3. Scientific Evidence

Section 3.11
Forensic Analytical Evidence

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3.11.1 Introduction

Forensic science is the application of scientific knowledge to legal problems in trials, civil disputes, and arbitration proceedings. Many forensic science disciplines have physical, chemical, and biochemical principles at their core. This includes drug identification chemistry, forensic toxicology, and several types of trace evidence analyses. There are computer innovations which have greatly increased the capability and accuracy of forensic analytical analysis, but at its core, there is an element of human judgment.

Forensic analysis of most physical and biological evidence is conducted for two purposes: identification and comparison. Identification determines what exactly a particular item or substance is. Is that green leafy substance marijuana or oregano? Is that brown stain dried blood of a human being or an animal? A forensic examiner may offer an opinion that the substance in question is present, not present, or that testing was inconclusive, and the presence of the substance cannot be ruled in or ruled out. Comparisons are made to find out whether a known and a suspect item or substance share a common origin. Did the fingerprint, hair, or blood come from the suspect? Does the paint smudge found on a hit-and-run victim's clothing match that of the suspect's car?

Paul Kirk, in an early treatise on forensic science, *Crime Investigation*, wrote:

> Wherever he steps, whatever he touches, whatever he leaves, even unconsciously, will serve as relevant evidence against him. Not only his fingerprints or his footprints, but his hair, the fibers from his clothes, the glass he breaks, the tool marks he leaves, the paint he scratches, the blood or semen he deposits or collects – all those bear mute witness against him. This is evidence that does not forget. It is not confused by the excitement of the moment. It is not absent because human witnesses are. It is factual evidence. Physical evidence cannot be wrong; it cannot perjure itself; it cannot be wholly absent. Only its misinterpretation can err. Only human failure to find it, study and understand it can diminish its value.[1]

There are few rules of thumb for judges, except one: Every field of forensic science has potential problems. Although infrequent, there are examples of rogue forensic examiners.[2] The American Society of Crime Lab Directors' Laboratory Accreditation Board candidly said, "Forensic scientists are human beings. As such they will sometimes make mistakes and, in some very rare instances, push the boundaries of ethical behavior."[3] Recent court decisions are forcing forensic scientists to improve both the science upon which the technology is based and the competence of expert witnesses in forensic science. Because of the many changes and improvements in the field, the adage "every once in a while, we should hang a question mark after things we take for granted" applies to a judge who must make a decision with forensic analytical evidence.

The qualifications of the forensic scientist are crucial. The more the particular type of forensic analysis is founded on medical research, the more trustworthy the analysis. For example, blood analysis dominates medicine. It is likely every judge has at one point in their life had lab work ordered by their doctor—few have had a personal experience with blood spatter pattern evidence.

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The RAND Forensic Technology Survey[4] study found that there is a pressing need for more and better forensic science technology—and for well-trained people to use it and present its results. Many crime laboratories have substantial backlogs of evidence not yet tested or otherwise processed. Clearing these backlogs is a major concern and goal of laboratory directors. The RAND Forensics Survey found that more than half of the forensic lab workload was for tests of controlled substances, about a sixth was for latent prints, and a ninth was for blood alcohol tests.

There are several highly reputable professional associations of forensic analysts. The American Academy of Forensic Sciences, for example, is a multidisciplinary professional organization that provides leadership to advance science and its application to the legal system. The objectives of the Academy are to promote professionalism, integrity, competency, education, foster research, improve practice, and encourage collaboration in the forensic sciences. However, only a small number of forensic experts are members of the American Academy of Forensic Sciences.

3.11.2 Toxicology

Toxicology is the study of the effects that chemicals, such as drugs, and other substances can have. Toxicology is part chemistry, part biology, and a large part medical research. Every substance can induce some form of toxic effect. The type and nature of effects will vary depending on the dose (amount of substance that finds its way into the body), route of administration (i.e., oral, inhalation, skin, injection), duration (days, weeks, months, years), and frequency (how many times per day, week, month, year) of exposure. Properly done, examining samples of blood, urine, other bodily fluid, or tissue samples can determine whether or not an individual has used, or is currently under the influence of, a wide variety of substances.

Typically, a toxicology report will include a list of samples being tested (e.g., hair, urine, blood), the methods used for testing the samples, the patient data (including any relevant medical information such as medical conditions or prescribed medication), laboratory results which indicate which drug or chemical was tested for and whether or not the drug or chemical was present in the given toxicology sample (these results are often presented in a table or graph format), and an explanation—in simple and clear terms—that analyzes the outcomes of the findings. The nomenclature of many of these reports can be difficult for judges and juries to understand.

Pathways are the means by which an environmental chemical may reach an exposed person. Chemicals can enter the body by four fundamental routes: (1) oral exposure (e.g., ingestion of the toxic substance directly, or in food or drinking water); (2) insufflation or inhalation (e.g., breathing air or inhaling dust contaminated with the toxic substance); (3) direct contact with the skin (e.g., spilling of a pesticide mixture on the body); or (4) by direct injection into the body (e.g., introduction of a drug by intravenous injection).

Xenobiotics are substances which are foreign to human beings. Xenobiotics include therapeutic medication, alcohol and other drugs, pesticides, toxins, and other poisons. The period of detection of a xenobiotic, or its metabolite from the last exposure to the time that it is last detectable in a specimen, is critical. For example, the period of detection of alcohol in a urine sample is 7–12 hours and 1–30 days for cannabinoids. Toxicants are classified into six groups (See Table 3.11.1) based on their physical and chemical characteristics and the manner by which they are extracted (isolated) from biological fluids and tissues for analysis.

Classification of toxicants based on physicochemical properties[5]

Class of Toxicant	Examples
Toxic gases or vapors	Carbon monoxide, hydrogen sulphide, diethyl ether, chloroform
Volatile liquid poisons	Benzene, toluene, aromatic hydrocarbons, glycols, aldehydes, essential oils of some plants
Acids and strong bases	Hydrochloric or sulphuric acid, sodium or potassium hydroxide
Inorganic anions	Permanganates, chromates
Metals or salts of heavy metals	Arsenic, mercury, lead
Acids, basic or neutral non-volatile organic chemicals and drugs	Most synthetic drugs, alkaloids, illicit drugs, insecticides.

Table 3.11.1

APPLICATIONS OF FORENSIC TOXICOLOGY[6]

Sub-discipline	Purpose	Applications	Toxicants Analyzed
Postmortem toxicology	Evaluate contributing factors, cause and manner of death	• Suspected drug intoxication or overdose • Suspected poison- or drug-related death	• Drugs and their metabolites • Ethanol, toluene and other volatile substances • Carbon monoxide and other gases • Metals • Other toxic chemicals in human fluids and tissues
Human performance toxicology	Evaluate effect or impairment of human performance or behavior	• Drug-facilitated assault, rape or other crime • Suspected driving under the influence of alcohol or other drugs	• Drugs in their metabolites • Alcohol (ethanol) and other drugs • Chemicals in blood, breath or other biological specimens

Applications of Forensic Toxicology[6]

Sub-discipline	Purpose	Applications	Toxicants Analyzed
Doping control	Protect the health of athletes, maintain fair competitive standards, and prevent wagering fraud	• Use of performance-enhancing drugs in human and animal sports	• Performance-enhancing drugs • Banned substances such as stimulants, anabolic steroids and diuretics in blood or urine
Forensic drug testing	Evaluate prior use or abuse	• Use of performance-enhancing drugs in human and animal sports	• Drugs and their metabolites in urine

Table 3.11.2

What Can Go Wrong with A Toxicology Analysis?

1. Problems with sample collection, transport and storage;
2. Problems with analytical methods used (for example, random sampling is an approach in which labs test only a portion of confiscated drugs. But some state courts, such as Minnesota, disfavor random testing);[7]
3. The nature of the substance(s) present;
4. Circumstances of exposure;
5. Pharmacological factors such as tolerance, interactions or synergy.

3.11.2.1 What Toxicological Breakthroughs are Possible?

Bloodstains may soon be able to give forensic analysists a crucial piece of information-- the age of the victim. A new method devised by University at Albany chemists Kyle Doty and Igor Lednev was recently published in the American Chemical Society Journal *Central Science*.[8] Using blood from 45 donors, they were able to distinguish unique profiles from the newborns, adolescents, and adults.

It is quite amazing what medical research is doing in blood testing. Scientists have now developed a blood test for Alzheimer's disease and found that it can detect early indicators of the disease long before the first symptoms appear in patients. The blood test offers an opportunity to identify those at risk and hopefully will open new avenues in treating Alzheimer's. Western Australian researchers have reported developing a blood test that can detect early stage melanoma skin cancers. Early detection and treatment are key to curing melanoma. Phlebotomy, the process of opening a vein and collecting blood for testing and diagnosis, is regularly used to measure cells, lipids, proteins, sugars, hormones, tumor markers, and other blood components. But the results from blood tests can often take days or weeks and therein lies a challenge for the next generation of toxicological breakthroughs: can accurate results be obtained in a shorter period of time?

3.11.2.2 What Kind of Testing?

Because there are wide variations in the physical and chemical properties of xenobiotics in blood and urine, there is no universal chemical screen. Qualitative analysis detects the presence of a substance. Quantitative analysis determines the concentration of the substance. Screening tests include color tests, immunoassays, spectrophotometry, and thin layer chromatography. Confirmatory tests consist of the detection of a chemical substance by non-specific tests and must be confirmed by a second more specific technique based on a different chemical principle. As a rule of thumb, while screening tests may be cheaper and quicker, they are far less accurate than more sophisticated tests such as thin layer chromatography.

Hair analysis can be used for the determination of drug use months after drug consumption. More recently developed methods offer excellent sensitivity and can make distinction between chronic heroin and codeine use, which was not possible earlier with radioimmunoassay techniques.

3.11.3 Fiber analysis

Fiber analysis cannot actually pinpoint a suspect in an investigation since it is not as reliable as DNA. A large share of forensic science techniques involving the analysis of physical evidence have never been validated scientifically. The National Academy of Sciences concluded that, with the exception of nuclear DNA analysis, no forensic method has been rigorously shown to consistently and with a high degree of certainty demonstrate a connection between evidence and a specific individual or source and have not developed evidence-based estimates of error rates.[9] The Academy report also noted that forensic analysts are subject to "contextual bias," which occurs when the analysts are influenced by knowledge about the suspect's background or other case information.[10]

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Forensic fiber analysis is a body of knowledge that involves laboratory testing of fiber samples found at crime scenes to determine their origin. Properly done, experts can identify the material present and link it to the same material somewhere else. ASTM, formerly known as the American Society for Testing and Materials, is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services. As stated in ASTM E2225-10 – Standard Guide for Forensic Examination of Fabrics and Cordage, gaining an understanding of "the construction, composition, and color of a textile can aid the examiner in including or excluding a textile for consideration in a forensic examination."[14]

The first step of the analysis of fibers of interest is their extraction. This part of the process sounds fairly simple, but the first part of the process needs to effectively prevent contamination of the sample. ASTM E2228-10 – Standard Guide for Microscopic Examination of Textile Fibers proposes several recommended extraction methods, including tweezers, tape lifting, and gentle scraping. Tape lifts should be placed on clear uncontaminated substrate, and efforts need to be made to keep all materials clean. After extraction, fibers are examined with a stereomicroscope, with which physical features, such as crimp, length, color, relative diameter, luster, apparent cross section, damage, and adhering debris, are noted. Observations of these can help to classify the fiber samples into broader groups, such as synthetic, natural, or inorganic. Narrowing down the originating options for a fiber prevents the forensic specialists from pursuing any false conclusions. For example, one can classify a fiber as a strand of animal hair if it carries its common morphological features: the root, medulla, cortex, and cuticle. Experts can then determine the species of the animal through additional features on the hair shaft.[15]

There are no set standards, for the number and quality of character other textiles are produced using the same fiber types and color. The inability to positively associate a fiber to a particular textile to the exclusion of all others does not mean that a fiber association is without value."[16] But to repeat, fiber examiners agree, however, that none of these characteristics is suitable for individualizing fibers (associating a fiber from a crime scene with one, and only one, source) and that fiber evidence can be used only to associate a given fiber with class of fibers.[17, 18]

3.11.4 Medico-Legal Death Investigation

Half a million deaths are the subject of a medico-legal death investigations each year.[19] Medico-legal death investigation involves the scientific examination of unexplained deaths including those from homicides, suicides, blunt-force injuries, sharp-force, gunshot, and toxicological.[20] These investigations should be performed in accordance with each state's laws.[21]

There are two types of medico-legal death investigation systems, the Medical Examiner system and the Coroner system. Twenty-two states utilize a statewide medical examiner systems, with eleven others using a coroner systems, while the remaining states use a hybrid system: where some counties served by coroners, others by medical examiners, and still others a combined system where the coroner refers cases to a medical examiner.[22]

The major differences between coroners and medical examiners arise in the manner of their selection by the electorate versus appointment by the executive branch. Medical examiners also have the medical and scientific expertise required for a physical examination of the deceased, while a coroner is not required to have any medical or scientific training.[23] Coroners can be elected or appointed. Some are also sheriffs or funeral home directors. Many coroners are not doctors. There are also medical examiners, who usually are medical doctors but may not be forensic pathologists trained in death investigation. The National Academy of Sciences has criticized the lack of mandatory standards for autopsies and the absence of oversight into the performance of coroners and medical examiners. The Academy recommended that the goal of every state should be to move to hire board certified forensic pathologists and put them to work as medical examiners.[24]

Autopsies are not for the faint of heart and the description of what occurs can be disturbing to jurors. In the U.S., the predominant technique used in an autopsy involves a Y-shaped incision. The incision begins at each shoulder and extends downward, meeting the midline of the body in the lower chest, then the incision extends to the top of the pubic bone. The chest plate is removed by cutting the ribs on both sides, exposing the heart and lungs. Samples of blood, bile, urine, and eye fluid are collected. Each organ is examined, removed, weighed, photographed, and dissected. Next the heart, lungs, pancreas, spleen, liver, kidneys, prostate, and gastrointestinal tract (small and large intestines) are removed. The brain is removed by first making an incision ear to ear, reflecting the scalp and exposing the skull, then using a reciprocating bone saw to create a circular cut of the skull allowing the removal of the skullcap and the brain. Microscopic slides are made of each organ. Typically, the collected body fluids are sent to a forensic toxicologist for analysis. That analysis generates a toxicology report that lists all the compounds by type and concentration detected in the different body fluids.

Because the expertise of those who perform medico-legal death investigations varies widely, the trial judge’s challenge is to determine whether their testimony is sufficient to offer expert testimony. A good example of this can be found in the case of *Verzwyvelt v.St. Paul Fire & Marine Ins. Co.*[25] Plaintiff brought suit alleging death from eating sausage meat contaminated with listeria. The coroner, had not tested specifically for the listeria bacteria, and admitted he had "little or no scientific knowledge concerning listeria, listeria infections, or the subfield of hematopathology."[26] The court allowed him to testify, as he was a forensic pathologist, but prevented him from testifying as to any opinion regarding the cause or nature of the bacterial infection that was presumably the cause of death as he was not qualified to do.[27]

3.11.5 Fire Debris / Arson, Explosion Analysis

The bombing of the Pan Am Flight 103 over Lockerbie, Scotland in 1988 created the largest crime scene in the world. It stretched for more than 1,200 square miles. By painstakingly piecing together the wreckage that was found in this area, investigators identified trace amounts of explosives that helped confirm the incident was indeed caused by a terrorist attack.

The Lockerbie explosion analysis was unique, but it illustrates what a well-funded investigation is capable of. Fire, explosion, and arson investigations examine the physical attributes of a fire or explosion. Evidence of accelerants and burn patterns may indicate criminal activity. These types of analyses can be mishandled,[28] but they can be accurate and there is support for improvement in the field. For example, the National Institute of Justice funds research to develop new and improved tools and techniques to interpret, identify, and analyze fire and explosion evidence.[29]

Since 1989, more than 50 people have been officially exonerated on the basis that there was no arson. However, fire debris and explosives analysis has become more reliable because of new technology.

Fire debris and explosives analysis has become more reliable because of new technology. Advances in analytical chemistry, digital imaging, robotics, and data recording are presenting new tools and technology. For example, the development and validation of instrumentation that is capable of indicating the probability match of ignitable liquids recovered from a fire scene, to ignitable liquids on the person, or in the possession of a suspect or victim. New technology could essentially provide a DNA analysis for fire debris. Instrumentation used in other analytical areas that may have an application are: two-dimensional gas chromatography whish mass spectral detection (GC x GC/MS);

Stable Isotope Ratio Mass Spectroscopy; Gas Chromotography with tandem mass spectral detection (GC/MSn) or Fourier Transform Ion Cyclotron Resonance Mass Spectroscopy. Another area of interest is development and validation of "expert system" software for GC/MS that can rapidly compare data from case samples with a reference library of ignitable liquid standards to form probability match lists.[30]

3.11.6 Practice Pointers For Trial Judges

"Slow and painful has been man's progress from magic to law." That proverb, which is mounted at the University of Pennsylvania Law School on a statute of Hsieh-Chai, a mythological Chinese beast with the power to discern guilt, serves as an important metaphor for trial judges dealing with forensic analysis.

Can a judge safely rely on established case law regarding forensic analysis? The short answer is: maybe. The law is somewhat fixed. A trial judge can find him- or herself in a difficult spot when there is an Appellate Court decision saying one thing, and new forensic technology saying another. When this happens, judges need to be prepared for the possibility that it may be time to depart from the current state of the law.

3.11.7 A Sampling of Cases on Scientific Evidence

Forensic Analysis of Fibers

Boyd v. State 200 So.3d 685 (2015). Trial counsel was not ineffective in failing to request a Frye hearing on forensic methodologies and evidence presented. Trace and microscopic fiber analysis, forensic odontology and bite-mark analysis, and short tandem repeat (STR) DNA technology were not new nor novel at the time of trial.

People v. Prieto, 124 P.3d 842 (2005). "The court found that the fiber examination may be considered subjective because the expert examined the fibers through the filter of her own eye. However, the expert was trained in fiber analysis at the FBI, fiber analysis is subject to CBI standard operating procedures, the standard operating procedures used are accepted within the forensic community, and her test was subject to peer review. The court noted that although this expert was not going to render a conclusive opinion, her findings of consistency among the fibers might be helpful to the jury and certainly would be relevant. We conclude that the court did not err in admitting the fiber expert's testimony."

Fox v. State, 266 Ga.App. 307, 596 S.E.2d 773 (2004). Trial court did not abuse its discretion in qualifying state's witness as expert in fiber analysis. "[T]he State's expert fiber analyst had worked at the Georgia Bureau of Investigation for two years as a microanalyst in the Forensic Sciences Division, and had a bachelor of science degree in Forensic Science. She also completed a nine-month training course in the hair and fiber fields, and 'completed several oral and written tests.' Her duties included analyzing, comparing, and evaluating physical evidence including hairs, fibers, and shoeprints. She had worked on approximately 50 cases while she was employed at the GBI. Previously, she had testified as an expert in hair analysis and physical evidence, but not as a fiber expert."

3.11.8 Endnotes

1. P.L. KIRK, CRIME INVESTIGATION at 4. (Interscience Publishers, N.Y., 1953)

2. For example, the Supreme Court of Massachusetts ordered the dismissal of more than 11,000 drug convictions, as they may be tainted by the misconduct of former Massachusetts forensics chemist Sonja Farak. Farak worked in a Massachusetts drug analysis lab from 2003 until her arrest in January 2013. She served an 18-month prison sentence after being convicted of tampering with evidence, stealing illegal drugs from the facility where she worked, and cocaine possession. For six months, Farak actually overlapped at the Hinton drug lab with another disgraced Massachusetts state forensic chemist, Annie Dookhan, who was sentenced to three to five years in prison in November 2013 after admitting to mixing evidence samples and falsifying results. The Massachusetts Supreme Court directed that nearly 22,000 criminal drug cases affected by Dookhan's misconduct be overturned. That was the largest dismissal of wrongful convictions in US history.

3. BRENT TURVEY, FORENSIC FRAUD: EVALUATING LAW ENFORCEMENT AND FORENSIC SCIENCE CULTURES IN THE CONTEXT OF EXAMINER MISCONDUCT 2 (2013).

4. WILLIAM SCHWABE, ET AL., CHALLENGES AND CHOICES FOR CRIME-FIGHTING TECHNOLOGY: FEDERAL SUPPORT OF STATE AND LOCAL LAW ENFORCEMENT (2001).

5. FORENSIC TOXICOLOGY – A PRIMER FOR LAWYERS, LAWGAZETTE.COM, http://v1.lawgazette.com.sg/2016-05/1565.htm.

6. *Id*.

7. *See* State v. Robinson, 517 N.W.2d 336 (Minn. 1994) (Unless suspected drug is so homogeneously packaged as to permit extrapolating the total weight of the drug from random sample testing, the state must present evidence that all of the substance necessary to meet the minimum statutory weight was tested and identified as the suspected drug.), Alan Julian Izenman, *Statistical and Legal Aspects of the Forensic Study of Illicit Drugs*, 16 STATISTICAL SCIENCES 1 35, 36 (2001).

8. Kyle C. Doty & Igor K. Lednev, *Differentiating Donor Age Groups Based on Raman Spectroscopy of Bloodstains for Forensic Purposes*, 4 AM. CHEMICAL SOC. CENT. SCI. 7, 862-867 (2018).

9. NAT'L RES. COUNCIL, STRENGTHENING FORENSIC SCIENCE IN THE UNITED STATES: A PATH FORWARD (National Academies Press, 2009).

10. *Id*.

11. JOHN GLAISTER, HAIRS OF MAMMALIA FROM THE MEDICO-LEGAL ASPECT (1931).

12. JOHN GLAISTER, A STUDY OF HAIRS AND WOOLS BELONGING TO THE MAMMALIAN GROUP OF ANIMALS, INCLUDING A SPECIAL STUDY OF HUMAN HAIR (MISR Press, Univ. of Egypt, 1931).

13. MICROSCOPY OF HAIRS: A PRACTICAL GUIDE AND MANUAL (Univ. of Mich. Libr., 1977).

14. ASTM STANDARD E2225-10, STANDARD GUIDE FOR FORENSIC EXAMINATION OF FABRICS AND CORDAGE, (ASTM International, 2010), www.astm.org

15. Brad Kelechava, *Forensic Fiber Analysis Standards*, American National Standards Institute, (July 18, 2018) https://blog.ansi.org/?p=7140.

16. FORENSIC EXAMINATION OF FIBRES 91 (James Robertson & Michael Grieve eds., 2d ed. 1999).

17. See e.g., R.R. Bresee, *Evaluation of textile fiber evidence: A review,* 32 J. OF FORENSIC SCIENCES 2, 510-521 (March 1987), Available at https://www.researchgate.net/publication/281246146_Evaluation_of_Textile_Fiber_Evidence_A_Review, which includes the following summarization in Section 5.4: "It can never be stated with certainty that a fiber originated from a particular textile because other textiles are produced using the same fiber types and color. The inability to positively associate a fiber to a particular textile to the exclusion of all others, however, does not mean that a fiber association is without value."

    See also SWGMAT, *Introduction to forensic fiber examination*, 1 FORENSIC SCIENCE COMMUNICATIONS 1 (April, 1999).

18. NAT'L RES. COUNCIL, STRENGTHENING FORENSIC SCIENCE IN THE UNITED STATES: A PATH FORWARD, COMMITTEE ON IDENTIFYING THE NEEDS OF THE FORENSIC SCIENCES COMMUNITY 161-163 (2009).

19. RANDY HANZLICK, INST. OF MED. (US) COMMITTEE FOR THE WORKSHOP ON THE MEDICOLEGAL DEATH INVESTIGATION SYS., MEDICOLEGAL DEATH INVESTIGATION SYSTEM (2003). https://www.ncbi.nlm.nih.gov/books/NBK221926/

20. MATTHEW LUNN, ESSENTIALS OF MEDICOLEGAL DEATH INVESTIGATION (Academic Press, 2017).

21. U.S. DEP'T. OF JUST. OFF. OF JUSTICE PROGRAMS DEATH INVESTIGATION: A GUIDE FOR THE SCENE INVESTIGATOR (2011). https://abmdi.org/documents/death_investigation_guidelines.pdf

22. *Id*.; For example: Idaho, some parts of California, Colorado, Kansas, Nebraska, Nevada, some parts of New York, South Carolina, South Dakota, some areas in Texas, some parts of Washington, and Wyoming use the coroner system.

Alaska, Alabama, Arkansas, Connecticut, Delaware, Georgia, Iowa, Kentucky, Maine, Maryland, Massachusetts, Mississippi, Montana, New Hampshire, New Jersey, New Mexico, North Carolina, North Dakota, Oklahoma, Oregon, Rhode Island, Tennessee, Utah, Vermont, Virginia, and West Virginia use the medical examiner system. Arizona and Michigan have medical examiners in each county, but they are not necessarily pathologists.

Washington, Texas, Hawaii, Minnesota, Wisconsin, Ohio, Illinois, Pennsylvania, and New York use both the coroner and medical examiner systems. Arkansas, Kentucky, Mississippi, Montana, and North Dakota have coroners in their counties, but they also have a state medical examiner.

23. *Id*.

24. Beth Pearsall, *Improving Forensic Death Investigation,* 267 NAT'L JUST. INST. J., (Winter 2010) https://www.nij.gov/journals/267/pages/investigation.aspx

25. Verzwyvelt v. St. Paul Fire & Marine Ins. Co., 175 F. Supp. 2d 881 (W.D. La., 2001).

26. *Id*.

27. *Id*.

28. Since 1989, more than 50 people have been officially exonerated on the basis that there was no arson, according the National Registry of Exonerations. http://www.law.umich.edu/special/exoneration/Pages/about.aspx (last visited March 21, 2019).

29. NAT'L INST. OF JUST., FIRE AND ARSON INVESTIGATION (August 23, 2017), https://www.nij.gov/topics/law-enforcement/investigations/fire-arson/pages/welcome.aspx.

30. H. Tsugawa, et al., *MS-DIAL: data independent MS/MS deconvolution for comprehensive metabolome analysis* 12 NATURE METHODS 523-526, (2015); T. Pluskal, et al., MZmine 2: *Modular framework for processing, visualizing, and analyzing mass spectrometry-based molecular profile data*, 11 BMC

BIOINFORMATICS 395 (2010); S. Tanaka, et al., *Mass++: A Visualization and Analysis Tool for Mass Spectrometry*, 13 J. PROTEOMO RES., 8, 3846-3853 (2014).