

# Combined radio-colour contrast in the examination of ballistic head models

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**Abstract** The conventional analysis of ballistic gelatine is performed by transillumination and scanning of 1-cm-thick slices. Previous research demonstrated the advantages of colour and radio contrast in gelatine for computed tomography (CT). The aim of this study was to determine whether this method could be applied to head models in order to facilitate their examination. Four head models of about 14 cm in diameter were prepared from two acryl hollow spheres and two polypropylene hollow spheres. Acryl paint was mixed with barium meal and sealed in a thin foil bag which was attached to the gelatine-filled sphere which was covered with about 3-mm-thick silicone. The head models were shot at using 9 mm × 19 expanding bullets from 4 m distance. The models were examined via multislice CT. The gelatine core was removed; the bullet track was photographed and cut into consecutive slices which were scanned optically. CT images were processed with Corel Photo-Paint. Optical and radiological images were analysed using the AxioVision software. The disruption of the gelatine within the head model was visualised by extensive distribution of paint up to the end of the finest cracks and fissures and along the whole bullet track. CT imaging with excellent radio contrast in the gelatine cracks caused by the temporary cavity allowed for multiplanar reconstruction. We conclude

that the combination of colour contrast in gelatine with contrast material-enhanced CT facilitates accurate measurements in ballistic head models.

**Keywords** Head model · Wound ballistics · Gunshot injury · Computed tomography · Radiological imaging

## Introduction

In wound ballistics, experimental shots into blocks of gelatine have been performed for decades to compare the effect and properties of different kinds of bullets. The bullet, depending on the dissipated energy, generates a temporary cavity which after collapsing leaves expansion cracks in the gelatine. The conventional analysis of ballistic gelatine comprises transillumination and scanning of 1-cm-thick slices. Previous research [1, 2] demonstrated the advantages of colour contrast in gelatine when foil bags with acryl paint were shot through. An analogous method was applied using barium to enhance radio contrast of gelatine models in computed tomography (CT) [3]. The aim of this study was to determine whether a combination of both methods is applicable and convenient with head models in order to facilitate and extend their examination.

## Method

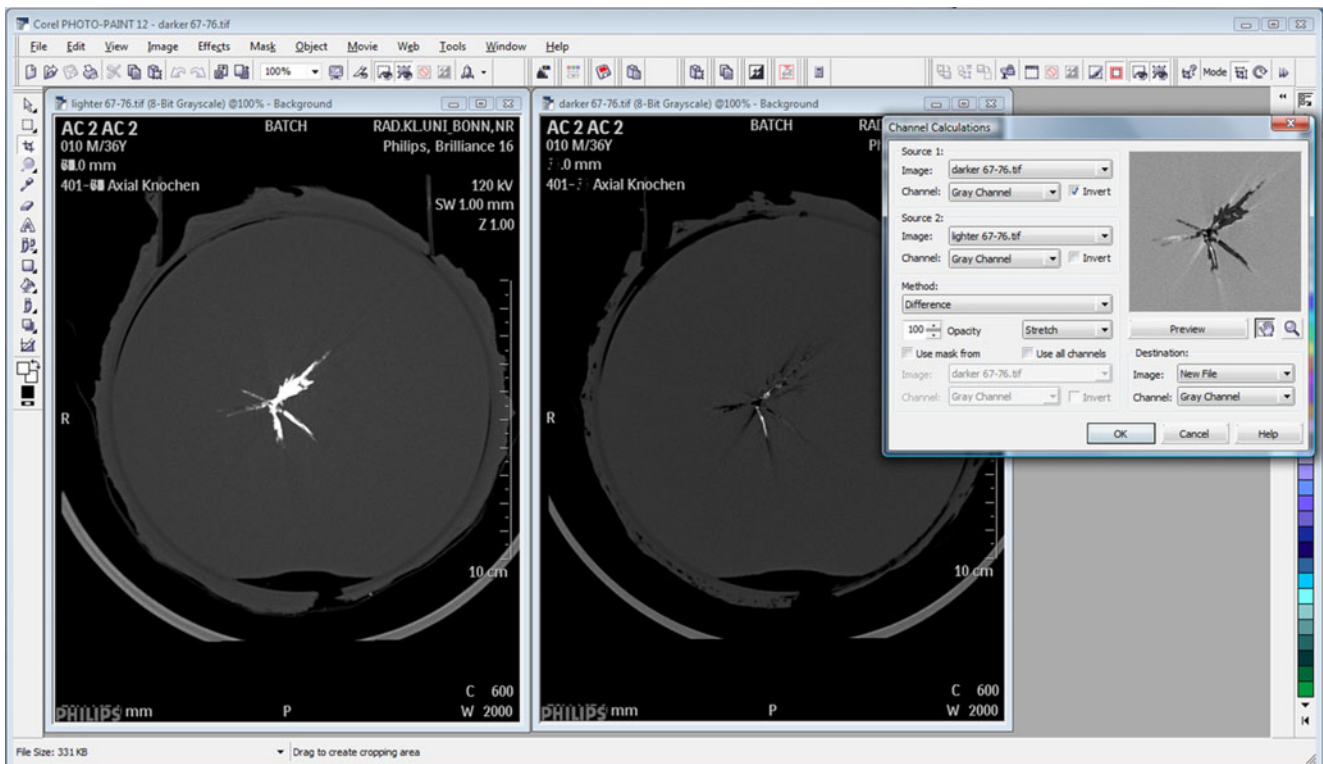
### Head models

Four head models of about 14 cm in diameter were prepared: each two from hollow spheres of transparent acryl (wall thickness of 2 mm) and white polypropylene (minimum wall thickness of 4 mm), respectively. Two millilitres

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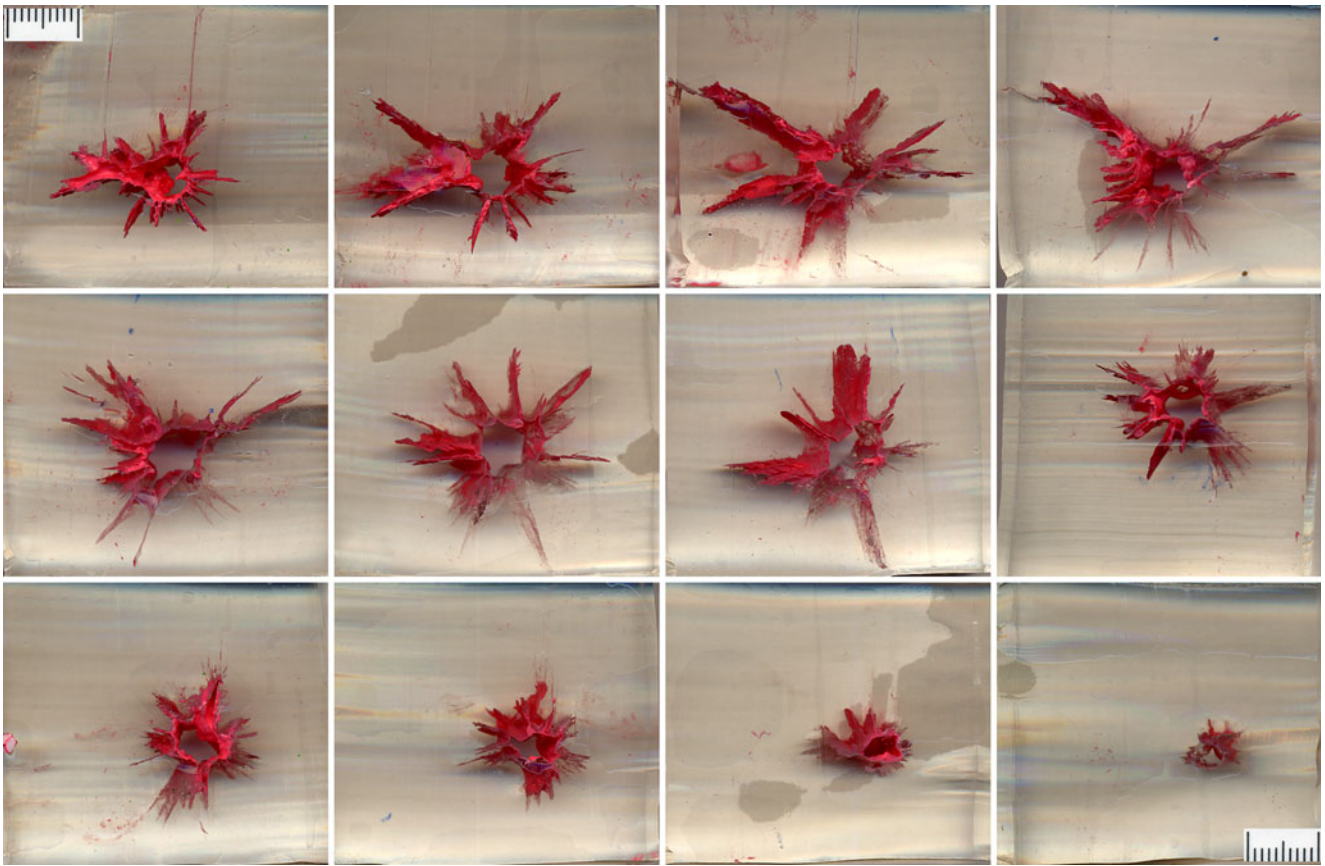
**Fig. 1** The screen shot of Corel Photo-Paint shows the image calculation mode “difference” to combine the “darker” and the “lighter” images which resulted from a recursive image processing of each ten images

of acryl paint and 2 ml of barium meal were mixed and sealed in a thin foil bag ( $5 \times 5 \times 0.2$  cm) which was glued onto the sphere. The spheres were then coated with 230 ml of silicone (for construction purpose) resulting in a layer of

about 3 mm thickness. The spheres were filled with 10 % gelatine solution “Ballistic 3” (Gelita, Eberbach, Germany) through a hole ( $\varnothing$  12 mm) that had been drilled into the top of each sphere. After 60 h of storage at  $4^{\circ}\text{C}$ , the head models

**Fig. 2** Exit hole of the polypropylene model after removal of the silicone coat. The volume rendering of CT image data realistically displays the fractures of the bone simulant





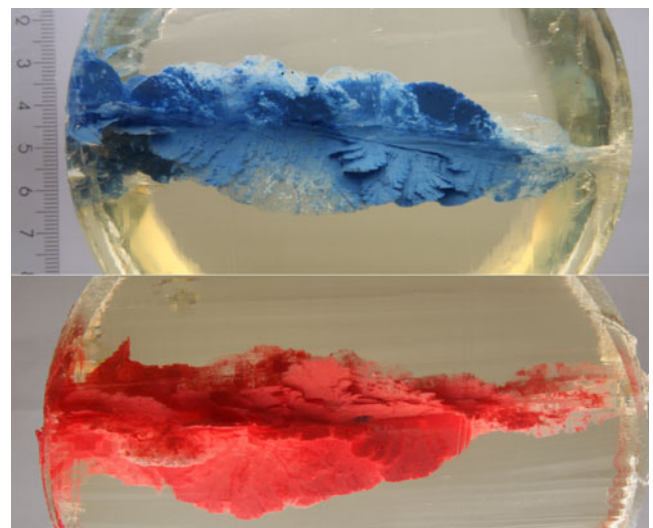
**Fig. 3** Gelatine slices of 2 to 13 cm of the bullet track in polypropylene model no. 1

were shot at using a SIG Sauer pistol P226 (calibre 9 mm × 19) loaded with 6.1 g Action-5 ammunition (RUAG) from 4 m distance.

#### Computed tomography

Twenty-four hours later the models were examined with multislice CT (Philips Brilliance 16). The scanning was performed with a tube voltage of 120 kV and a tube current of 320 mA. A spiral mode was used with a detector setting of  $16 \times 0.75$  mm and a pitch of 0.688. Reconstructed slice thickness was 0.8 mm with overlapping slices and a gap of  $-0.4$  mm. A bone filter was found to be the best reconstruction kernel for the delineation of the concentrated contrast medium versus air versus gelatine in the projectile course. The following image post-processing was performed on a Philips workstation (Extended Brilliance Workspace, Version 2.0). To interpret images, the Window width and level were adjusted to best visual impression according to the contrast medium. In order to compare the optical images with CT images, axial slices were reconstructed from the 3D dataset by multiplanar reconstructions with 1 mm slice thickness. The slice orientation of the axial slices could easily be arranged perpendicular to the

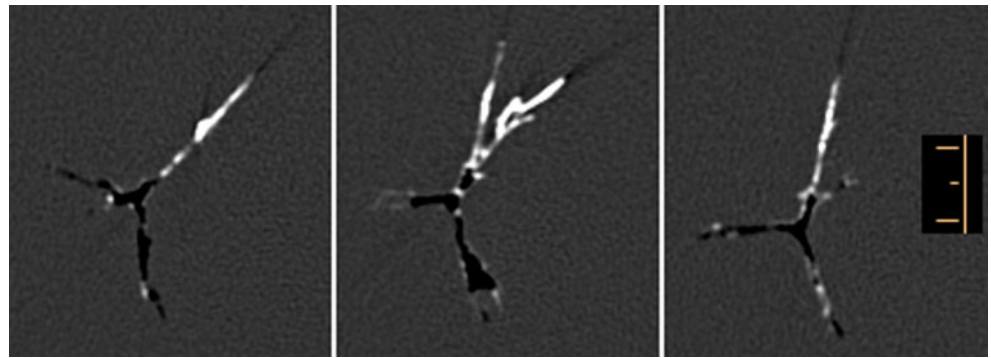
axis of the bullet's trajectory. Single slices were then exported in TIF format.



**Fig. 4** 9 mm × 19 Action-5 in acryl (13 cm, *above*) and polypropylene sphere model (14 cm, *below*). Gelatine core with colour-contrasted temporary cavity. Identical scale



**Fig. 5** Three CT slices of acryl sphere No. 1 show contrast by barium (*white*) and air filling (*black*) of the gelatine cracks



## Evaluation

First, the gelatine core was carefully removed from the sphere. The bullet track was photographed and manually cut into consecutive slices of 1 cm thickness which were scanned optically in a flatbed scanner (Epson Perfection 3200) at 300 dpi resolution. Each ten consecutive CT images representing  $10 \times 1$  mm thickness were processed with Corel Photo-Paint 12. In the first stage, the condition “if lighter” (menu Image/Calculations) was used, in the second stage “if darker”. This procedure was recursive: image  $n$  and image  $n + 1$  were combined to “new-1”, new-1 and image  $n + 2$  were combined to “new-2”...image  $n + 9$  and “new-8” resulted in “new-9”, called depending on “darker  $n - n + 9$ ” or “lighter  $n - n + 9$ ”. The two resulting images were combined using the “difference” mode (menu Image/Calculations) and setting the “inverted” button to “darker image” (Fig. 1). Images were analysed using the software AxioVision 4.7 (Zeiss, Oberkochen, Germany). The evaluation was performed via Fackler’s method [4] and the polygon method [1, 2].

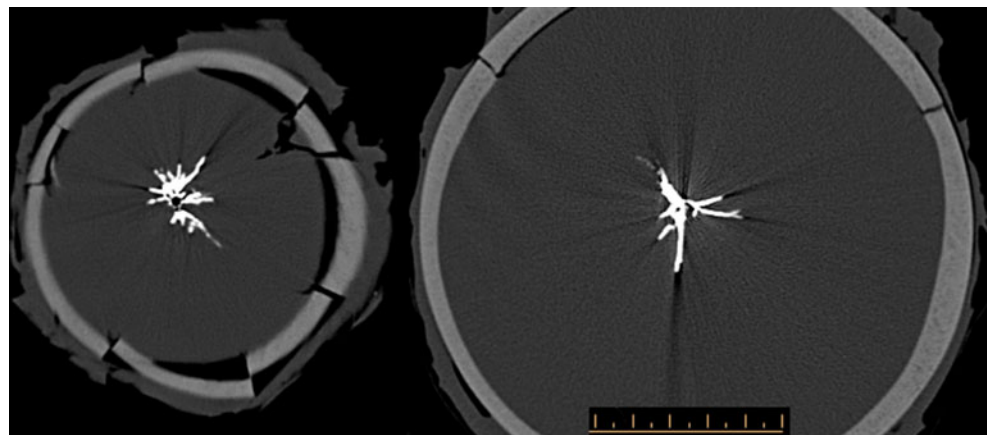
## Results

All shots penetrated the attached paint pad, passed through the head models and fractured them. The fragments were held in place by the silicone coating. While the fragments of the acryl models were too flimsy (only 2 mm thickness), the polypropylene fragments exhibited a morphology of entry and exit defects reminding of the characteristics of bone fractures (Fig. 2).

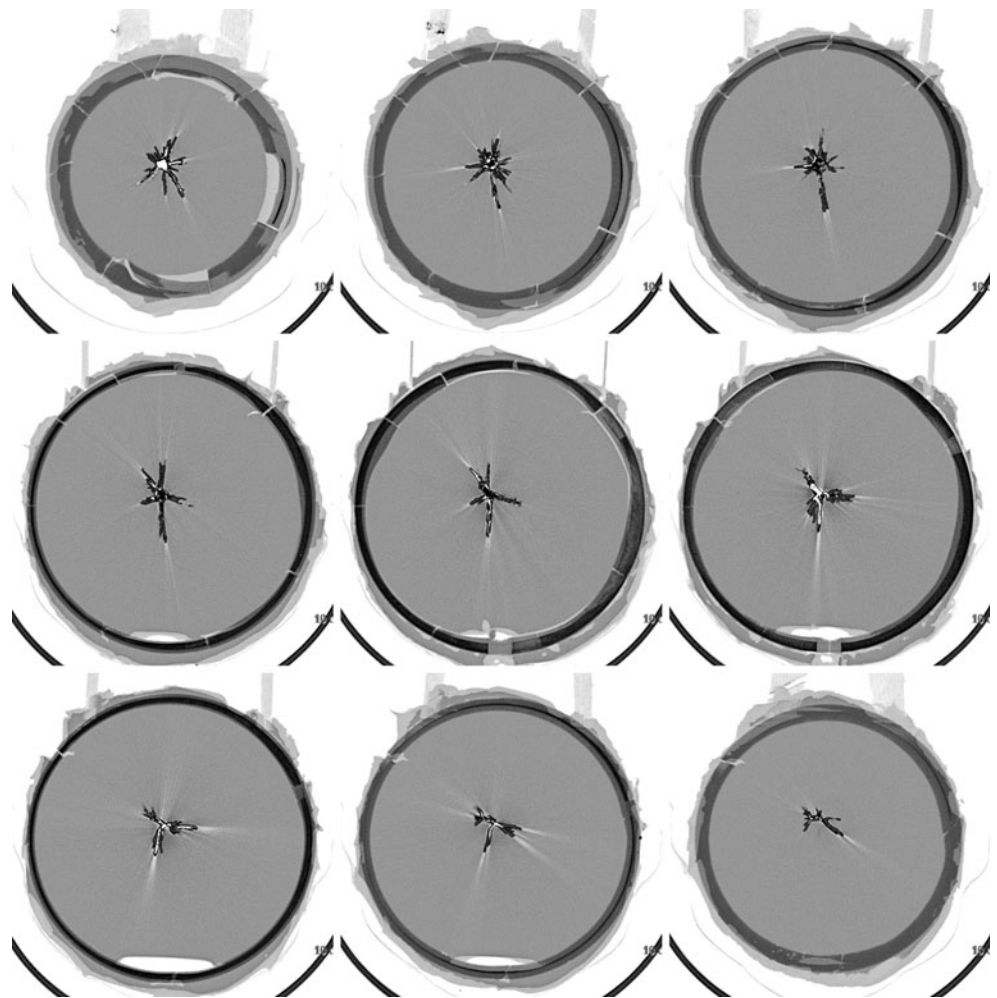
As expected, the expanding monobloc brass bullets generated an extensive temporary cavity. The corresponding disruption of the gelatine was visualised by rich distribution of paint up to the end of the finest cracks (Fig. 3) and along the whole bullet track (Fig. 4). This success was achieved by attaching the paint pad beneath the silicone layer.

The evaluation of the gelatine cracks along the bullet track was performed as described. CT images showed the cracks contrasted by barium as well as by internalised air (Fig. 5). This was the reason why the image processing was conducted cumulating the bright zones by barium contrast (“lighter” corresponding to high X-ray absorption) on the

**Fig. 6** Beam hardening artefacts provoked by high barium contrast



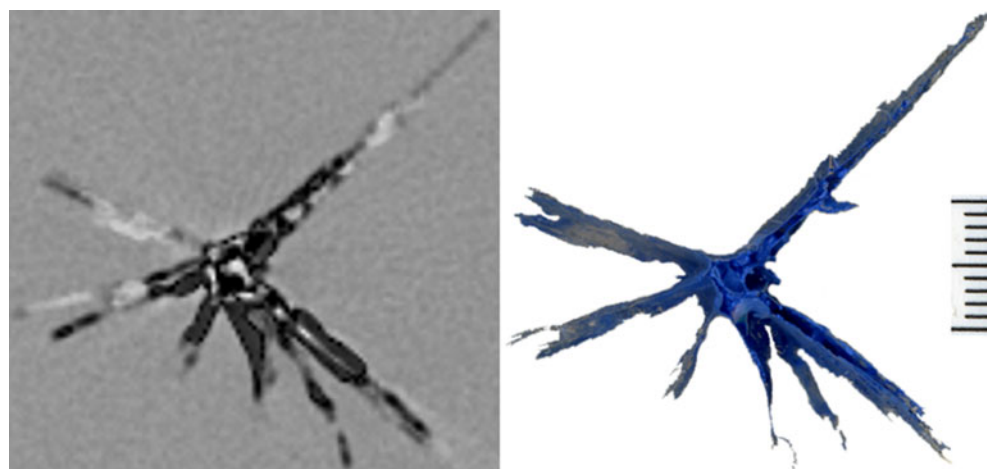
**Fig. 7** Processed CT images of polypropylene sphere no. 2 representing each 1 cm of the bullet track beginning with 2 up to 10 cm

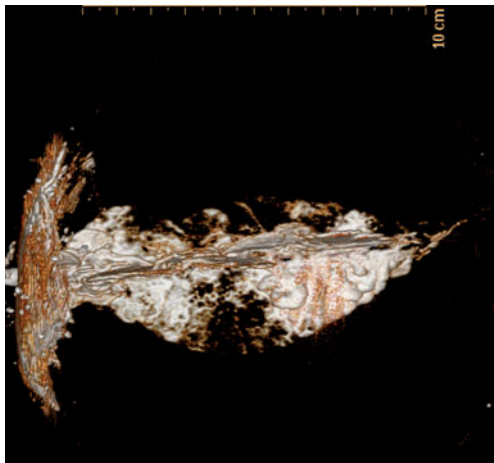


one hand and focussing on the dark zones (air inclusions, low absorption) on the other hand. The high concentration of barium in the cracks caused typical streak artefacts (beam hardening) with extinction phenomenon (Fig. 6). The greatest interference was of course provoked by the foil bag

containing the major part of barium. To obtain better images the bullet track was oriented along the axis of the CT so that the foil bag was perpendicular to the gantry. The described image processing helped also to minimise these artefacts which facilitated the evaluation.

**Fig. 8** Slice 6 cm in an acrylic sphere. Left processed CT image, right isolated tears in gelatine





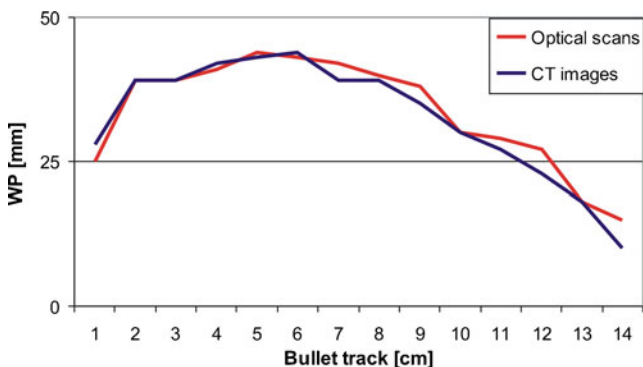
**Fig. 9** Reconstructed three-dimensional destruction zone in gelatine

Figure 7 shows the processed CT images of a polypropylene sphere (additional images of the other models are available as supplementary data). A direct comparison of the tears in gelatine as observed with the naked eye and by CT shows a neat conformity of the destruction morphologies (Fig. 8). The marked radiographic contrast allowed for a three-dimensional reconstruction of the damage caused by the temporary cavity (Fig. 9).

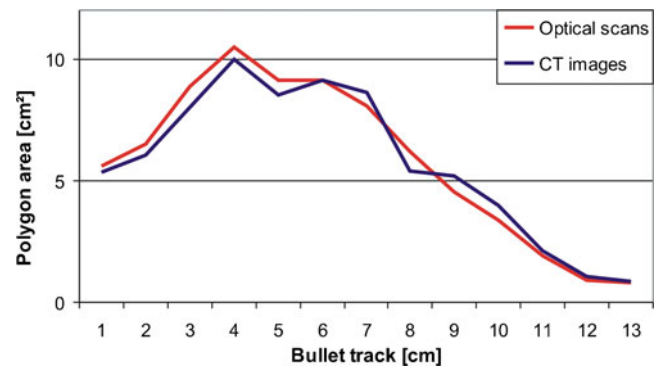
The evaluation of optical and radiographic images showed a good correlation (Figs. 10 and 11). The comparison of the four head models revealed some individual differences which are most suitably displayed by the polygon area (Fig. 12).

## Discussion

The successful application of radiological imaging to ballistic models has been described by several groups [3, 5–7], and we already discussed the feasibility of using CT for the



**Fig. 10** Polypropylene model no. 2: evaluation of the destruction in gelatine using Fackler's Wound Profile, the addition of the two longest cracks

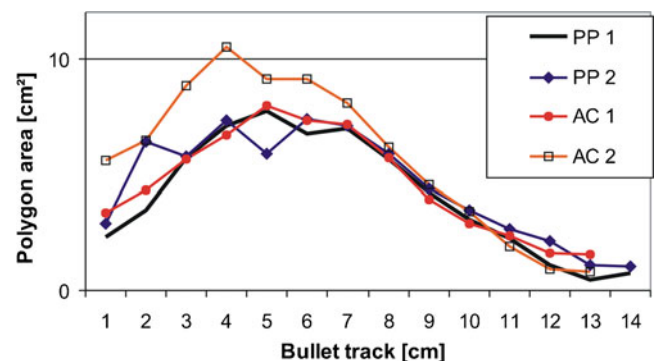


**Fig. 11** Acryl sphere no. 2: evaluation of the destruction in gelatine using the polygon area

examination of ballistic head models [3]. However, it had not been put into practice before. This study is now first to prove the feasibility of combining colour and radio contrast in ballistic head models. The quality of radiological imaging was excellent although the CT was performed 24 h after shooting [3]. Five hundred forty CT images each representing 1 mm of the bullet track were processed in about 1,100 operations. The resulting calculated CT images were compared to the images generated by optical scanning. Overall, correlation of optical and radiological measurements was satisfactory. Minor differences could be ascribed to the lesser resolution of CT images. Essentially, the four head models displayed a similarity with “individual” differences that may be explained by the heterogeneity of the “hand-made” silicone coatings.

## Conclusion

Combined radio and colour contrast imaging generates excellent images which allow for accurate measurements even in ballistic head models. This finding will be fundamental for future experimentation to study the influence of different bone simulants.



**Fig. 12** Comparison of all four head models with the polygon area based on colour-contrasted optical scans

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**Conflict of interests** None

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