN BODY |
|-----------------------------------------------|
| MALES-FEMALES / AGE: 20-50 yrs / Normal Weight / AREA: Thorax / Mass Density Units-gr/cm³ |
| SKIN | SD | SUBCUTANEOUS | SD | MUSCLES | SD | BONES | SD | LUNG | SD | LIVER | SD | HEART | SD |
|------|----|---------------|----|---------|----|-------|----|------|----|-------|----|-------|----|
| 0.974| 0.0043 | 0.894793062 | 0.0043 | 1.051469 | 0.0052 | 1.2029 | 0.093 | 0.1707 | 0.0438 | 1.06938 | 0.00734 | 1.06319 | 0.00683 |
| 1.057| 0.0469 | 0.918667831 | 0.0241 | 1.056473 | 0.0227 | 1.1499 | 0.166 | 0.1639 | 0.0297 | 1.05423 | 0.03318 | 1.04235 | 0.02132 |
| 0.958| 0.0056 | 0.885676736 | 0.0079 | 1.046073 | 0.0136 | 1.1956 | 0.07 | 0.1792 | 0.0098 | 1.08183 | 0.00886 | 1.0963 | 0.00758 |
| 0.99 | 0.0072 | 0.894094178 | 0.0017 | 1.037573 | 0.005 | 1.3175 | 0.231 | 0.16 | 0.0234 |
| 1.139| 0.0686 | 0.920996063 | 0.0256 | 1.047923 | 0.0327 | 1.1876 | 0.286 | 0.1551 | 0.0588 |
| 0.924| 0.0018 | 0.892615303 | 0.0053 | 1.044802 | 0.003 | 1.1916 | 0.18 | 0.2237 | 0.0581 |
| 0.992| 0.0046 | 0.908781648 | 0.0063 | 1.044281 | 0.0075 | 1.2033 | 0.016 |
### Table 1: Measurements of density (gr/cm³) performed from three patients (males) after CTs (numbers in bold show the average values).

| AREA       | DENSITY | SD  | DENSITY | SD  | DENSITY | SD  | DENSITY | SD  | DENSITY | SD  |
|------------|---------|-----|---------|-----|---------|-----|---------|-----|---------|-----|
| THORAX     | 1,012792| 0,026461 | 1,008  | 0,0378 | 0,989  | 0,0251 | 0,954  | 0,0185 |
|            | 0,906249| 0,013857 | 0,906217| 0,0121 | 0,92572| 0,0173 | 0,908994| 0,0065 |
|            | 1,047548| 0,01398 | 1,05191| 0,01 | 1,053772| 0,0131 | 1,061856| 0,0083 |
|            | 1,19948 | 0,01345 | 1,2901 | 0,1653 | 1,511  | 0,177 | 1,5519 | 0,192 |
|            | 1,7544  | 0,037251 | 0,35299| 0,01536 |        |       |        |       |
|            | 1,002307| 0,010932 | 1,06723| 0,01834 |        |       |        |       |
|            | 1,06848 | 0,016455 | 1,095201| 0,019788 |        |       |        |       |
|            | 1,06728 | 0,01911 | 1,094355| 0,018579 |        |       |        |       |
|            |        |       | 1,091729| 0,006767 |        |       |        |       |
|            |        |       | 1,091182| 0,010749 |        |       |        |       |
| AVERAGE    | 0,934947| 0,033112 | 1,105891| 0,031478 | 1,119188| 0,056325 | 1,119736| 0,058125 |

### Table 2: Density (gr/cm³) for the areas of thorax, abdomen, arms-forearms & thigh from normal weight patients.

### CONCLUSIONS

The biophysical analysis in wound ballistics provides a further application of CT, which is commonly used for diagnostic and therapeutic purposes in various medical disciplines. The ability in taking measurements of the density and the thickness from the layers of human bodies gives the opportunity to calculate values on average, especially to the density according to which ballistic gelatine can be produced for more pragmatic and accurate results. Through experimental shootings in these materials that simulate human body, we can realize and approach the estimated performance of bullets after perforating different parts of human body. This is a study in progress and the final results are expected to be published soon.

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