CASE REPORT

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Three-Dimensional Reconstruction of a Bullet Path: Validation by Computed Radiography

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ABSTRACT: Three-dimensional visualization is an important tool in the evaluation and demonstration of injury. Creating convincing graphics, however, requires strict distinction between illustrative and reconstructive visualizations and a method of validation. We present a case in which we used a radiation-planning tool to provide a 3-dimensional illustrative visualization of a contact gunshot wound to the head, and validated the result by comparing computed radiographs with radiographs taken at autopsy. We discuss the use of visualization tools for data exploration in forensic pathology.

KEYWORDS: forensic science, ballistics, visualization, imaging

The use of three dimensional graphics in the courtroom is becoming increasingly widespread, but there has been little published in the use of these techniques for scientific visualization in forensic pathology. The purpose of tool development for most scientific visualization techniques is to allow humans to explore data more easily with their naturally-developed visual cognitive abilities. The resulting product, or visualization, does not create new classes, data, or organizational features in the data, but instead allows the investigator to appreciate features already there more easily. In addition, visual reality is not the goal of most scientific visualizations. Like a medical illustration, it attempts to demonstrate specific aspects within the data at the expense of strict realism and makes use of artistic conventions [*3*].

The paradigm for scientific visualization is the simple graph. A graphical representation of tabular data contains no more information than the underlying tables. However, it does provide, at a glance, a more intuitive feel for relationships in the data, and may provide pointers for further investigation that might have otherwise been overlooked. Scientific visualization methods attempt to extend this sense of intuitive interaction with the data [*4*].

Recent studies by Rheingans showed that, indeed, interactive representations convey information more accurately than other representations. In her studies, subjects were more confident about judgments made using interactive representations, and interactivity may affect the types of features a viewer notices in the data. Dynamic representations convey information about shapes in bivariate patterns more accurately than static displays [*5*].

Requirements of such an interactive visualization tool for forensic pathology would include a user interface that makes the tool useful to relatively technically naive users and real-time positioning of objects within the three-dimensional image space. It would need to create graphics from a number of descriptions, including geometric objects, biologic data, photographic data. Finally, there would have be some method of validating the result.

While such a tool may also be useful for the production of courtroom exhibits, its purpose is not the development of static courtroom illustrations. Instead, an interactive tool would allow investigators to derive insight into their data. It would allow the forensic pathologist to perform the same kind of three-dimensional data exploration now being used so effectively in craniofacial surgery planning and ergonomic design [*8*].

Case Report

In March 1991, a soldier went to his neighbor and said that he had just found the body of his (the soldier's) wife. The local Military Police were called and found the body of a 35-year-old white female in the master bedroom slightly propped up in the bed as if reading or sleeping. The covers were half over her body; her right hand, clasping her husband's .22 cal. revolver, lay over her chest. Examination of the death scene revealed three envelopes containing handwritten suicide notes and a list of problems with her life, all of which were judged after laboratory analysis to be by her hand. Autopsy revealed a contact gunshot wound to the right temple. The decedent had a history of depression but no previous suicide gestures. The case was signed out as a suicide. The husband had the body cremated immediately after it was released.

That night, various family members called the police claiming

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that the husband had psychologically abused his spouse. Further investigation revealed a history of marital discontent, that the husband was having an affair with the person who provided his alibi, and inconsistencies concerning the whereabouts and activities of husband became apparent. Insurance claims amounting to $150,000 were paid as a result of the suicide. Though laboratory analysis determined that the decedent had indeed written the multiple suicide notes, they had been written with two different pens and on two different types of paper, suggesting that they had been written at different times. Witnesses stated that the wife acknowledged months before her death that she had written suicide notes; her husband had found and confiscated them. Analysis of the saliva that sealed one of the envelopes matched the blood type and DNA of the husband, but not of the decedent.

A final problem with the case concerned the way the decedent held the revolver. When her body was found, she clasped the grip of the revolver with all five digits: the four fingers were wrapped over the grip anteriorly well below the trigger guard, and the thumb was between the revolver and the body. The investigating officers felt that it would be difficult for her to change from the more traditional grip to this grip after firing the weapon, but that this would be the most likely grip had the gun been placed in her hand following her death. However, cases have been reported in which the gun was gripped with all four fingers and the trigger pulled with the thumb [*1*].

The investigating officers requested a three-dimensional reconstruction of the bullet path to help them visualize how the gun might have been placed up against the head—whether the bullet path itself might help determine whether the wound was self-inflicted. Unfortunately, a full clinical workup of the skull, including a CT scan, was not performed because the decedent was declared dead on arrival to the hospital. Further, photographs taken at autopsy were more concerned with documenting that the wound was a contact wound and its general direction rather than providing spatial data for a reconstruction. No photograph of the calvarium was present. However, there was a description of the bullet path in the autopsy protocol, and two skill films were taken—an AP and lateral skull film, which showed the approximate location of the bullet path (Fig. 1).

Methods

The orthogonal X-rays were sufficient to localize any individual feature in three-dimensions, but insufficient for a full reconstruction of the skull. To provide a three-dimensional representation, the bullet path had to be localized with anatomic landmarks and positions on stock skull data. To provide such localization in a 3D data set, we modified a radiation treatment planning tool, called PlanUNC, developed at the University of North Carolina Department of Radiation Oncology. PlanUNC provides interactive manipulation of the rendering, including lighting, view angle, cut surface, and opacity of various tissues. This tool currently makes use of specialized hardware, such as the PixelPlanes5 graphics engine [*7*].

More important, we could use PlanUNC to provide a validation of the localization by direct comparison with the autopsy X-ray data. A method of reconstructing a radiograph from three-dimensional CT data has been developed, called the computed radiograph or digitally reconstructed radiograph (DRR) (Fig. 2). The DRR is used as an aid in treatment planning. Films printed from the DRR can be compared with live fluoroscopic images to verify that the beam orientation is correct [*2*].

The bullet path was visualized as a cylindrical beam of radiation, without ricochet. Digital radiographs of the stock skull with the same orientation as the autopsy radiographs were created (Fig. 3). The beam was then placed to intersect the DRR in the same anatomic locations on the stock skull as the entrance and impact locations on the autopsy radiographs.

Results and Discussion

Two visualizations are shown in Fig. 4. The autopsy report indicated a small amount of ricochet, but the behavior of the bullet beyond its initial flight was irrelevant to the question asked by the investigators. The path was allowed to extend beyond the skull to emphasize the angle of the path and to re-enforce that this was an image derived from sparse data, and not a true reconstruction of the decedent's skull.

The modified visualization tool allowed interactive positioning of the beam in a three-dimensional model with direct comparison of the computed radiographs to the autopsy X-rays. It further

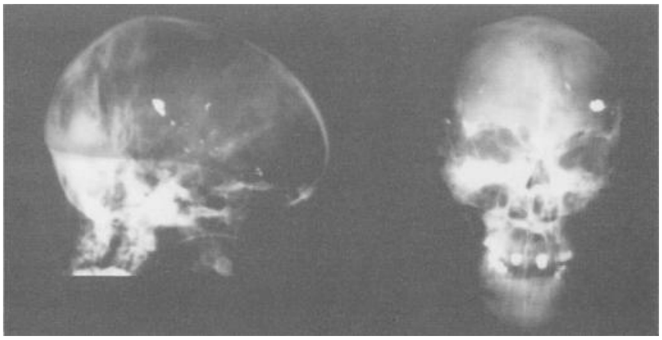

FIG. 1—*Autopsy radiographs. The entrance wound is in the right temporal area. Exact placement of the impact point using the X-rays was difficult and required advice from consulting radiologists.*

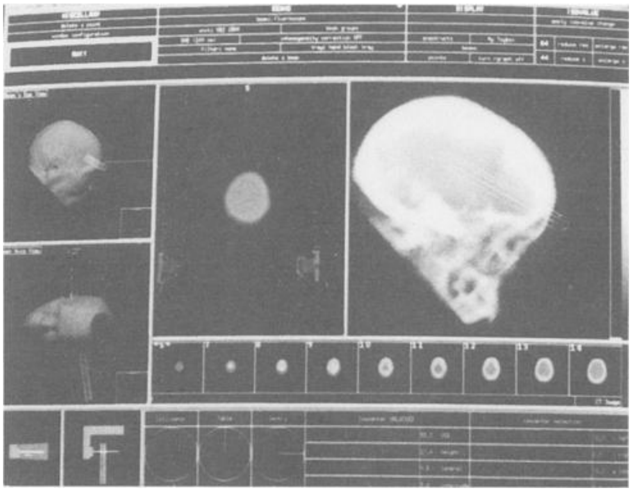

FIG. 2—*User interface for beam planning tool. At the far left are two orthogonal low resolution 3-D renderings for orientation. In the center is a CT slice with the surrounding beam housing. At the far right is the computed radiograph. Below the main display are a series of thumbprint CT slices to allow the user to visualize the beam placement in the CT data. The radio dial widgets are for orientation and movement; movement may also be accomplished by drag and drop methods.*

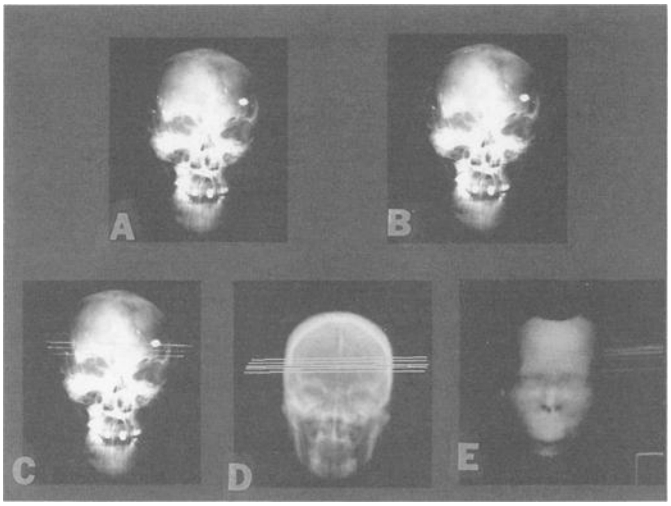

FIG. 3—*Sequence used in performing reconstruction.* A. *Original X-ray.* B. *Localization of entrance and impact points.* C. *Orientation of rays through entrance and impact points.* D. *Placement of beam in matching position through digitally reconstructed radiograph of stock anatomic CT data oriented to match the autopsy radiograph.* E. *Thumbprint 3D reconstruction. This was performed with both AP and lateral views for 3D validation.*

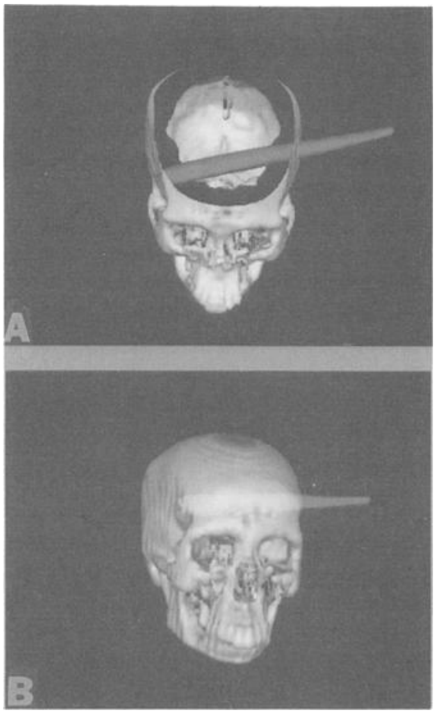

FIG. 4(A,B)—*Two views of the full reconstruction. The narrowing of the beam is due to modeling of radiation attenuation. The skull is constructed from stock CT data. The beam was localized by comparing computed radiographs from the CT scans with the autopsy radiographs.*

allowed interactive movement of the resulting 3D model, addition and subtraction of other anatomic features, such as muscle and skin, movement along cut planes, and modification of transparency. The tool also provided the visualization of intermediate soft tissues and structures in the path of the bullet, though in this case we found them unhelpful. After evaluating the data in this case, including the reconstruction, the consulting pathologists concluded that the path of the bullet was not conclusive for any manner of holding the gun.

In our example, we used stock CT data and a radiation isodose visualization tool to represent a three-dimensional bullet wound track. The use of the computed radiograph allowed us to demonstrate that the resulting graphic accurately demonstrated the features the investigators wished to visualize even with a number of simplifying assumptions. It also aided in the positioning of the path by allowing direct comparison of the computed radiographs with the autopsy X-rays.

While this specific visualization required modifying a tool meant for an unrelated purpose, the adaptation of this tool or the development of a similar tool to allow the interactive merging of geometric objects (such as representations of bullet paths) and more traditional medical image data may be of great use to investigators seeking to understand the physical relationships of wounding. The ultimate usefulness of such a tool will depend upon determining exactly what needs would be best met by such visualization, and by performing the appropriate observer studies to drive the modification of that tool. A great deal of work for tools in medical specialties other than forensic pathology has already been done [*6*].

Moreover, an examination of the validation mechanisms is necessary. In a preliminary experiment, an observing radiologist was asked to place mock entrance and exit points at visually the same anatomic locations in computed radiographs from different individuals. The skulls were then warped by means of a thin plate spline so that all major anatomic landmarks matched one skull, in essence morphing one skull into the other. The resulting bullet paths, identical "by eye" to the radiologist, diverged between 5 and 10 degrees when the skulls were merged. Further observer studies are being planned [*9*].

Static images produced by this tool are no more than could be produced by a competent medical illustrator or by a plastic model of a skull and a probe, but the medical illustrator could not allow the interactive exploration of the visualization. Re-drilling the holes in a plastic skull for multiple positionings or re-casting the skull for multiple cut planes and interactive positioning of tissues is impractical. The positions of the entrance and exit points were determined by examination of the original X-rays, and thus were dependent upon the radiologic capabilities of the consultants. As one reviewer pointed out, any good radiologist could would have been able to ascertain the bullet track with a fair degree of certainty. However, an interactive tool for comparing bullet wound tracks and anatomic localization of injury might well aid non-radiologists by allowing them to visualize the results of consultation, comparing and merging multiple cases, and as an aid in directing questions to consulting experts.

This tool is currently implemented on specialized hardware, but it could be adapted for more standard configurations. The increasing availability of parallel and RISC architectures to the desktop level, combined with the increasing standardization and speed of graphical user interfaces makes it reasonable to expect that such a tool could be made practical on widely available configurations soon. This represents a first attempt at the development of such a tool for the practicing forensic pathologist.

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