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Forensic Radiology and Virtual Autopsy: An Overview

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Introduction

Forensic radiology is a branch of radiology which focus on studying forensic signs in living or postmortem cases for medico-legal reasons to identify the cause of death, identify the harm in living cases, identify the corpus (species, age, gender, and race or confirming a particular person from previous radiological records) using medical imaging techniques. Brogdon's defines forensic radiology as "Forensic Radiology usually comprises the performance, interpretation, and reportage of those radiological examinations and procedures that have to do with the court and/or the law [1]." An X-ray can show a bullet, it's path, and it's effect in the human's body. As well, an X-ray can help in identifying a corpus (i.e., comparative identification) by the shape of the frontal sinuses, bony features, dental features, any metallic internal fixation, and personal jewelry. The second type is general or detective identification which uses imaging to determining species, age, gender, and race of the victim. For example, determination of the age by a simple hand X-ray using Greulich and Pyle (GP) method, the Tanner-Whitehouse (TW2) method, or any modified method. Gender can be identified by using oxford method which differentiate between males and females. Forensic radiology is not limited to presented cases in a court-of-law. An X-ray or a CT scan can help medical professionals to see drug smuggled in the digestive tract of the smuggler [2]. But radiology reaches more than what have been mentioned. Now, using CT scan, it might replace the regular autopsy procedure to become touch-free autopsy.

Forensic Radiology History

Forensic medicine is an older field than radiology and Medical Examiners have been protected from retribution to conduct their duty by doctrine of sovereign immunity since medieval times. Radiology started with making the first X-ray by Roentgen in 1895 and forensic radiology came after that. The 1st case using an X-ray was presented in a court-of-law in England, it was for an actress who was injured during her duty in a local musical hall in 1895 where they used a comparison of radiographs as the first case in the United Kingdom. In 1896, a British court used X-rays

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to compare between a murder case and a living patient case. The pathobiology of human disease: A dynamic encyclopedia of disease mechanism [3], they claim that the 1st case was presented in a court in north America where they used a radiograph was in the 24th of December of 1895! The first X-ray was ever made in the United States was in the 3rd of February of 1896 [4], one year after Roentgen made his announcement and published his paper. The book claimed that the X-ray was in court before Roentgen submits his paper by three days! Which does not make any sense! Whether the X-ray was made outside the United States-simply because they do not have X-ray machines yet- then send it to the United States which is another story then the book made unsubstantial claims. The 1st X-ray in America was made ever was in 1896 by Frank Austin and Dr. Gilman Frost who approved to use it with a school boy who broke his wrist and his name is Eddie McCarthy's and the X-ray was made in Dartmouth college in New Hampshire [3]. It is not possible for the Americans to have the X-ray machine before the Europeans and the British. A paper published by Laura Filograna et al. (2018) about virtopsy said the first X-ray was used in an American court room was in 1896 [5]. The main author of the book is Linda M. McManus with other authors (the main author of the forensic radiology chapter is Elifritz) from university of Texas San Antonio. Then the authors contradicted what they claimed in the same book in the same page. According to Elifritz et al. (2014), forensic radiology is well established in other countries outside the United States [3]. Which contradicted what they said before. If forensic radiology was used in an American court even 3 days before roentgen publish his paper, then you write in the same page that forensic radiology is not popular in America which is seem to be a good example of cognitive dissonance and the book is full of very contradictory statements! Dental radiographs were introduced in 1896 when Keening made the first intraoral X-ray to evaluate restorations. After that, forensic odontology was implied in 1940 in Russia to identify Adolf Hitler. Forensic odontology is important because in many cases, the only surviving recognizable tissue is the teeth in cases of charred remains or decomposed corpuses. As well, radiographic identification of mass fatality and charred remains was useful in 9/11 attacks. In America, the Disaster Mortuary Operational Response Team (DMORT) which is responsible for mass-fatalities. This organization have Disaster Portable Morgue Unit (DPMU) which is full equipped and mainly use radiographs as the initial and primary tool of identification of the victims. Similarly in the United Kingdom, CT is integrated into Britain's national disaster response plan after Rutty and colleagues conducted a proof of the necessity of imaging in such cases. In Australia, imaging for identification of 163 decedents from the 2009 Victorian bush fire where they used CT scan for identification for the 1st time. In 1920, identification of paranasal sinuses on X-ray was done and in 1986, age estimation was done on X-ray images. Frontal sinuses are evident on X-ray at age of 5-6 years and fully developed at the age of 10-12 years of age. Symmetry & variability of development, shape, size and area are important for identifying the remains of a person. Identification can be done thru identifying unique skeletal features previously imaged for medical uses. Some of these features are; patterns of degenerative diseases, healed fractures, surgical implanted devices, orthopedic hardwares, etc.

Prominent Forensic Radiology Centers

There are three so called "prominent" forensic institutions of forensic radiology around the world like; institute of Diagnostic Radiology in Zurich, Switzerland, The Royal Pathology Unit in Southeast England, United Kingdom, and the Victorian Institute of Forensic Medicine in Melbourne, Australia. In Japan, many hospitals use postmortem imaging as a triage for autopsy or even replace autopsy. There are only three offices of medical examiners in the United States where they use postmortem imaging; 1- The Chief Medical Office Examiner in Baltimore, Maryland, 2- The Medical Investigator in Albuquerque, New Mexico, and

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3-The Armed Forces Medical Examiner office in Dover, Delaware.

Important Forensic Radiology Organizations

The International Association of Forensic Radiographers (IAFR) was called the established in 2008, but it was Association of Forensic Radiographers (AFR) in 2005 [6]. The International Society of Forensic Radiology and Imaging (ISFRI) was established in 2012 [7]. The IAFR is established earlier than the ISFRI which indicates the curial role of radiographers compared to other specialties.

Virtual Autopsy

Virtopsy comes from the latine words 'Virtus" and "autos-opsomei". Virtus means efficient, useful, and good. Autos-opsomei means self and I will see. Autopsy come from the combination of the two (i.e., autos-opsomei) which means to see with one's own eyes. Virtual autopsy is omitted the "autos" which results in the term virtopsy. Virtopsy uses CT or MRI scan with photometric 3D based images of the body's surface to study the living or dead body. Then it merges the CT scan or MRI scan images with the surface 3D images. It started in the 1990s with developing the photometric 3D based images and since then it replaces the regular autopsy in many cases. In 2005, Prof. Richard Dirnhofer from Switzerland started the virtopsy project and came to the conclusion that it provides similar results like a regular autopsy. In court, presenting virtopsy pictures is less gruesome than a picture of the real dead body which has undergo an autopsy and it might prevent some of the jury to not to look at it. Virtopsy will show the dead body and what harm have been done to the victim in a 3D picture to help the jury to understand how severe was to the injury. Virto Angio or postmortem CT angiography will be used to assess the harm that have been done to the vascular system. This will be done by inserting a catheter in the femoral vessels. In addition, it is required a cardiopulmonary bypass machine a.k.a heart-lung machine. A biopsy or any specimen can be to taken by using virtobot which will allow a robot to take a biopsy and confirm the biopsy location under the CT scan. So, virtopsy allows taking a biopsy and it allows studying it with Micro-CT (i.e., bones) and with Micro-MRI (i.e., soft tissue) which then can give a histological study. Both Virto Angio and virtobot was invented by Richard Dirnhofer and Peter Vock. At the end all images presented on a digital virtual autopsy table which can manipulate the windowing for the forensic pathologist to see and analyzed. The advantages of using virtopsy are using teleradiology to ask for other experts' opinions. Virtopsy can save, display, and document the findings, while in regular autopsy, it is finished with an opinion without storing the body prevent tampering give ability to reexamine it after burring the body. It is a nondestructive or prevent tampering with the forensic evidence (i.e., the dead body) and it is minimally invasive which is better for religious reasons according to many authors! It gives a better visualization of the areas where it is difficult to do autopsy like the face, neck, and pelvis. As well, it is better with contaminated bodies by toxic substances, infections, radioactive materials, bio-hazards, etc. Virtopsy allows more improvement in the forensic field. The disadvantages are; virtopsy has a high cost of the machines and maintenance. In some cases, not from head to feet (i.e. not full body scan) and the positioning the arms and the legs of the corpus for the CT can be difficult which depend on the skills of the examiner and on the postmortem changes. Another limitation is one only sees what one knows which depends on the optical memory of the examiner. As well, incomplete archiving or damage to the archiving system can lead to loss of the virtopsy. As well, radiology scan can have low resolution which result in poor images. The color of the organs is not seen since it is grey scale images which will not help the pathologist to see the color of the organ to assess if there is any inflammation process in the organ. Pathological changes or surface anatomical feature like color change, pigmentation, and petechiae can't be seen on the scan. The coloration of the organs in CT scans was

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suggested before by Mr. Alahmari [8]. Decomposition of tissue can be mistaken as a pathology. Multiple gun shoots crossing can make false tracks that is difficult to differentiate. Some can be pros and cons in the same time like the lack of graphic and gross pictures of the corpus which can allow the jury to see fewer graphic details and in the same time it might not shows how brutal the death of the victim was?

Prominent Scientists in the Field

B.G. Borgodan received an honorary member award from the ISFRI for contributions in forensic radiology [9]. And already had his book in 1998 named "forensic radiology". Richard Dirnhofer and Peter Vock are the founders of the Virtopsy project [9]. Dirnhofer in 1997 developed forensic photogrammetry and without photogrammetry, no virtopsy; therefore; Dirnhofer and Vock are the founding fathers of virtopsy [10]. The important point is to remember three names "Borgodan" and "Dirnhofer" & "Vock" are the most important names in the forensic radiology and virtopsy respectively.

Cross-Sectional Imaging

Both Post Mortem Computed Tomography (PMCT) and Post Mortem Magnetic Resonance Imaging (PMMRI) can show and reveal most of life−threating injuries similar to traditional autopsy. A study of traffic fatalities showed a 94% similar result between autopsy and PMCT findings. A CT scan can show more details than an X-ray when checking for fractures and even associated soft tissue injuries. A CT scan was proven to provide additional information which may not be detected in a regular autopsy especially with patterns, extent, neonatal chronic trauma, in infants and children in unexpected death cases. As well, there are same hidden parts in the lung that is hard to look into, but with CT scan it can show any hidden areas (i.e., costophrenic angles, cardiophernic angle, mediastinum, the face, the pelvis, etc.) [11,12]. A CT scan preserve the findings more than a regular autopsy. For example, in case of drowning which can softened & liquefied the brain partially. A CT scan detect projectiles, foreign bodies, broken bones, or other findings which need to be documented then conduct an autopsy in a certain direction according to the findings of the CT scan.

Child Abuse Imaging

Now, skeletal X-ray survey is the 1st line of imaging in child abuse cases. The recommendation of the American Association of Pediatrics in 1991, includes the skeletal X-ray survey as imaging protocol for non-accidental traumas. The American College of Radiology defines the skeletal X-ray survey or "babygram" as "a serious of radiographs encompass the entire skeletal system" which takes images of each part of the skeleton separately. For example, the upper limb must have hand X-rays, forearm X-rays, elbow X-rays, arm X-rays, shoulder X-ray, and scapula "Y" view X-ray. The wrist X-rays is not required when full hand X-rays is done from the tip of fingers to distal part of the forearm, so technically the wrist is included! Each part must be imaged two perpendicular images on each other. The entire limb can't be imaged in one or two radiographs for the entire limb. Therefore, a simple "babygram" which is an Anterior Posterior (AP) view of the whole body of the baby is not sufficient to evaluate pediatrics trauma, it provides poor imaging quality, and it may cutout some anatomical details which is important for diagnoses. Another statement published in 2004 by the National Association of Medical Examiners and the Society for Pediatric Radiology stating that pediatric radiologists must provide assistance to forensic pathologists in interpreting of child abuse images [13]. The skeletal X-ray must be interpreted by a consultant radiologist specialized in pediatric imaging and to be board-certified when radiology services are not available for forensic pathologists. The professional fees of the pediatric radiologist must charge less to not obstruct the justice [13]!

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Decomposition and Putrefaction

The most common sign of decomposition on an X-ray or a CT is the air filling anatomical spaces due to putrefaction. This sign can be seen in the portal system, mesentery, and the bowel then be misdiagnosed as ischemia, but it is air in the bowel as a result of the decomposition and putrefaction. Usually in decomposition, there will be a collection of fluid or liquefaction which is formed with putrefaction in corpuses.

Other Applications of Forensic Radiology

Forensic imaging is not limited to ante-mortem and post-mortem cases only, but scanning the passengers and their luggage to detect drug, uncover contraband, explosive, and weapon. According to Elifritz, et al. (2014) wrote that post-mortem imaging is used to image ancient mummies in order to gather information about mummies like age, sex, injury, health, and mummification technique used [3,14]. The book claims that Archi radiology is part of forensic radiology which contradicts the IAFR guidelines. Another application of forensic radiology is examining strangulation cases which can be evaluated by preforming a neck MRI scan which will show a hemorrhage in the soft tissue of the neck.

Virtopsy Religious Argumentation

The book named "The pathology of Human Disease: A Dynamic Encyclopedia of Disease Mechanisms" in page 3455 of the book the author Elifritz et al. (2014) claim that Islam stand against autopsy which is not true. The claim that the act of disfigurement or delay of burial is prohibited which is not true in cases of suspicious death. When there is a murder case and the family needs to know what happened to their relative and loved ones, Islam gives permission to do what is necessary for the family and for the victim. They give claims without supporting it with a "Fatwa", so their far-fetched theories and claims about the religious necessity is not true. They claim that some courts up held "sanctity of the body" of religious beliefs to be protected by the 1st amendment and the court will required from the medical examiner to take the permission from the family of the victim to be sensitive to religious beliefs requirements. The family must approve performing the autopsy on the dead body of their relative.

Status Quo of Forensic Radiology

A recent study showed that a 72% of the National Association of Medical Examiner would use CT scanner in their work if the CT machines already available and it has a low cost. In 2010, American Society of Radiologic Technologist (ASRT) made a task force to find any practice discrepancies in America. Large gaps where found and recommendations of training curriculum were made, but no standards are set for forensic imaging in America. The forensic imaging standards are different in different locations within the United States. The ASRT in 2008, found that 88.3% of medical examiners offices reported having radiography equipment's, but most of them are X-ray machines only. There are a 70% of them do not have CT scanners. Furthermore, using of MRI is more limited than CT because it is not available. The congress report "Status Needs of Forensic Science Service Providers: A Report to Congress" which covers forensic science as a field and how is affected by education, training, equipment's, and qualified personal. The standards vary as in training and practice within different states and even within one state due to lack of policies. As well, the forensic imaging standards varies between the United States and other countries. For example, in the United Kingdom, only a qualified radiographer can conduct imaging on human subjects. In 2008, a guideline was made in the United Kingdom by the IAFR for whom and how to generate forensic imaging. According to the IAFR policies, a radiographer must reach a specific level of competence and the radiographer must be registered with the IAFR or the Society and College of Radiographers (SCoR). Registration will be mandated for

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forensic radiographers. The aim of this registration is to provide the best image quality to make the accurate decision regarding death and to be provided to a court as evidence. In different regions the person who interpret forensic imaging are different. For example, in the United States, the New Mexico Office of Medical Investigator, a board-certified radiologist is in charge of interpret CT, MRI, and other imaging modalities for forensic reasons. In Australia, the Victorian Institute of Forensic Medicine, a forensic pathologist will interpret and report the CT and MRI scans for forensic reasons and backed up by a radiologist. The issue is both radiologists and forensic pathologists do not have training on forensic radiology (i.e., radiology residency programs do not offer training in forensic radiology as a specialty). As well, the forensic pathologists are not trained on image interpretation, basic physics, and artifacts. Therefore, this is a good opportunity for forensic radiographers since they have training programs in forensic radiology. As well, the IAFR was established more earlier than ISFRI. Interpretation programs for radiographers are available to make them reporting radiographers in the United Kingdom [15]. In addition, forensic radiology programs are available at Teesside University in the United Kingdom and University College Dublin in Ireland. The IAFR must push toward a bigger role of radiographers in forensic radiology since no one have expertise in the field better than radiographers. Many issues still standing today about injuries categories and imaging sensitivity and specificity. Whether this imaging technology will add more value more than autopsy in many aspects and which cases that need to use virtopsy instead? Whether CT scan can be comprehensible to the jury or less mischievous than a regular courtroom exhibition? Whether forensic centers can afford to buy CT and MRI machines? Whether the forensic pathologists will get the help-that the need- from radiologists? In academia, the forensic pathologists have access to their radiologist's friends, while in clinical practice is more limited. There are forensic pathologists in the United States who see virtopsy as a threat to their jobs and practice (which is true). If autopsy is taken from them, then nothing left for them. There are around 400 forensic pathologists in the United States and 40 new trained forensic pathologists every year. To transform from coroner to medical examiner system, they need to add 600 more forensic pathologists according to the National Research Council. If CT scans were used, a 330 autopsies will not be required anymore every year and one fewer forensic pathologist is needed according to Elifritz, et al. (2014). Elifritz claims are very fallacious and as seen before easy to be proven wrong. CT scanners are a great help for pathologists to direct their autopsy in one direction, not reducing the forensic pathologists by one! Elifritz claims' sounds like the story she brought in the beginning of her chapter when the author said the first forensic X-ray was in an American court before roentgen even submit his paper by three days! According to Elifritz, et al. (2014) teleradiology can help forensic pathologists to get the help from radiologists. As well, the American Board of Pathology is expecting from forensic pathologists to study and have expertise in forensic imaging to maintain the registration. A fellowship program in forensic radiology can fill the gap between radiologists and forensic pathologists. Even there is a new field now known as the radiologic-pathologic correlation which knowing disease on the scan based on histopathological appearance which is still developing. In Japan, a national autopsy imaging program using CT and MRI in hospitals to allow more post-mortem imaging and expertise. This program is called Autopsy Imaging Information Center which is a teleradiology program applied in Japan.

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