Informatics and Autopsy Pathology

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KEYWORDS

• Autopsy • Pathology • Forensic • Informatics • Synoptic • Virtopsy • Images

ABSTRACT

Many health care providers believe that the autopsy is no longer relevant in high-technology medicine era. This has fueled a decline in the hospital autopsy rate. Although it seems that advanced diagnostic tests answer all clinical questions, studies repeatedly demonstrate that an autopsy uncovers as many undiagnosed conditions today as in the past. The forensic autopsy rate has also declined, although not as precipitously. Pathologists are still performing a nineteenth century autopsy procedure that remains essentially unchanged. Informatics offers several potential answers that will evolve the low-tech autopsy into the high-tech autopsy.

OVERVIEW—WHAT IS AN AUTOPSY?

An autopsy is a systematic examination of a deceased human body to document the cause of death and document the extent of disease or injury. The word autopsy originally comes from the Greek roots *autos* (self) and *optos* (sight). In combination they have been expressed as "to see for oneself" or "eyewitness." The history of the autopsy stretches back for 5000 years, but the autopsy as currently conceived has its origins during the Renaissance, with physicians such as Andreas Vesalius and Giovanni Morgagni. In the nineteenth century, Carl von Rokitansky performed thousands of autopsies using a method of in situ examination of the organs, although many investigators have erroneously ascribed the en bloc removal method of Maurice Letulle to Rokitansky. Rudolf Virchow is credited with incorporating the widespread use of the microscope with autopsies in addition to the organ-by-organ evisceration technique.[1]

The autopsy procedure begins with an examination of the exterior of the body, which includes a description of the body, basic measurements such as height and weight, and documentation of significant external findings. The body is then opened with a Y-shaped incision of the anterior torso and a bitemporal incision of the scalp. The internal organs are removed, weighed, measured, and examined. Sample tissues from the organs are typically submitted for microscopic examination. In many instances, more typically in forensic examinations, blood and other body fluids are examined for the presence of drugs or poisons. Occasionally microbiology cultures are obtained or other ancillary testing is performed. The autopsy procedure practiced today has changed little from the procedure performed in the second half of the nineteenth century by Rokitansky and Virchow.

The medical autopsy performed in hospitals is to be distinguished from forensic autopsies performed in medical examiner and coroner offices. Autopsies in a hospital setting are typically requested by a clinician or family member and require the informed consent of legal next of kin. Clinicians frequently have general and specific questions to be answered by the pathologist performing the autopsy. Families, besides wanting to know why their loved one died, are increasingly interested in identifying any inheritable risk that might have an impact on the health of surviving family members.[2] A medical autopsy may identify disease that had not been diagnosed or even suspected by the clinical team.[3–5] It is also an excellent tool for the investigation of the utility and potential complications of new diagnostic tests, treatments, or procedures.

In contrast, forensic autopsies are ordered by a medical examiner or coroner in deaths involving injury, chemical intoxication, or unexpected natural deaths and do not require the permission of the next of kin. The goals of forensic autopsies are focused on detailed documentation of injuries

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in trauma cases, quantization and interpretation of substances found within the body in poisonings or intoxications, and determination of the medical cause(s) of death for sudden unexpected natural deaths. A forensic pathologist anticipates the questions that the criminal justice or public health systems might have regarding these deaths and attempts to answer these questions through their examination. These examinations are typically more focused compared with hospital autopsies, although they may involve more extensive dissection in certain instances.

DECREASE IN THE AUTOPSY RATE

In the early years of the twentieth century, the autopsy rate in American hospitals hovered at approximately 10% of all hospital deaths. After the issuing of the Flexner Report in 1910, there was a steep rise in the autopsy rate into the middle of the century, with approximately half of all hospital deaths receiving an autopsy in 1950. Then began a gradual decline in the autopsy rate to approximately 45% in the middle 1960s and approximately 30% in 1970. In 1971, the Joint Commission on Accreditation of Hospitals eliminated the minimum autopsy requirement for hospital accreditation. The autopsy rate continued its decline and a century after the Flexner Report has come full circle, once again at less than 10%. Academic teaching hospitals have variable rates generally higher than 10%, but many community hospitals perform no autopsies at all (**Fig. 1**).[6–8]

Not only have the autopsy rates changed over time but also the distribution of the types of deaths and ages of those autopsied have changed over time. Although the autopsy rate for deaths from disease decreased from 16.9% to 4.3% between the years 1972 and 2007, the autopsy rate for deaths due to external causes increased from 43.6% to 55.4%. Of the 10 most common causes of death autopsied in 2007, only 1 (pregnancy, childbirth, and puerperium) was related to disease. Over the same years, the age distribution of those autopsies has also changed, with fewer autopsies performed with increasing age (**Figs. 2** and **3**).[9]

This decrease in the autopsy rate led George Lundberg, in an editorial in 1998, to state, "The autopsy is not dead, but it slumbers deeply, apparently the victim of a vast cultural delusion of denial."[10]

REASONS FOR AUTOPSY RATE DECLINE

Dr Lundberg goes on in his editorial to opine, "In fact, there is still a giant gap between what high-tech diagnostic medicine can do in theory in ideal circumstances and what high-tech diagnostic medicine does do in practice in real life circumstances."[10] Approximately 20 years after this editorial many people still wonder whether the autopsy remains relevant in the twenty-first century.

There are many postulated reasons for the decline in the autopsy rate (**Box 1**).

Joint Commission Eliminates Minimum Autopsy Rate

Many persons point to the 1971 decision of the Joint Commission on Accreditation of Hospitals to eliminate a minimum autopsy requirement for hospital accreditation. Although that decision may be a contributing factor, the reality is that the hospital autopsy rate was already declining prior to 1971, raising the question as to whether the Joint Commission decision was their reaction to a perceived change in the value of the autopsy within the health care community.

Clinicians' Better Diagnostic Skills

Another explanation for the decrease in the autopsy rate is greater diagnostic confidence by

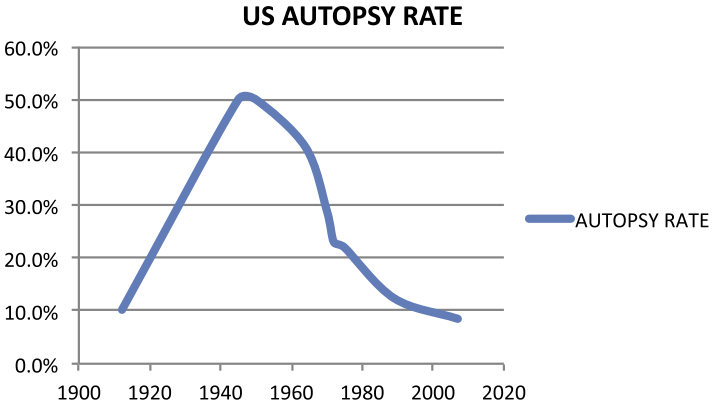


Fig. 1. Changes in the US autopsy rate: 1910–2010. (*Data from* Refs.[6–8])

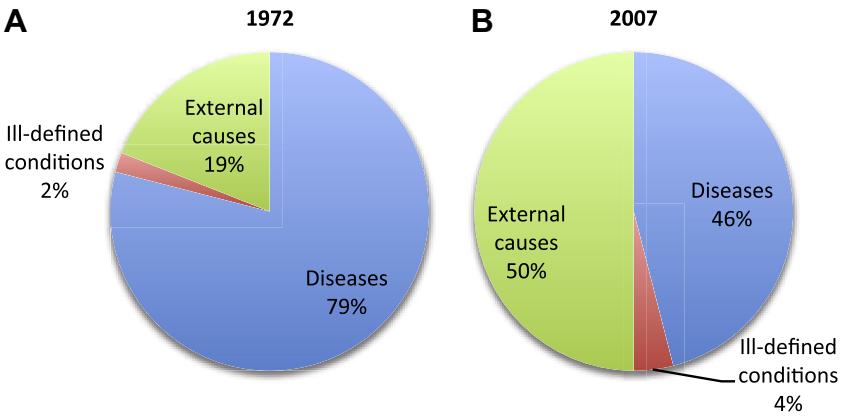


Fig. 2. Percent distribution of cause of death for autopsied deaths: United States, 1972 (*A*) and 2007 (*B*). (*From* Hoyert DL. The changing profile of autopsied deaths in the United States, 1972–2007. NCHS data brief, no. 6. Hyattsville (MD): National Center for Health Statistics; 2011; with permission.)

clinicians, primarily due to the increase in the quantity and quality of medical diagnostic tools. There have been many studies over the decades studying the rate at which autopsies reveal previously unknown diagnoses, which helps address the question of whether "high-tech diagnostic medicine" has actually improved diagnostic capability. The overwhelming evidence is that although there may have been some improvements, autopsies still regularly discover significant diagnoses and conditions not recognized prior to death.

A retrospective study of 100 randomly selected autopsies from 1960, 1970, and 1980 revealed 1 of 10 deaths in each of the 3 decades contained 1 or more class I major missed diagnoses, in which "detection before death would in all probability have led to a change in management that might have resulted in cure or prolonged survival" (**Fig. 4**).[3] A more extensive review and analysis of 53 autopsy series over a 40-year period looked at both major missed diagnoses (missed diagnoses involving the primary cause of death) and class I discrepancies. They concluded that although there were statistically significant decreases in both rates from decade to decade, in 2003 a US hospital with an autopsy rate of 5% could observe a major missed diagnosis rate of 24.4% and a class I discrepancy rate of 6.7%. This represents 71,400 deaths per year, with up to half of these patients surviving to discharge had these diagnoses been known prior to death.[4] A more recent study of patients dying in an ICU of a tertiary cancer center with an autopsy rate of 13% discovered a major missed diagnosis rate of 26%, with more than half representing class I discrepancies. Opportunistic infections and cardiac complications were the most commonly missed class I discrepancies. The authors concluded, "The autopsy remains an invaluable tool for retrospective diagnostic understanding of difficult cases, medical education and quality assurance."[5]

Discrepancies between clinical diagnosis and autopsy findings are not limited to natural deaths. A study analyzed trauma-related deaths in Utah for

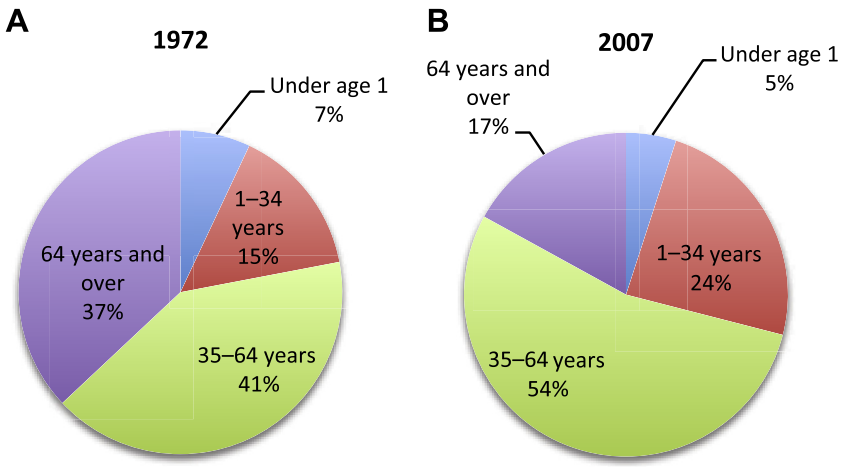


Fig. 3. Percent distribution of age for autopsied deaths: United States, 1972 (*A*) and 2007 (*B*). (*From* Hoyert DL. The changing profile of autopsied deaths in the United States, 1972–2007. NCHS data brief, no. 6. Hyattsville (MD): National Center for Health Statistics; 2011; with permission.)

Box 1
Reasons for decline in autopsy rate

The Joint Commission eliminated minimum autopsy rate for accreditation.

Clinicians have greater confidence in diagnostic skills and tools.

Autopsies only lead to malpractice lawsuits.

Pathologists are not interested in performing autopsies.

Families do want autopsies on their loved ones.

a 1-year period. They determined that among persons dying in hospitals the cause of death opinion based on clinical findings was changed after autopsy in 13% of these hospital deaths.[11] Although this study does not directly measure major or class I discrepancies, the changes in the cause of death indicate significant missing information from the clinical evaluation of these trauma victims and confirms the value of the autopsy in the forensic setting.

Autopsy Only Leads to Malpractice Lawsuits

Another misconception by clinicians is that obtaining autopsies only reveals information that can be used to initiate and support malpractice lawsuits. The College of American Pathologists studied state court records of malpractice actions over 30 years. They discovered that in 61% of cases where the autopsy favored the plaintiff (revealed major discrepancies that would have affected treatment) and 100% of cases where the autopsy favored the defendant, the defendant physicians were acquitted of malpractice.[12] The autopsy only becomes a point of contention in malpractice actions when there are issues over the quality of the autopsy, delays in generating autopsy reports, or inconsistencies between the autopsy report and death certificate.[13]

It seems that poor communication between health care providers and families regarding the cause of a loved one's death is one major driver of malpractice actions.[14] If true, then a thorough well-written autopsy designed to provide answers to clinicians and families in a timely manner will go a long way to preventing unnecessary malpractice litigation.

Pathologists and the Autopsy

Pathologists also seem to have lost interest in performing autopsies. The reasons for this change are multifactorial. Pathologists are busier than ever both in the areas of surgical pathology and clinical pathology. The lower numbers of autopsies mean that fewer pathologists have sufficient autopsy expertise to be able to perform an autopsy efficiently. Busy pathologists simply do not have sufficient time in their schedule to perform autopsies. Autopsies do not generate revenue and represent a cost center to pathology departments and hospitals.[15] There is also the perception that clinicians do not appreciate autopsies and may be antagonistic if an autopsy reveals missed diagnoses or technical errors in procedures. As a result, the few autopsies that are obtained are treated with low priority within pathology departments, contributing to a negative feedback cycle between clinicians and pathologists. This attitude is not shared by resident physicians in pathology, who believe that autopsies are important for education, answer clinical questions, have value for medical research, and are important for quality control in medicine.[16]

Family Misconceptions Regarding the Autopsy

Families, although commonly believed to be opposed to autopsies, in reality tend to be inclined to agree to the examination despite several

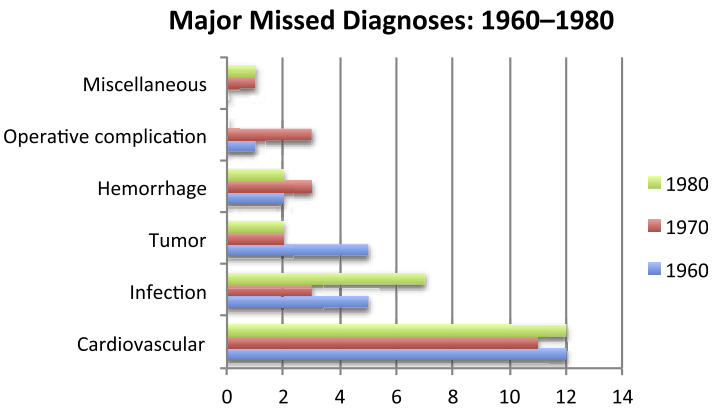


Fig. 4. Major missed class I and II diagnoses by type: 1960–1980. (*Data from* Goldman L, Sayson R, Robbins S, et al. The value of the autopsy in three medical eras. N Engl J Med 1983;308:1002.)

misconceptions regarding the autopsy among the general public. These misbeliefs include that autopsies do not add anything of value, the deceased has suffered enough, the patient is too young or old for autopsy, autopsy mutilates the body and prevents open-casket viewing, and autopsy creates delays until burial or cremation.[17,18] A large part of this misunderstanding involves poor communication between health care providers and families regarding the autopsy and poor consent processes.[19]

The issue of religious objections also frequently arises as a barrier to autopsy. It is commonly believed that there are well-established broad prohibitions to autopsy in several of the major religions, notably Islam and Judaism. The reality is more complicated depending on the different subdivisions of each religion.[20] Although the religious prohibition to autopsy among Orthodox Jews is perhaps one of the more commonly known and accepted, even within this group there is disagreement as to whether the prohibition to autopsy is superseded by the greater commandment of saving of a life, when the autopsy may result in the saving of other lives.[21] In the end, it is typically the personal religious beliefs of the next of kin, rather than the specific religion to which they belong and the religion's opinions on the autopsy, that is most important.

INFORMATICS APPLICATIONS TO AUTOPSY PATHOLOGY

Therefore, the question is whether to allow the hospital autopsy to die a "natural" death despite the obvious evidence that postmortem examinations remain relevant, desirable, and valuable. The alternative to continued dwindling of the hospital autopsy is to study how to "resurrect" the autopsy, taking advantage of newer medical technologies and clinical informatics to catapult the autopsy from the nineteenth to the twenty-first century and restore its prominent place in health care and quality improvement.

VALUE OF THE AUTOPSY TO ITS CUSTOMERS

To improve the autopsy, the potential value of the autopsy from the point of view of the consumers of the autopsy must first be better understood. In cases of hospital autopsies, there are families and clinicians. In the forensic world, the criminal justice and public health systems also need to be considered. What these very different groups expect from the autopsy, what they are currently receiving, and which of their needs are currently not being met need to be asked. Once this gap is identified, which informatics techniques and tools might eliminate this gap can be examined.

Clinicians' Needs from the Autopsy

Despite evidence that clinicians still value the autopsy, their inclination to order one is at its lowest level in a century (**Box 2**, **Table 1**). A 1996 study exploring the factors that influence clinicians' decisions to request an autopsy revealed that the benefits of requesting an autopsy include confirming clinical diagnoses, increasing a clinician's medical knowledge, aiding medical research, and the autopsy's educational value, whereas the drawbacks are the request is time consuming, concern that relatives may be distressed by the request, and discomfort of the requestor.[22] A survey of internal medicine residents confirms the factors that discourage physicians from ordering autopsies, with their top 3 reasons for not obtaining autopsy consent being the family is distraught/extremely agitated, the clinician perceives that the family is unwilling, and requesting an autopsy is unpleasant.[16] These residents also agree that autopsies are important to medical education, answer clinical questions, and are valuable for medical research, quality control, and public health. They believe that having a brochure explaining autopsies that can be provided to families would be most helpful in obtaining more autopsies.[16] Better training of health personnel in requesting autopsies as well as education of the general public on the importance of autopsies is also believed to be important in increasing the autopsy rate.[23]

Looking at the attitudes of physicians to current autopsy reports gives insight into their needs. A survey of general practitioners revealed that a majority find autopsy reports useful to both themselves and families, yet only a minority plan to discuss reports with families. Overwhelming majorities agree that the clinical circumstances were clearly summarized; the reports were clearly written and interesting to them. A majority stated that an autopsy report was the first indication they received of how their patient died and more

Box 2
Why clinicians value the autopsy

- Confirm clinical diagnoses
- Increase own medical knowledge
- Educational value for residents and students
- Quality control/assurance in medical practice
- Important for medical research

Table 1
Influencing physician behavior

Encourage Ordering Autopsies	Discourage Ordering Autopsies
Training in requesting autopsies	Requests are time consuming
Brochure about autopsies for families	Requests are unpleasant to perform
Better communication with pathologist throughout autopsy process	Families may be distraught or angry regarding request

than 20% agreed that the cause of death was a complete surprise, representing a missed opportunity by pathologists to improve communications with clinicians.[24] Better communication between clinicians and pathologists and quicker turnaround times for autopsy reports will help increase the autopsy rate.[23]

Communications between clinicians and pathologists need to be bidirectional. Pathologists require the input of clinicians to provide the clinical history, and a conversation often reveals details and nuances that are not easily obtained from medical records. It is valuable for pathologists to know what questions a clinical team has for the pathologist to answer, and it is incumbent on pathologists to provide those answers clearly. One study looking at 125 autopsies found that specific reasons for autopsies are provided by clinicians only 55% of the time. Of the 103 clinical questions asked, only 88% of the questions were answered in the autopsy report and more than 10% of those answers were not in the final anatomic diagnosis summary, but in another part of the report, with the implication that the clinician would have to search for these answers.[25]

Families' Needs from the Autopsy

It is no surprise that families are also interested in wanting answers to questions regarding how their loved ones died. Families are interested in better understanding the cause of death of their loved ones, have a desire to learn about any infectious or inheritable conditions that could have an impact on the health of surviving family members, and are open to the concept that autopsy findings can help the health of society at large.[2,26,27] The general public has a generally positive attitude toward autopsy, and family members are likely to consent to autopsy when its value is presented to them sufficiently, their questions are answered, and their concerns are allayed.[18,28] As with clinicians, it is apparent that an autopsy report that can be read by or discussed with families, provided in a timely manner with respect for their needs at a time of great loss, can go a long way to increasing the autopsy rate.

The Public's Needs from the Autopsy

Public health surveillance is collecting, analyzing, interpreting, and disseminating data for specific public health needs. Although the basic purposes and goals of public health surveillance have not significantly changed, they are being transformed in the twenty-first century by the evolution of electronic methods of storing health information, the rapid increase in the quantity of data to analyze, and new challenges.[29] Syndromic surveillance can have a significant impact on protection of the public health as has been documented with infectious diseases and heat-related illness/mortality.[30,31]

The National Violent Death Reporting System (NVDRS), although currently limited to 32 states, is an excellent example of how the collection of data from forensic autopsies can be successfully used for public health.[32] The National Missing and Unidentified Persons System (NamUs) is another successful application of using informatics to match unidentified bodies with missing persons.[33] Both of these systems, unfortunately, do not pull information directly from autopsy reports or medical examiner databases but require the forensic offices to enter this information directly into the respective NVDRS or NamUs databases. Creating systems surrounding autopsies, both hospital and forensic, that permit direct mining of information would greatly enhance the utility of the treasure trove of information collected through the autopsy.[34]

INFORMATICS SOLUTIONS TO ADDRESS NEEDS

Workflow Analysis

Autopsies are complex procedures with many different steps and stages, each of which represents a potential source of delay. Although most people think of the autopsy as a procedure that starts with the first incision on the body and ends when the body is sewn closed, the entire autopsy procedure includes many facets both before and after the examination of the body. Just as in other areas of pathology and laboratory medicine, there are preanalytical, analytical, and postanalytical phases.

The preanalytical phase includes confirming the autopsy permit, reviewing the medical history,

discussing the case with a clinician, and identification of the body. The analytical phase, in addition to the autopsy procedure itself, includes obtaining images, tissue for histology, and specimens for other associated testing. After the examination of the body is the generation of the provisional anatomic diagnoses (PAD), preparation and review of microscopic slides, performance and review of other laboratory tests, and additional dissection of organs that have been fixed and saved, such as the brain, culminating in the completion and dissemination of the final autopsy report. In the forensic world, chain of custody also needs to be maintained.

Accreditation standards exist for the production of the PAD and final autopsy report. The College of American Pathologists accreditation standards require the PAD be submitted to the attending physician and medical record within 2 days and the final autopsy completed for all cases within 60 working days.[35] The Joint Commission standards require the PAD be recorded in the medical record within 3 days and the autopsy report included in the medical record within 60 days.[36]

In the world of forensic pathology, the requirements for autopsy report production are even less stringent. The National Association of Medical Examiners (NAME) Inspection and Accreditation Checklist from 2009 required that 90% of nonhomicide autopsy reports be produced within 60 days and 90% of homicide autopsy reports be produced in 90 days.[37] Those standards were loosened in the 2014 revision of the NAME accreditation checklist so that the 90% in 90-day requirement applies to all autopsy report and not just homicide cases.[38] The NAME Autopsy Performance Standards makes no mention of any report turnaround time.[39] The International Association of Coroners and Medical Examiners accreditation checklist has the same standard, 90% of reports completed in 90 days, as NAME.[40]

It can be easily argued that these accreditation standards in both the hospital and forensic autopsy environments are not sufficient for reporting of the results of an autopsy.

Hospital autopsy results can and should be made available to clinicians in a more timely fashion. Families likely contact clinicians looking for answers from the autopsy within a short period of time, and it is important that pathologists support their colleagues by providing them with this information quickly.[41] Timely feedback to clinicians when a case is fresh in their minds is also important in order for these cases to be used effectively for quality improvement and patient safety. Supporting clinicians' conversations with families by providing them autopsy results when they require them instead of when pathologists can get around to producing them will encourage clinicians to request more autopsies.

Forensic autopsy reports are used by law enforcement and district attorneys in making decisions regarding criminal charges as part of their investigations. These forensic reports are also increasingly important for monitoring risks to public health and safety by myriad government agencies at local, state, federal, and international levels. Families are also looking for answers and closure. Timely completion of forensic autopsy reports should also be encouraged, not discouraged. Complaints by families or government agencies regarding unacceptable delays in the production of autopsy reports can lead to negative media reports and political difficulties for forensic offices.[42–46]

The production of timely autopsy reports is not as difficult as it may seem. Lean production is a well-studied system to eliminate waste in production. Lean's basic assumption is that anything that does not add value to the customer is waste and should be eliminated from the production process. Although commonly associated with the Toyota Production System, lean is believed by many people to have had its first practical applications by Henry Ford as far back as 1927.[47,48]

The principles of lean production have been applied to the production of an autopsy report. A system that defined and evaluated 12 essential steps in the autopsy process and increased their priority reduced the autopsy completion time from a mean of 57 days to a mean of 4.8 days.[49] Another study that formally applied lean principles identified a total of 77 steps and multiple queues that introduced delays in their autopsy process. This pathology department was able to reduce the number of steps by 8% and minimize queues. The department's autopsy turnaround time was reduced from a mean of 53 days to 25 days. They increased the percentage of final reports completed within the 60-working-day CAP guideline from 71% to 100% and the percentage of PADs completed within 2 days from 26% to 87%. Most significantly, 85% of surveyed clinicians stated they were receiving reports sooner and 71% believed the autopsy service was functioning better.[50]

Autopsy Report

Autopsy reports are the main method by which autopsy and forensic pathologists communicate their work and thus their value to their clinical colleagues and the larger community. So it is not only the timeliness but also the content of the autopsy report by which pathologists are judged. The importance of reports has been long recognized

in radiology, a field of medicine similar in many ways to pathology. Radiologists list the attributes of a good radiology report as the 8 Cs: clarity, correctness, confidence, concision, completeness, consistency, communication, and consultation, along with timeliness and standardization.[51]

The autopsy report has changed little over the years. In both the hospital and forensic worlds, the autopsy report is basically narrative, with some sections in outline form, notably the PAD and final anatomic diagnoses. The length of the report can vary greatly depending on the level of detail and the thoroughness of the descriptions. Features that are incorporated into other pathology and medical reports, such as coding, structured reporting, and images, have not yet been adopted into the autopsy report.

The organization of an autopsy report also varies greatly. The specific locations of different sections of the report vary from hospital to hospital or medical examiner to coroner office. For example, the clinical correlation, a major feature of hospital autopsy reports, may be placed at the beginning or end of the autopsy report. In other cases, a section contained within one institution's autopsy report, such as the microscopic description, may be a separate report in another institution. Some stillborn autopsy reports contain the description of the placenta whereas others have a separate surgical case report referenced by the autopsy report.

The Autopsy Committee of the College of American Pathologists recommended a set of consistently used headings for all autopsy reports. They opined that these headings would be useful by reducing of errors of omission, facilitating the location of information from the report by pathologist and third parties, and enhancing electronic data analysis.[52]

Structured reporting

As the era of paper medical records moves to electronic medical records, many areas of medicine are taking advantage of the opportunities inherent in digital documents. In this new era of electronic medical records, an autopsy report needs to be more than a text dump or a pdf file transferred into an electronic health record or e-mailed to a local law enforcement agency. Relevant data within autopsy reports need to be structured, which will facilitate searching, analyzing, and researching these invaluable data in numerous ways.

Radiologists have recognized the opportunities and advantages offered by structured reporting compared with the traditional free text reporting in the new era of pay for performance, evidence-based medicine and the physician quality reporting initiative. They are actively investigating structured reporting to add value to radiology reports and their profession.[53] Similarly, there are numerous articles related to synoptic or structured reporting in surgical pathology, especially with regard to cancer.[54–57]

In contrast, there are no articles identified in the summer of 2014 when searching for different combinations of the terms, *autopsy report*, *structured*, and *synoptic*. Yet there is no doubt that structuring autopsy reports would have similar benefits for autopsy and forensic pathologists that structuring surgical pathology reports have had for pathology and radiology reports for radiology.

For example, in an evaluation of suicide risk assessment, it was recognized that a structured, systematic approach toward collecting information is critical to formulating suicide risk.[58] The integration of this historical data with results of autopsy reports on persons who have successfully committed suicide (including method used, evidence of prior attempts, significant medical diagnoses, and so forth) could be invaluable in helping to identify those at highest risk and in most need of intervention and treatment.

Images

The incorporation of images is another area where the value of autopsy reports can be greatly enhanced. Digital images are being included in surgical pathology reports, especially among private pathology groups that are focused on providing services to their clinician customers. These are typically digital snapshots from a microscopic slide showing relevant diagnostic information that frequently is not adequately annotated. In these cases, the image is little more than a marketing tool and not a value-added educational tool to assist clinicians in treating patients.

Properly annotated images can add value to an autopsy report, creating an image-enhanced report (IER) that can serve as an invaluable educational tool. Clinicians who were surveyed after the institution of IER perceive the inclusion of properly annotated images as adding value to the autopsy report and assisting them in understanding the death.[59] When using digital images in medical reports, it is important to use appropriate guidelines in how these images are selected, edited, annotated, and used.[60]

Issues involving the use of images in forensic autopsy reports are complicated by the frequently sensitive nature of these images, the fact that many states consider autopsy reports public record whereas other states specifically restrict the release of digital forensic autopsy images, and the needs of public safety during the

investigation of deaths. The public reaction to the publication of autopsy images showing the gunshot wounds on a person shot by law enforcement or a reaction of a family member to an image of a loved one in a state of advanced decomposition can be imagined. Yet even within forensics, the use of properly prepared and annotated images could add great value to the narrative report of a forensic pathologist in helping to explain the death (**Fig. 5**).

The Virtual or Minimally Invasive Autopsy

This discussion has involved how changes in the reporting of autopsy findings through the use of informatics might have a significant positive impact on the practice of autopsy pathology, help restore the value and importance of the autopsy, and lead to an increase in the autopsy rate. Attention is turned to how applying modern technology and informatics might change the autopsy procedure itself.

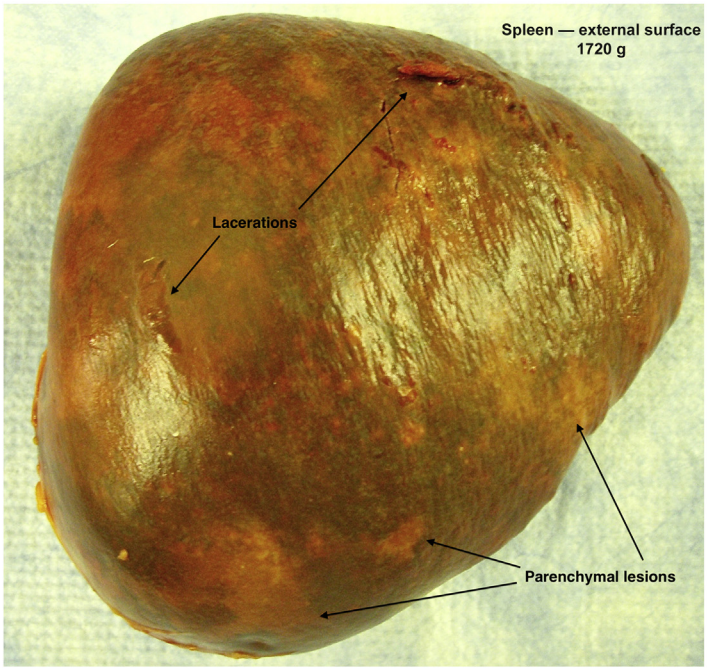
A

Spleen:

Gross: The spleen is enlarged and weighs 1720 g. The capsule is gray-blue, smooth, and glistening with 2 superficial lacerations measuring 3.0 and 2.5 cm in length, respectively. The cut surface is dark red with multiple tan to brown ill-defined patches in a geographic pattern, the largest of which measures 10 × 5 cm.

Microscopic: The capsule is unremarkable. There are nodular expanded foci of extramedullary hematopoiesis that contains all 3 hematopoietic cell lines. There are increased numbers of enlarged megakaryocytes with bizarre-shaped nuclei. Myeloid and erythroid lines are present but due to poor preservation the extent of maturation could not be determined. There are foci of autolysis.

B



C

Fig. 5. (*A*) The gross and microscopic text description for a spleen from an autopsy. (*B, C*) Annotated gross images showing the surface and cut section of the spleen.

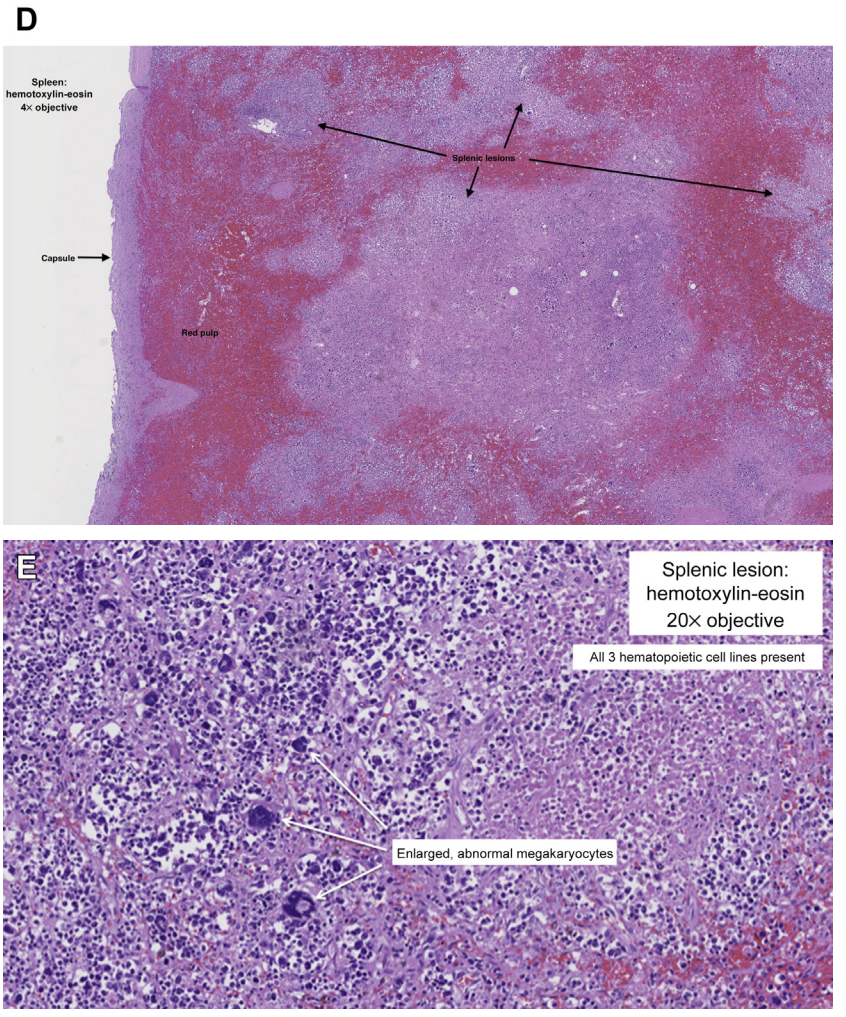


Fig. 5. *(continued).* (*D, E*) Annotated low- and high-power microscopic images of the spleen.

A virtual autopsy is a nondestructive or minimally destructive examination of the body utilizing scanning modalities, such as CT or MRI scans. The promise of a virtual autopsy is that equivalent or superior information can be gathered as a result of the examination without the destruction of the physical evidence or damage to the deceased body.

Virtual autopsies to date have been primarily involved with the practice of forensic medicine. In Europe, virtual autopsies were first used in academically situated forensic offices to study alternatives to the traditional autopsy. In the United States, the virtual autopsy got its start in the military setting with the use of these techniques to support, not replace, the traditional autopsy. There are only a few examples of virtual autopsies being studied for nonforensic hospital deaths.

Virtopsy project

The Institute of Forensic Medicine of the University of Bern, Switzerland, has been one of the early leaders of the study of virtual autopsy in Europe. It is this group that created and trademarked the term, *Virtopsy*. The group started their revolutionary work in the 1990s with a study of 3-D photogrammetry-based optical scanning of the external surfaces of the body as a way to better document external injuries and compare them to alleged weapons or mechanisms of injury. Within a few years they began using both multislice CT (MSCT) and MRI scans of deceased bodies and compared them with conventional autopsy. They discovered that MSCT is equivalent and even superior to conventional forensic autopsies in the evaluation of skeletal injuries, the detection of pneumothorax or gas emboli, and the location

and recovery of foreign bodies. MRI is well suited for the evaluation of soft tissue injuries but is not nearly as effective for documenting the common causes of sudden natural death, especially cardiac.[61]

Postmortem angiography has been performed for many years, primarily by infusing the coronary arteries after removal of the heart at autopsy; however, the ability to properly perfuse a deceased body using methods similar to living patients has been technically difficult.[62] The Institute of Forensic Medicine investigated different methods to perfuse the vascular system with contrast, finally discovering an adequate method through the use of a modified heart-lung machine. They demonstrated that this method was able to detect not only significant coronary artery disease with the same accuracy as conventional autopsy but also other vascular diseases, such as aortic dissection, pulmonary emboli, and aneurysms of the major vasculature (**Fig. 6**).[63]

The Institute of Forensic Medicine also studied the use of image-guided biopsy to obtain specimens to document disease histologically. In the same study in which they studied CT angiography in sudden deaths due to chest pain, they also obtained biopsies of the heart, lungs, and blood clots from the pulmonary arteries under CT guidance. In 2 of 3 cases, the myocardial biopsy was concordant with the histologic sections obtained from conventional autopsy. Sampling error was responsible for instances where the biopsy did not reveal the histopathology. This method was also adequate in distinguishing a pulmonary embolus from postmortem clot in the pulmonary artery and a pulmonary neoplasm.[63]

Studies have also demonstrated that postmortem CT scans are comparable to autopsy in the evaluation of free blood in the abdomen,[64] pericardial effusion, and hemopericardium[65] and in organ volume measurements for most internal organs in infants dying of sudden unexpected death (**Figs. 7** and **8**).[66]

The Institute of Forensic Medicine has combined this technology into a virtual autopsy system, called the *Virtobot*. This system can perform automated 3-D surface documentation of injuries and image-guided robotic needle biopsies. Surface scanning has recently been reduced from 30 minutes to 10 minutes per side of the body, although the complete documentation takes between 2 and 3 hours. They have used this system to surface scan a variety of blunt, sharp, and gunshot injuries. Needle biopsy accuracy currently averages 1.4 mm from the target.[67]

Armed Forces Medical Examiner virtual autopsy

In the United States, the Office of the Armed Forces Medical Examiner (OAFME), responsible for the postmortem examination of all active duty military personnel, began to use multidetector CT

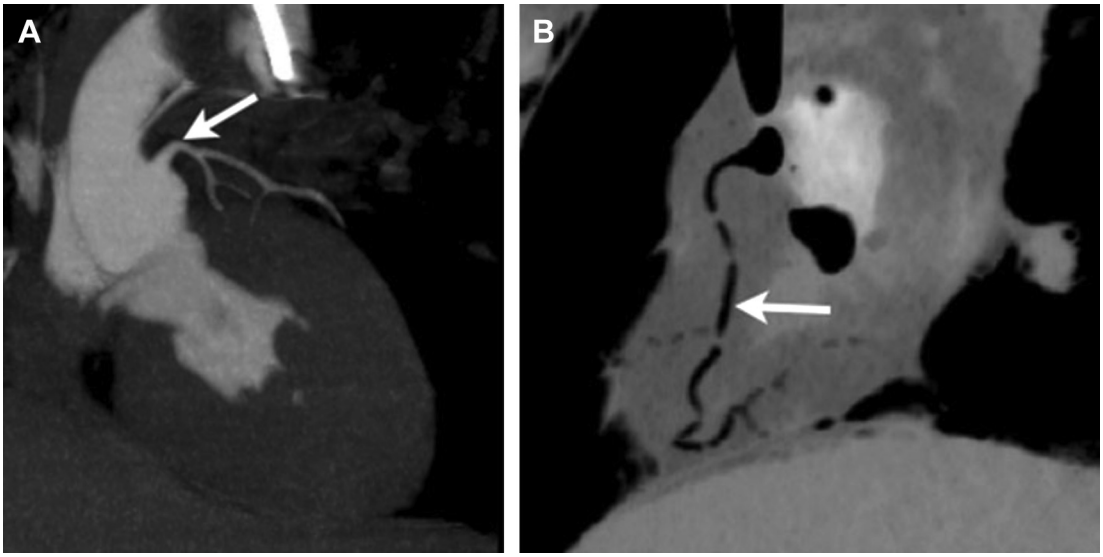


Fig. 6. Postmortem CT angiography showing a normal left coronary artery (*arrow*) opacified by contrast (*A*) and right coronary artery (*arrow*) filled with air (*B*). (*From* Saunders SL, Morgan B, Raj V, Rutty GN. Post-mortem computerized tomography angiography: past, present and future. Forensic Sci Med Pathol 2011;7:276; with permission.)

Fig. 7. Axial CT images of the abdomen at 3 distinct levels (*A*–*C*). The free abdominal blood is manually marked during segmentation (*red colored areas*). (*From* Ampanozi G, Hatch GM, Ruder TD, et al. Post-mortem virtual estimation of free abdominal blood volume. Eur J Radiol 2011;81:2134; with permission.)

(MDCT) scanning to detect unexploded ordinance in military personnel prior to autopsy. They quickly realized that CT scans combined with autopsy have the potential to provide better evaluation of the nature of wounds sustained by military personnel in combat. They were able to better define wound tracks and locate metallic fragments from high-velocity gunshot wounds.[68]

Once combat wounds were better characterized, it became easier to retrospectively evaluate these injuries for potential survivability, separating these injuries into not survivable (NS) and potentially survivable (PS). Understanding the nature of these injuries will allow the military to not only identify injuries that are PS so they can quickly receive life-saving medical treatment but also develop techniques and equipment to minimize exposure to wounds that are NS.[69,70]

The OAFME has also studied the implications of using postmortem MDCT for nonmilitary situations. During the response to January 2010 Haiti earthquake, the OAFME had the responsibility to examine and repatriate US citizens who were victims of that mass fatality disaster. They discovered that using MDCT in combination with digital radiographs and external examination allowed them to triage cases for virtual or conventional autopsy.[71] This has the potential to greatly improve the

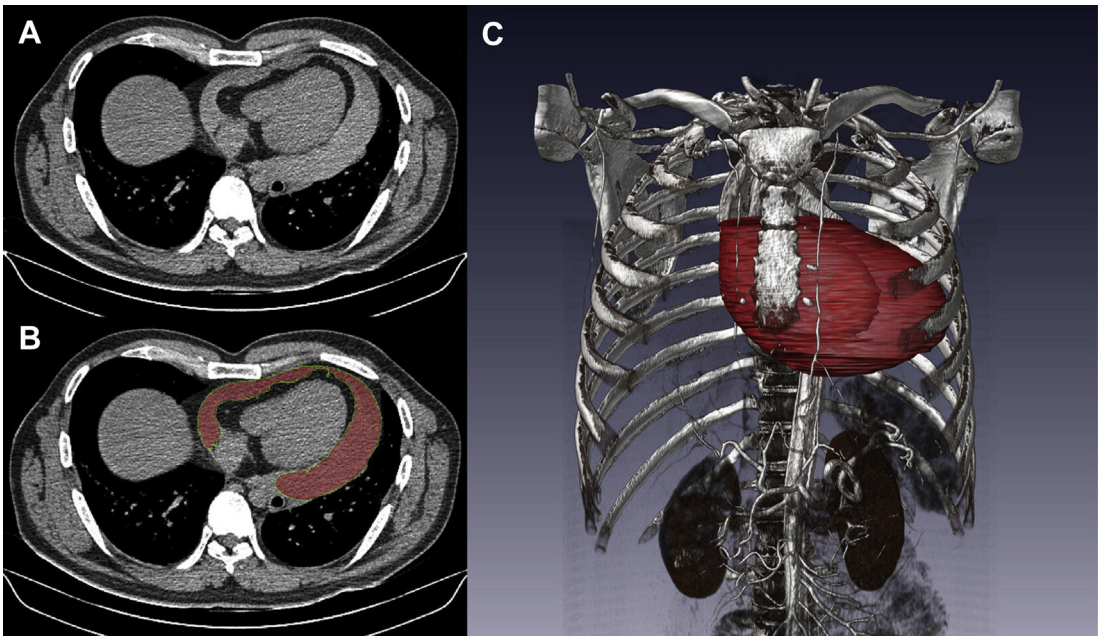


Fig. 8. (*A*) Volume measurement by segmentation using axial CT images. (*B*) Pericardial effusion is marked manually for each slice or resampled slices. (*C*) 3-D reconstruction of segmented pericardial effusion. (*From* Ebert LC, Ampanozi G, Ruder TD, et al. CT based volume measurement and estimation in cases of pericardial effusion. J Forensic Legal Med 2012;19:127; with permission.)

efficiency of the response of medical examiners to mass fatality incidents, directing appropriate levels of scarce resources to where it is most needed.

Virtual autopsies in the hospital setting

Virtual autopsies have been studied in the hospital setting. Similar to the studies in forensic practice, the use of a single modality (CT or MRI) revealed significant deficiencies in the accuracy of virtual autopsy compared with conventional autopsy.

When compared with the gold standard of the traditional autopsy, major discrepancy rates of 32% for CT alone, 43% for MRI alone, and 30% for combined CT-MRI have been reported, with the most common missed diagnoses ischemic heart disease, pulmonary emboli, and pneumonia. Radiologists in this study identified cases in which they thought traditional autopsy would not be necessary, and in those cases the major discrepancy rate fell to 16% for CT, 21% for MRI, and 16% for CT-MRI imaging.[72] The approximately one-third major discrepancy rate for postmortem CT was confirmed in another study, which determined the positive predictive value for cause of death by postmortem CT at 75%. Demonstrating the potential value of using postmortem CT as an adjunct to autopsy instead of a replacement, the same study reported a combined diagnostic yield of 133% compared with autopsy alone.[73]

The ability of ultrasound-guided needle biopsy to increase the accuracy of virtual autopsy in hospital autopsies yielded a sensitivity of 94% and specificity of 99% compared with conventional autopsy, with agreement on the cause of death in 77% of cases. The major area of deficiency in this study was related to cardiac deaths.[74]

These studies show some promise for the use of CT and/or MRI to either increase the value of the autopsy or replace it in selected cases. One potential advantage of a virtual autopsy is the increased likelihood that families will consent to a non- or minimally invasive procedure, especially in cases of religious objections.[75] Adapting some of the techniques pioneered in the forensic Virtopsy project, especially the use of postmortem angiography and image-guided needle biopsies, has the potential to raise the accuracy of the virtual procedure to near that of the conventional autopsy. Intelligent triaging of cases through the use of scanning to determine which deaths require a conventional autopsy can also help to increase efficiency in ever busier pathology departments.

The potential downside of adoption of virtual autopsy involves the logistics and expense of providing this service. Given that there are currently no government or private insurer reimbursements for conventional autopsies, it is unlikely that there will be reimbursements for virtual autopsy. The costs for CT and MRI scanners are significant. They require specially shielded rooms as well as properly trained technicians to operate them. In contrast, the cost of autopsy space, equipment, and personnel is considerably less. Either radiologists will provide the interpretations or pathologists will have to be trained to interpret them.

Fig. 9. An autopsy case presentation on a pathology department's multitiled high-resolution display running the scalable adaptive graphics environment (SAGE). Autopsy data, gross images, and whole-slide images can be viewed simultaneously and discussed with participants both in the space and through videoconferencing.

SUMMARY

The hospital autopsy, despite the decline in autopsy rates over the past 3 decades, still has a significant role to play in patient care. Even in the twenty-first century world of high-tech medicine, the autopsy discovers unexpected findings on a regular basis. As an era of personalized medicine and accountable care is entered, the autopsy is well positioned to provide insight and evidence to support new therapies and enhance patient safety.

The autopsy cannot remain unchanged from how it has been practiced for more than a century. It needs to adapt to the changing demands of medicine by adopting informatics and new technology to keep pace with the rest of clinical care and pathology. For example, at the University of Illinois at Chicago, the Department of Pathology and the Electronic Visualization Laboratory (EVL) in the Department of Computer Science developed an application to display whole-slide images within EVL's collaborative SAGE, expanding SAGE's existing capacity to simultaneously display and share a variety of high-resolution images, video, and data (**Fig. 9**).

Pathologists need to take leadership of the evolution of the autopsy, document the value of the autopsy to patient care, and advocate for appropriate financial reimbursement for this medical procedure.

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