Radiology in Forensic Medicine

From Identification to Post-mortem Imaging

Giuseppe Lo Re
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Editors
Giuseppe Lo Re
Policlinico Paolo Giaccone Radiology Department
Palermo
Italy

Massimo Midiri
Institute of Radiology University Hospital
Palermo
Italy

Antonina Argo
Department of Health Promotion, Maternal and Child Care
Policlinico Giaccone
Palermo
Italy

Cristina Cattaneo
Department of Biomedical Sciences
University of Milan
Milan
Italy

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Foreword

Forensic medicine is a growing scientific field in our time, due to the latest researches in the understanding of the causes of death and the increasing number of mass disasters.

In fact, we all have assisted a large number of victims of mass disasters such as terrorist attacks and environmental disasters, which carry the necessity of a fast and secure way of reporting the causes of body lesions or death.

Forensic radiology plays a pivotal role in this new scenario thanks to its faster and accurate detection possibility of body injuries, sometimes in the same place where the disasters occurred, with different techniques: X-ray, computed tomography. Sometimes, magnetic resonance could also be useful in the forensic field, especially in neurological lesions.

The use of radiological examinations together with conventional autopsy has increased the diagnostic accuracy of causes of death, shortening the execution time of forensic studies.

Consequently, in the last years, the term "virtual autopsy" was coined, which refers to a new diagnostic radiological tool that is helpful especially in the examination of burned corpse, shot bodies, orthopedic fractures, or in case of massive emphysema.

3D images also help in court discussion for forensic cases, and the recorded radiological data can also be used for many years after first evaluation, unlike conventional autopsy.

The Italian Society of Medical and Interventional Radiology (SIMR) looks at this new field of radiological studies with great interest; altogether with forensic medicine, it is sure that forensic radiology will have a large visibility in the near future.

I've read the chapters written by all the authors of this book, and I think that it is an important knowledge tool in forensic science, both for forensic and radiological specialists, primarily as a result of a complete and simple description of different forensic aspects and of the high iconographic quality of images.

Corrado Bibbolino
Ethical and Forensic Section
Italian Society of Medical and
Interventional Radiology (SIMR)
Genoa, Italy

Preface

To date, medical examiners have relied primarily on cadaveric inspection, as well as the conclusions drawn from conventional autopsy and laboratory methods, in order to define a decedent's cause of death and contextualize it in terms of corresponding judicial findings. Only in particular cases—such as those in which the decedent had sustained multiple traumas or had lesions which were caused by a firearm—was imaging used as additional evidentiary support. In fact, the possibility to obtain a direct view of the body has permitted, and continues to permit, medical examiners the power to approach the state of the cadaver and its present lesions in a more holistic way.

There are, however, instances in which the work of medical examiners appears to be especially difficult. For example, when it comes to the identification of traumatic bone lesions (like those which occur in the ribs, spine, splanchnocranium, or at the base of the skull) and the establishment of these specific aspects in correlation to the eventual presence of collected areas (subcutaneous, respiratory, abdominal, cerebral); the study of lungs in drowning victims; or the evaluation of vascular lesions. Under no circumstances do these scenarios present an insurmountable level of difficulty, but here, the use of imaging methods improves the quality of and speed at which diagnoses can be reached by medical examiners.

In this sense, forensic radiology plays an important role that should be well defined with respect to radiology as it is used in living patients. Recently, forensic radiology has made its way from the margins of conventional practices to now becoming a more structured, widely used method. Perhaps this resulted after the introduced concept of virtual autopsy, sometimes a "substitute" for physical autopsy, which allows for a single diagnostic application for the photographic documentation of the corpse, the study of computed tomography (CT) scans either with or without the injection of contrast, the RM of the SSN study, and histological evaluation by automated guided biopsy. Finally, with the frequency of mass disasters that occur worldwide, the topics on the ways in which we can scientifically address these crises are prevalently discussed.

Over the years, the medical-legal community have had the opportunity to witness the growing interest in the comparison of imaging methods as they apply to the forensic sciences, both by forensic doctors and those within the judicial system.

The use of simple and low-cost radiological methods, such as CT/MRI scans of the body, could significantly help medical examiners to obtain more

accurate results when used in conjunction with autopsy findings. This, of course, is possible without being disruptive to the normal radiological or medical routine, and/or without causing a significant increase to labor and material costs.

For members of both the medical and legal professions, there are undeniable advantages to the possibility of obtaining images of cadavers that could continuously be re-visited and re-evaluated. Namely, it relieves some of the burden of this work by speeding up processing time.

It is already common for radiologists and forensic physician, in the spirit of collaboration, to share experiences and diagnostic information with each other. We therefore find that, in fact, we have a shared purpose which allows both medical subspecialties to support, rather than replace, one another.

In this text, the authors addressed these questions and shared their own operational experiences hoping that they can garner the interest of the broader scientific community and medical-legal environment.

Palermo, Italy — Giuseppe Lo Re
Palermo, Italy — Antonina Argo
Palermo, Italy — Massimo Midiri
Milan, Italy — Cristina Cattaneo

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A Brief History of Forensic Radiology

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Roberto Lagalla

Since its discovery in 1845, thanks to the Nobel Prize William Conrad Roentgen, radiology was used not just for medical-diagnostic purposes on the living but also in lawsuits and for the evaluation of cadaveric remains.

Among the first applications of forensic radiology, in 1896, a unique use of radiology is reported for the evaluation of an Egyptian mummy at the Natural History Museum in Vienna. Indeed, the museum had purchased an Alexandrian mummy as a human mummy; however, the bandages covering the mummy referred to an animal. Thus, the mummy, which was not violated to avoid the corruption of the content, underwent an X-ray study that depicted the beautiful radiological image of a big bird mummy.

Many cases of application of radiology purposes with "paleoradiological" purposes have been reported and the introduction of CT, especially of the newer multislice CT scanners, has further widened the applicability and usefulness of radiologic techniques in the study of corpses preserved over the millennia.

Indeed, the possibility of studying the corpses without any alteration of their integrity represents the greater radiological inspection advantage compared to human direct corpse inspection, so that it is reported as nondestructive examination (NDE) technique.

Many diagnostic possibilities in the identification of the mummies have been demonstrated by radiology, as the possibility to define the age, presence of preexisting diseases, and the causes of death of the mummy itself, as well as the mummification process.

Concerning this matter, the English Heritage published in 2006 the guidelines of the X-radiography of archaeological metalwork.

Over the years, forensic radiology applications have also addressed to the evaluation of the artifacts, and it demonstrated to be particularly suited for the definition of their historical period and the methods used for their production.

Important mingling between forensic and radiological applications have been demonstrated not just for paleoradiological purposes.

Since the beginning, in fact, the important role of radiology in the assessment of the causes of responsibility in criminal cases has been understood. Indeed, radiology methods offer the coroner and the magistrate, the possibility to "fossilize the time" in the identification of pathological processes caused by third parties, so that they can be always evaluated by the magistrate and the experts/appraisers who follow one another over the years during a legal process.

Moreover, the forensic radiological findings are not just re-evaluable over the years

R. Lagalla (✉)
Department of Pathobiology and Medical Biotechnologies, University of Palermo, Palermo, Italy
e-mail: roberto.lagalla@unipa.it

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with the same diagnostic accuracy, but also easily disclosed and shareable, conversely to conventional autopsy findings that is intrinsically a unique procedure that cannot be entirely re-performed.

In addition, forensic radiology provides new real points of interpretation of detrimental events, being able to provide an overview of the body without compromising its integrity; this last point finds its practical manifestation when radiology is required for the detection of the causes of death. This is why forensic radiology is actually routinely referred in the scientific literature and forensic clinical practice, with the term "Virtopsy."

The term Virtopsy, neologism composed by the fusion of the words virtual and autopsy, summarizes the ability to perform a minimally invasive preliminary assessment of bodies that must, inevitably, be followed in most of the cases by an assessment through conventional forensic autopsy. According to the writer and to the most recent and prestigious scientific publications, the two procedures cannot and should not be considered as alternatives to each other, but as two distinct moments, the forensic and the radiological one, of a single overall diagnostic procedure which has as its ultimate goal the identification of the deceased, determine causes of death, and distinguish premortem and postmortem structural alterations in cases of dubious criminal responsibility.

Italy has been one of the forerunners nations in autopsy studies. It is important to remember the pioneering autopsy forensic research performed by Andrea Vesalius, who worked in the XVI century at the University of Padua.

However, forensic radiology finds its application not just in the study of the deceased; indeed, immediately after the discovery of X-rays, these have been used to assist particularly difficult legal and forensic investigations in criminal cases.

The first court case involving the conventional radiography was reported in North America where, on Christmas Eve of 1895, Mr. Tolson Cunning was shot in the legs by Mr. George Holder. Given the failed first attempt of the surgeon to find the bullet and being Mr. Cunning symptomatic, despite the healed wound, the surgeon asked the advice of a professor of physics at McGill University, John Cox, to take a wounded limb radiography. After an exposure of 45 min, the radiograph obtained showed the bullet flattened between the tibia and fibula enabling the surgeon to remove the bullet and to Mr. Cunning to bring proof of attempted murder. To date, radiology is still used in cases needing age estimation of people without documents. This aspect is particularly useful in those border nations, as Italy, in which a significant number of migrants leaving the African and Eastern countries hoping to reach Europe and improve their quality of life arrives every year. It would be really impossible in some cases for forensic scientists to determine with reasonable certainty the age of subjects, sometimes even accused of particularly heinous crimes such as smuggling of migrants.

However, as in a singular and sad carousel, the different aspects of forensic radiology outlined so far are gathered each other. It is well known all over the world, the high number of deaths in the Mediterranean routes of this human migration. Radiology section of the Department of Palermo has recently been involved in an important and fundamental assessment procedure involving both autopsy and virtopsy in a large number of dead bodies recovered from a navy shipwrecked off the coast of Libya, and that I want to remember as "Melilli's forensic radiology hope operation." Melilli is the name of the Sicilian military base where the forensic operations were performed.

To date, there are many applications in which radiology and forensic medicine have melted their interests and applications, but further developments are predictable. Thus, we can imagine a future in which the two medical specialties, although maintaining their intrinsic specific characteristics, are considered essential to each other in the evaluation necropsy cases and in some medical-legal lawsuits.

2 Strength and Limits of Conventional Forensic Medicine

Burkhard Madea

2.1 Introduction

Since about 20 years Forensic postmortem imaging was developed systematically at first in Bern, then whole Switzerland and now worldwide [1–5]. Richard Dirnhofer, the father of "Virtopsy",[1] summarizes the scientific development of postmortem imaging techniques as follows [1]:

> *It was against the background of rapid technological advances in various imaging techniques, that at the turn of the century, the academic concept of the "Virtopsy" research programme was realized at the University of Bern in Switzerland. The aim of this project has been to develop a minimally invasive autopsy procedure in which evidentially relevant findings are obtained from a corpse predominantly by means of medical imaging methods. Depending on the individual case and the specific issue involved, this leaves, the option open to perform a conventional autopsy to acquire further relevant facts, such as histological, toxicological and bacteriological examinations.*
>
> *The international impact of this idea has been reflected in an exponential increase in scientific publications around the world dealing with forensic radiology. For instance, the recently published study by M. Baglivo et al. showed a tenfold increase in the volume of publications compared to the turn of the millennium, when the "Virtopsy" project started.This academic "hype" in the field of postmortem radiology has had a very positive influence on the attractiveness of radiology for the new generation of academics in forensic medicine.*
>
> *In short, the results of these numerous publications documents that postmortem imaging is not only equal to autopsy in many respects but that this method can even achieve better results than conventional autopsy procedures. This has also called into question the status of conventional autopsy as the "gold standard" for obtaining and recording forensic medical findings.*

He questions already if the traditional autopsy is still the "gold standard" for obtaining and recording forensic medical findings.

The purpose of this chapter is not to argue for or against traditional autopsy or postmortem forensic imaging but to briefly address evolution, importance and decline of the traditional autopsy.

The importance of the different imaging techniques in solving different forensic questions has been outlined especially by Dirnhofer [1–3] and Grabherr [4, 5].

There is no doubt about the importance of forensic imaging.

2.2 Technique, History and Tasks of the Autopsy

The modern autopsy has been defined as follows [6]:

> An autopsy is the systematic external and internal examination of a body to establish the presence or

[1]The term "Virtopsy" is a neologism comprising the words "virtual" and "autopsy". It is used for imaging in Forensic Medicine, especially postmortem imaging (CT, MRT, surface scanning, Angiography).

B. Madea (✉)
Institute of Forensic Medicine, University Hospital Bonn, Bonn, Germany
e-mail: b.madea@uni-bonn.de

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absence of disease by gross and microscopic examination of body tissues. The pathologist makes a surgical incision from shoulder to shoulder and from the midpoint of the shoulder-to-shoulder incision to the pubic bone. The skin is reflected, and each organ in the chest, including the neck structures, abdomen and pelvis, is removed and carefully examined. An incision is also made from the mastoid bone on the right to the mastoid bone on the left, and the scalp is pulled forward and the bony cap removed to reveal the brain. The brain is removed and examined. The pathologist takes a small sample or biopsy of all tissues and archives them in formalin to maintain them for future references.

For hospital autopsies, depending on the list or permissions given by the person qualified to give permission, tissues and organs may be retained for study, research, or other investigations. The pathologist submits small 2 × 2 cm sections of tissue to the histology laboratory, where thin slices a few microns thick are subjected to chemical treatment to preserve them. The tissue blocks are shaved, so that a thin layer can be mounted on a glass slide and stained with dyes to differentiate cells. The pathologist can recognize diseases in the stained tissue. Medicolegal autopsies are conducted to determine the cause of death; assist with the determination of the manner of death as natural, suicide, homicide, or accident; collect medical evidence that may be useful for public health or the courts; and develop information that may be useful for reconstructing how the person received a fatal injury. [6]

Autopsies have been performed to:

- Establish the cause of death.
- Assist in determining the manner of death (i.e. homicide, suicide).
- Compare the premortem and postmortem findings.
- Produce accurate vital statistics.
- Monitor the public health.
- Assess the quality of medical practice.
- Instruct medical students and physicians.
- Identify new and changing diseases.
- Evaluate the effectiveness of therapies such as drugs, surgical techniques and prosthesis.
- Reassure family members.
- Protect against false liability claims and settle valid claims quickly and fairly [7].

Bowman and Anderson et al. also summarized the uses of autopsy [8].

Bowman (1983)	Anderson et al. (1979)
Assisting in development and quality assurance of new technologies, procedures and therapies	Instrument of quality assessment of medical care by peer review
Quality assurance for clinical diagnosis and treatment	Continuing education of physicians
Improving accuracy and value of vital statistics	Provision of reliable database on causes of death and disease
Source of organs and tissues for transplantation	Recognition of harbingers of disease
Evaluation and distribution of insurance benefits	Grief counselling for family
Monitoring and identifying environmental disease	Identification of communicable diseases
Medical education	Forensic pathology
Forensic pathology	Monitoring and identifying environmental disease
Disclosing the nature of an individual death	Materials and problems for basic research
Risk management	Medical education
Reassurance to family	
Explaining unknown or unanticipated complications of disease	
Identifying communicable diseases	

Table 2.1 Types of autopsy (according to [9])

• Anatomic autopsy
– Structure and function of human body
– Andreas Vesalius (1514–1564)
– Great progress in the sixteenth to eighteenth centuries
• Clinical autopsy
– Cause, locus, aetiology, pathogenesis of disease
– Giovanni Battista Morgagni (1682–1771)
– Marie François Xavier Bichat (1771–1802)
– Carl von Rokitansky (1804–1878)
– Rudolf Virchow (1821–1902)
• Forensic autopsy
– Cause and manner of death
– Causality of external violence for death
– Live birth or stillbirth determination
– Medical malpractice
– Johannes Bohn (1640–1718)
– Johann Ludwig Casper (1796–1864)
– Eduard von Hofmann (1837–1897)

There are three types of autopsy: the anatomic autopsy, the clinical autopsy and the forensic autopsy (Table 2.1). The anatomic autopsy studies the structure and function of the human body. The clinical

autopsy studies the cause, locus, aetiology and pathogenesis of disease, and was the main method for medical research in the nineteenth and early twentieth centuries. The forensic autopsy is essential in determining the cause and manner of death and the causality of external violence for death.

The anatomic autopsy was largely developed at Italian universities, especially at the University of Padua [9–20]. Andreas Vesalius (1514–1564) published his famous series of books on human anatomy, *De Humani Corporis Fabrica Libri Septem.*

Clinical autopsy also developed at the University of Padua [14, 16, 18–20]. Giovanni Battista Morgagni (1682–1771) performed autopsies to study the cause and locus of disease and wrote his famous book *De Sedibus et Causis Morborum* based on his studies. Morgagni looked for diseases of the organs as the cause of death.

Marie Xavier Bichat (1771–1802) studied tissues ("membranes") as the cause of disease and death [21].

The history of the development of pathology at the Paris Hospital was well described by Erwin Ackerknecht in 1967 and later by Michel Foucault in his book, *The Birth of the Clinic* (1994) [10, 11, 22, 23].

Further major developments in clinical pathology were achieved in Vienna by the pathologist Carl von Rokitansky (1804–1878), who personally conducted more than 30,000 autopsies at a small morgue in the neighbourhood of the Vienna General Hospital [11, 24–29]. Rokitansky wrote famous handbooks on both general pathology and special pathology. Furthermore, he wrote a book on atrial septal defects and built a new Institute of Pathology, which still exists today.

Further developments in clinical pathology were made in Berlin by Rudolf Virchow, who studied the cell as the cause of death and disease [9, 11, 28, 30, 31].

Rudolf Virchow (1821–1902) was the founder of cellular pathology. He also founded the Museum of Pathology, which still stands in the Charité area of Berlin, and which displays specimens from Virchow's collection [31]. Virchow was not only responsible for the ongoing development of clinical pathology, but also for developing the methods of forensic autopsy. He published a book on autopsy techniques, *Die Sections-Technik im Leichenhause des Charité Krankenhauses*, which was very important for the standardization of autopsy rules in practice. Similar books were published in other German countries and in Austria. Meanwhile, the Council of Europe published recommendations for the international harmonization of autopsy rules.

Handbooks on autopsy techniques are available worldwide [24, 32–40].

Clinical autopsy was the main method of medical research in the nineteenth and early twentieth centuries [8, 28]. Many diseases have been discovered or critically clarified through autopsy. A partial list of these diseases is shown in Table 2.2.

Even in the twentieth century new diseases were discovered by the systematic analysis of autopsy results (f.i. AIDS).

The forensic autopsy was developed in the nineteenth century [9, 14, 30, 41]. However, as early as the seventeenth century professors of forensic medicine working at the University of Leipzig were requesting autopsy rather than wound inspection to determine the cause and manner of death. In Germany, Johann Ludwig Casper (1796–1874) played an essential role in the development of forensic medicine and forensic autopsy. Casper wrote his well-known handbook of forensic medicine based on his personal experiences at autopsies. The morgue at the Institute of Forensic Medicine in Berlin was modelled after the morgue at the Institute of Forensic Medicine in Paris. In Austria, Eduard von Hofmann (1837–1897), who wrote a famous handbook on forensic medicine as well as an atlas of forensic medicine, was instrumental in the further development of forensic medicine and forensic autopsy.

As in clinical pathology, forensic pathology revealed new autopsy findings and allowed critical evaluation through further systematic observations and experiments, including

- Hydrostatic lung test.
- Contrecoup lesions of the orbit in cases of falling on the back of the head.
- Simon's bleedings (haemorrhages of the intervertebral disk of the lumbar spine) in cases of hanging.
- Inner knee sign in death due to hypothermia.