FIGHTING CRIME WITH SCIENCE

BY **JIM DAWSON**

NIJ research and development projects hold promise for significantly improving forensic science disciplines.

In crime laboratories across the country, scientists and technicians spend countless hours analyzing a never-ending flow of evidence. The challenging work involves multiple scientific disciplines, including almost every field of the physical and life sciences and computer science.

For example, while a toxicologist in a crime laboratory is working to identify a complex designer drug that killed a college student, a biotechnician may be trying to identify a murderer by amplifying DNA taken from under the victim's fingernails. A trace evidence expert may be examining carpet fibers on a victim's clothing, while a forensic anthropologist is determining the age, sex and ancestry of human bone fragments discovered in a field and a digital (or computer) forensic analyst is searching for evidence on a computer hard drive.

In addition to the complexity of the scientific work, the demands on crime laboratories to process evidence faster while lowering costs have increased dramatically over the past decade. A key to helping the crime laboratories catch up to and keep pace with these growing demands is the development of better technology and analytical methods based on state-of-the-art research.

The hundreds of projects that NIJ has supported over the past five years cover a wide range of forensic science disciplines, including the following:

- DNA research, which involves basic research directly for forensic purposes and adapting other DNA research to the forensic field

- Trace evidence analysis, which includes examining glass, hairs, fibers, gunshot residue, paint and explosive residues
- Fingerprint comparison, firearm matching and blood spatter pattern interpretation
- Toxicology, which focuses on drug and poison identification in biological fluids and tissues
- Digital forensics, one of the fastest-growing areas of forensic science, which specializes in recovering and analyzing material found in digital devices
- Crime scene investigation, which concentrates on efficient and accurate ways to identify, collect and preserve all relevant evidence at a crime scene

The current projects supported by NIJ represent the cutting edge of forensic research. Much is basic research, such as efforts to construct a near-photographic image of an individual from a strand of DNA. Some research, such as sophisticated software that assists in the reconstruction of bone fragments from mass graves, is ready for field testing by experts and may soon provide crime laboratories with new forensic tools.

This article highlights several of these ongoing projects that hold promise for significantly improving their fields in forensic science. All are aimed at advancing NIJ's overall goal of strengthening forensic science to improve justice.

Studying Drugs at Electronic Dance Music Festivals

For the last two years, chemist and toxicologist Barry Logan has parked a rented RV as a mobile research station and positioned his team of researchers about 100 yards from the main entrance of the Ultra Music Festival in Miami. The event, which typically sells more than 160,000 tickets, has a longstanding reputation for attracting youth who use designer drugs or, as the *Miami Herald* wrote, "a smorgasbord of psychotropic uppers and downers."

As the concertgoers pass by Logan's RV on their way into the festival, he asks whether they want to contribute to science. Surprisingly, he says, many do and voluntarily offer some combination of oral fluid, urine or blood samples. Those who provide oral fluid and urine samples are rewarded with bottled water and candy. Those willing to be stuck with a needle and donate blood receive a $20 Dunkin' Donuts gift card. Over the past two years, about 400 individuals have provided samples for this NIJ-supported study.

When the 145 volunteers tested during the first sample year were asked whether they had taken medicinal or recreational drugs within the past week, 72 percent said that they had. Scientists at Logan's research organization, the Pennsylvania-based Center for Forensic Science Research and Education, found that 38 of the 66 blood samples taken (58 percent) screened positive for "a common drug of abuse" (primarily cocaine) or a novel psychoactive substance — the term that investigators and researchers use to describe a designer drug.

Synthetic chemists in Asian laboratories primarily manufacture these drugs on a large scale, according to Logan. They are an emerging group of compounds in the designer drug movement that belong to the "bath salts" chemical family and "Molly," slang for "molecular," which originally referred to the stimulant and hallucinogen MDMA, and the proliferating synthetic cannabinoid, or "fake pot," market. "The recreational drug users are at the mercy of the clandestine dealers and manufacturers who supply this market," Logan said.

Many of the volunteers believed that they had purchased a specific designer drug; however, testing their samples revealed that they had ingested a different drug, Logan said. Knowing exactly what drug is being taken is a serious and ongoing problem in the designer drug market, and although most of the concertgoers said that they were aware of the problem, they insisted that the drugs they used were

different. "They trusted their dealers," Logan said, some of whom told their customers that the drugs were "Swedish research-grade materials."

Designer drugs typically come packaged as incense, potpourri or bath salts and are often labeled "not for human consumption." (Photo credit: Drug Enforcement Administration)

Of the 104 urine samples taken, more than 70 samples showed metabolites, or byproducts, of an array of drugs, including cocaine and several designer drugs. Metabolite identification is important because researchers have yet to link many of the metabolites directly to the parent designer drug; as a result, urine samples used in drug tests are inconclusive in determining specifically what a person has taken.

"With this research, we know what the parent drug is [because of the blood and oral samples], and then we can find the metabolites, which helps us develop better tests and drug screening approaches for death investigations, drug-facilitated sexual assault and impaired driving cases," Logan said. The research also "provides better information to emergency responders and medical toxicologists."

Logan's group is currently examining data from the second Miami sampling, which involved 250 participants, and is planning to return to the next Miami Ultra Music Festival. The researchers also want to investigate regional differences in drug use patterns and planned to take samples at the TomorrowWorld electronic dance festival in Chattahoochee Hills, Georgia. The researchers have built a library that links parent drugs to metabolites and that will eventually be available to the medical and forensic toxicology communities.

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Detecting Explosives With Microfluidics

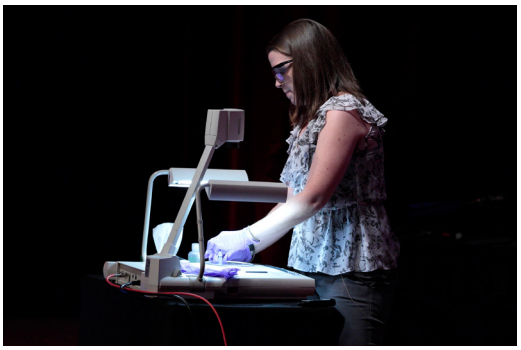
In an age of terrorism, the ability to detect improvised explosive devices or trace chemical elements from the explosives is critical. Explosive-detecting dogs and costly technology, such as ion mobility spectrometers, now form the front line for detecting explosives. Yet both the dogs and the technology are limited in their ability and require extensive training for those who use them.

Starting with the idea that a simple, small, inexpensive detector would be a more useful way to detect and identify explosives in the field, Florida International University chemist Bruce McCord and graduate student Kelley Peters developed a paper "chip" that, through capillary action, can test for five types of explosives. The postage stamp-sized chip consists of chromatography paper printed with wax-based ink in a design that looks like a child's outline drawing of a tree.

The chip, developed with NIJ support, is designed not only to confirm that an unknown substance is an explosive but also to indicate the exact type of explosive. The tree has five branches, each impregnated with a reagent that reacts to a particular explosive, McCord said. An investigator confronted

with a suspected explosive can take a small sample, place it in a vial filled with liquid — Peters used diluted nail polish remover — and then place the "root" of the paper chip into the liquid through a slot in the cap.

The liquid flows up the paper, McCord said, and the appropriate reagent reacts to the explosive and shows the reaction as a colored dot on one of the branches of the tree. The chip can detect both inorganic and organic explosives, including RDX, TNT, nitrites and nitrates. McCord said that he is developing a chip that identifies metallic powders found in metallic explosive fuels, as well as primer and gunshot residues.



Scientist Kelley Peters demonstrates the microfluidic chip during a TEDx talk at Florida International University. (Photo credit: Florida International University)

The idea for the paper chip came from more sophisticated medical microfluidic devices used as biosensors, McCord said. First responders, soldiers and others who might deal with explosives can easily carry the chip in their pocket. The chip can be used with minimal training, and because it consists primarily of paper, waxed ink and a reagent, it costs only pennies.

Working under another NIJ grant, McCord is developing a similar chip that could allow law enforcement officers to identify a variety of drugs in the field.

Reconstructing Fragmentary Skeletal Remains

When mass graves are unearthed, the bones are often commingled, presenting forensic anthropologists with the daunting problem of sorting and matching hundreds, sometimes thousands, of bone fragments in an effort to determine the number of dead, as well as their age and sex.

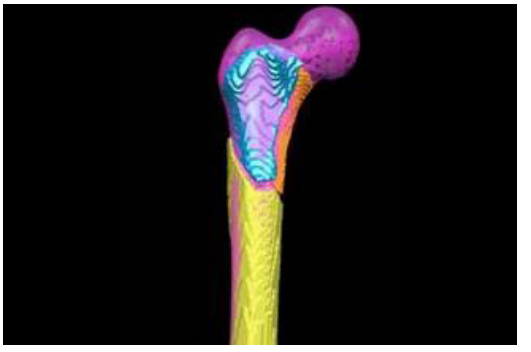
The current method of piecing together fragmented bones from multiple people relies on a geographical information system designed to store, analyze and manipulate spatial geographical data. The system is not specifically designed to analyze bone fragments and is not very efficient at doing so, said Mohamed Mahfouz, a biomedical and systems engineer with the University of Tennessee.

Mahfouz has been working for several years to develop software that will aid in the reconstruction of fragmented bones, with a particular focus on mixed fragments from multiple individuals. The first iteration of the software, developed with NIJ support, is ready for testing by the forensic and anthropologic communities, he said.

"Our goal is to make [skeletal reconstruction] easier for law enforcement and paleoanthropology — anyone, really — who is trying to reconstruct bones," Mahfouz said. "It is intended to help the anthropologist sort out and combine bone fragments and determine how a bone should look."

Mahfouz and his team designed the software to work on fragments of four skeletal elements: the femur, humerus, pelvis and skull. Fragments from a mass grave, for example, undergo CT or laser scanning, and then features are taken from each bone fragment by measuring surface roughness. Those features are matched to corresponding features on a "template" bone. The templates are derived from a database

of 2,061 scanned bone fragments from the Morton Shell Mound, an ancient ossuary in Louisiana that has yielded about 24,900 human bone fragments.



Software guides investigators by matching fragments to a template, in this case a human femur. (Photo credit: Mohamed Mahfouz)

A newly scanned fragment can be visualized and then compared to template bones until a match is found. Currently, the software compares fragments to the templates and suggests which bone the fragment is from (left or right femur, for example). The ultimate goal, Mahfouz said, is improving the software so that it can automatically scan, score and reconstruct fragments from commingled bones. The data involved in such a comprehensive analysis are enormous, and the process is too time-consuming to be practical at the moment, he said.

As Mahfouz works toward automation, he is making the current version of the software available "so people can use it, play with it and suggest improvements."

Finding Your Face in DNA

"We are not even at the end of the beginning," geneticist Richard Spritz said, as he described his progress toward identifying and understanding the genes that determine what a human face looks like. What you see when you look in the mirror, he said, "involves multiple genes, environmental factors and chance."

Spritz, program director of the University of Colorado's Human Medical and Genetics Program, is one of several NIJ-supported researchers at a number of institutions who are investigating different aspects of the human phenotype and trying to determine what segments in a person's DNA are responsible for physical appearance, including hair, eye and skin pigmentation, as well as facial features. Although the genetic determinants are enormously complex, the link between genes and appearance "is what your grandmother is responding to when she says you look like your father," Spritz said.

The forensic importance of being able to determine what a person looks like based on a strand of DNA is clear: A physical portrait of a suspect could be developed from DNA left at a crime scene; in the aftermath of fires or other destructive events, DNA from unidentifiable human remains could make them recognizable; and DNA from bone fragments could help identify individuals in mass graves.

Research to understand the underpinnings of phenotypes has progressed significantly in the past decade. Scientists can now use DNA to determine, with more than 75 percent probability, an individual's eye and hair color and heritage. But, as Spritz noted, while recreating a person's face may be the ultimate goal, getting there is far from ensured.

"There are some genetics that are relatively simple, like a disease," he said. "There are some that are intermediate, like height, and some that are unimaginably complex, like determining your facial shape [and features]."

At a research laboratory at Indiana University-Purdue University Indianapolis, geneticist Susan Walsh is refining DNA phenotyping to predict the quantitative (precise) color of eyes, hair and skin. Earlier work by Walsh and others identified the pieces of DNA known as single-nucleotide polymorphisms (SNPs), which drive pigmentation. "That is categorical identification:

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brown versus blue eyes, blond versus brown hair," she said. "Our goal now is real color definition, like the RGB value on Adobe Photoshop."

What spurred Walsh to try to identify real color from DNA was a request from molecular geneticist Turi King, who asked her to determine the eye and hair color of Richard III, whose remains were found under a parking lot in England in 2012. King used mitochondrial DNA to confirm that the remains were Richard III's and then turned to Walsh to determine which of the portraits of the king — all painted after he was killed in battle in 1485 — was the most accurate. Based on Walsh's phenotype analysis, King determined that one of the earliest paintings of Richard III, the 1510 "Arched-Frame Portrait," best matches the genetic information.

Geneticist Susan Walsh determined that Richard III's DNA phenotype information most closely matched this 1510 portrait of the king. (Photo credit: *Richard III,* c.1510-40 (oil on panel), English School (16th century)/Society of Antiquaries of London, Bridgeman Images)

"We were still dealing with categories [of color], because we're not at the quantitative level yet," Walsh said of her determination of Richard III's hair and eye color. "But [King] wanted something physical to see, and that's what spurred me to move toward quantitative so strongly, because I could always say to someone 'blue' or 'blonde,' and they would say, 'I need to see this physically.' So that is what I'm working on now. I want to produce that result."

Walsh has gathered DNA phenotype data from 2,000 people in Ireland, Greece and the United States and is currently collecting data from another 3,000 people from the same countries to create a phenotype-genotype database and prediction model. For forensic purposes, she would like to be able to start with a "blank person" and, using DNA, determine the quantitative eye, hair and skin pigmentation.

Yale University geneticist Kenneth Kidd, another NIJ-supported researcher, is focused on using DNA to determine an individual's ancestry. Kidd has developed a panel of 55 "ancestry informative SNPs" (AISNPs), which divide people into eight geographical regions, such as Europe, East Asia and the Pacific. DNA from a bone fragment found in Vietnam, for example, could be screened against the AISNP panel to determine whether the person was Asian or a white North American. If that person were African-American, however, the results could come back as Ethiopian because that is a mix of European and African genes, Kidd said.

Kidd is currently expanding the AISNP panel to include two more geographical regions, and he expects the work to continue far into the future. Like Spritz, Kidd noted, "With the sort of research I'm doing, I'll never be finished."

About the Author

Jim Dawson is a forensic science writer with Palladian Partners, Inc.

For More Information

To read more about NIJ's forensic science research and development projects, go to NIJ.gov, keywords: forensic science.

This article discusses the following grants:

- "Computerized Reconstruction of Fragmentary Skeletal Remains for Purposes of Extracting Osteometric Measurements and Estimating MNI," grant number 2011-DN-BX-K537.
- "Paper Microfluidic Systems for Rapid and Inexpensive Presumptive Detection of Drugs and Explosives," grant number 2012-DN-BX-K048.
- "Aptamer-Based, Exonuclease-Amplified, Paper Device for Point of Collection Screening of Cocaine and Methamphetamine in Oral Fluid," grant number 2013-DN-BX-K032.
- "Identification and Prevalence Determination of Novel Recreational Drugs and Discovery of Their Metabolites in Blood, Urine and Oral Fluid," grant number 2013-DN-BX-K018.
- "Genetic Analysis of Facial Shape and Appearance," grant number 2013-DN-BX-K005.
- "High Resolution SNP Panels for Forensic Identification of Ancestry, Family, and Phenotype," grant number 2013-DN-BX-K023.
- "Improving the Prediction of Human Quantitative Pigmentation Traits Such as Eye, Hair and Skin Color Using a Worldwide Representation Panel of US and European Individuals," grant number 2014-DN-BX-K031.
- "Continued Development of FROG-kb: A Forensic Resource/Reference on Genetics Knowledge Base," grant number 2014-DN-BX-K030.

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