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Without a Trace?
Advances in Detecting Trace Evidence

Shards of glass are found at the scene of a hit and run. It's the same type of glass used to make most standard headlights.

A single hair might belong to a missing woman, but it is coated with conditioner, making microscopic analysis impossible.

Investigators at the site of a plane crash search for minute quantities of explosives in the wreckage.

At the scene of a rape and murder, officers hope to find blood or semen from the assailant.

Currently, law enforcement has no accurate way to match the glass shards or coated hair to known samples, and locating tiny particles of explosive material or body fluids might be difficult or impossible. But all that's about to change, as new and improved techniques for detecting and distinguishing trace evidence—minute quantities of materials such as blood, chemicals, fibers, glass, hair, plant material, or plastics—are very close to being added to the law enforcement arsenal.

Connecting a person or object to a specific crime scene is often essential to proving guilt or innocence. Developing such a link is frequently based on identifying and comparing trace evidence. Because trace evidence samples can look similar and the environments where they are found are often complex, identifying unique characteristics and establishing a link can be difficult. Older techniques often cannot distinguish such evidence due to these challenges.

New technologies for trace evidence may help eliminate many of these obstacles, allowing more trace evidence to be found and identified. Here are four of the most promising new techniques.

Distinguishing Glass Evidence

On a small Caribbean island, a witness called the police to report seeing a body on the side of a road. A woman walking home from work shortly after midnight was apparently struck by a vehicle. Her death might have been prevented had the driver stopped to provide medical assistance instead of leaving the scene. The accident became a felony hit and run.

A local constable was called to the scene. Among other items, he recovered nine large pieces of glass that appeared to come from a car headlight.

Eleven days later, local officials identified a suspect. No body fluids were found on the suspect's car, but the front fender showed signs of recent damage: a broken headlight and pieces of glass lodged inside the bumper.

Island police shipped the evidence to the Miami-Dade Police Department Crime Laboratory for analysis. There Dr. José Almirall was working on ways to analyze glass samples using a process called inductively coupled plasma-atomic emission spectroscopy (ICP–AES). He was asked to see if there was a connection between the glass fragments found at the crime scene and the broken glass found on the suspect's car.

Analyzing the elements of glass specimens helps to locate the original source of glass pieces. The elements that make up headlight glass are different from those in other glass products. ICP–AES effectively measures the various elements to distinguish among auto headlights.

Dr. Almirall first used a conventional approach, measuring and comparing the refractive index (RI) properties of the glass recovered from the crime scene with the glass fragments from the suspect's car. The problem with this method—the primary one used by crime labs—is that automobile headlights all have similar refractive indexes, making it difficult to distinguish among them. Although Dr. Almirall found an RI match, such a match does not weigh heavily as evidence in court when it involves auto headlights.

The lab then put the glass fragments through ICP–AES analysis. A quantitative analysis of the fragments found that the glass pieces recovered from the street and those from the suspect's car were indistinguishable from one another. At a preliminary hearing on the hit-and-run charges, Dr. Almirall testified that the ICP–AES analysis showed strong evidence of an association between the glass fragments. Just days before the trial, the prosecutor and defense reached a plea agreement.

Dr. Almirall, now associate director of the International Forensic Research Institute, recognizes the need for highly discriminating techniques in the analysis of glass evidence. He collaborates with Dr. Douglas Duckworth of Lockheed Martin's Oak Ridge National Laboratory. They have since developed an even better method for analyzing glass elements using a process called inductively coupled plasma-mass spectrometry (ICP–MS).

ICP–MS combines enhanced sensitivity with a multielement capability. This higher level of glass analysis is a valuable tool for distinguishing among all types of glass, including cookware, float glass from windows, headlights, and leaded glass. ICP–MS's high level of sensitivity allows for the analysis of very small fragments.

The two scientists are incorporating the analytical techniques and data generated from ICP–MS into a practical application for the forensic lab. They are developing a large database of trace element concentrations using ICP–MS that will be able to rank the strength of an association between known and questioned glass samples. Research continues on ICP–MS, and its use is encouraged through interlab validation, publication, and training.

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HOW DOES STATIC SIMS WORK?

Secondary ion mass spectrometry (SIMS) can be divided into two operational types: dynamic and static. The semiconductor industry has used dynamic SIMS for years, mainly for analyzing bulk metals. Static SIMS provides information about organic compounds "adsorbed" onto a surface. (Adsorption is the binding of a substance on the surface of another and is distinguishable from total absorption.)

The principle behind static SIMS is simple: the trace sample is bombarded with a high-energy atom. The term "static" indicates that the degree of surface bombardment is low enough so the chemical composition of the surface is not changed. Intact molecules, their fragments, and atoms are "sputtered" into a gaseous state from the surface. Some fraction of these particles are charged, or ionized, and can then be measured using a mass spectrometric detector. The detected masses help to identify the surface chemistry of the trace evidence. For example, an ion at mass 550 indicates a hair conditioner chemical and is easily differentiated from an ion having a mass of 270, which is derived from heroin.

Identifying Chemical Composition

Forensic scientists continue to search for new ways to find chemical residues on clothing, fingernail, hair, and skin samples. Such residues may provide a link between a suspect and a chemical weapon or agent.

Many chemicals are designed to endure and to absorb into substances, but detection can still be difficult. Research conducted by scientists at the Idaho National Engineering and Environmental Laboratory (INEEL) focuses on the persistent nature of chemicals. Static secondary ion mass spectrometry (static SIMS) is used to distinguish trace chemicals and residue on various materials. The goal is to find links between suspected sites and possible offenders. Static SIMS may possibly change future methods for detecting chemical residues.

Chemical characterization of trace evidence is not always successful. Conventional analysis attempts to break down the sample into separate chemical entities—simplifying identification, but destroying the sample in the process. With this method, the samples tend to be small and, therefore, analyses are often not precise enough to detect the chemicals involved.

Static SIMS uses a different approach. It identifies the chemical composition of the *surface* of extremely small trace evidence samples—as small as 1/10,000 of an inch. This method generates atomic and molecular information from only the top-most molecular layer of the sample, leaving it largely intact for further analyses.

INEEL scientists conducted tests using static SIMS in combination with pattern recognition techniques. They were able to differentiate a wide range of coating samples by manufacturer, and often by specific coating product. Although the samples looked similar, the chemical makeups of their various coatings were considerably different.

Static SIMS shows real potential for distinguishing chemicals in forensic samples well beyond current analytical approaches. This technique differentiates and identifies specific samples of physical trace evidence, including coating materials, fingernail polish, and paint. For example, it provides a wealth of information about chemicals found on hair and fiber samples.

SIMS and related techniques may be used more frequently once small, easy-to-use SIMS instruments are developed. Static SIMS may be applied more widely in the near future as the cost of analysis decreases and the technique becomes simpler to use.

DETECTING AND ANALYZING CHEMICAL CONTAMINANTS ON HAIR AND FIBER

Idaho National Engineering and Environmental Laboratory (INEEL) researchers did studies using various static secondary ion mass spectrometry (SIMS) instruments. They used ion trap SIMS to distinguish trace hair samples using consumer chemicals as identifiers. Chemicals found in hair conditioning products produce distinctive chemical signatures, allowing the identification of hair samples based on the product used. SIMS is unaffected by the presence of hair dyes, which complicate microscopic techniques.

Scientists typically characterize forensic human hair samples using a microscope. The presence of colorants and chemicals commonly present on human hair defeats this method. SIMS takes advantage of the presence of these chemicals to improve identification.

Static SIMS easily detects illegal drugs such as cocaine and heroin on the surface of single synthetic fiber samples. It can detect environmental contaminants as well—for example, insecticides or pinacolyl methylphosphonic acid, the principal eroding product of the nerve agent Soman (GD). This technique can be used to look for the presence of nerve gas, perhaps in a suspected terrorist attack. INEEL researchers recently used SIMS to assess the erosion of the nerve agent VX on concrete surfaces. Changes in the chemistry of samples exposed over time to VX are key to determining the history of exposure of a particular area or crime scene.

Collecting and Analyzing Explosives

American Airlines flight 587 left John F. Kennedy International Airport early on November 12, 2001. Shortly after takeoff, the plane crashed into a nearby neighborhood, killing all 260 aboard and 5 people on the ground. Just 2 months after the Nation's worst terrorist attack, the crash triggered fears that another assault had been perpetrated against the United States.

For weeks, the Nation anxiously awaited word on what caused flight 587 to break apart. Months later, investigators still had not found any evidence of an inflight explosion or fire indicating sabotage. Onsite explosives analysis could have detected bomb residue and quickly reduced fear—had it been available.

Large bombing scenes pose special challenges for detecting and identifying small quantities of explosives residue among large amounts of debris. Dr. Michael Sigman, a researcher at Oak Ridge National Laboratory, looks for ways to refine and validate technology that allows rapid analysis of organic explosives at a crime scene.

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A new method of collection allows trace evidence to be gathered using dry, durable Teflon® surface wipes. These wipes offer

WHAT IS THERMAL DESORPTION?

Scientists use thermal desorption to transfer explosives residue from a Teflon® wipe into a special type of tubing called a gas chromatography column. The wipe is heated to well above room temperature. At the higher temperature, the organic explosives become a gas and are gently swept onto the gas chromatography column. The gas chromatography column is at room temperature, so the explosives' vapors condense onto the walls at the entrance to the column for later separation and analysis.

Portable gas chromatographs or hand-held ion mobility spectrometers, already commercially available, could be adapted to bring dry sampling directly to a crime scene. This portability is needed because environmental factors may speed up sample decomposition.

several advantages over the many different physical and chemical techniques traditionally used to collect and analyze chemical evidence from blast debris:

- Teflon® is shred resistant, making it a more effective choice for gathering samples of trace evidence from rugged or jagged surfaces than conventional cotton wipes.
- Dry-sampling is preferable in cases where pieces of debris are too large to use solvent extraction methods effectively or to conduct microscopic investigations.
- Teflon® surface wipes can be used for sampling explosives residue from other surfaces, including clothing, hands, and luggage.

One commonly used method of collection involves extracting debris with organic solvents and water. The problem with this method is that it can also extract other substances, such as oils or paint. As a result, the sample must be "cleaned up" before lab analysis can take place. Thus, samples gathered with organic solvents typically require lab-based processing and all but prevent onsite analysis.

Teflon® wipes offer a better alternative. When an explosion occurs, traces of some chemical components from the explosive device do not dissipate. Some components vaporize and can be found condensed on the debris. Evidence collected using dry-surface wipes is transferred into a special tube called a gas chromatography column by means of thermal desorption for analysis. (See "What Is Thermal Desorption?") This simple method can easily and inexpensively be adapted for use in forensic labs, which generally already have gas chromatographs.

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Locating Body Fluids and Fingerprints

In April 1999, a woman was found dead in the back seat of her car. Albuquerque police suspected a sexual assault. The assailant left the woman's body to decompose in a closed car in the hot New Mexico sun for several days, making it difficult for investigators using conventional methods to locate possible traces of semen.

The investigators turned to Colin Smithpeter, a scientist who worked nearby at Sandia National Laboratories and who had devel-

USING CLU FLUORESCENCE RATHER THAN CONVENTIONAL FLUORESCENCE

Semen Stains

The advent of DNA technology and databases has made semen stains found at the scene of a sexual assault the most valuable piece of evidence. The problem is that the semen stains must first be located and sampled.

The conventional method—fluorescence detection—illuminates the crime scene with light from a high-intensity lamp while an investigator views the area through optical filter glasses. This method has a number of drawbacks. Although semen fluoresces, the light it emits is weak compared to surrounding room light, thereby hindering detection. If the crime scene is outdoors, investigators must wait until nightfall to use the technique. If the crime scene is indoors, investigators must turn off all lights and black out the windows to maximize the method's effectiveness. This takes time and effort and increases the possibility that investigators will contaminate the area.

Moreover, when blacking out a room, many other substances besides semen fluoresce, such as food spills and animal urine. In order to complete their search in a reasonable amount of time, investigators often collect all questionable fluorescing materials. Thus, detecting and documenting semen stains become the task of technicians back at the crime lab.

It would be best to photograph potential evidence at the crime scene. However, setting up a camera is time consuming, and investigators often do not have enough time for this step. If the police do photograph evidence at a crime scene, there is no guarantee of any evidentiary value until the film is developed.

The use of a Criminalistics Light-Imaging Unit (CLU) at the crime scene offers significant improvements over conventional approaches. CLU allows investigators to find fluorescing evidence under normal lighting conditions and to easily view and highlight images of suspected evidence at the crime scene. Furthermore, CLU greatly reduces the chances of crime scene contamination.

Blood Spatter Patterns and Trails

Investigators often reconstruct a crime using blood trails and spatter patterns, both of which are difficult to see on dark surfaces. Police commonly spray the chemical reagent luminol on suspected areas. When luminol encounters blood, it reacts and phosphoresces, giving off a faint glow.

But luminol has a number of limitations. First, blood treated with luminol produces such a faint glow that it is difficult to see and photograph. Investigators must either wait for or create a dark environment to take the needed photos. Second, the reagent occasionally gives false reactions, causing the possible loss of several genetic markers. Third, luminol causes latent and possibly bloody impressions to smear, and it makes some diluted stains unavailable for further analysis. Fourth, luminol is cumbersome and expensive to use on large areas. Visualizing blood trails and spatter patterns through CLU's reflectance-imaging capability will reduce the need for luminol use.

Fingerprints

CLU's fluorescence reflectance capability may allow fingerprints to be found without pretreatment. Conventional fingerprint detection involves pretreating evidence and using physical and/or chemical development processes. In some cases, these processes are ineffective, require additional illuminating equipment, and involve safety risks.

Advances in technologies for detecting and distinguishing trace evidence are finding their way to police precincts and forensic labs. These improvements do not guarantee courtroom success, of course, but they do hold great promise for speeding up evidence collection, limiting contamination, and easing analysis. By generating stronger evidence, these more precise forensic tools will benefit every facet of law enforcement.

oped the Criminalistics Light-Imaging Unit (CLU). This camera is able to uncover the type of evidence needed by police working on cases like this one.

CLU is a multispectral imaging system that uses various colors of light to view the substance or structure being examined. It can locate body fluids at crime scenes under normal lighting conditions. By using a strobe lamp, signal processing, and improved optics, CLU rejects surrounding light and thereby improves both the sensitivity and specificity of the area being viewed. CLU is five times more sensitive than current fluorescing methods.

Smithpeter teamed with Catherine Dickey, a forensic scientist on the Albuquerque police force, to examine the woman's body. Using a conventional blue light and tinted goggles, Dickey searched the body for evidence, but was unable to find any fluorescing traces of semen. Smithpeter used his CLU and found three very small stains on the skin. A lab test showed that one of the stains was dried semen. The evidence was sent to the New Mexico State crime lab for DNA analysis. Although the woman's killer remains at large, investigators now have something tangible on which to build a case.

Smithpeter's camera may be able to detect other types of evidence through a process called reflectance imaging. This technique uses the visible rather than the ultraviolet spectrum of light, allowing for the location and identification of blood evidence on dark surfaces. CLU also can detect untreated fingerprints on transparent, dark, and multicolored surfaces.

The camera's video-recording feature works like a camcorder. This allows investigators to view and record the entire search process. Law enforcement personnel can produce individual images of possible evidence for presentation in court.

Sandia National Laboratories is working to refine the CLU prototype for law enforcement fieldwork. Commercial cameras currently used by local law enforcement do not include the reflectance-imaging capability. Scientists are working on a handheld version of the camera for crime-scene investigators so they can do both fluorescence and reflectance imaging.

Benefits for Law Enforcement and the Courts

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