Post-processing software in the analysis of external and terminal ballistics of bullets in firefights

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Purpose

The use of programs of post-processing of MDCT (Multi Detectors Computed Tomography) images as an aid to the radiologist for identification of the angle of shot of bullets has been previously described, however, to the best of our knowledge, the uses of programs in the identification of both terminal and external ballistic of projectile have never been reported.

The objective of this work is to use a software commonly applied to localize the tumor for treatment planning in the field of radiation therapy, to define the spatial position and the trajectory of the bullets, shot during firefights, in case of uncertain external ballistics and firing point.

The application of these positional algorithms, may help to define the internal and external ballistics of the bullet, and, through spatial estimates, define from where the shot was fired. The applicability of this instrument, is desirable, first of all, into an emergency contest, in order to define the internal ballistics of the bullet, and to identify more precisely the injured human tissues, and could be also useful in forensic analysis, in determining the position of the individual who fired the shot.

Methods and Materials

We evaluated two cases of gunshot injuries.

A 16-Row MDCT scans (GE lightspeed plus 16) total body was performed for the first patient, that received 120 ml of contrast medium (Iomeprol, 350 mgI/ml), with an injection rate of 4 ml/sec. The automatic bolus triggering software program was applied to a circular region of interest positioned at the level of the descending aorta and a threshold for triggering preset at 150 HU.

The second patient undergone a CT scans of the head: he received 40mL of contrast medium (Iomeprol, 350 mg of iodine per milliliter), with an injection rate of 4 ml/sec.

We acquired images without contrast, in arterial and in portal phase.

The images were processed with contiguous 3-mm-thick transverse CT scans viewed at mediastinal and lung window settings and post-processed using our dedicated software (Volume Viewer 2, General electric). The imaging were observed by a radiological team with at least 15 years of emergency radiology experience and examined in two stages: first of all at the workstation using two-dimensional MIP (Maximum Intensity Projection) and MPR (Multi Planar Reformation) reconstruction algorithm in axial, sagittal and coronal planes, and VR (Volume Rendering).
After, the images were stored into a software dedicated to radiation therapy ("External Beam Planning 6.5" Varian Medical system), where three-dimensional reconstructions were obtained. After, the coordinates of the point of penetration of the projectile and the point output were marked, in the two specific cases the objects remained inside the body and a contornation was performed on the bullets themselves.

Subsequently, was marked the point of passage of the projectile, previously identified by the radiologist, as passages through bone or air bubbles in soft tissue.

The final analysis, means of mathematical statistics, identified the angle of penetration of the projectile in the tissues, and then the trajectory of the bullets.

**Results**

**CASE ONE: STUDY OF EXTERNAL BALLISTIC**

A patient was taken to the emergency room with gunshot wounds, he appeared ill and sweaty, with a bullet entrance hole in the left sacral wing, no abdominal pain, no hematuria.

The CT scan identified high density object in the subcutaneous inguinal region close to the right femoral artery. The entrance hole was located in the left gluteal region, the bullet penetrated at the posterior edge of the iliac wing and crossed the sacral sincondrosis passing through the posterior wall of the first left sacral foramen. The journey continued with sacral fracture and leakage from the body of S2. In peritoneal space at the back of the internal iliac neurovascular bundle, was observed hyperdensity involvement without traumatic changes of opacification of the right internal iliac artery. The density of the subcutaneous tissue of the inguinal region was increased type blood, as a landmarks of the projectile.

CMPR (Curved Multi Planar Reformation) reconstruction algoritm, showed the passage of the projectile through the structures and his journey (Fig. 1).

The images were then uploaded to the software (External Beam Planning 6.5 "Varian Medical System) and 3D reconstructions demonstrated the path of the projectile through the bony structures and soft tissues (Fig. 2)

In this case, the evaluation of transitions and the subsequent reconstruction of the direction identified the trajectory of the projectile.

After the reconstruction it was possible to identify the angle of penetration of the projectile in the skin. In this case, we could hypothesize that the projectile was fired from left to right, top to bottom with an angle of penetration of 29° over the X axis (an imaginary line parallel to the ground) (Fig.3)
In this case the internal ballistics appeared substantially linear, the projectile was decelerated throughout his initial velocity from the bony structures and the crossed muscle, and then it had no sufficient kinetic energy to pierce the skin of the opposite side, so it was stuck in the inguinal canal.

The trajectory of the bullet allowed us to conclude that the shot was fired from behind, from above downwards pointing the patient from the waist down, and was shot by an assailant located to the left, approximately 80-90cm from the victim.

The last distance was calculated by an approximate simple trigonometric calculation in which a cathetus is equal to the other cathetus multiplied the cotangent of the adjacent angle, (Fig.4) where the cathetus missing is the distance and the cathetus inserted in the formula corresponds to the estimated distance of the gun to the point of retention (in this case the length in an average man from the shoulder to the groin).

The distance between the groin and the middle third of the humeral head of the patient "AB" is about 61.8 cm, this estimate was calculated by a MIP reconstruction in the sagittal plane (Volume viewer2, GE) (Fig.4a). Assuming that the patient and the aggressor had a medium and equal height, it is possible to estimate, on a rather approximate the cathetus C1. The cotangent of the angle of the shot is 1.81, which is the cotangent of 29°. The result of that trigonometry is 111.85cm.

At this distance we have to subtract the distance "CD" (the distance of the bullet from the opposite side of the body), that was calculated in axial view, from the projectile to the opposite cutaneous margin, that was estimated 23.6 cm (Fig.5b). We can therefore conclude with a summary that the distance was about 88cm.

**CASE TWO: STUDY OF TERMINAL BALLISTIC**

Unknown male patient was taken to the emergency room in a deep coma (GCS 3), he was spontaneously breathing (28 breaths / min), no brain stem reflexes were present, with a severe facial trauma from a possible accidental fall and copious nose and throat bleeding. Tracheal intubation was carried and the patient was put in invasive external respiration.

CT scan examination revealed in the left occipital lobe the presence of an high density material to report as a projectile.

The entrance hole was identified at the hard palate, with multifragmentary fractures involving the posterior wall of the sphenoid sinus and the left frontal and ethmoidal sinus. The presence of a subdural hematoma in the left frontal-parieto-temporo-occipital lobes with a maximum thickness of about 17mm, caused compressive effects on the surrounding brain structures, and a midline shift to the right of around 11mm.
The CT images were included in the dedicated software, which revealed the trajectory of the projectile and his steps.

The mark of the holes allowed to highlight ultimately the terminal ballistics of the bullet in the skull, reconstructing the movement in a more accurate mood.

The shot, had been fired at the level of the hard palate in the left paramedian zone, then was decelerated by the bony structures of the hard palate and the sphenoid, losing the kinetic energy needed to break through the skull, was then deflected by the structure of the frontal bone in the fossa of the superior sagittal sinus, it lost more kinetic energy, bouncing in the parietal bone and finally crashed against the left external occipital protuberance and having lost all its kinetic energy found its final location at the ipsilateral occipital brain parenchyma.

After the post-processing, and using a software for imaging manipulation (GIMP 2.6.11, GNU Image Manipulation Program) to connect the displayed points, it was clearly evaluable the internal trajectory of the bullets and it was possible to define that the shot was fired with an inclination from right to left, from bottom to top (Fig.7), which allowed to conclude that the patient had the gun in his right hand, and assuming that the patient was a right handed, we could exclude the involvement of third parties in the event.

Images for this section:
Fig. 1: Sagittal view reconstruction using MPR curve shows that the bullet (1) passes through the bony structures (2) and the air bubbles of the soft tissues (3)
**Fig. 2:** The holes marking allows to identify the points of passage of the projectile
Fig. 3: Reconstruction of the angle of shot

\[ c_2 = c_1 \cdot \tan \gamma_2 = c_1 \cdot \cot \gamma_1 \]
Fig. 4: Measure of a cathetus is equal to the product of other cathetus multiplied the cotangent of the adjacent angle.

Fig. 5: Distance AB from the groin to the middle third of the humeral head of the patient was calculated by a MIP reconstruction in the sagittal plane. The distance CD was estimate in axial view from the bullet to the opposite side of the body.

Fig. 6: The reconstructions made possible to highlight the entry point (A) and end point (B)
Fig. 7: Marking the intermediaries we can highlight the way of the shot.
Conclusion

The decision to use tools of radiotherapy planning CT image processing in order to obtain three-dimensional images, came from a study by Oliver et al in 1995 [1], where the radiation oncology software was used to create a three-dimensional reconstruction of the path of a bullet in the skull.

This study was repeated at other times, as an implement to forensic diagnostics. In particular, Marchetti et al [2] demonstrated the usefulness of tomographic reconstructions using the software "Plato" to identify the angle of shot, starting from vector fragments of a bullet in the skull. The reconstruction and mathematical estimates allowed us to identify the precise location of the attacker and they were used as evidence by a medical office.

More recently studies have been conducted on the corpses of a medical office, to define the possible use of computed tomography as an aid to analysis necropsy [3],[4]. These studies confirm the diagnostic accuracy of this procedure, because the autopsy in many cases is affected by post-mortal alterations, and by any surgical intervention, so MJ et al, in several studies in this field coined the term "Virtuopsy"[5] taking into account as methods of investigation both computed tomography and magnetic resonance.

A limitation to the applicability of this method post-death is that the MDCT is typically done with the victim in the supine position. The traces of the projectile are related to the position of the victim at the time of the attack, and these lesions may be difficult to appreciate in supine position. In particular, the lungs, mediastinum and heart can be moved significantly during or after the death due to hemorrhage or pneumothorax.

To the best of our knowledge, the use of post-processing software to study the terminal ballistic of bullet in vivo has never been described in literature. The use of these softwares, and her application could be a valuable source of scientific data, not only for a purely clinical care, but also from a forensic point of view, as evidence to be provided in court, and for developing additional ballistic studies.

References


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