

The role of computed tomography in terminal ballistic analysis

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Abstract Terminal ballistics concerns the science of projectile behaviour within a target and includes wound ballistics that considers what happens when a projectile strikes a living being. A number of soft tissue ballistic simulants have been used to assess the damage to tissue caused by projectiles. Standard assessment of these materials, such as ballistic soap or ordnance gelatine, requires the block to be opened or that a mould to be made to visualize the wound track. This is time consuming and may affect the accuracy of the findings especially if the block dries and alters shape during the process. Therefore, accurate numerical analysis of the permanent or temporary cavity is limited. Computed tomography (CT) potentially offers a quicker non-invasive analysis tool for this task. Four commercially purchased ballistic glycerine soap blocks were used. Each had a single firearm discharged into it from a distance of approximately 15 cm using both gunshot and shotgun projectiles. After discharge, each block was imaged by a modern 16 slice multi-detector CT scanner and analysed using 3-D reconstruction software. Using the anterior–posterior and lateral scout views and the multi-plane reconstructed images, it was possible to visualize the

temporary cavity, as well as the fragmentation and dispersal pattern of the projectiles, the distance travelled and angle of dispersal within the block of each projectile or fragment. A virtual cast of the temporary cavity can be also be made. Multi-detector CT with 3-D analysis software is shown to create a reliable permanent record of the projectile path allowing rapid analysis of different firearms and projectiles.

Keywords Forensic · Radiology · Firearms · Computed tomography · CT · Mobile · Ballistic soap · Cavity

Introduction

Terminal ballistics concerns the science of projectile behaviour within a target and includes wound ballistics that considers what happens when a projectile strikes a living being [1–3]. A number of soft tissue ballistic simulants have been used since the introduction of ballistic gelatine in the 1940s for the investigation of the wound track, permanent cavity, projectile fragmentation and injuries incurred. These characteristics are important for the assessment of determining the legitimacy of a weapon and its ammunition as well as the surgical treatment of the injury incurred. The difficulty arises, however, with the use of materials such as ballistic soap or ordnance gelatine that unless the material is translucent, the block must be opened or a mould must be made to visualize the wound track and thus accurate numerical analysis of the permanent cavity is limited [4].

In 2001, Korac et al. [5] described the use of computed tomography (CT) for non-invasive analysis of gelatine blocks, although the full potential of the use of CT was not explored. Although other authors have also described the use of CT for both actual and simulated head gunshot

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wound investigation, these have not considered or expanded upon the true potential for the use of CT for the analysis of ballistic blocks [6–8].

We present an illustrated paper demonstrating the analysis of ballistic glycerine soap with CT. We expand upon the original papers of Korac et al. [4, 5] and, through the use of both gunshot and shotgun projectiles, illustrate how modern CT and volume rendering post-processing software can be used as a rapid non-invasive method for the analysis of terminal ballistics.

Materials and methods

Four commercially purchased glycerine ballistic soap blocks were used (Victoria Soap, Sweden, <http://www.victoriasoap.se/>). Each block measured approximately 17×17×26 cm. Each had a single firearm discharged into it from a distance of approximately 15 cm by a Forensic Firearms Officer (PB). The weapons and ammunition used were as follows: S&W revolver model 66 .357 Magnum JHP (jacketed hollow point, 10.27 g 360 m/s), FN FAL rifle 7.62×51 mm (9.43 g 810 m/s) FMJ (full metal jacket), SA80 rifle 5.56 mm FMJ (3.56 g 960 m/s), 12 Gauge shotgun SG shot (9 shot; lead 3.71 g 270 m/s). After discharge, each block was imaged; two blocks were imaged

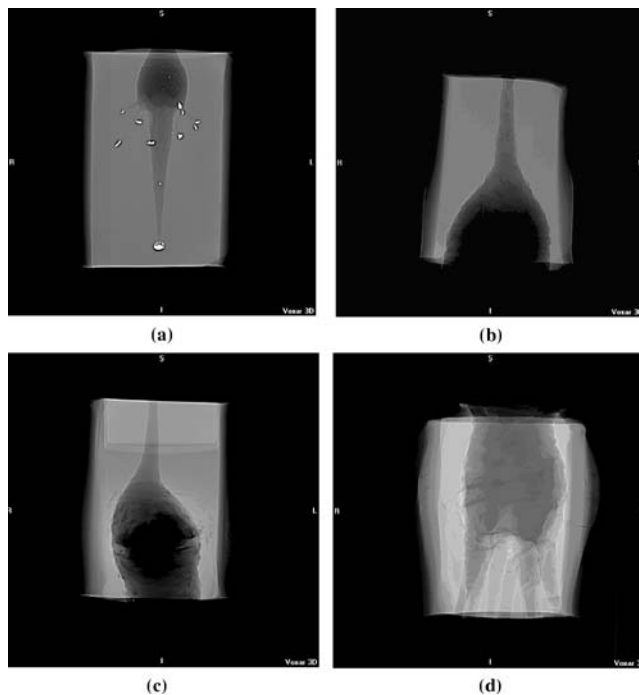


Fig. 1 AP scout views of the four blocks illustrating the temporary cavity, fragmentation and dispersal pattern of the projectiles. **a** S&W model 66 .357 Magnum JHP (with retained fragmented jacket and projectile) **b** FN FAL 7.62×51 mm FMJ, **c** SA80 5.56 mm FMJ, **d** 12 gauge shotgun SG shot (9 shot). Uppermost aspect to all blocks=entrance, lower aspect=exit

using a mobile CT scanner and the other two using a hospital-based scanner. Both scanners were GE Lightspeed 16-detector CT scanners with Microsoft® Advantage workstations. The CT examination consisted of anterior–posterior (AP) and lateral “scout” views (these are routine 2-D CT images used to plan the full CT scan; they have a similar format and appearance to a standard plain film X-ray) undertaken at between 120–140 KV and 250–300 mA (block dependent). This was followed by a ‘spiral’ scan using either a 1-cm X-ray beam slice thickness and 16×0.625 mm detectors, or a 2-cm X-ray beam slice thickness and 16×1.25 mm detectors, with subsequent slice reconstructions interleaved at 0.625 or 1.25 mm, respectively. The CT images were saved to optical and compact disc and post-processed using Voxar 3D imaging software (Barco, Kortrijk, Belgium). Post-processing included creating multi-plane reconstructed images (thin slices in the axial, coronal and sagittal planes) and 3-D reconstructions.

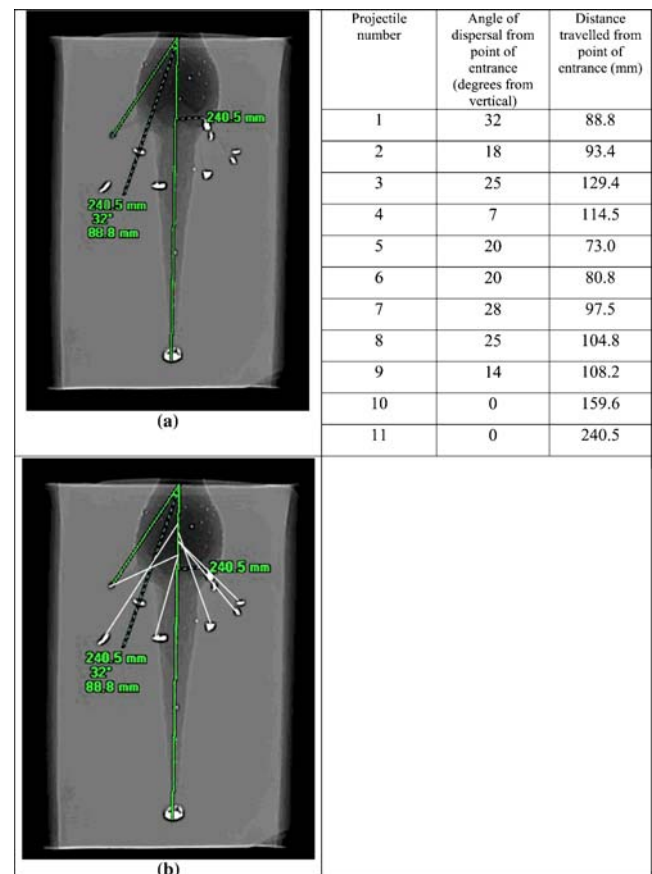


Fig. 2 **a** AP scout view of the projectile discharged from S&W model 66 .357 Magnum JHP showing the measurement of the distance travelled by the main projectile within the block from the point of entrance. In this example, the values within the table are the distances travelled by the fragments and angles of dispersal from the point of entrance as illustrated in **(a)**. **b** Examples of other angles and distances that could be similarly measured

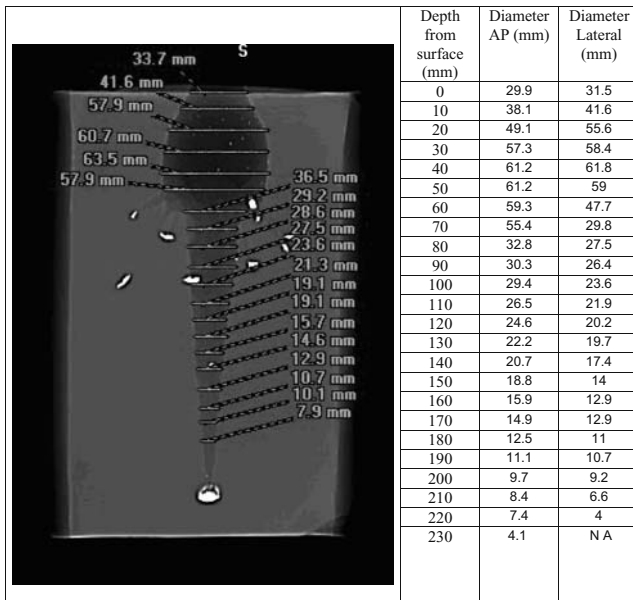


Fig. 3 AP scout view of the projectile discharged from the S&W model 66 .357 Magnum JHP showing the diameter of the temporary cavity at every 10 mm along the projectile path

Results

Block dimension

Each of the four block dimensions were measured manually and from the reconstructed CT images using the imaging

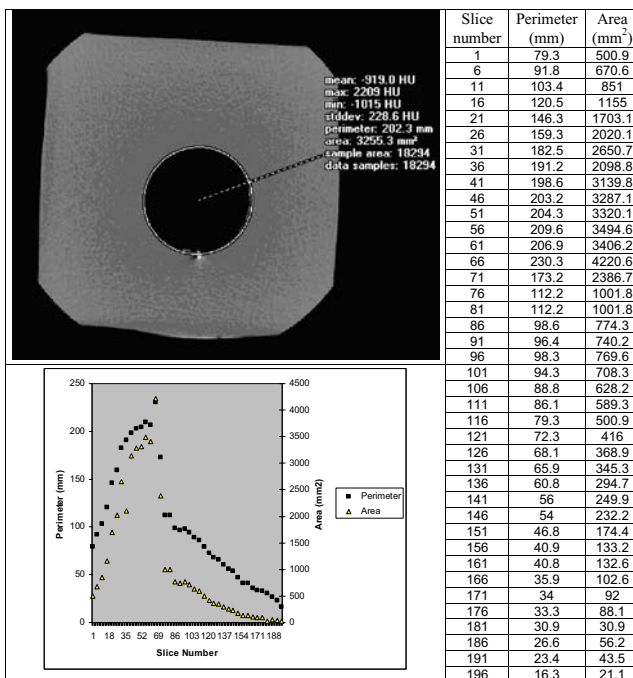


Fig. 4 Perimeter and area values for the temporary cavity created using S&W model 66 .357 Magnum JHP

software. The theoretical accuracy of CT (excluding observer error) is approximately ±1 mm for this study. This depends on the spatial resolution of the reconstructed images and is variable depending on the size of the object to be imaged and the slice thickness. For this study, the voxel sizes were approximately 0.5×0.5×0.125 mm for blocks 1 and 2 and 0.5×0.5×0.625 mm for blocks 3 and 4.

Temporary cavity, fragmentation and dispersal

Using the AP and lateral scout views, it was possible in glycerine soap to visualize the temporary cavity, as well as the fragmentation and dispersal pattern of the projectiles (Fig. 1). The S&W model 66 .357 Magnum JHP jacket fragmented, and the projectile remained in the block, whereas the other three types of projectiles all exited the blocks.

Using both the scout views and the multi-plane reconstructed images, it is possible to measure the distance travelled and angle of dispersal within the block of each projectile or fragment. By measuring these parameters in all planes, average distances and angles can be generated. It was found that where there were multiple fragments in

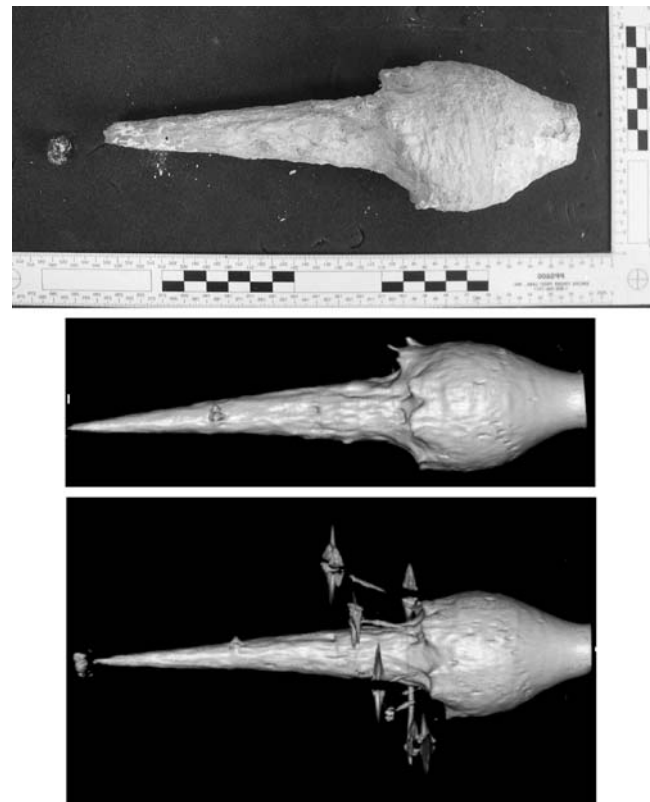


Fig. 5 a The cast of the temporary cavity created by the S&W model 66 .357 Magnum JHP. b A 3-D CT reconstruction of the temporary cavity created by the S&W model 66 .357 Magnum JHP. (c) As (b) but with the projectile and the additional cavity paths of the fragments

close proximity, the identification of each fragment from the scout views became difficult and that multi-plane reconstructions were then required. This is an advantage of CT scans, as the scout views are comparable with a standard X-ray image. Example measurements generated for one of the blocks are shown in Fig. 2.

Assessment of temporary cavity

Using both the scout views and the multi-plane reconstructed images, the diameter of the temporary cavity can be assessed. This can be done at set distances from the entrance point. An example of the measurements taken every 10 mm in both AP and lateral views are shown in Fig. 3.

Using the multi-plane reconstructed images, the perimeter and area of the temporary cavity, again, can be assessed at set distances from the entrance. The standard distances are set by examining an image at a given slice interval. An example of this is shown in Fig. 4 where the measurements are taken every six slices (equivalent to every 7.5 for 1.25-mm and 3.75 for 0.625-mm slices).

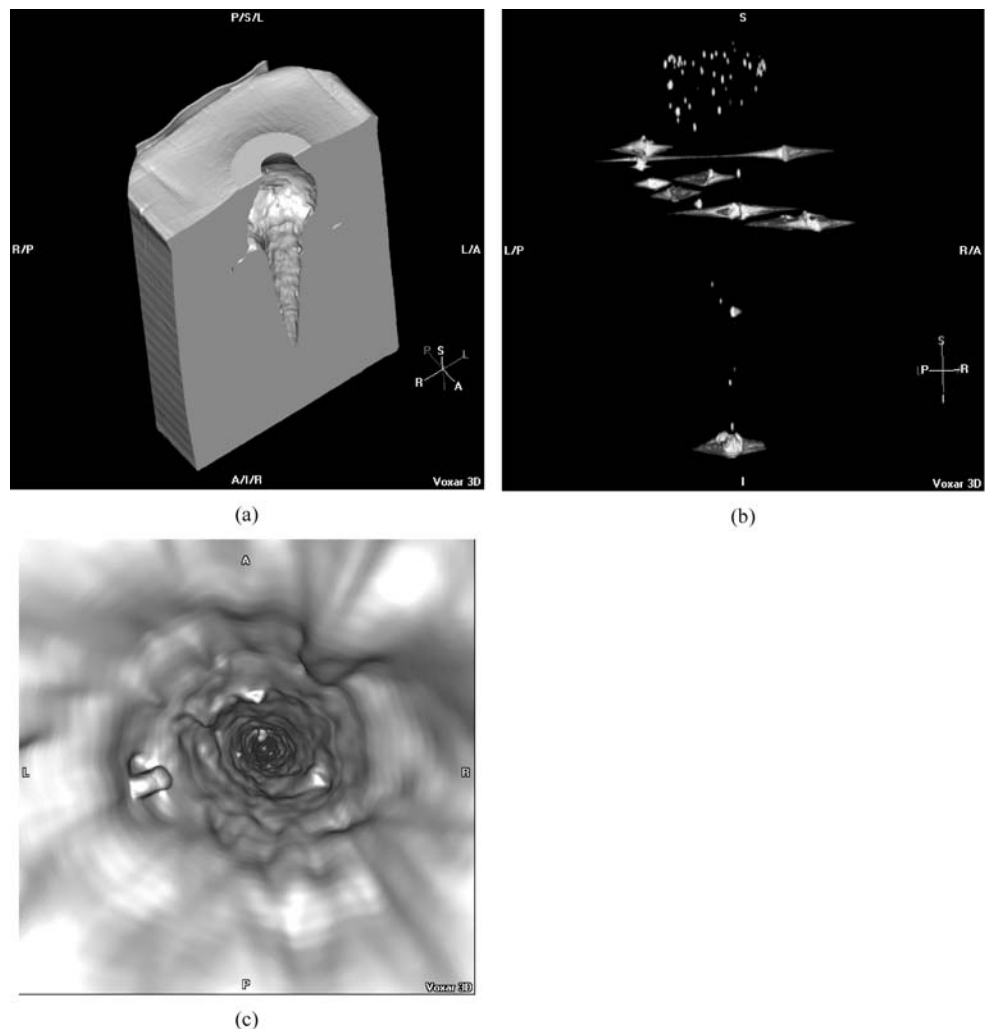
3-D reconstructions

The final assessment is the examination of the block in 3-D. Using the thin interleaved reconstructed slices, a 3-D model of the block can be made. This can be manipulated to show the block as solid or, alternatively, the air in the cavity as solid to mimic a cast (Fig. 5). It is also possible to analyse the temporary cavity caused by the main projectile or analyse the fragmentation or dispersal pattern of the projectiles. The block can be sliced through using a virtual saw to demonstrate it in *x*-, *y*- or *z*-planes. The block itself can be removed just to consider the projectiles or endoscopic “tunnelling” views that can be used to create 3-D fly-through views to travel through the block from one end to the other. Examples of these features are shown in Fig. 6.

Discussion

Over the last 20 years there has been an increase in the consideration of terminal ballistics with the use of materials

Fig. 6 3-D reconstruction of the block shot with the S&W model 66 .357 Magnum JHP. **a** The use of a virtual saw to look at the temporary cavity in 3-D. **b** The block is removed to show the projectile and fragmented jacket only. **c** A static image created from the fly-through views of the temporary cavity (so-called endoscopic tunnelling)



such as ballistic soap or ordnance gelatine. The visualization of missile paths through the use of transparent gelatine and high-speed video cameras has allowed the imaging and consideration of the temporary and permanent cavity; numerical analysis of which can be used for consideration of surgical treatment or the investigation of humane and inhumane missiles [4, 5].

Although the use of CT for terminal ballistic analysis was first described by Korac et al. [4, 5], as their original papers, CT technology and volume rendering software has developed significantly, allowing more information to be gathered from the analysis of the blocks without the necessity to open the blocks as we have illustrated in this paper.

Thus, not only can one numerically analyse the cavity using axial slices, as described by Korac et al. [4, 5], but one can consider the entire wound tract and projectile dispersal paths both in 2- and 3-Ds without the necessity to cut open the soap block. As the blocks ultimately dry out and shrink, the CT data and images provide a rapid and permanent record of the projectile path. This in turn can be used to illustrate the effect of different calibres of weapons to courts using modern information technology, such as scout views, 3-D and fly-through tunnelling. This could replace or be shown in conjunction with traditional casting of the cavity. These digital reconstructions could also be superimposed on standard anatomical 3-D bodies to provide a ‘virtual’ demonstration of potential wounds from shots to different areas of the body.

We believe that, through this paper, we have illustrated the extended use of CT and volume rendering software

within the field of terminal ballistics, which will be of use to firearms officers and surgeons alike.

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