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Review Article

Digital Autopsy: Popular Tools for an Unpopular Procedure

التشريح الرقمي للجثث: أدوات مألوفة لإجراءات غير مألوفة

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Abstract

Digital autopsy is the future of postmortem examination of the human body through digital visualization. Imaging modalities such as CT scanners and MRI scanners use X-rays and magnetic fields to visualize the structures within the human body. The outputs from these modalities are obtained in a DICOM (Digital Imaging and Communications of Medicine) format. They are in gray-scale consisting of information in every slice taken during the scan. This is rendered and visualized as the full body in a digital format during the digital autopsy procedure. The visualization rendering produces a three-dimensional body, further presented in colour format based on each structure of the human organ system. Digital autopsy is a technology which allows pathologists to navigate and explore deeper into the human body. It allows analysis to be done in both two-dimensional and three-dimensional perspectives. Digital autopsy involves analysis of human pathology and anatomical findings for diagnostic purposes. It can also be used for education and research purposes. Another advantage of digital autopsy is the availability of information and data that can be easily and securely transferred to a different digital autopsy facility at a different location. Thus, digital autopsy provides an efficient, fast, cheaper and accurate post-mortem data enabling a forensic pathologists to play a more effective role in the criminal justice system.

Keywords: *Forensic Sciences, Three-Dimensional, Visualization, Postmortem CT, Forensic Pathology.*

المستخلص

التشريح الرقمي للجثث هو مستقبل الفحص بعد الوفاة للجسم البشري من خلال التصوّر الرقمي. تستخدم طرق التصوير مثل التصوير المقطعي المحوري CT والتصوير بالرنين المغناطيسي MRI الأشعة السينية والمجالات المغناطيسية على التوالي، وتستخدم عادة لتصوير الأعضاء والهياكل داخل جسم الإنسان. ويتم الحصول على نتائج قراءات هذه الطرائق على شكل ملفات وفقاً لمعيار DICOM (التصوير الرقمي واتصالات الطب). وهي موجودة في نطاق رمادي يحتوي على المعلومات في كل مقطع تصويري أخذ أثناء الفحص، والذي سيتم تقديمه وتصويره كجسد كامل في شكل رقمي أثناء إجراء التشريح الرقمي. ينتج عن هذا التجسيد جسم ثلاثي الأبعاد، ويُعرض كذلك على شكل ملون حسب شكل كل عضو من الجسم البشري. تشريح الجثة الرقمي هو التكنولوجيا التي تسمح للأطباء للتنقل واستكشاف أعمق أجزاء من جسم الإنسان، ويسمح بأن يُجرَى التحليل الذي يتعين القيام به على المستويات ثنائية الأبعاد وثلاثية الأبعاد. ويشمل التشريح الرقمي تحليل الأمراض البشرية والموجودات التشريحية لأغراض التشخيص والتعليم والبحث أيضاً. ميزة أخرى مهمة للتشريح الرقمي هي توافر المعلومات والبيانات بصيغة يسهل نقلها بشكل آمن إلى مرافق التشريح الرقمي في أماكن مختلفة. وعليه يوفر التشريح الرقمي كفاءة وسرعة ورُخص لعملية التشريح ودقة في المعلومات المتحصلة ما بعد الوفاة، ويمكن أخصائيي الطب الشرعي على لعب دور أفضل في نظام العدالة الجنائية.

الكلمات المفتاحية: علوم الأدلة الجنائية، ثلاثي الأبعاد، التصوير، التصوير المقطعي المحوري بعد الوفاة، علم الأمراض الشرعي.

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1. Introduction

The rate of clinical autopsies has seen a declining trend, and though there has been no decrease in forensic autopsy rates, the practice has been criticized for being invasive and violating religious principles [1]. This is also compounded by other issues like the possible transmission of communicable diseases to the people handling the body.

Traditionally, postmortem imaging techniques have been limited to X-rays with the conventional autopsy procedure being higher in cost and more time-consuming [2]. Only recently, there has been an attempt globally to use digital autopsy as an alternative to the conventional invasive procedure to address forensic issues. Certain conditions like intracranial bleeds, lung pathology, and ruptured aneurysms can be better identified through computed tomography (CT). A digital autopsy is an advanced, noninvasive process, which involves various modalities like CT and magnetic resonance imaging (MRI), etc. The acquired data can be investigated, revisited, and reinvestigated without the loss of quality of information. Medical experts in different locations can also provide opinions by examining the same data using remote visualization software.

2. Modality

2.1 Computed Tomography (CT) and Computed Tomography Angiography (CTA)

Cross-sectional images (slices) generated by a Computed Tomography (CT) through computer-processed X-rays can be reformatted into multiple planes to form 3D images and viewed on a computer monitor. In addition, CT scan is a low-cost scanning method and provides fast scanning time. Computed Tomography Angiography (CTA) is a specialized radiography procedure used to study the lumen or blood flow in the blood vessels, especially for the arteries, veins, and heart chambers. CTA assists in diagnosing and evaluating diseases of blood vessels and related conditions such as injury, aneurysms, blockages (blood clots or plaques), disorganized blood vessels, and blood supply to tumors.

2.2 Magnetic Resonance Imaging (MRI)

Magnetic Resonance Imaging (MRI) is a radiology technique based on the principles of nuclear magnetic resonance (NMR) which produces detailed pictures of organs, soft tissues, bone, and virtually all other internal body structures. Postmortem whole-body MRI has overall high sensitivity for depicting soft-tissue lesions. Using postmortem MRI with ancillary investigations has now been shown to be as accurate as conventional autopsy in fetuses, newborns, and infants [3]. It is particularly useful for cerebral, cardiac, and genitourinary imaging. MRI requires longer scanning time and is an expensive method.

3. DICOM

The images from all modalities and medical imaging devices are stored as DICOM files. DICOM is not only a file format but also a pervasive standard containing protocols for communication with modalities and managing storage of files [4]. The software solution that is compliant with DICOM is called a picture archiving and communication system (PACS). It provides features and gateways for communicating with modalities and other medical information systems, as well as managing the best archiving model for these DICOM files [5]. Communication of PACS with a CT scanner (or any other modality) is one of the basic functions, whereas another aspect is communication with a radiology information system (RIS) [6].

The intensity in almost all modality outputs is monochrome, mainly in gray (black and white). These values were mapped to real tissues of the human body in Hounsfield units (HU) [7]. In addition, a set of default measurements defined by Sir Godfrey N Hounsfield for CT scanners is available for matching and viewing these organs and tissues (Table-1).

4. Digital Autopsy Visualization

4.1 Three-Dimension (3D) Visualization

The most important technique to transform layers of CT image data into 3D images (models) is the rendering technique comprising the following three steps [8]:

4.1.1 Volume Formation

A typical volume formation step includes resizing of each volume element (voxel), image smoothing, and data editing.

4.1.2 Classification

The classification step consists of evaluating each voxel based on the types of tissue and assigning colour and other visual properties to the voxel.

4.1.3 Image Projection

The final step is projecting the data as an image that represents a view of the 3D volume on the user's display. A window width and a level of HU approximately define a percentage that will show the particular tissues in the display to the users. For instance, a window width of 600 HU and level of 400 HU will show the bone.

4.2 Multiplanar Reconstruction (MPR)

The DICOM files of CT or MRI scanners are reconstructed and rendered to produce the 3D model of the body. The CT scanner produces DICOM with parallel high-contrast images. Another usual technique for the rendering of medical images is the multiplanar rendering (reconstruction). Multiplanar reconstruction (MPR) needs less calculation than volume rendering. That is why this technique is suitable for low-configuration computers. The common axis of CT images is transverse slices of the body. Hence, the user would be able to explore the body by scrolling a series of 2D CT images. Other directions like coronal and sagittal can only be viewed after image reconstruction or rendering [9].

4.3 Color Transfer

There are not many types of medical images in colour; medical images are dominantly in grayscale. As mentioned earlier, the HU has been defined to codify a certain number of these shades in groups that are determined by window width. These categories help the viewer understand and relate the images with the corresponding tissues. The same grouping approach has been employed to add colour to these images. Technically, it is called colour transfer. For example, if we select roughly red colour (as a muscle) for the HU of muscles, the result will be similar to the natural colour of muscles. It is the same when we use different colours for different tissues.

Table 1- *CT numbers in Hounsfield units (HU) for different tissues.*

Tissues/organs	HU
Lung	-700
Fat	-50 to -100
Cerebrospinal fluid	15
White matter	~20 – 30
Gray Matter	~37 – 45
Blood	30 – 45
Muscle	10 – 40

5. Digital Autopsy Tools

While we have 3D digital bodies, we will use a digital scalpel to provide efficient views of the body. The following are the tools (functionality) to conduct the digital autopsy:

5.1 Navigation Tools

5.1.1 Move, zoom, and rotate in all possible axes.

5.1.2 Observe the body in different views as in 2D slices, MPR, and 3D (Figure-1 & 2).

5.2 Exploration Tools

5.2.1 Region-of-interest (ROI) functionality allows forensic pathologists to view a designated part of the body. (Figure-3)

5.2.2 Sculpting functionality enables the pathologist to view different layers of the body (skin, muscle, organ and bone).

5.3 Analytical Tools

5.3.1 Various measurements such as length, diameter, angle and area (mm, cm, inch and Hounsfield units). (Figure-4)

5.3.2 Explore the 3D digital body to find metallic particles such as bullets.

5.3.3 Annotating findings and recording tools for documentation purposes.

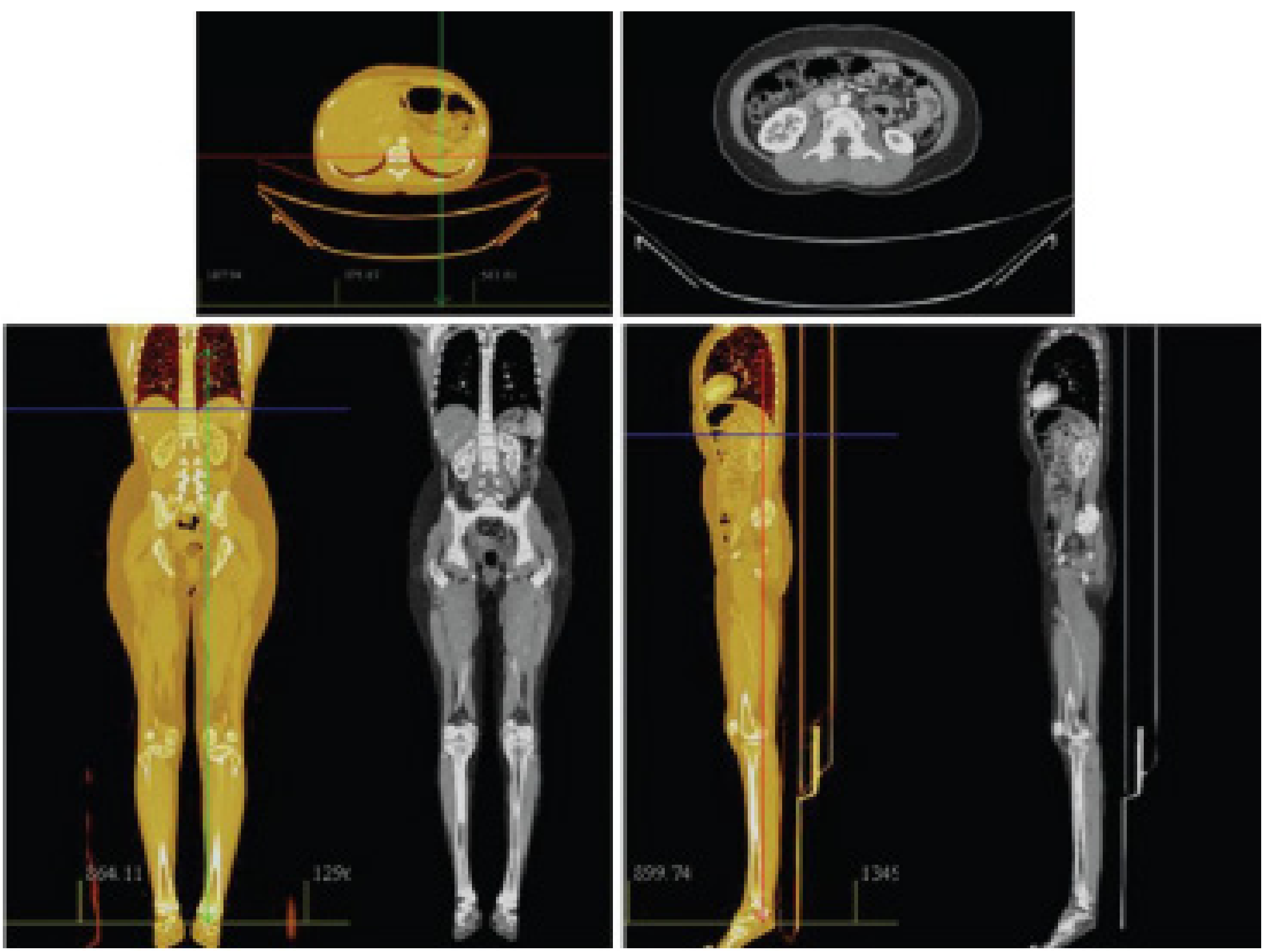

Figure 1- a) *Axial,* **b)** *Coronal and* **c)** *Sagittal views of the body (MPR).*

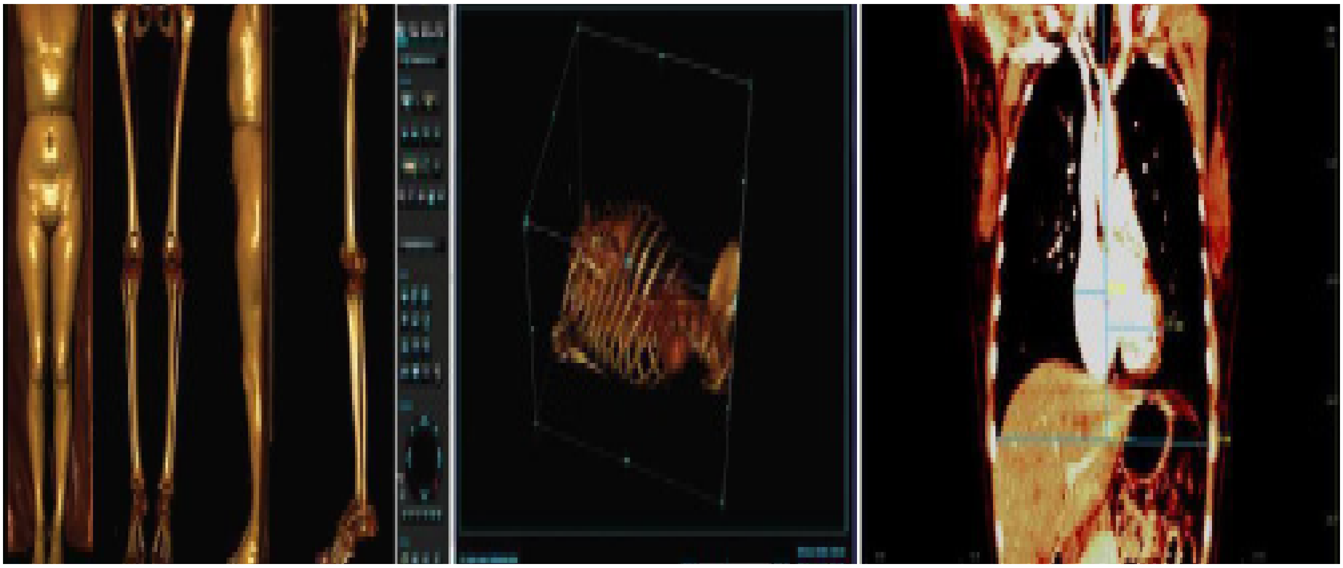

Figure 2-4- *Navigation tool, exploration tool, and analytical tool.*

6. Pathological Exploration through Digital Autopsy

Digital autopsy (DA) is an integral part of forensic investigation in the future. Blunt force impact is the most common form of trauma. Digital autopsy is vital to visualize blunt injury patterns. DA of head, spine, and pelvic injuries may facilitate the understanding of the mechanism of injury. Cerebral contusions occurring on the gyral crests appear as focal punctate or linear areas of hyperattenuating hemorrhage. Edema may be located adjacent to contusions. Extradural hematomas are typically biconvex in shape and have a mass effect on the adjacent brain. Subdural hematomas are crescent-shaped and do not cross dural attachments. Acute extradural hematomas and subdural hematomas are classically hyper-attenuating on DA. Chronic subdural hematomas typically demonstrate fluid attenuation on DA. Subarachnoid hemorrhage is seen as a thin layer of high attenuation in the cerebrospinal fluid spaces, cisterns, and sulci on DA. Decomposition makes the diagnosis of subarachnoid hemorrhage more challenging [10, 11].

Metallic fragment analysis and the pattern of fragment deposition along the gunshot wound track are excellently depicted on 2D Multiplanar and 3D images that have thresholds adjusted for metal attenuation. Digital autopsy not only depicts the entry and exit wounds but also skin-surface features such as wound shape, pigmentation, discolouration, and soot deposition [10-12].

DA also provides a rapid anatomic survey of the head and body. It provides supportive information and excludes occult trauma when atherosclerotic coronary artery disease is the cause of death. In this setting, high attenuation hemorrhage will be present. Haemopericardium is characterized by a hyper-dense inner ring and hypodense outer ring. Diffuse subarachnoid hemorrhage is characterized by high attenuation throughout the subarachnoid spaces that interdigitate between the cerebral gyri and in the basilar cistern [10-12].

7. Digital Autopsy as a Service

7.1 Telemedicine

Telemedicine implies real-time interactive communication of the physician or practitioner at the distant site with minimum use of interactive telecommunications equipment in audio and video form.

7.2 Tele-radiology

The ability to obtain scanning modality images from a different location and viewing them remotely for diagnostic or consultative purposes. Major advances in telecommunications and computer systems and advances in the ability to capture medical information in digital form have accelerated the ability to apply telemedicine methods in a practical and affordable manner.

7.3 Tele-forensics

Tele-forensics is a subset of telemedicine and teleradiology wherein various forensic services like autopsy are facilitated via the electronic communication system.

8. Advantages of Digital Autopsy

- Non-invasive process.
- Lowers costs and helps families whose religions prohibit post-mortem dissection [13].
- Conditions like intracranial bleeds, lung pathology and ruptured aneurysms can be better identified.
- High-quality non-invasive imaging of the coronary arteries in less than 10–15 seconds.
- Human pathology and anatomy are investigated for diagnostic, educational and research purposes (Figure-5).
- Provides an environment to navigate, explore and analyze the body from two-dimensional and three-dimensional perspectives.
- Measure different parts of the body including wounds from various forensic aspects of measurement such as length, diameter, angle and area.
- Anthropological assessment of the bones without defleshing the body.
- Implants such as prosthetic implants or artificial heart valves are easily identified.
- Used for disaster victim identification or road traffic

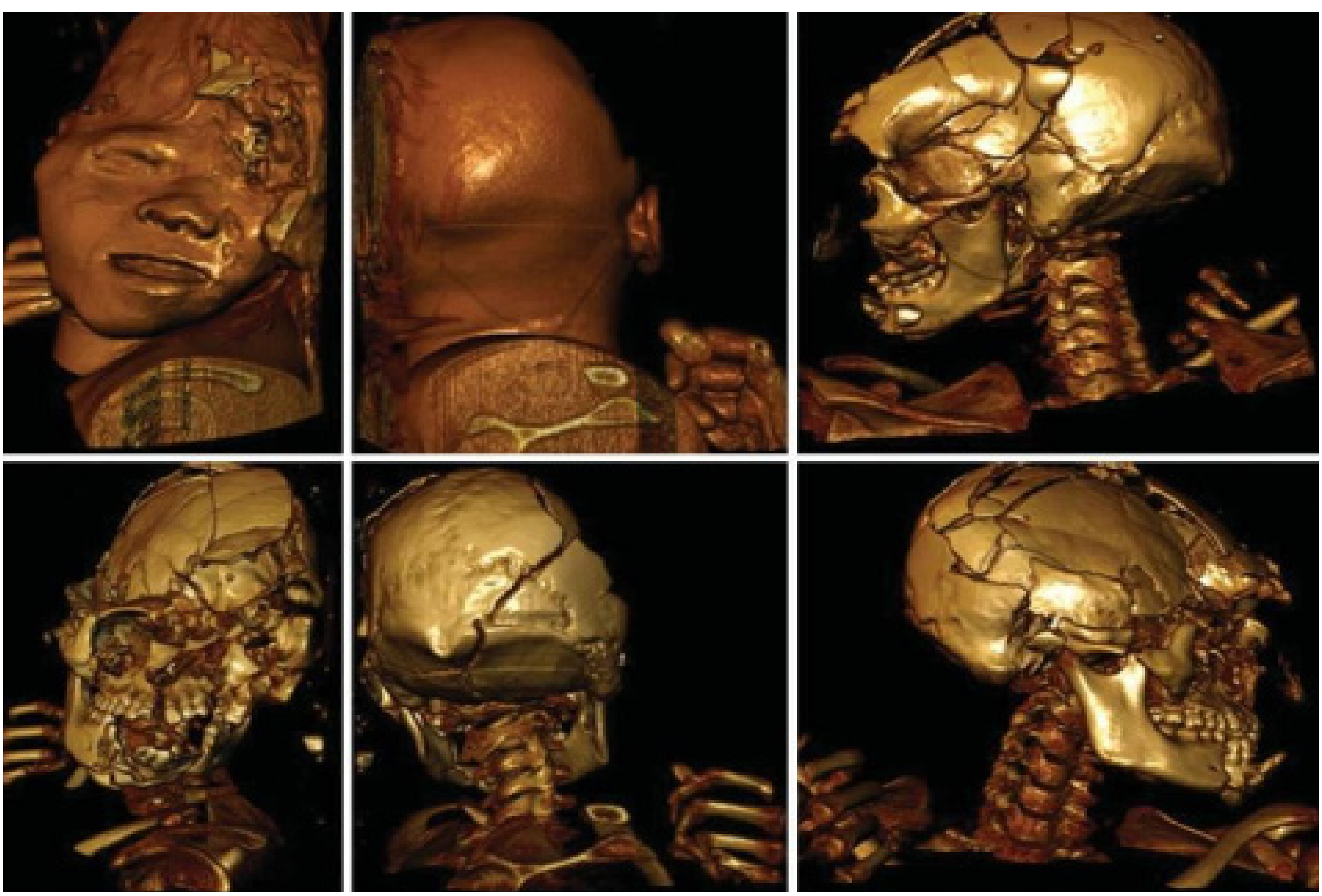

Figure 5- *Skin and bone 3D view of a comminuted depressed skull fracture viewed in anterior, posterior and lateral position which is used for diagnostic, educational and research purposes.*

accident fatalities.

- Assisting investigation in exhumation cases and identification of dismembered bodies [14].

8.1 Disadvantages of digital autopsy

- Digital autopsy techniques do not detect all causes of death.
- Certain relatively minor but critical findings can be missed on imaging autopsy studies.
- A great majority of imaging autopsy experience reported to date comes from trauma and forensic medicine, and it is unclear how CT and MRI techniques will be helpful in postmortem evaluations in the general medical/surgical population.
- Certain imaging artifacts (i.e., intravascular or intrahepatic air) on postmortem CT/MRI studies are still being investigated and their meaning remains to be fully elucidated.

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Conflict of interest

None.

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