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INDUSTRY FOCUS

Forensics & Toxicology

An exclusive collection featuring top-tier articles, visionary experts, and essential industry insights

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TABLE OF CONTENTS

Foreword

Welcome to the latest edition of our Industry Focus eBook, where we spotlight the ever-evolving disciplines of forensics and toxicology. As scientific innovation continues to enhance investigative capabilities, forensic science is embracing new tools and techniques that push the boundaries of accuracy, reliability, and speed.

Integrating next-generation technologies is reshaping how investigators uncover the truth, from the crime scene to the laboratory. In Unlocking the Future of Forensics, we explore the emerging trends and breakthroughs that are setting new standards in the field. The intersection of biology and material science comes into focus in Sensors Monitor Soft Tissue Desiccation for Forensic Applications, offering novel insights into postmortem interval estimation.

Pollen may not be the first thing that comes to mind when thinking about crime-solving, yet The Use of Forensic Palynology in Solving Crimes highlights how microscopic clues can lead to significant breakthroughs. Artificial intelligence, too, is proving to be a powerful ally. In AI Discovers Intra-Person Fingerprint Similarity and What Role Does AI Play in Modern Forensic Science?, we explore how machine learning transforms fingerprint analysis and case assessment.

The fusion of neuroscience and digital tools takes center stage in AI Tool for Forensic TBI Investigations, where we explore how AI assists in identifying traumatic brain injuries. Spectroscopy-based methods continue to gain ground in forensics, with Analyzing Forensic Samples with Raman Spectroscopy and Advancing forensic analysis and crime scene investigation with FTIR demonstrating how chemical analysis is vital in evidence processing.

Finally, How Forensic Labs Investigate Automobile Paint Chip Layers examines how seemingly mundane traces can yield critical leads in criminal investigations.

This eBook combines the latest advances and applications in forensic science, offering a compelling look at how innovation drives justice forward. We invite you to dive in and discover how science is making our world brighter and safer.

Analyzing Forensic Samples with Raman Spectroscopy

Material identification and analysis are crucially important within the forensic analysis field. Similarly to how there is no pre-determined set of materials that comprises all forensic lab analytes, no single technique is always utilized for the identification and examination of samples.

However, irrespective of sample form, Raman spectroscopy offers useful information concerning the molecular structure of various materials, such as paints, powders, makeup, and fabric.[1,2]

To further increase the Raman spectroscopy's range of analytical abilities, the Thermo Scientific™ DXR3 Flex Raman Spectrometer provides many sampling modes to capture rapid, high-quality data on any quantity of samples.

This includes a bulk material "macro" sampler, a single-point microscope accessory with fiber optic probes, and a manual stage. The three sampling modes provide benefits depending on the samples' form, size, and shape, but when used in combination, they provide a comprehensive range of sampling capabilities.

To construct a representative image of the utilization of distinct sampling modes on various sample types, a selection of various sample materials of interest was analyzed. The samples and their analysis goals include:

- The quantification of the distribution of mixed powder samples
- The identification of distinct brands of duct tape
- The identification of distinct brands and shades of lipstick, especially *in situ* on a cup[3]
- The identification of powdered particulate dissolved in alcohol

The following table presents an overview of the samples tested with each sampling mode. A check mark denotes a suitable analysis method for the given material.

Table 1. Source: Thermo Fisher Scientific – Chemical Analysis

Sample Type	Micro Stage Sampler	Macro Sampler	Fiber Probe
Mixed Powders	✓	✓	✓
Lipstick in situ	*	*	✓

Particulate Dissolved in Alcohol		✓	✓
Duct Tape	✓	✓	✓

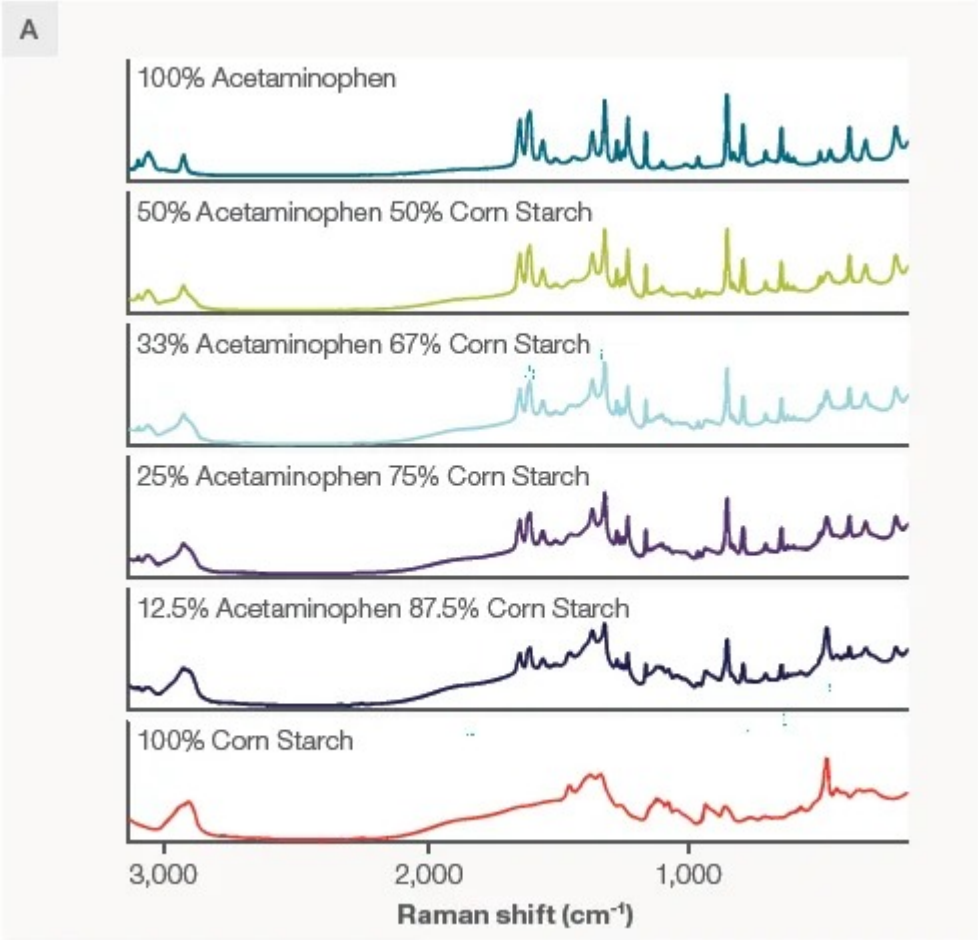
**A good Raman signal can be achieved with the technique but doing so requires an extra step of sample preparation, involving removing a small sample of the lipstick.*

Figure 1. *A) A view of the DXR3 Flex Raman Spectrometer with labelled features. B) The microscope sampling accessory. C) The macro sampling accessory. D) The fiber probe sampling accessory. Image Credit: Thermo Fisher Scientific – Chemical Analysis*

Quantification of Mixed Powders

These samples are representative of the broader forensic demand for the identification of unknown drugs and to identify and quantify cutting agents. Specific peaks in the Raman signal of a mixed powder can be utilized to identify components within the mixture positively.

Various ratios (by volume) of corn starch and acetaminophen are displayed in Figure 2, alongside spectra of pure corn starch and acetaminophen for reference.



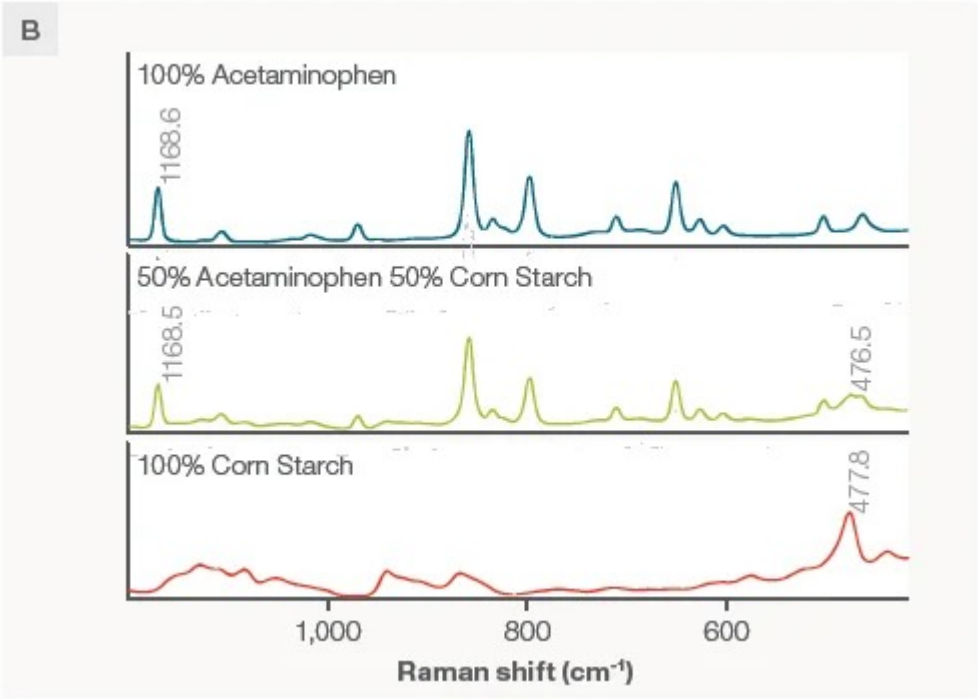


Figure 2. *A) Spectra of various acetaminophen/corn starch mixtures. Spectra were collected using a 785 nm laser and the macro sampler with powders in a glass vial. Each spectrum is the average of 4 collections to ensure representative sampling and an excellent signal to noise ratio, taking about 4 minutes per scan. B) The peaks of interest used to build the calibration. Image Credit: Thermo Fisher Scientific – Chemical Analysis*

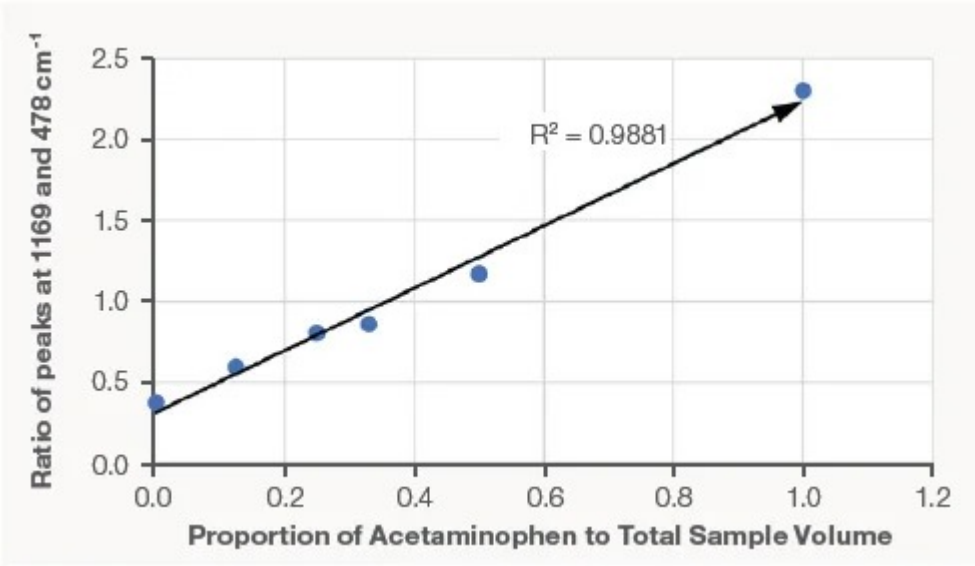


Figure 3. *A calibration plotting the volume percentage of acetaminophen to the peak intensity ratio of the 1169 acetaminophen peak and 478 corn starch peak. The result is highly linear with an R^2 value of 0.9881. Image Credit: Thermo Fisher Scientific – Chemical Analysis*

This calibration curve can subsequently be utilized for the quantification of the ratio of

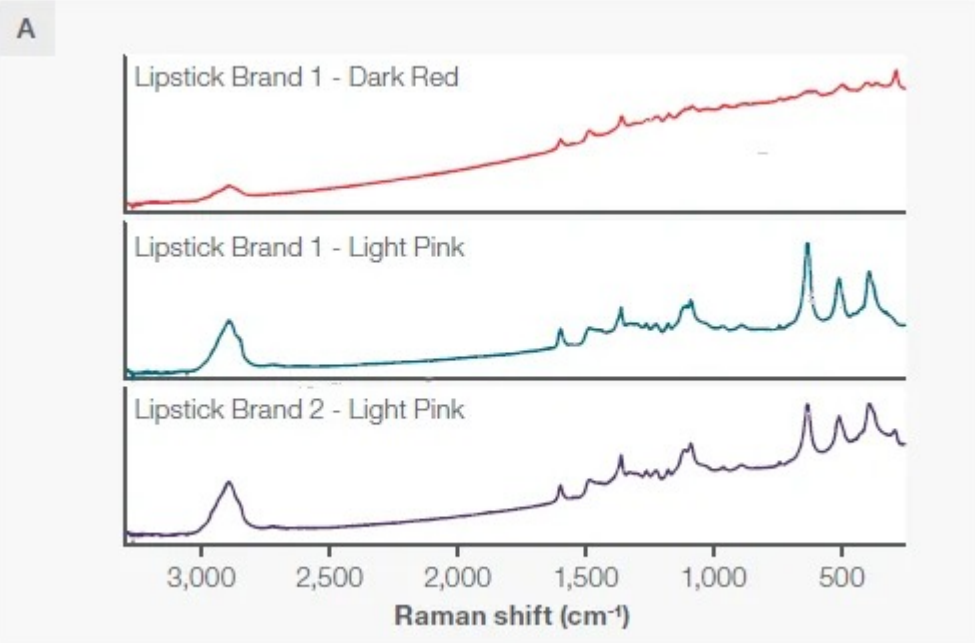
acetaminophen to corn starch from any powder mix based on the Raman spectrum.

The high R^2 value of the linear fit suggests a very strong correlation in the samples. All three modes work well with these samples, however, the macro sampler has the greatest spatial averaging, making it well-suited for bulk and averaged sampling.

Identification of Lipstick *in situ*

Raman spectroscopy is advantageous compared to many other methods because of its non-destructive nature and minimal sample preparation requirements.

To further leverage this, fiber optic probes enable the sampling of large objects that cannot easily be analyzed using traditional modes. The identification of lipstick brands left on the surface of a cup are representative of this.



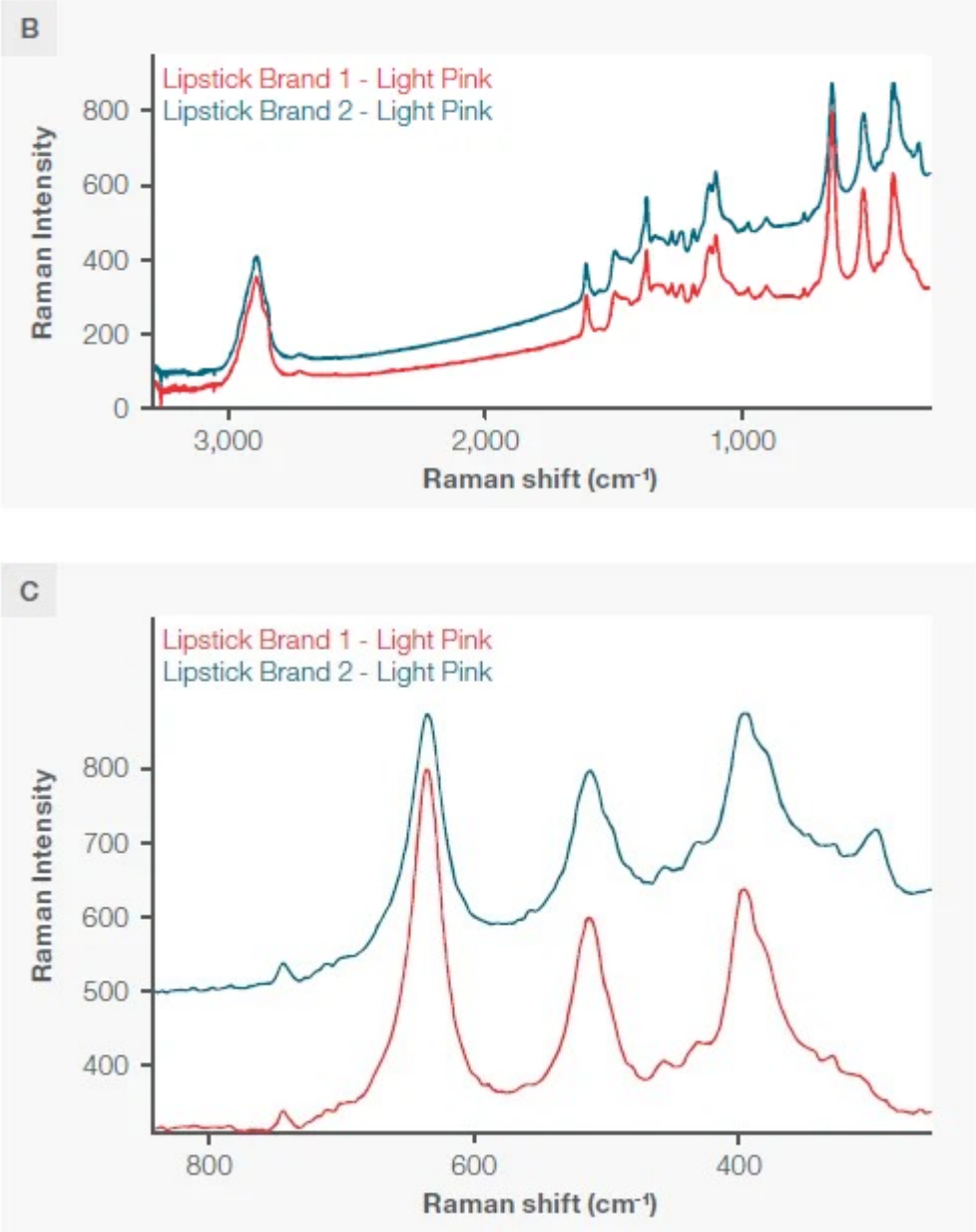


Figure 4. *A) Three distinct lipsticks, two of the same brand and two of different brands but the same shade. B) The two matching shades displayed on the same y axis scale. C) A zoomed-in view showing the spectral differences if the main peaks. All spectra were collected with a 785 nm excitation laser and fiber probe accessory. Each spectra had the background Raman spectrum of the cup subtracted. Image Credit: Thermo Fisher Scientific – Chemical Analysis*

Figure 5. *An in situ measurement of lipstick on a cup through the fiber probe accessory. Image Credit: Thermo Fisher Scientific – Chemical Analysis*

Despite the two identical lipstick shades from different brands exhibiting nearly identical peak positions (except for the peak at 300 wavenumbers), they have distinct and measurable peak ratios, particularly in the three large peaks at 396, 514, and 637 wavenumbers, as well as a unique peak at 297 wavenumbers.

All three sampling modes can differentiate between the three sampled lipsticks. However, the fiber probe facilitates non-destructive *in situ* measurements on materials that do not easily fit under a microscope or on the macro sampler—in this case with measurements taken directly on a cup.

Identification of Additives in Drinks

Raman spectroscopy enables the identification of common forensic liquids (including alcohols) as well as trace additives in those liquids, which enables the identification of "spiked" drinks.

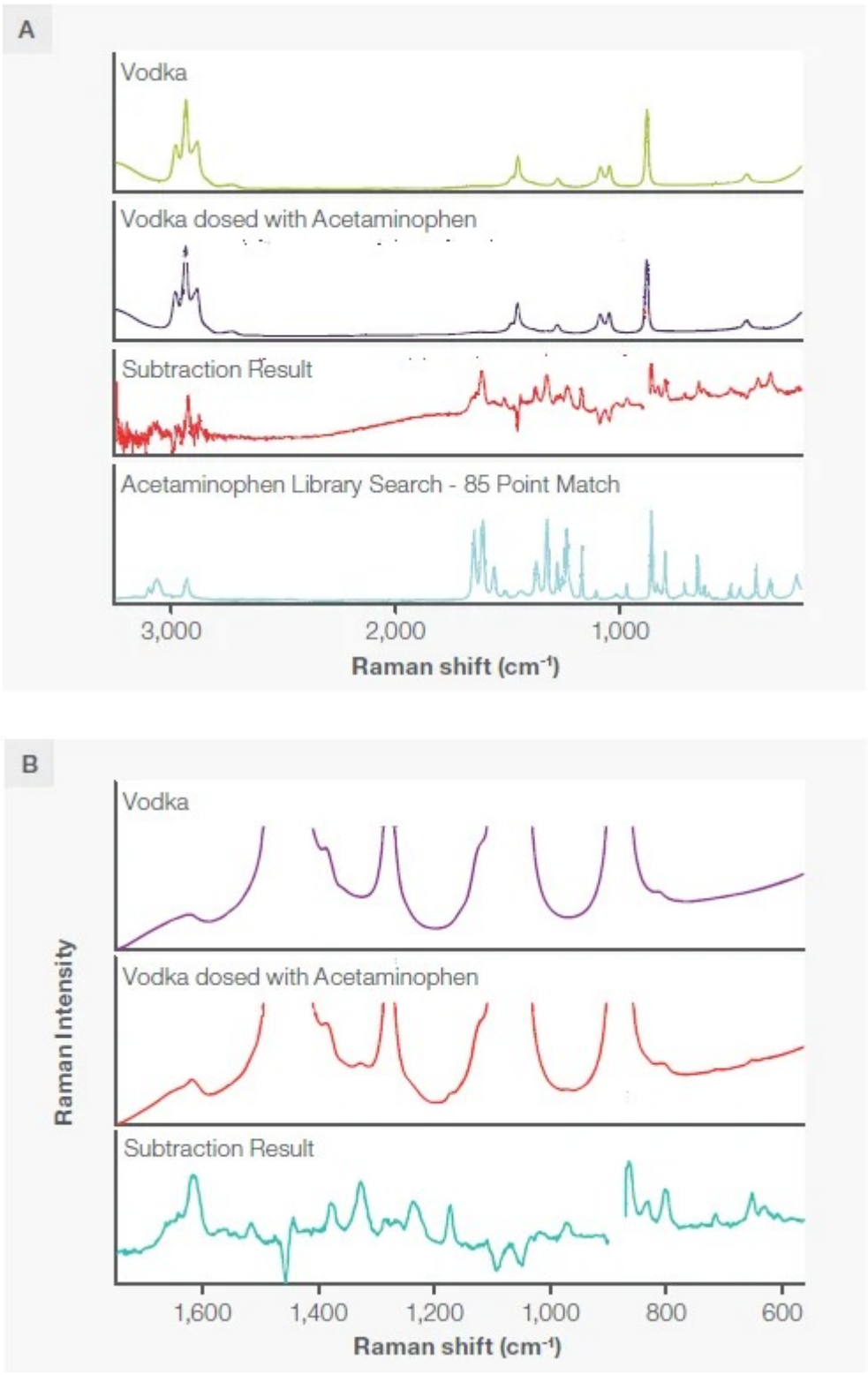


Figure 6. *A) A comparison of unadulterated vodka and vodka adulterated with acetaminophen. Although there is no obvious difference between the Raman spectra of two, a subtraction of the two reveals underlying and identifiable acetaminophen peaks, matched with a library spectrum of acetaminophen. B) A slight rescaling of the y axis reveals the presence of these peaks, readily visible in the rescaling at 650, 712, 967, 173, 1327, and 1618 wavenumbers. All spectra were collected with the macro sampling accessory at 785 nm. Note that the blank in the "Subtraction Result" spectrum is the location of a negative peak omitted to optimize the field of view. Image*

Credit: Thermo Fisher Scientific – Chemical Analysis

Liquid samples (in glass containers for these measurements) respond extremely well to the bulk sampling methods of the macro sampling and fiber probe accessories.

Trace liquids may be measured as individual drops under a microscope, but the small volume may impact the overall Raman signal, particularly when attempting to identify a small amount of additive.

Identification of Brands of Duct Tape

The identification of specific material is highly important, particularly if it can differentiate between different brands of the same material. Different brands of duct tape were sampled on the outside, waterproofed surface.

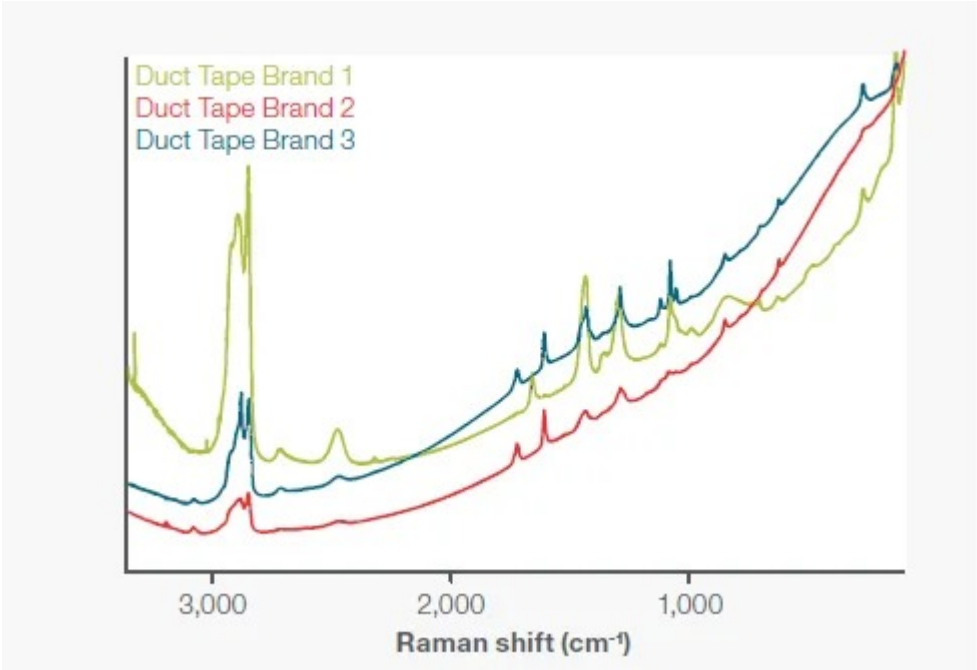


Figure 7. *Spectra for three different brands of duct tape. All three spectra were collected with a 785 nm laser and the microscope stage accessory to provide accurate spatial sampling. Brands 2 and 3 have matching peak locations but very discernable peak height ratios unique to their molecular structures. Image Credit: Thermo Fisher Scientific – Chemical Analysis*

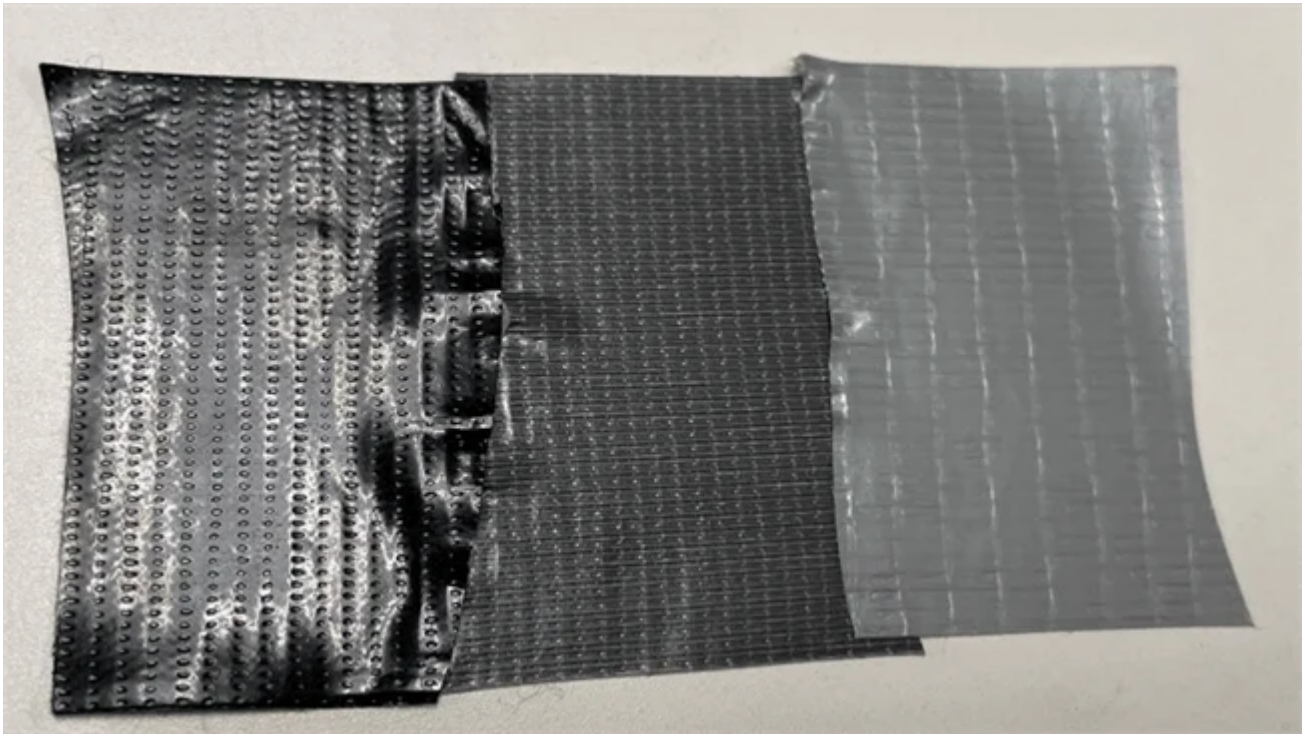


Figure 8. *Shown here are the three sampled duct tapes with different coloration. From left to right: Brand 1 is described as an adhesive with waterproof coating, Brand 2 is a rubber-based adhesive with all-weather shell, and Brand 3 is a rubber adhesive with waterproof backing. Image Credit: Thermo Fisher Scientific – Chemical Analysis*

Almost all duct tapes are available in several colors and have indistinguishable surfaces. This makes the chemical identification of distinct structures in the formulation of each brand crucial to forensic identification.

All three Raman sampling modes can differentiate between the brands of duct tape, with the best fit being dependent on the shape and size of the sample undergoing analysis.

For example, trace tape fibers are best analyzed under the microscope accessory, while the analysis of tape residue works best with the free motion capabilities of the fiber probe.

Conclusion

The DXR3 Flex Raman Spectrometer can analyze numerous types of potential forensic samples due to multiple sampling accessories which can be changed by the user within minutes.

Although the spectra collected in this study utilized a 785 nm excitation wavelength to address the inherent fluorescence of some samples, the spectrometer is compatible with four

different excitation laser wavelengths, namely 455, 532, 633 and 785 nm.

Shorter wavelengths lead to greater Raman intensity for samples that have lower signal-to-noise ratios and lasers can easily be swapped by the user (within minutes) in the system.

With its compact footprint, the DXR3 Flex Raman Spectrometer is an ideal research-grade instrument to transport between laboratory spaces, enabling easy interfacing between Raman spectroscopy and other analytic forensic methods.

References and Further Reading

1. https://doi.org/10.1016/j.trac.2017.12.003
2. https://doi.org/10.1016/j.forsciint.2010.11.012
3. https://doi.org/10.1016/j.forsciint.2013.07.007

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Unlocking the Future of Forensics

Forensic science is a multidisciplinary field that allows the analysis of different biological data when solving a crime. The complexity of the data, such as DNA, RNA, protein, and epigenetic markers, requires advanced processing supported by computers.[1]

The use of CRISPR-Cas technology, which has revolutionized the field of biotechnology through its precise therapeutic application, has shown potential for forensic DNA analysis.[2]

Additionally, emerging technologies, including artificial intelligence, machine learning, computer vision, microfluidic chip technology, and advanced spectroscopy, have enabled advancements in forensic science in how data is analyzed and interpreted.[1,3,4]

Forensics" />*Image Credit: Drazen Zigic/Shutterstock.com*

Exploring CRISPR in Forensics

Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) sequences were discovered in several bacteria species including *E.coli*. Interestingly, CRISPR relies on the Cas9 enzyme, which can target any DNA sequence with the right programming and its genome editing applications hold significant implications for many diseases.[2]

A CRISPR-dependent technique was found to be more beneficial compared with Next Generation Sequencing (NGS) techniques for assay design and sequencing efficiency. Due to this, it can be useful in forensic science as many samples at crime scenes are found to be degraded, carrying fragmented DNA, which can be resolved with CRISPR-Cas9 technology using DNA repair and replication.[2]

Additionally, CRISPR-Cas9-dependent PCR-independent techniques can be used when analyzing complex DNA mixtures that consist of multiple DNA profiles, which are usually a significant challenge for forensic scientists.[2]

CRISPR technology can be used to link each sequence to a specific DNA molecule to identify various DNA profiles and find the true suspect.[2]

Another benefit of using CRISPR technology over traditional PCR technology is the lack of PCR artefacts, which is usually a concern and can impact the results.[2]

Unleashing the Power of AI

AI and machine learning have innovated many fields and have the potential to transform forensic science in the modern era, as the use of digital evidence in criminal investigations has risen, as well as cybercrime.[5]

Advanced technology is required to collect and analyze digital evidence during investigations, and AI and machine learning may enable the processing of significant amounts of data quickly and efficiently to detect critical evidence.[5]

AI can be used in forensic science to improve the performance of experts and overcome subject bias limitations of traditional approaches.[6]

It can also be used to collect new information, recognizing patterns from large datasets, reduce human errors and subjectivity. AI can provide tools that reinforce the scientific method, providing an alternative opinion on a crime case, leading to faster crime scene analysis and more efficient workflows.[6]

Training AI forensic tools to recognize specific patterns and anomalies that may go undetected by the human eye can be beneficial for finding concealed evidence, enabling more accurate and reliable results.[5]

Convolution Neural Network (CNN) is an example of a deep learning algorithm that is used in

pattern recognition and image processing, with the main benefit of detecting critical features without requiring any human supervision. This algorithm can be used in forensic science for many applications, including determining age or gender.[7]

Additionally, implementing three-dimensional CNN may improve the morphology of facial soft tissues when attempting facial reconstruction from a skull, a goal currently limited by available technology in forensic science.[7]

Exploring Other Emerging Technologies

Other emerging technologies such as microfluidic devices, may also provide benefits for forensic DNA analysis, including decreasing the risk of contamination, reducing time on analysis, and offering more direct application at the crime scene.[3]

Microfluidic chip technology is revolutionary for medical applications, such as for point-of-care use. Interestingly, it can also be used for forensic science, with this innovative technology being used to analyze trace evidence of biological samples that may contain human DNA at the crime scene.[3]

Using microfluidic chip technology for this purpose may have significant impact in forensic science, as the DNA analysis process in forensic laboratories can take days, and the outcome may not be as relevant as first thought. Waiting for results may hinder the progress of a crime investigation, giving the perpetrator time to destroy relevant evidence or commit another crime.[3]

Additionally, advanced spectroscopy is also a significant technology used in forensic science. Raman spectroscopy, for example, is a versatile analytical technique that can be used to analyze various bodily fluids, fibers, explosives and even gunshot residue. The advantage of this technique is that it is non-destructive and does not need sample preparation, enabling the samples to be preserved for repeated analyses, if required.[4]

Having a biological trace evidence analyzer in the field enables the case to progress quickly and eliminate innocent suspects that might have been mistakenly taken into custody.[3]

The first hours of investigation are known as the “golden hours” and having relevant information as quickly as possible is strongly needed during this time to provide direction and progression for investigators on the case.[3]

Challenges and the Road Ahead

While new technologies are being explored for various fields, including forensic science, some challenges may limit their progression.[2,3]

The evolution of CRISPR technology is progressing rapidly; however, some obstacles from a technology and application perspective includes, off-target cutting, non-specific DNA binding, and the need to standardize a gold-standard technique for delivering CRISPR components into cells.[2]

Additionally, the challenges of applying AI in forensic science include feasibility, as in-depth processes cannot currently explain the approaches used by computational methods to create inputs in order to gain reliable results.

Computational models also require training by large datasets to provide effective and efficient performance. While some promising studies on future applications exist, they may not be fully ready for current implementation.[6]

The challenge facing microfluidic technology for forensic science is that most microfluidic devices use a biological sample in a solution or pure DNA as the input material, but commercially available machines require swabs as the input. Integrating trace sampling through swabs on a chip device can be difficult and has not yet been overcome at the research level.[3]

Conclusion

With various emerging technologies finding success in different fields, collaboration with other professionals, such as scientists, forensic investigators and legal professionals, may lead to more effective advancements in forensic science.[2,6]

The use of advanced technologies can have significant implications for the future of forensic science and may enable a faster and more effective approach to solving crime with innovative strategies.[2,3,4,6]

References

1. Sessa F, Esposito M, Cocimano G, et al. Artificial Intelligence and Forensic Genetics: Current applications and future perspectives. Applied Sciences. 2024;14(5):2113. doi:10.3390/app14052113

2. Dash HR, Arora M. CRISPR-CASB technology in forensic DNA analysis: Challenges and solutions. Applied Microbiology and Biotechnology. 2022;106(12):4367-4374. doi:10.1007/s00253-022-12016-8
3. Bruijns B, Van Asten A, Tiggelaar R, Gardeniers H. Microfluidic devices for forensic DNA analysis: A Review. Biosensors. 2016;6(3):41. doi:10.3390/bios6030041
4. Doty KC, Lednev IK. Raman spectroscopy for forensic purposes: Recent applications for serology and gunshot residue analysis. TrAC Trends in Analytical Chemistry. 2018;103:215-222. doi:https://doi.org/10.1016/j.trac.2017.12.003
5. Dunsin D, Ghanem MC, Ouazzane K, Vassilev V. A comprehensive analysis of the role of artificial intelligence and machine learning in modern digital forensics and incident response. Forensic Science International: Digital Investigation. 2024;48:301675. doi:https://doi.org/10.1016/j.fsidi.2023.301675
6. Galante N, Cotroneo R, Furci D, Lodetti G, Casali MB. Applications of artificial intelligence in forensic sciences: Current potential benefits, limitations and perspectives. International Journal of Legal Medicine. 2022;137(2):445-458. doi:10.1007/s00414-022-02928-5
7. Thurzo A, Kosnáčová HS, Kurilová V, et al. Use of Advanced Artificial Intelligence in Forensic Medicine, Forensic Anthropology and Clinical Anatomy. Healthcare. 2021;9(11):1545. doi:https://doi.org/10.3390/healthcare9111545

Further Reading

- What is Digital Forensics?
- Expanding Forensics Through Forensic Intelligence
- Impact of Ethics in Forensics
- What is Cell Culture Forensics?

Sensors Monitor Soft Tissue Desiccation for Forensic Applications

In a recent article published in the journal *Scientific Reports*, researchers investigated the desiccation process of soft tissue during decomposition, specifically in the context of the Western Cape region of South Africa. The primary aim was to quantify how environmental factors interact with the desiccation of soft tissue.

Image Credit: EVA CARRE/Shutterstock.com

Additionally, the research aims to establish a correlation between the extent of desiccation and the post-mortem interval (PMI). Understanding this relationship is crucial for forensic science, as it can improve the accuracy of estimating the time since death, which is essential for criminal investigations.

Background

Decomposition is a complex biological process influenced by various environmental conditions. Previous studies have highlighted the significance of moisture content in determining the rate of decomposition, with desiccation playing a critical role in the mummification of remains.

Connor et al. introduced a qualitative method known as the total body desiccation score (TBDS), which correlates well with accumulated degree days (ADD) during advanced stages of decomposition. Building on this foundation, researchers have explored quantitative methods, including bioelectrical impedance analysis, to assess tissue moisture content.

The Current Study

This study employed a comprehensive approach to investigating the desiccation of soft tissue during decomposition. Four 60 kg domestic pigs (Sus scrofa domesticus) were used as models for human remains. The pigs were sourced from a local farm and transported to the research site without refrigeration to simulate realistic conditions.

Upon arrival, the animals were dressed in clothing typical of local medico-legal cases, including cotton T-shirts and denim pants, which were tailored to fit based on measurements taken from a live pig to account for anatomical differences.

The experimental setup involved the deployment of the pigs in two distinct research sites, ensuring that the conditions reflected both summer and winter seasons. The bodies were placed in the field within two and a half hours post-mortem to minimize the effects of environmental exposure prior to data collection.

To measure moisture content, custom-designed printed circuit boards (PCBs) were embedded within the soft tissue of the pigs. These PCBs were equipped with conductive plates and thermometers, allowing for the continuous monitoring of tissue resistivity, which serves as a proxy for moisture levels. The sensors were strategically positioned in major body regions, including the head/neck, abdomen, and limbs, to capture data at multiple depths.

Data collection occurred at 15-minute intervals, enabling the researchers to obtain high-resolution temporal data on moisture loss throughout the decomposition process. The resistivity measurements were analyzed using a multi-level mixed effects model, which accounted for variations in environmental conditions such as temperature, humidity, and solar radiation. This statistical approach facilitated the identification of significant predictors of desiccation and allowed for the establishment of correlations between resistivity and the post-mortem interval.

Results and Discussion

The study revealed significant patterns in the desiccation of soft tissue, with resistivity measurements proving to be a reliable indicator of moisture content. It was found that

environmental factors, especially temperature and humidity, critically influenced the rate of desiccation. Higher temperatures accelerated moisture loss, while elevated humidity levels slowed the process.

The research also identified a distinct "point of mummification," where the tissue reached a state of extreme dryness, profoundly affecting the overall decomposition timeline. Additionally, a correlation was established between the extent of desiccation and the post-mortem interval (PMI). The study developed a framework for more accurately estimating PMI by analyzing resistivity data alongside environmental conditions.

This advancement is particularly relevant for forensic investigations, where precise time-of-death estimations can be critical in solving cases. The use of porcine models was validated, as the results closely mirrored expected human decomposition patterns, reinforcing the applicability of these findings to forensic contexts.

Conclusion

In conclusion, this study provides valuable insights into the desiccation process of soft tissue during decomposition, with a focus on the interplay between environmental factors and the post-mortem interval. By employing innovative measurement techniques and porcine models, the research advances the understanding of how moisture content influences decomposition rates.

The findings underscore the significance of local environmental conditions in forensic investigations, paving the way for more accurate estimations of time since death. As forensic science continues to evolve, this research serves as a critical step toward refining methodologies for assessing decomposition, ultimately aiding in the resolution of medico-legal cases.

The integration of quantitative approaches and environmental considerations marks a significant advancement in the field, highlighting the importance of interdisciplinary collaboration in addressing complex forensic challenges.

Journal Reference

Adams K.S., Finaughty D.A., et al. (2024). Drying the mystery: a novel electronic sensor to quantify soft-tissue desiccation and natural mummification for forensic taphonomy. *Scientific Reports* 14, 18294. DOI: 10.1038/s41598-024-69446-9, https://www.nature.com/articles/s41598-024-69446-9

How Forensic Labs Investigate Automobile Paint Chip Layers

Forensic laboratories are often tasked with reconstructing the evidence when a hit-and-run accident has been reported and one of the vehicles involved has fled the scene.

Residual evidence can range from fragments of glass, headlights, tail lamps, or bits of the bumper, as well as skid marks and paint residues. When a collision between a vehicle and an object or person occurs, paint transfer in the form of smears or chips is quite likely.

Automobile paint is typically a complex mixture of different components applied in several layers. While such complexity makes analysis challenging, it also offers a wealth of potential key information for identifying a vehicle.

Raman microscopy and Fourier transform infrared (FTIR) are some of the principal techniques used to help overcome such challenges and facilitate non-destructive analysis of specific layers within the overall paint structure.

Paint chip analysis starts with the acquisition of spectral data, which can be compared directly to a control sample or used in combination with a database to determine the vehicle's make, model, and year of manufacture.

The Royal Canadian Mounted Police (RCMP) is responsible for maintaining one such database, the Paint Data Query (PDQ) Database. Access is readily available to participating forensic laboratories that help to maintain and expand the database.

This article focuses on the first step in the analysis process: using FTIR and Raman microscopy to gather spectral data from chips of paint.

Paint Chip Sample Preparation

Using a Thermo Scientific™ Nicolet™ RaptIR™ FTIR Microscope, FTIR data was acquired; whole Raman data was collected with a Thermo Scientific™ DXR3xi Raman Imaging Microscope. The chips of paint were taken from damaged sections of a vehicle; one paint chip originates from a door panel, and the other is from a bumper.

A standard means of mounting samples for cross-sectioning is to embed them in epoxy resin, but there is a risk that analysis can be compromised if the resin penetrates the sample. To prevent this, the paint chips were placed between two sheets of poly(tetrafluoroethylene) (PTFE) while subjected to cross-sectioning.

The cross-sections of paint chips were separated manually from the PTFE before running analysis, and pieces were positioned on a barium fluoride (BaF_2) window. FTIR mapping was performed in transmission mode using a 10 x 10 μm^2 aperture, an optimized 15x objective and condenser, and 5 µm steps.

The same samples were used for Raman analysis to maintain consistency, despite thin cross-sections on BaF_2 windows not being necessary. It is important to note that BaF_2 has a Raman peak at 242 cm^{-1} that can be perceived as a weak peak in some of the spectra. This signal should not be affiliated with the paint chips.

Raman images were acquired using image pixel sizes of 2 µm and 3 µm. Analysis of the spectra was conducted for the main component peaks and compared against commercially accessible libraries by employing methods such as multi-component searching to aid the identification process.

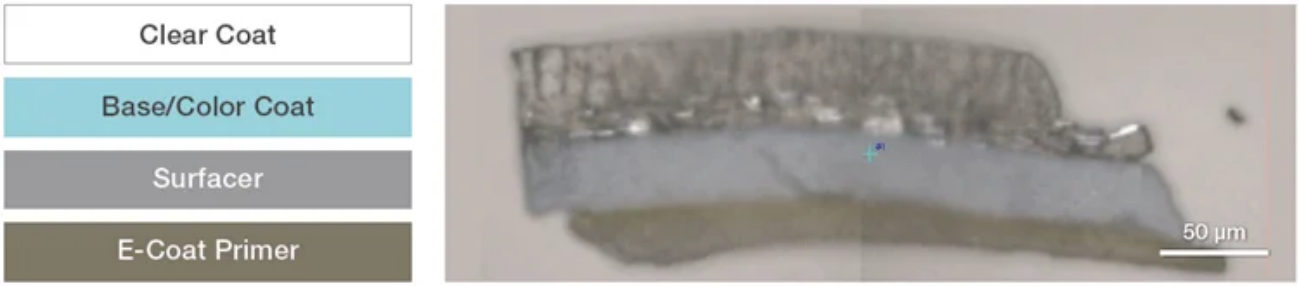


Figure 1. *Schematic of a typical four-layer automobile paint sample (left). Video mosaic image of a paint-chip cross-section taken from the door of an automobile (right). Image Credit: Thermo Fisher Scientific – Materials & Structural Analysis*

Automobile Paint Composition

While the number of paint chip layers may vary within a sample, samples tend to be comprised of around four layers (Figure 1). The layer directly applied to the metal substrate is an electro-coat primer layer (approx. 17-25 µm thick), which is applied to protect the metal from the environment and act as an adherent surface for the subsequent paint layers.

The next layer is an additional primer, the surfacer layer (approx. 30-35 µm thick), which provides a smooth surface for the next series of paint layers. Then, there is a basecoat or color coat (approximately 10-20 µm thick), which is made up of the primary pigments of the paint. The final layer is a clear protective coat (approx. 30-50 µm thick), which also provides a glossy finish.

One of the main challenges when it comes to analyzing trace paint evidence is that all the layers of paint on the source vehicle will not necessarily be present in paint chips and smears. Additionally, samples from various areas might have different compositions. For example, a

paint chip from a bumper may be comprised of bumper materials as well as the paint finish.

FTIR Paint Chip Analysis – Automobile Door

A visible image of the paint-chip cross-section is exhibited in Figure 1. Four layers can be seen in the visual image, which relates to the four layers determined by infrared analysis.

Individual layers were identified using FTIR images of various peak areas after mapping the entire cross-section. Representative spectra from the four layers and associated FTIR images are displayed in Figure 2. The first layer is consistent with a clear acrylic coat and includes polyurethane, melamine (peak at 815 cm^{-1}), and styrene.

The second layer, the base (color) coat, and the clear coat are chemically similar and consist of acrylic, melamine, and styrene.

While they share similarities, and no specific pigment peaks were identified, the spectra still demonstrate differences, primarily in the peak intensities. The spectrum from Layer 1 shows more intense peaks at 1700 cm^{-1} (polyurethane), 1490 cm^{-1}, 1095 cm^{-1} (C-O) and 762 cm^{-1}.

The intensity of peaks in the spectrum from Layer 2 increases at 2959 cm^{-1} (methyl), 1303 cm^{-1}, 1241 cm^{-1} (ester), 1077 cm^{-1} (ester) and 731 cm^{-1}. Spectra from the surfacer layer match those with library spectra of an alkyd based on isophthalic acid.

The final electro-coat primer layer is comprised of epoxy and, possibly, polyurethane. Ultimately, results are consistent with what is usually found in automobile paints.

The analysis of the various components in each layer was conducted using commercially available FTIR libraries rather than automobile-paint-specific databases, so while matches are representative, they may not be absolute.

Utilizing databases designed specifically for this type of analysis would enhance identification and could even be used to identify the make, model, and year of the automobile.

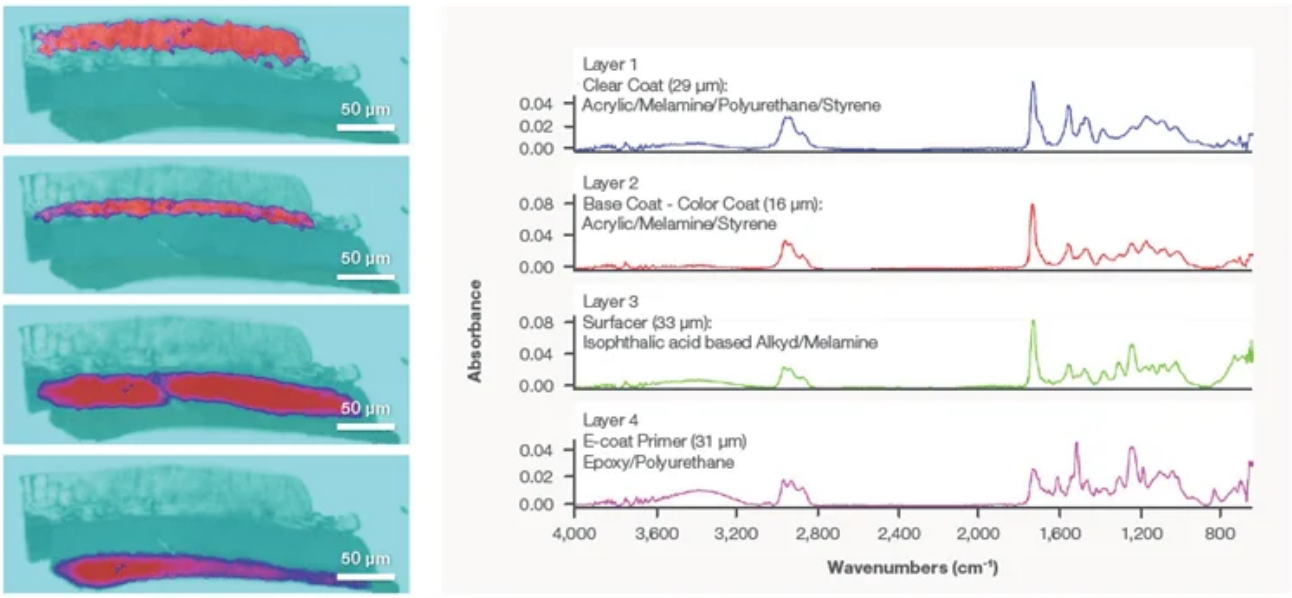


***Figure 2**. Representative FTIR spectra from the four identified layers in the door paint-chip cross-section. Infrared images are generated from peak areas associated with the various layers, which are then superimposed on the video images. The red areas show the location of the various layers. The infrared image covers an area of 370 x 140 µm^2 using a 10 x 10 µm^2 aperture and 5 µm steps. Image Credit: Thermo Fisher Scientific – Materials & Structural Analysis*

FTIR Paint Chip Analysis - Bumper

A video image of a bumper paint-chip cross-section is displayed in Figure 3; at least three layers are clearly distinguishable.

Infrared images of the cross-section verified three distinct layers (Figure 4). The outer layer is a clear coat that is likely to be a polyurethane material with acrylic, which, when compared with clear coat spectra from a commercial forensic library, demonstrated a match.

While the spectrum from the base (color) coat is extremely similar to the clear coat, it was still unique enough to be distinguished from the outer layer. There are considerable differences in relative peak intensities.

The third layer is potentially the bumper material itself and is comprised of polypropylene as well as what appears to be talc. Talc may be used as a reinforcing filler with polypropylene to enhance a material's structural properties.

The two outer layers are both consistent with paint layers used in automobile paint, but no specific pigment peaks were determined in the base coat layer.

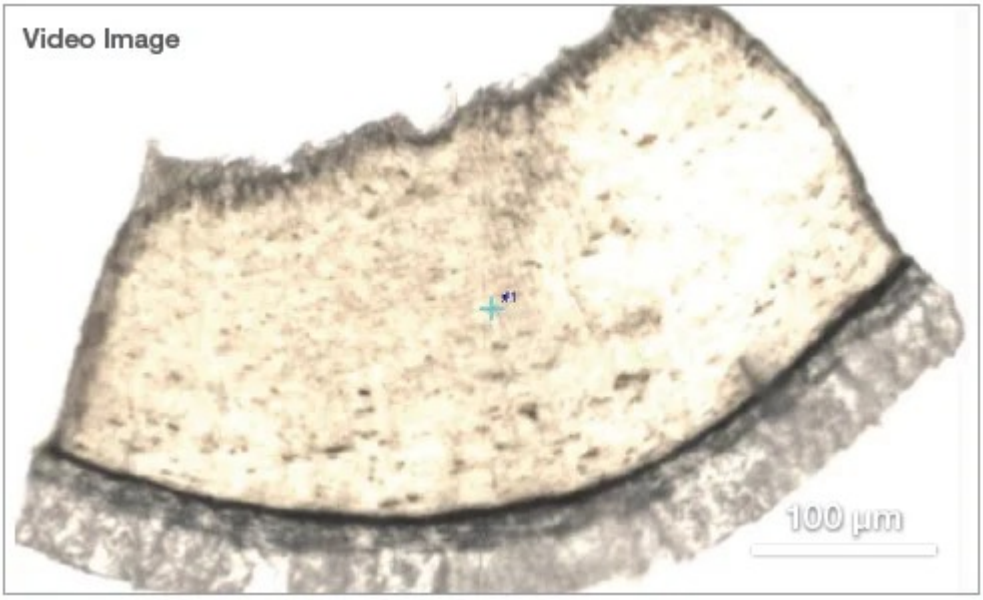
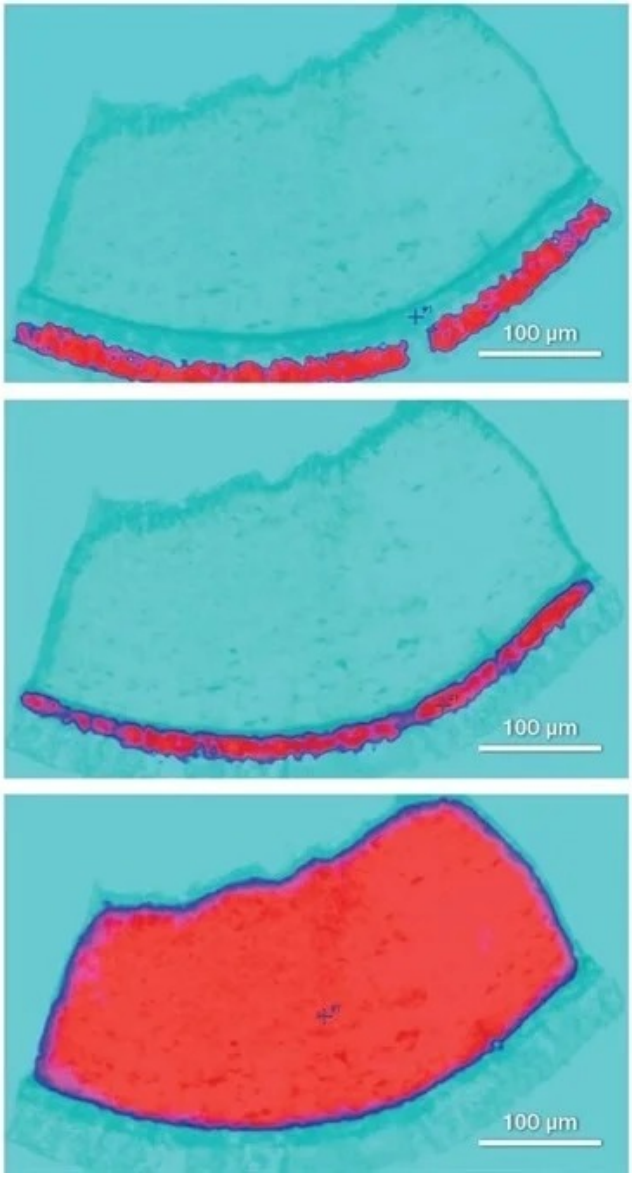


Figure 3. *Video mosaic image of a paint-chip cross-section taken from the bumper of an automobile. Image Credit: Thermo Fisher Scientific – Materials & Structural Analysis*



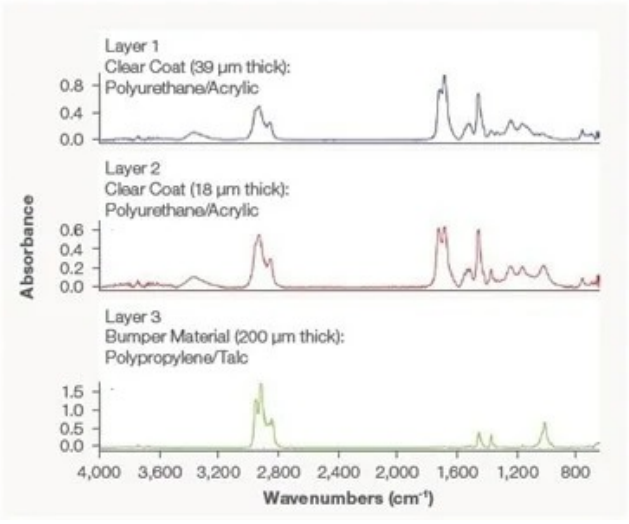


Figure 4. *Representative FTIR spectra from the three identified layers in the bumper paint-chip cross-section. Infrared images are generated from peak areas associated with the various layers, which are then superimposed on the video images. The red areas show the location of the various layers. The infrared image covers an area of 535 x 360 µm^2 using a 10 x 10 µm^2 aperture and 5 µm steps. Image Credit: Thermo Fisher Scientific – Materials & Structural Analysis*

Raman Microscopy

A Raman imaging microscope was used to analyze a sequence of cross-sections to acquire additional information on the samples. The Raman analysis, however, was further complicated by fluorescence from the samples. A number of different laser sources (455 nm, 532 nm, and 785 nm) were tested to assess the balance between fluorescence and Raman signal intensity.

For the door paint chip analysis, a 455 nm laser offered the best results; while there was still fluorescence present, it could be offset using a baseline correction. This approach, however, was unsuccessful with the epoxy layer because the extremity of the fluorescence was too much, and the material was vulnerable to laser damage.

While some lasers were better suited than others, none were a practical choice for the epoxy layer's analysis. A 532 nm laser was applied for the Raman analysis of the bumper paint-chip cross-section. There were still fluorescence contributions, but these were tackled with a baseline correction.

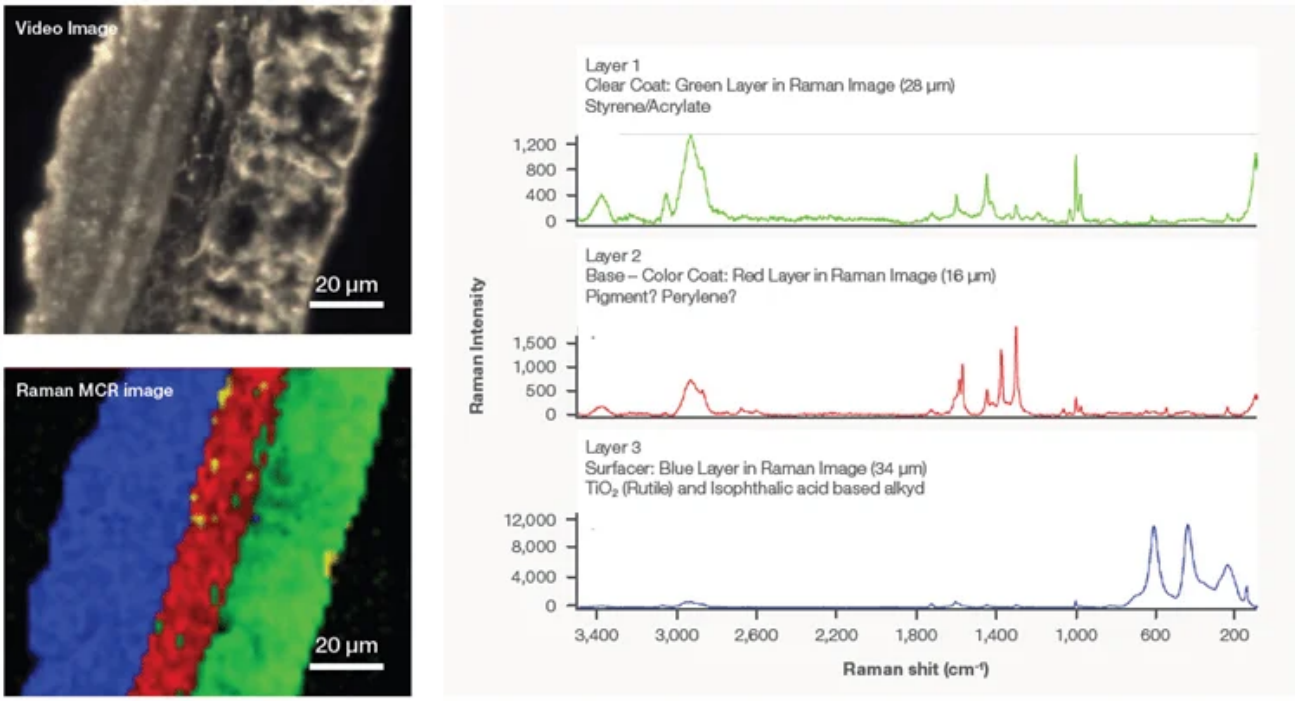


Figure 5. *Representative Raman spectra from the first three layers of the door paint-chip sample (right). The fourth (epoxy) layer was lost during sample preparation. The spectra have been*

baseline corrected to remove fluorescence contributions and were collected using a 455 nm laser. An area 116 x 100 µm^2 was imaged using a pixel size of 2 µm. Video mosaic image of the cross-section (top left). Raman multivariate curve resolution (MCR) image of the cross-section (bottom left). Image Credit: Thermo Fisher Scientific – Materials & Structural Analysis

Raman Paint Chip Analysis – Automobile Door

The Raman imaging analysis of the door paint-chip cross-section is shown in Figure 5; this sample did not reveal the epoxy layer as it was lost during preparation. However, since it had been determined that Raman analysis of the epoxy layer was problematic, this was not considered to be an issue.

The presence of styrene was much more widespread in the Raman spectra from Layer 1, while the carbonyl peaks' intensity was much lower than the infrared spectra. There was a considerable difference in the spectra from the first and second layers in the Raman analysis compared to FTIR.

The closest Raman match to the base-color coat was perylene; while it was not an exact match, it is widely known derivatives of perylene are used for pigments in automobile paint, so it could denote the pigment in the color layer.

Surface layer spectra were consistent with an isophthalic acid base alkyd; however, they also revealed that titanium dioxide (TiO_2, rutile) was present in the sample, which can sometimes be tricky to observe with FTIR, depending on the spectral cutoff.

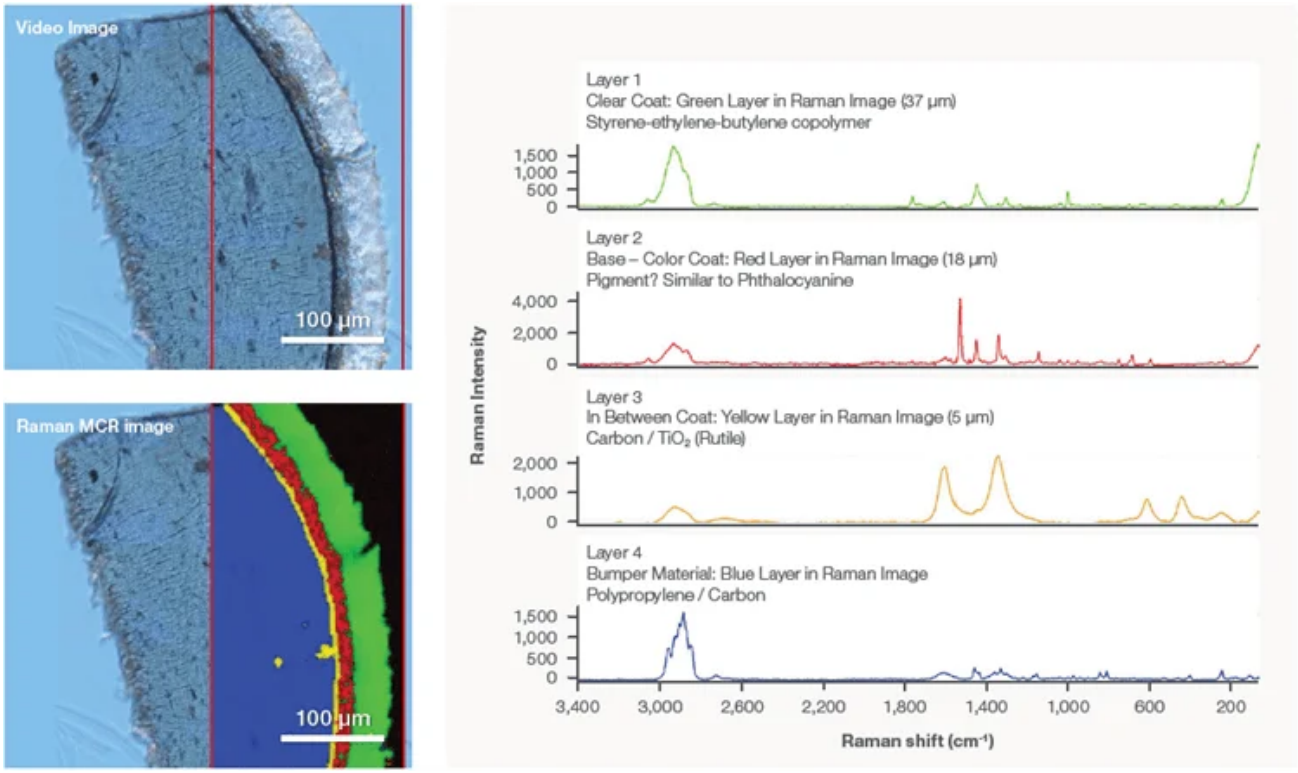


Figure 6. *Representative Raman spectra from the bumper paint-chip sample (right). The spectra have been baseline corrected to remove fluorescence contributions and were collected using a 532 nm laser. An area 195 x 420 μm^2 was imaged using a pixel size of 3 μm. Video mosaic image of the cross-section (top left). Raman MCR image of a portion of the cross-section (bottom left). Image Credit: Thermo Fisher Scientific – Materials & Structural Analysis*

Raman Paint Chip Analysis - Bumper

Figure 6 reveals the Raman results for the bumper paint-chip cross-section. An additional layer (Layer 3) was exposed, which was not previously detected with FTIR.

The closest match for the outer layer was a styrene-ethylene-butadiene copolymer, but there was also an indication of an additional unknown component illustrated by a small carbonyl peak that could not be accounted for.

The spectrum from the base-color coat is supposably representative of a pigment component because, to some extent, the spectrum matched phthalocyanine compounds that are used as pigments.

The layer that was previously unknown is quite thin (5 μm) and is comprised of carbon and rutile in part. Due to the thickness of the layer, and the fact that is difficult to detect TiO_2 and carbon using FTIR, it is not surprising that it was not detected by the infrared analysis.

In agreement with the FTIR results, the fourth layer (bumper material) was determined to be polypropylene, but Raman analysis also revealed the presence of some carbon. While the presence of the talc seen with FITR cannot be excluded, exact identification was not possible as the corresponding Raman peaks were too small.

Conclusions

Automobile paints are intricate mixtures of components, and while this can reveal a wealth of identifying information, it also makes analysis a significant challenge. Paint chip evidence can be probed effectively utilizing a Nicolet RaptIR FTIR Microscope.

FTIR is a non-destructive analytical technique that provides practical information about the different layers and components in automobile paints.

This article discussed the spectral analysis of paint chip layers, but closer inspection of the results, either by direct comparison with a suspected automobile or dedicated spectral database, could offer even more precise information to match the evidence with its source.

Raman analysis with the DXR3xi Raman Imaging Microscope delivered additional information

on the paint chip samples. While both FTIR and Raman are vibrational spectroscopy technologies, this article outlines how they can be applied to identify the various components of paints.

In combination, these techniques offer a more comprehensive and complementary view of the samples. The extent of information these techniques can provide relative to the individual paint layers makes them valuable resources for the complex task of forensic paint analysis.

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The Use of Forensic Palynology in Solving Crimes

Trace evidence analysis is a significant component of modern forensic investigation and involves analyzing DNA or fingerprints left at a crime scene.[1] When biological evidence is absent at a crime scene, trace evidence may be the only evidence available to fill in the blanks.[1,2]

Palynology, the study of pollen and spores, is utilized in forensic science to examine evidence linked to crime scenes. First applied over half a century ago, it remains relatively underutilized in many parts of the world.

Image Credit: Igor Klyakhin/Shutterstock.com

The Power of Pollen and Spores

Pollen and spores are effective forensic tools due to their ubiquity in the environment, which can be advantageous when investigating a crime.[4]

Several types of pollen and spores are dispersed in high quantities in the air, carried by air

currents, before falling onto the ground in a thin coating called pollen rain.

In some areas, the high volume of pollen and dispersed spores can cause exposed land and water surfaces to turn yellow due to the pollen rain. Though it may not be a high-level measurement of the vegetation in the area, pollen rain can be used as a snapshot of the vegetation of a certain region. It can become a 'pollen print' to identify the region.[4]

Additionally, because pollen and spores are microscopic and invisible to the naked eye, they can easily become trapped on nearly any surface. This characteristic makes them valuable in criminal investigations, as they can be used to link a suspect or piece of evidence to a specific region or crime scene.[4]

Analyzing Pollen Evidence

Forensic palynologists typically undertake two specific types of investigations.[4]

The first type involves specific situations with victims, suspects, crime scenes, and objects suspected to be evidence associated with one of these situations. This investigation requires the palynologist to visit the crime scene, collect comparison samples and then examine other kinds of evidence that may be related to the crime scene.

The palynologist must have knowledge of plant ecology and communities around the crime scene, as well as other factors that may impact it, such as soil and climatic features, including vegetational changes.[4]

The second type of investigation involves establishing a geolocation for samples of an unknown origin. This would require the forensic palynologist to remove vacuumed samples of clothing from suspects or take samples from contents of items seized as evidence, such as packages, laptops, suitcases, abandoned vehicles and more. These samples may reveal pollen and spore clues that may lead to the origin or location of where the objects were made or used.[4]

Forensic palynologists may use several different types of analytical methods for investigating pollen and spores collected from crime scenes and suspects, including microscopy, spectroscopy, and molecular methods for pollen analysis.[4]

DNA barcoding may also be used to identify the species, which targets specific parts of the plant genome unique to a particular species.[5]

As pollen analysis is a destructive process, further forensic testing and analytical sequence have to be considered to reduce the risk of contamination, as the evidence may have to be analyzed again.[5]

Solving Crimes with Pollen: Case Studies

An Austrian murder mystery in the 1950s consisted of a man that disappeared whilst traveling. The investigation led to a suspect, who was found to have mud on his boots contaminated with fossilized pollen grains that were 20 million years old.

These pollen grains could be tracked to being from only one small area on the Danube River. After confronting the suspect with this evidence, he confessed and led the police to the body, to the exact location the pollen suggested.[6]

Applications of Forensic Palynology

Forensic palynology can also be used for other applications, including investigating historical events or items, such as the Shroud of Turin, a cloth that some believe was used to cover Jesus' body before burial. This was one of the highest-profile examples of pollen being used as a critical piece of evidence to verify the origin of an object.[6]

Another high-profile case authenticated the Gondar Hanging, which was gifted to the Royal Ontario Museum in Toronto, Canada. This item was reported to have been produced in Ethiopia in the 17th or early 18th century, and the museum curators wanted to confirm its authenticity through the pollen trapped in the fabric.[6]

Other applications also include identifying the season of the crime or helping to reconstruct the environment in which a crime occurred.[4,5]

Challenges and Considerations

While forensic palynology has its advantages for many applications, this discipline also faces some challenges.[5]

Like most forensic evidence, a key challenge for palynologists includes timing. Forensic palynologists need to be called early on when investigating a crime to ensure the better value of the samples collected and reduce contamination.[5]

Pollen and spores are light, small, and easily recycled, and this means a crime scene can be

easily contaminated with shoes or search teams that cut or remove foliage while looking for evidence.[5]

Additionally, pollen retrieved from a suspect matching evidence from a crime scene does not necessarily mean they have committed a crime, and it could just suggest the person visited the area recently.[6]

It could also have been transferred and not have been due to visiting the area themselves.[4]

Another challenge includes accurate interpretation of evidence, as there may not be a large population of people that are trained to analyze palynological samples, and due to the extent of knowledge that is required to be a forensic palynologist, it may be difficult to come to an agreement depending on the level of understanding of various factors such as soil and climate.[4,6]

The Future of Forensic Palynology

With the rapid evolution of technology and advancements in many scientific industries, the future of forensic palynology may grow exponentially to aid in effective crime scene investigation.[6]

Advanced technologies within laboratories have also shown that DNA can be recovered from a single pollen grain, and DNA barcoding can be used to identify multiple taxonomy groups and parts of an organism that do not show in the morphology.

DNA barcoding is the fastest way to differentiate between pollens, and this can be used to propel evidence used in crime cases.[6]

Additionally, high-throughput DNA sequencing, which has led to spore DNA barcoding, can enable researchers to sequence many samples of DNA simultaneously without separating them first.[6]

Using these scientific methods and others demonstrates the potential of forensic palynology, with significant implications for more sophisticated crime-solving applications.[6]

References

1. What is forensic science? BBC Science Focus Magazine. Accessed June 11, 2024. https://www.sciencefocus.com/the-human-body/what-is-forensic-science.

2. Trace evidence: The role in forensic science " forensic science " college of pharmacy " University of Florida. UF monogram. Accessed June 11, 2024. https://forensicscience.ufl.edu/2022/10/14/trace-evidence-the-role-in-forensic-science/.
3. Carloss T. A piece of evidence the size of a quarter helped Akron Police solve a 2000 murder. News 5 Cleveland WEWS. March 5, 2018. Accessed June 11, 2024. https://www.news5cleveland.com/news/local-news/oh-summit/this-piece-of-evidence-the-size-of-a-quarter-helped-akron-police-solve-a-2000-murder.
4. Bryant VM. Pollen and spore evidence in forensics. *Wiley Encyclopedia of Forensic Science*. Published online March 14, 2014:1-16. doi:10.1002/9780470061589.fsa085.pub2
5. Ezegbogu MO. Identifying the scene of a crime through pollen analysis. *Science & Justice*. 2021;61(3):205-213. doi:10.1016/j.scijus.2020.12.002
6. Alotaibi SS, Sayed SM, Alosaimi M, et al. Pollen Molecular Biology: Applications in the forensic palynology and future prospects: A Review. *Saudi Journal of Biological Sciences*. 2020;27(5):1185-1190. doi:10.1016/j.sjbs.2020.02.019

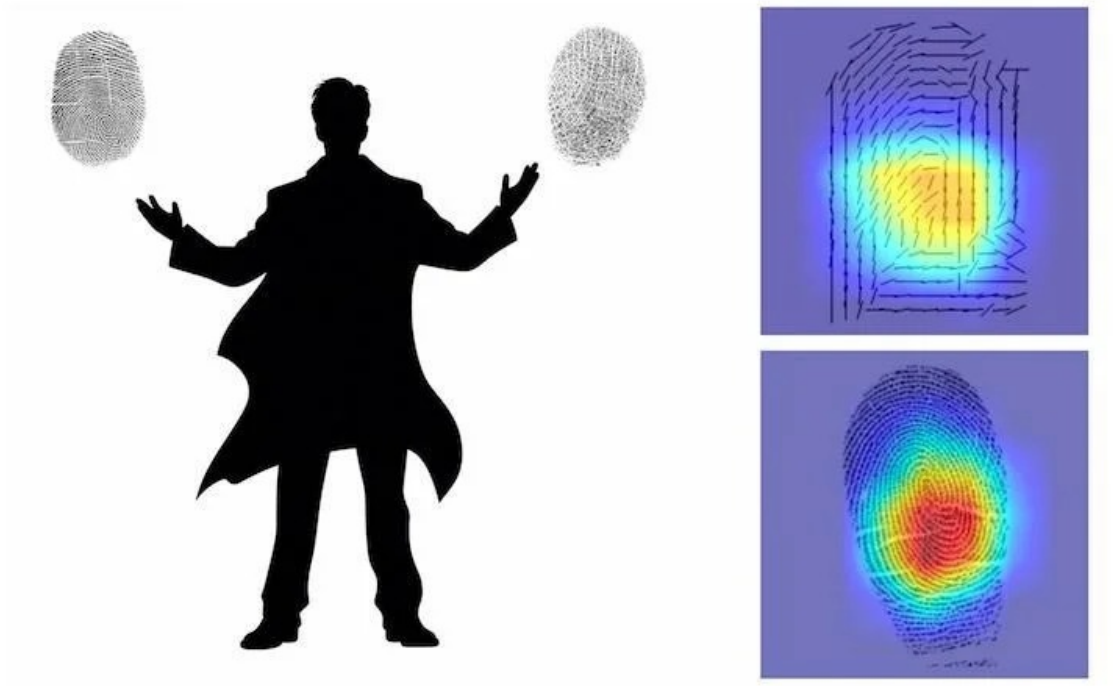
Further Reading

- All Forensics Content
- Collecting Evidence at a Crime Scene
- Using Forensics to Tackle Child Exploitation
- Forensic Investigations of Natural Disasters
- Forensic Identification in Mass Disasters

More...

AI Discovers Intra-Person Fingerprint Similarity

Fingerprints have been the go-to method for connecting offenders to crime detectives, both in real life and in television shows like "Law and Order" and "CSI." However, it can be exceedingly challenging to connect two crime sites when a criminal leaves prints from various fingers, and the evidence could vanish.



AI discovers a new way to compare fingerprints that seem different, but actually belong to different fingers of the same person. In contrast with traditional forensics, this AI relies mostly on the curvature of the swirls at the center of the fingerprint, as shown by the heatmap. Image Credit: arco-Marcil Montoto, Columbia Engineering, generated with Dall-E

In the field of forensics, it is well acknowledged that fingerprints from various fingers on the same individual—also known as "intra-person fingerprints"—are distinct from one another and cannot be matched.

Research Led by Columbia Engineering Undergraduate

This commonly accepted belief was contested by a group led by senior Gabe Guo, an undergraduate student at Columbia Engineering. Guo, who has no prior experience with forensics, discovered a database of over 60,000 fingerprints kept by the public US government

and entered the images in pairs into a deep contrastive network, an artificial intelligence system.

The pairings occasionally belonged to distinct persons, and occasionally they belonged to the same person (but with different fingers).

AI Has Potential to Greatly Improve Forensic Accuracy

The scientists created the AI system by tweaking an innovative framework, and it improved over time in identifying which seemingly distinct fingerprints belonged to the same individual and which ones did not. Just one pair had an accuracy of 77%. The accuracy increased significantly when numerous pairings were shown, which might more than tenfold increase the current level of forensic efficiency.

The study was published in *Science Advances* and was a partnership between Wenyao Xu's lab at the University at Buffalo, SUNY, and Hod Lipson's lab at Columbia Engineering's Creative Machines lab.

Study Findings Challenge–and Surprise–Forensics Community

The team promptly forwarded the data to a reputable forensics publication after verifying its findings, but a few months later, they were rejected.

The anonymous expert reviewer and editor added, "*It is well known that every fingerprint is unique.*"

Therefore, even if the fingerprints were from the same individual, it would not be feasible to identify any similarities.

The group persevered. They intensified their efforts, providing their AI system with additional data, and watched as it continued to advance. Knowing that the forensics community would not be buying into their story, the team decided to send their work to a wider audience.

Lipson, the co-director of the Makerspace Facility and the James and Sally Scapa Professor of Innovation in the Department of Mechanical Engineering, filed an appeal when the study was turned down once again.

> *I don't normally argue editorial decisions, but this finding was too important to ignore. If this information tips the balance, then I imagine that cold cases could be revived, and even that innocent people could be acquitted.*
>
> *Hod Lipson, Sally Scapa Professor of Innovation, Department of Mechanical Engineering, Columbia University in the City of New York*

Although the accuracy of the system is insufficient to formally determine a case, it can assist in prioritizing leads in instances where there is uncertainty. The work was eventually approved for publication by *Science Advances* following more back and forth.

Unveiled: A New Kind of Forensic Marker to Precisely Capture Fingerprints

The topic of what alternative information the AI was really using—which had eluded decades of forensic analysis—was one of the main grounds of contention. The team deduced that the AI system was using a novel form of forensic marker following meticulous visualizations of its decision-making process.

> *The AI was not using 'minutiae,' which are the branchings and endpoints in fingerprint ridges – the patterns used in traditional fingerprint comparison. Instead, it was using something else, related to the angles and curvatures of the swirls and loops in the center of the fingerprint.*
>
> *Gabe Guo, Head Teaching Assistant, Columbia University in the City of New York*

Ph.D. candidate Judah Goldfeder and senior engineer Aniv Ray of Columbia Engineering, who assisted with the data analysis, pointed out that their findings are preliminary.

> *Just imagine how well this will perform once it's trained on millions, instead of thousands of fingerprints.*
>
> *Aniv Ray, Senior Engineer, Columbia University in the City of New York*

A Need for Broader Datasets

The group is conscious of possible biases in the information. When samples were available, the authors' evidence showed that the AI functions equally for both genders and ethnicities. However, they point out that if this method is to be applied in real-world scenarios, more meticulous validation must be carried out using datasets with wider coverage.

Transformative Potential of AI in a Well-Established Field

According to Lipson, there will be more unexpected discoveries from AI, like this one.

Lipson noted, "*Many people think that AI cannot really make new discoveries–that it just regurgitates knowledge. But this research is an example of how even a fairly simple AI, given a fairly plain dataset that the research community has had lying around for years, can provide insights that have eluded experts for decades.*"

He concluded, "*Even more exciting is the fact that an undergraduate student, with no background in forensics whatsoever, can use AI to successfully challenge a widely held belief of an entire field. We are about to experience an explosion of AI-led scientific discovery by non-experts, and the expert community, including academia, needs to get ready.*"

Journal Reference:

Guo, G., *et. al.* (2023) Unveiling Intra-Person Fingerprint Similarity via Deep Contrastive Learning. *Science Advances*. doi:10.1126/sciadv.adi0329

Source:

http://www.columbia.edu/

Advancing forensic analysis and crime scene investigation with FTIR

Drugs and fibers are among the materials collected in forensic and criminal laboratories. Some of these samples can be quite small, and light microscopes are frequently employed to examine evidence gathered at the crime scene.

An optical microscope can help investigators see the evidence more clearly, particularly at the microscopic level. However, in some cases, more information is required to prove beyond a reasonable doubt whether a person is guilty or innocent.

As a result, a reliable and adaptable analytical technique is required to offer visual and chemical information.

Fourier transform infrared spectroscopy (FTIR) is a macroscopically useful technique for forensic scientists. FTIR microspectroscopy expands the application of standard FTIR by enabling rapid, nondestructive investigation of samples as small as 10 microns.

The Thermo Scientific™ Nicolet™ iN10 Infrared Microscope combines an optical microscope and an integrated FTIR. The Nicolet iN10 analytical equipment allows forensic scientists to visually and chemically evaluate illicit pills, hair, fibers, inks, and paints.

The Nicolet iN10 is a powerful, small FTIR microscope thanks to its integrated architecture, which eliminates the need for an external spectrometer.

Evidence is an important aspect of any court case. For the first time, the unique ability to check microscope performance using software gives the investigator and the jury confidence that the data is reliable.

The Nicolet iN10 may be used without liquid nitrogen, allowing the lab to quickly evaluate evidence in any location. The Thermo Scientific™ OMNIC™ Picta™ Software simplifies and speeds up microscopy operations, even for inexperienced users. Powerful wizards assist the user with reflection, transmission, and ATR analysis.

Image Credit: Thermo Fisher Scientific - Vibrational Spectroscopy

Ink on paper

Counterfeiting is one of the earliest known illegal activities. Technological improvements have enabled criminals to create counterfeit notes without using highly sophisticated offset printing procedures. An inexperienced person with access to a photographic copier or scanner can create high-quality counterfeit cash.

However, the paper and ink used in the printing process have different properties that can be used to identify counterfeit notes and even track their origins. Ink is typically evaluated using elemental analysis, X-rays, and mass spectroscopy. These methods provide thorough characterization but are damaging and time-consuming.

Because of the high infrared absorbance from cellulose between 1200-950 cm^{-1}, infrared spectroscopy has not been properly employed in the identification of ink and pollutants on

paper.

The rapid and non-destructive nature of infrared imaging and Attenuate Total Reflectance (ATR) FTIR microscopy provides a significant benefit for assessing criminal evidence. Thermo Scientific Nicolet iN10 Microscope can now be used to analyze fake documents.

Analyzing suspect inks can disclose the type of ink and how it was applied to the paper. Visual inspection often distinguishes between ink applied using photostatic or inkjet processes and offset printing techniques. However, with modern printing technology, this is getting increasingly challenging.

FTIR microscopy enables rapid chemical imaging of both ink and paper materials. This yields unambiguous data that may be directly compared to actual documents.

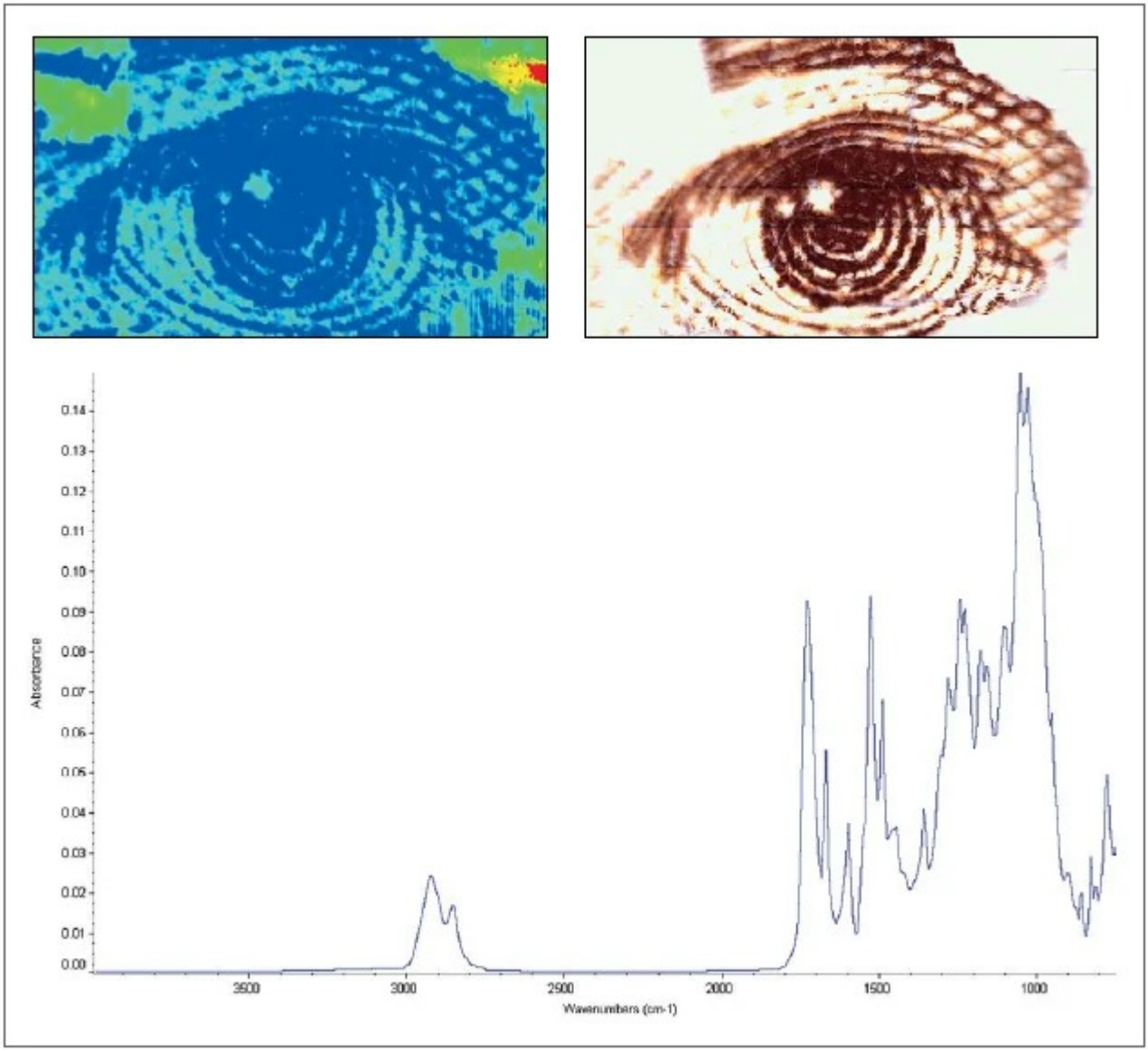


Figure 1. *(Upper left) Chemical image of Andrew Jackson's eye on $20 U.S. currency (Upper right) Video mosaic of Jackson's eye (Lower) Black ink spectrum collected by Tip ATR. Chemical imaging highlights the distribution, while ATR analysis provides detailed spectral information of the ink. Image Credit: Thermo Fisher Scientific - Vibrational Spectroscopy*

Figure 1 depicts a chemical picture of a US twenty-dollar bill. The black ink is chemically distinct from the paper and the surrounding background ink. The chemical and visual pictures can be contrasted, demonstrating the remarkable resolution of infrared microscopic data.

Once the desired information has been discovered using rapid chemical imaging, ATR analysis can offer detailed spectrum data with minimal interference from the cellulose contribution.

Fiber and hair analysis

Many fibers are often discovered at crime scenes and can provide useful or even critical information.

Forensic scientists, for example, are trained to recognize and associate physical hair traits and looks with specific ethnic groups. This information can help identify potential suspects, but it cannot distinguish one from another.

FTIR microscopy can combine visible microscopic hair fiber examination with useful and discriminating infrared chemical information. Hair fiber chemical information can indicate residual hair styling agents (such as hairspray and conditioners) as well as protein structural alterations caused by chemical treatments (such as bleaching). This new information may help identify a suspect.

Hair can oxidize chemically or through exposure to natural sunshine. Bleaching products commonly contain chemical oxidizers such as hydrogen peroxide and persulfates. The amino acid cystine can be oxidized to cysteic acid in hair, increasing S=O stretching absorbance.

Hair fibers examined using reflection absorption and Ge Tip ATR clearly distinguish between untreated and chemically treated hair. Figure 2b depicts the spectrum changes caused by cystine oxidation to cysteic acid in the range of 1400–900 cm^{-1}.

Bleaching causes a rise in the S=O symmetric cysteic acid stretch at around 1040 cm^{-1} and the asymmetric S=O stretch at 1175 cm^{-1}, as shown in the top spectrum.

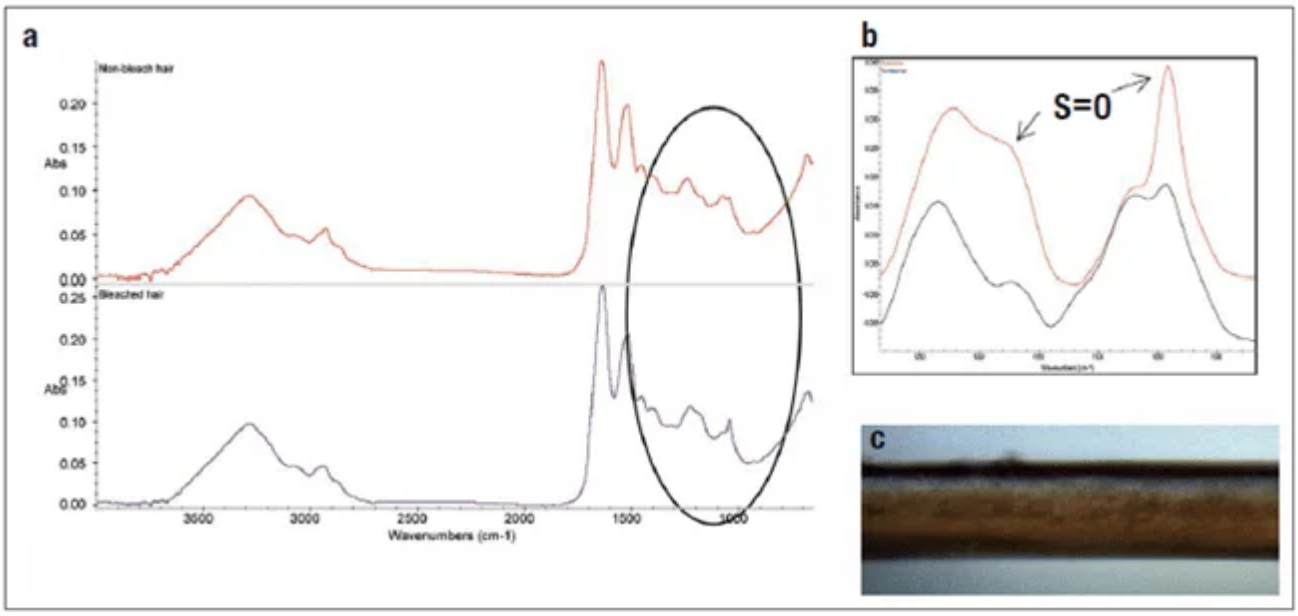


Figure 2. *(a) Spectra of non-bleached (red) and bleached (purple) hair. (b) Expanded region showing S=O stretching regions (c) Video image of unbleached hair fiber. Image Credit: Thermo Fisher Scientific - Vibrational Spectroscopy*

Visual microscopy is also used to distinguish between natural and synthetic fiber evidence. A highly experienced forensic scientist can recognize the physical properties that distinguish several generic fiber types.

Additional investigation, including chemical analysis, is required to determine the chemical subclass.[1] FTIR microscopy has evolved as a powerful analytical method for rapidly determining a fiber's subclass in a non-destructive manner with minimal sample preparation. All this is significant in the forensic community, where preserving evidence is crucial.

Recently, federal money mints have added unique fibers to the paper as an additional barrier against counterfeiting. Figure 3 shows how to inspect the minuscule security fibers in a circulating banknote using attenuated total reflection (ATR) on the Nicolet iN10.

The Nicolet iN10's visual image clearly shows the red fiber, and the ATR data confirms that it is nylon. ATR microspectroscopy yields high spectral quality with minimal cellulose contribution,

enabling outstanding library identification.

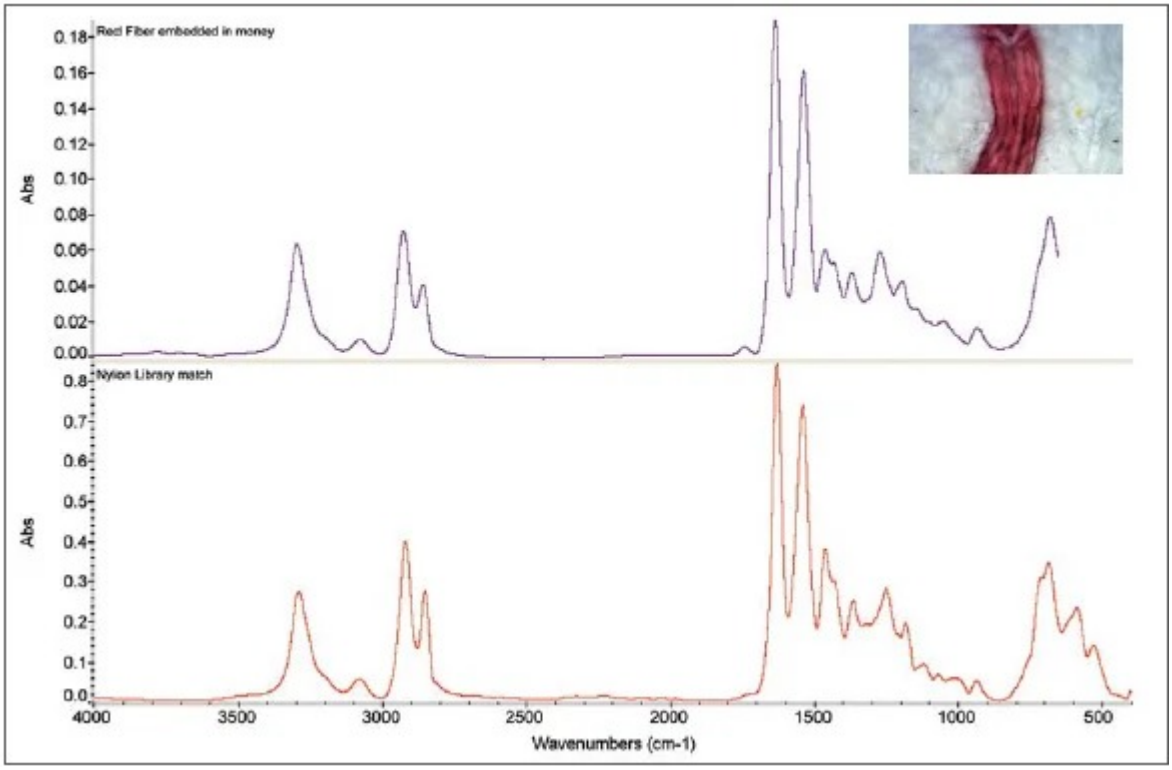


Figure 3. *(Upper spectrum) Spectrum of Nylon fiber embedded in currency. (Lower spectrum) Nylon Spectral library match. (Right) Visual image captured by OMNIC Picta software. Image Credit: Thermo Fisher Scientific - Vibrational Spectroscopy*

Tablets

Rapid analytical approaches for determining the chemical composition and distribution of active components for illicit drug tablet analysis are critical in forensic investigations. Sentencing guidelines might be based on both possession and amount, therefore qualitative and quantitative data is required.

Imaging with the Nicolet iN10 MX Infrared Imaging Microscope is a rapid and nondestructive analysis approach suitable for both homogeneous and heterogeneous tablets.

Unlike other macroscopic analytical techniques, FTIR microspectroscopy does not require sample dissolution, which can degrade evidence and result in insoluble or re-crystallized products.

The Nicolet iN10 MX, OMNIC Picta Software, and Thermo Scientific™ OMNIC™ Specta™ Analysis Tools offer drug composition data and insights into the illegal production process. When combined with the system verification tools, the investigator can obtain valuable information for use in court.

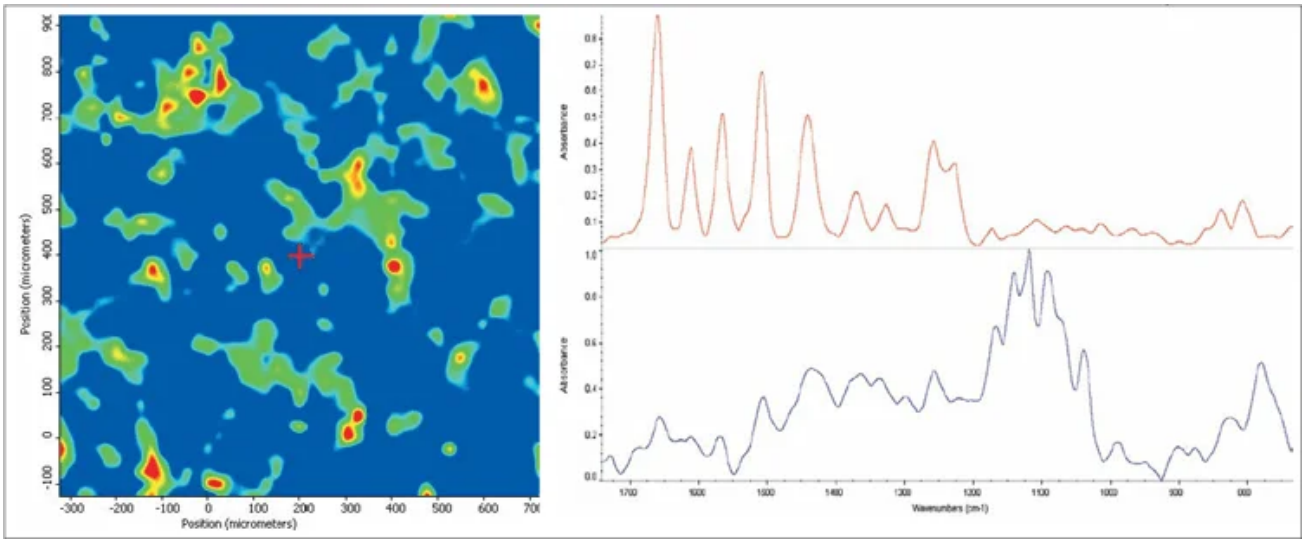


Figure 4. *(Left) Chemical image of prescription drug. (Right) Red spectrum is the active ingredient and the blue spectrum is the excipient. Image Credit: Thermo Fisher Scientific - Vibrational Spectroscopy*

The Nicolet iN10 MX Imaging Infrared Microscope is the first instrument designed exclusively for chemical imaging analysis, while maintaining the speed, sensitivity, and resolution of conventional infrared microscopy. Figure 4 depicts a chemical image of a prescription drug pill obtained using rapid imaging mapping on a Nicolet iN10 MX.

Infrared data was obtained across a 5 × 5 mm area in approximately five minutes. The chemical image shows the active ingredient in blue; this is the bulk of the material.

However, the green and red contours show that another component is there. Simply clicking within one of the green/red contours shows the spectrum of the second tablet component, which in this case is an unregulated excipient.

The OMNIC Picta Software has automatic collection and analysis wizards. For example, the random mixture wizard may examine and identify many components with a single click. Figure 5 is the multicomponent wizard screenshot for an over-the-counter tablet.

The wizard generates a list of the main components by cross-correlating the collected map spectra. The wizard estimates individual component area contributions and offers semiquantitative distribution data. Each component can then be recognized using spectrum library information, which provides additional chemical information.

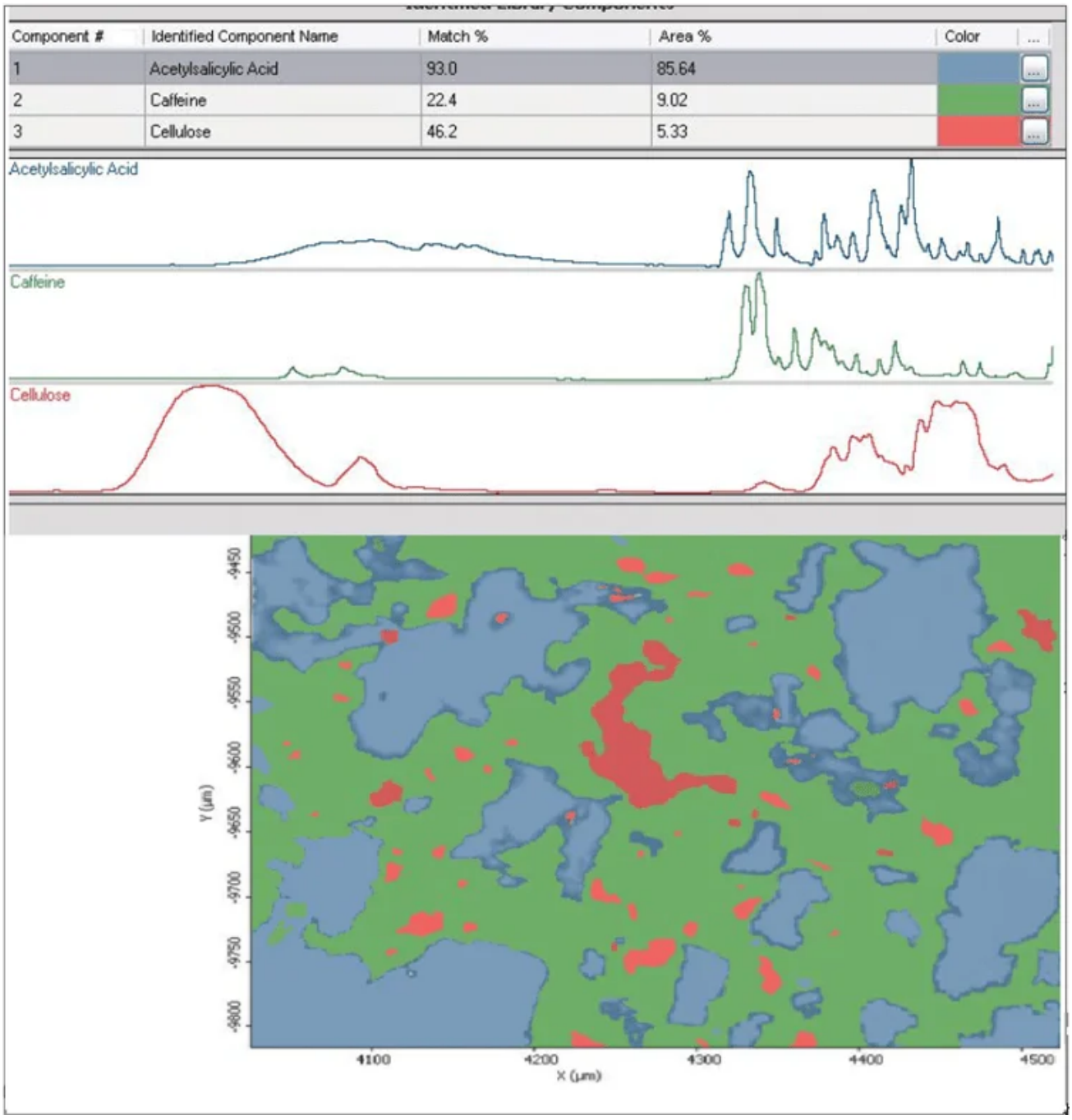


Figure 5. *Tablet analysis of an over-the-counter tablet by Picta Multicomponent Wizard. Image Credit: Thermo Fisher Scientific - Vibrational Spectroscopy*

Trace analysis

Fingerprint information can help identify or confirm a suspect's involvement in a crime. While fingerprints are unique to an individual, they include more information than just the fingerprint pattern. FTIR microspectroscopic examination can reveal chemical information left behind by fingerprints.

This chemical information can be used to trace a suspect's final steps before committing a crime.

Figure 6 depicts the chemical and video images of a 2 x 2 mm fingerprint impression on a reflecting microscope slide. The primary component of the fingerprint is natural sebum oil from the skin (triglyceride esters).

Some minor curves outside the fingerprint point to another component. The lower right chemical picture in Figure 6 depicts a fingerprint region that contains a small quantity of fibrous wood particles. Chemical imaging instantly determines the unique fingerprint pattern while exposing essential and unexpected trace chemical information.

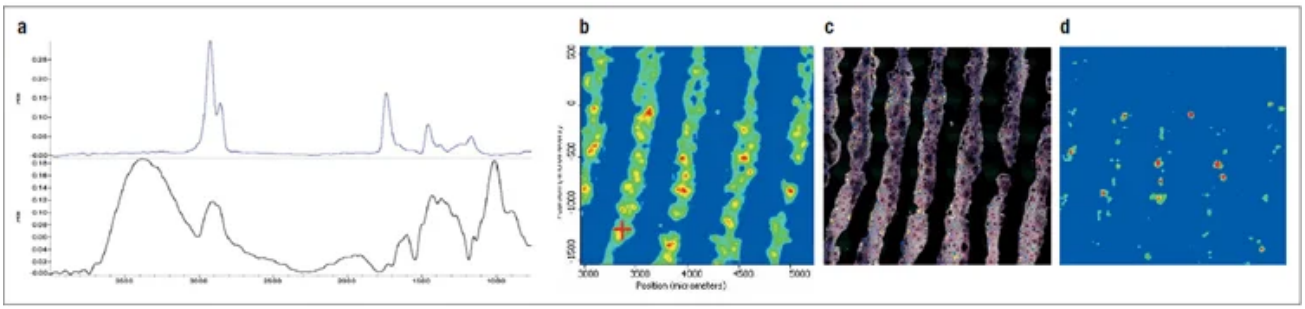


Figure 6. *(a) Spectrum of natural triglyceride esters; (b) chemical image of fingerprint; (c) video image of fingerprint; (d) chemical image highlighting the fibrous wood contaminate. Image Credit: Thermo Fisher Scientific - Vibrational Spectroscopy*

Paint analysis

Paint chip evidence can be collected at a crime scene involving an automobile. In most circumstances, the paint or paint chip is transferred to a victim or object involved in the collision.

Automotive paint is made up of several layers of chemically diverse materials, such as binders, primers, pigments, and protective resins, which are applied separately to a car's plastic or metal surface.

A chip of paint usually contains information about the different paint layers and can be viewed under an optical microscope. Typically, chemical identification of paint layers necessitates dissolution and chemical extraction.

Fast mapping FTIR microscopy enables immediate chemical identification of each layer. The images in Figure 7 depict the investigation of a multi-layer paint sample. Layer 1 is the outside protective polyurethane coating, layer 2 is the base coat and polypropylene polymer (the bumper's primary component), and layer 3 is the paint binder layer.

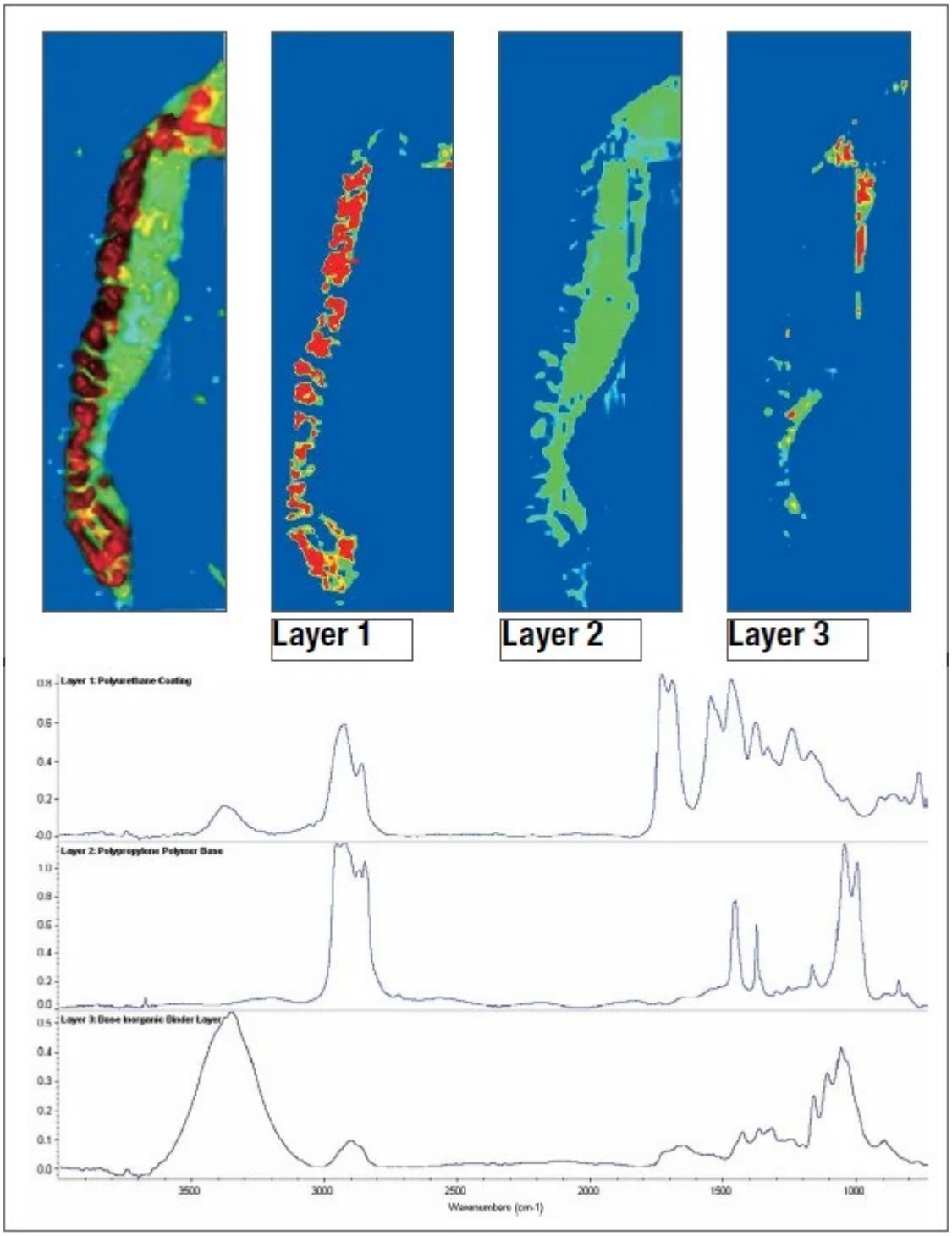


Figure 7. *(Upper) Chemical image of a car bumper paint chip layers. (Lower) Spectra of identified layers: Layer 1: protective coating. Layer 2: base coat and polypropylene polymer, Layer 3: binder layer. Image Credit: Thermo Fisher Scientific - Vibrational Spectroscopy*

Residues

Chemical residues from crime scenes can provide crucial information and clues. Residues are generally sensitive to evidence handling and should be evaluated with little interaction. FTIR

microscopy may detect and evaluate trace contaminants without requiring sample preparation or removal.

Figure 8 shows the sensitivity of infrared microscopy in this application. A fragment of a 10-cent Euro coin was examined with the Nicolet iN10 MX Imaging Microscope. The detailed chemical image (top left) shows a thin pink outline surrounding the stamped coin marks.

The residue spectrum reveals that the material is protein-based and most likely derived from human skin and oil residues. However, this shows how rapidly evidence may be evaluated for trace materials.

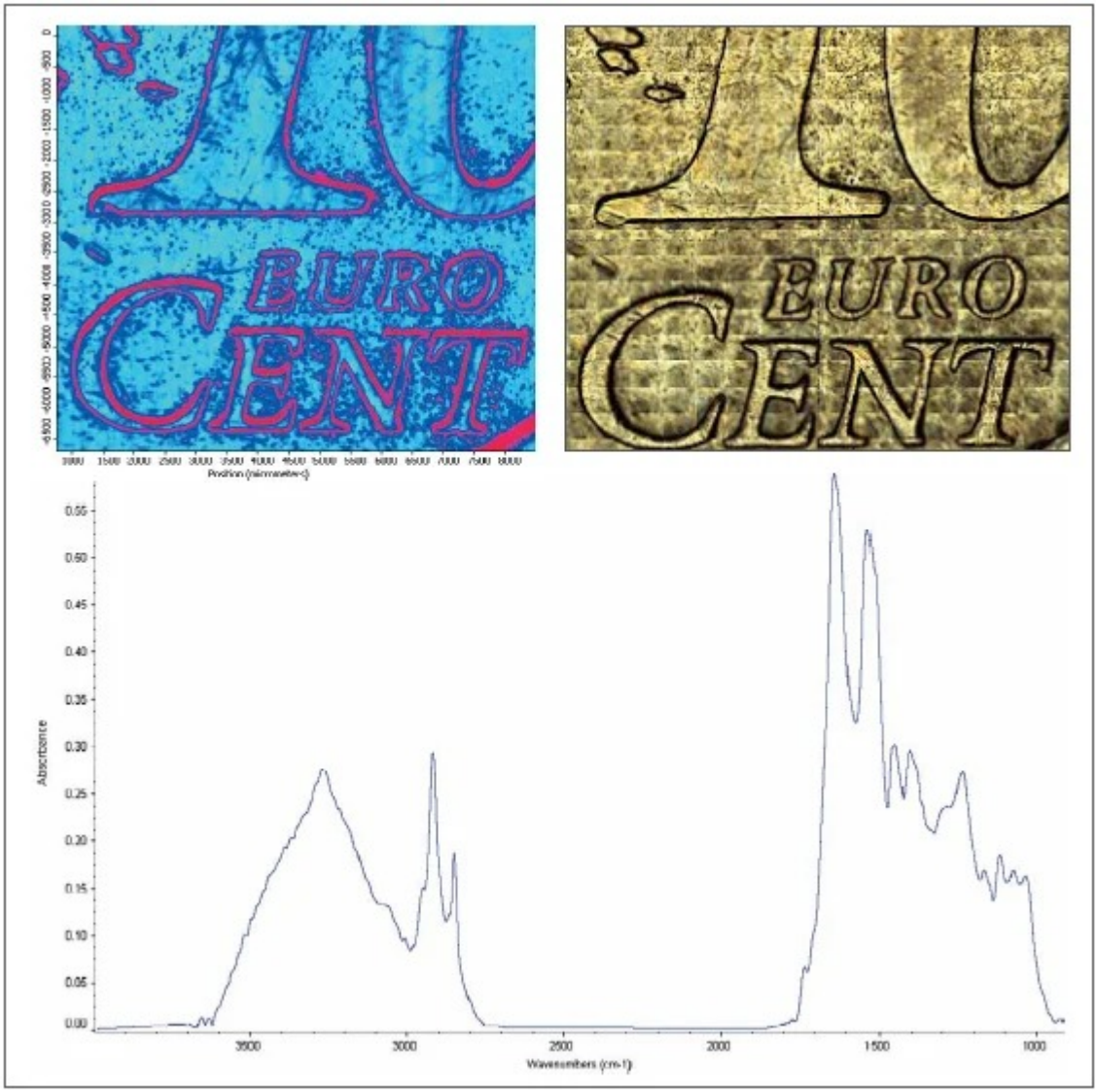


Figure 8. *(Upper Left) Chemical image of 10-cent Euro coin (Upper Right) Mosaic video capture of coin sample area (Lower) Spectrum of amide residue. Image Credit: Thermo Fisher Scientific -*

Summary

The Nicolet iN10 Infrared Microscope and Nicolet iN10 MX Imaging Microscope provide forensic scientists with immediate visual and chemical information for a wide range of samples. Infrared is sensitive and non-destructive, allowing for correct interpretation while conserving evidence.

The spatial resolution and sensitivity of linear array imaging enable the rapid detection of trace materials. OMNIC Picta's performance verification and validation package provides confidence in the results, which is critical when presenting data in court.

In addition, Thermo Scientific provides unique OMNIC Specta Software, which boasts the most advanced peak and multicomponent search functionality.

References

1. Tungol, M.W., Bartick, E.G. and Akbar Montaser (1990). The Development of a Spectral Data Base for the Identification of Fibers by Infrared Microscopy. *Applied Spectroscopy*, 44(4), pp.543–549. https://doi.org/10.1366/0003702904087451.

About Thermo Fisher Scientific - Vibrational Spectroscopy

With over 50 years of experience in spectroscopy innovation, Thermo Fisher Scientific's vibrational spectroscopy solutions—including near-infrared (NIR), multi-range Fourier transform infrared (FTIR), and Raman instruments—deliver the performance, reliability, and ease-of-use you need to succeed.

Perform raw material identification, differentiate between polymorphs, and analyze formulated products with specificity, speed, and reliability. Analyze biological samples for protein structure elucidation, protein stability, protein-protein interaction, lipid modifications, tissue imaging, analyzing plant extracts, and more with complementary vibrational spectroscopy techniques. With software tools to support data integrity and required

validation protocols, and hardware modules designed to work 24-7-365 with minimal re-qualification needs, these spectrometers help you comply with pharmacopeia regulatory requirements while getting the job done.

The Thermo Scientific™ Nicolet™ family of spectrometers are designed to be used in research labs, at-line production, and even at the loading dock to provide the information you need to make critical decisions fast, and with confidence. From drug development and quality control to the identification of the chemical structure of samples and detection of defects and contaminants, Thermo Scientific Raman spectrometers make it easy to characterize molecular structures without becoming a Raman expert.

What Role Does AI Play in Modern Forensic Science?

Forensic investigations have evolved dramatically, moving from human-driven analysis to AI-powered solutions that enhance speed, accuracy, and scalability.

Image Credit: Jackie Niam/Shutterstock.com

In the past, forensic scientists had to manually compare handwriting samples, analyze video footage, and sift through massive amounts of data—an often time-consuming and error-prone process. While human intuition remains valuable, it can also introduce cognitive bias and inefficiencies. AI is changing that by automating forensic analysis and making investigations more objective and data-driven.1-3

In this article, we'll explore how AI is revolutionizing different areas of forensic science, from DNA analysis and digital forensics to facial recognition and forensic biomechanics. We'll also discuss the challenges, ethical considerations, and future of AI in forensic investigations.

AI in Action: Smarter, Faster Forensics

AI's applications in forensics are vast, ranging from deoxyribonucleic acid (DNA) evidence analysis and pattern recognition to crime scene reconstruction, digital forensics, and

psycho/narco-analysis. By automating complex tasks, AI reduces human error and accelerates the interpretation of evidence, making forensic investigations more efficient. For instance, AI-driven tools can analyze vast datasets in digital forensics, detect cyber threats, and improve biometric identification methods such as facial recognition and fingerprint analysis.[1-3]

However, forensic standardization remains a challenge due to the absence of formalized methodologies for AI applications in digital investigations. The opaque nature of AI models and their non-deterministic outputs make transparency and reproducibility difficult. Addressing these concerns requires dedicated evaluation, standardization, and optimization frameworks tailored to forensic needs.

Confidence scales (C-Scales), for example, can quantify the reliability of AI-generated evidence, while optimization techniques can enhance forensic accuracy and efficiency. Establishing standardized approaches will ultimately strengthen the credibility and admissibility of digital evidence in legal proceedings.[4]

AI in Forensic Biomechanics: Cracking the Code of Movement

The integration of machine learning (ML) and computer vision technologies into biomechanics has opened new possibilities for forensic applications. By leveraging these advancements, critical biomechanical parameters like three-dimensional body shapes, anthropometrics, and kinematics can be estimated from simple single-camera images or videos. This is particularly valuable in forensic scenarios, where traditional methods requiring complex multi-sensor

systems or specialized equipment are often impractical.

For example, in accident reconstructions, where biomechanical analysis serves as evidence in legal proceedings, the only available data may be a single piece of footage. AI-driven tools, such as pose estimation algorithms (Blazepose, ICON, MeTRAbs) and three-dimensional body shape reconstruction models (PIFuHd), can extract detailed biomechanical data from such limited inputs, enabling accurate analysis of spinal kinematics and segmental mass estimations.[5]

AI also aids in analyzing complex biomechanical events, such as whiplash injuries in car accidents or workplace lifting incidents, by reconstructing body movements and estimating external loads. These data-driven insights enhance the objectivity and reliability of forensic investigations, strengthening the evidence presented in court. However, challenges remain, including ensuring prediction accuracy, accounting for complex human interactions, and refining load estimation techniques.

Despite these hurdles, AI's role in forensic biomechanics is expanding. By integrating traditional musculoskeletal modeling with ML and computer vision, AI is making biomechanical analysis more accessible, efficient, and reliable—paving the way for broader applications in forensic science.[5]

Digital Forensics: AI vs. Cybercriminals

AI, including ML and deep learning (DL), along with automation, is revolutionizing digital forensics by improving efficiency, accuracy, and cost-effectiveness.

Digital forensics involves the scientific identification, collection, examination, and analysis of digital data while ensuring a strict chain of custody and preserving data integrity. With cybercrimes such as hacking, data breaches, malware attacks, and phishing scams on the rise, advanced forensic tools have become essential.

The annual cost of cybercrime now exceeds $2 trillion, prompting organizations to increase investments in detection and prevention. Traditional forensic methods, which require manually sorting through vast amounts of data, are both time-consuming and resource-intensive. AI and automation help overcome these limitations by enabling faster, more precise analysis of digital evidence—even in non-cyber crimes where key evidence is stored on devices like cell phones and computers.[6]

AI-powered ML and DL algorithms can process extensive datasets, identify patterns, and generate insights with minimal human intervention. ML models use both supervised and unsupervised learning to analyze past data and detect anomalies, while DL leverages artificial

neural networks (ANNs) to process complex data types, such as images, audio, and text. These AI-driven tools automate tasks like data extraction, analysis, and decision-making, reducing human error and improving the scalability of forensic investigations.

When combined with automation, AI creates intelligent systems capable of autonomously performing forensic tasks, such as detecting malicious network activity or tracing fraudulent financial transactions. Real-world applications, such as Intrusion Prevention Systems (IPS), demonstrate how AI-driven automation can proactively identify and mitigate cyber threats. As AI continues to advance, its role in digital forensics will only expand, making forensic investigations more efficient and reliable.[6]

AI and Facial Recognition: A Double-Edged Sword

Facial recognition, a key application of AI-driven biometrics, has evolved from early human identification based on facial features to modern automated systems powered by artificial intelligence. Historically, people relied on visual cues such as forehead shape, nose structure, and unique markings like freckles or birthmarks to distinguish individuals.

Today, these characteristics are digitized and analyzed by automated facial recognition systems (AFRS), which compare facial features in images and videos to identify individuals. This technology is widely used in applications such as smartphone unlocking, locating missing persons, and tracking attendance in workplaces and schools.[7,8]

Facial recognition systems operate by scanning facial features and converting them into a mathematical representation called a faceprint. This faceprint is then matched against a database of stored images. Deep learning algorithms, primarily convolutional neural networks (CNNs), power this process by analyzing key facial landmarks—such as the distance between the eyes, jawline shape, and nose structure—to create a unique biometric profile.

For example, India's National Crime Records Bureau (NCRB) has proposed using AFRS to identify criminals, recognize unidentified corpses, and integrate with existing databases, such as CCTV footage, for criminal investigations.[7,8]

Despite its potential, facial recognition technology faces significant challenges. Privacy concerns and algorithmic bias raise ethical questions, particularly regarding fairness and discrimination. Studies have also shown that facial recognition systems can have higher error rates for certain demographic groups, leading to concerns about bias and reliability. Additionally, the lack of comprehensive legislation complicates its regulation. Countries like the United States, the United Kingdom, and Australia are struggling to balance public safety benefits with the need to protect individual privacy.[7,8]

DNA and Genetic Forensics: AI Unlocking Hidden Clues

AI is increasingly being applied to DNA and genetic forensics, offering significant advancements in the analysis and interpretation of genetic data. The two primary applications of AI are haplogroup analysis and short tandem repeat (STR) profile analysis. In haplogroup analysis, AI algorithms classify DNA samples into specific genetic groups, enhancing the speed and accuracy of the classification process. For STR profiles, AI reduces the risk of misinterpretation by automating the analysis of complex genetic data, leading to more precise individual identification.[9]

AI tools, such as ML and ANN, are particularly effective at processing large datasets and uncovering patterns that traditional methods might overlook. For example, ANNs have been used to predict age based on DNA methylation patterns, outperforming traditional regression models. AI also aids in analyzing biological data, including DNA, RNA, and epigenetic markers—essential for distinguishing human evidence from non-human samples in forensic investigations.[9]

Ethical Dilemmas: Can We Trust AI in Forensics?

With great power comes great responsibility, and AI in forensics is no exception.

AI-driven forensic tools raise significant ethical concerns, including the potential for bias amplification due to non-diverse datasets, privacy risks associated with biometric data collection, and opaque decision-making processes that can undermine trust. Ensuring fairness requires diverse training data, clear regulations, and AI systems that offer transparency and interpretability.

Legal standards must evolve to address the reliability and admissibility of AI-generated evidence, ensuring that it meets rigorous forensic requirements. At the same time, overreliance on AI could sideline human expertise, raising concerns about accountability and the role of forensic professionals in investigations. Additionally, disparities in access to AI tools between well-funded and underfunded agencies create ethical and practical challenges, potentially widening gaps in forensic capabilities.[10]

As AI continues to shape forensic science, balancing innovation with ethical safeguards will be essential to maintaining public trust and ensuring justice.

What's Next for AI in Forensic Science?

The future of AI in forensic science is set to move beyond automation and pattern recognition

toward intelligent, adaptive forensic systems capable of uncovering insights with unprecedented accuracy. Over the next decade, breakthroughs in AI-driven forensic technologies will enhance investigations, refine legal processes, and introduce new ethical and regulatory challenges that demand careful navigation.

One of the most promising advancements is in crime scene analysis, where AI is expected to evolve from passive data processing to real-time, autonomous forensic assessments. Smart drones and robotic investigators equipped with AI-driven sensors could soon collect and analyze evidence on-site, reducing the time and human effort required for forensic examinations.

AI-powered 3D reconstructions will integrate data from digital devices, security footage, and environmental sensors, creating highly detailed, dynamic visualizations of crime scenes. Future AI systems may even be capable of synthesizing information from multiple sources—videos, audio recordings, and physiological responses—to provide a more complete, data-driven understanding of events.

In forensic DNA analysis, AI will push the boundaries of genetic profiling, making it possible to extract meaningful information from even the most degraded or complex DNA samples. Advances in AI-driven forensic sequencing could allow for rapid, near-instantaneous DNA matching, reducing backlog delays and improving accuracy in cold cases.

As AI enhances the ability to predict phenotypic traits from genetic markers, forensic investigations may soon incorporate advanced predictive modeling to generate composite sketches based solely on DNA, a development that brings both investigative potential and ethical considerations. AI-powered ancestry tracing will also become more refined, improving the ability to link unidentified remains to missing persons or criminal suspects with unprecedented precision.

Predictive analytics will also play a larger role in forensic science, moving beyond crime hotspot identification toward proactive crime deterrence. Machine learning models trained on behavioral patterns, financial transactions, and social network activity could help law enforcement anticipate criminal activity before it occurs.

While these advancements promise to improve public safety, they also raise concerns about privacy, bias, and accountability. Addressing these challenges will require the development of transparent AI auditing frameworks, as well as legal and ethical guidelines to govern how predictive models are used in investigations.

As AI-generated evidence becomes more common in courtrooms, explainability and reliability

will be critical. The forensic community will need to ensure that AI tools provide clear, interpretable results that meet evidentiary standards. AI may eventually play an active role in legal proceedings, not only assisting forensic experts but also shaping how evidence is presented and understood in trials. Ensuring fairness in AI-driven forensic science will require interdisciplinary collaboration between forensic scientists, legal professionals, and AI researchers, along with continuous efforts to mitigate biases in algorithmic decision-making.

With these advancements, forensic science is on the brink of a transformation that could improve investigative accuracy, expedite case resolutions, and enhance overall efficiency. However, the success of AI in this field will ultimately depend on how well ethical, legal, and privacy concerns are addressed.

Preparing forensic professionals for this shift will be essential, requiring ongoing education in AI ethics, digital evidence handling, and algorithmic bias detection. If implemented responsibly, AI has the potential to not only revolutionize forensic science but also strengthen the integrity of criminal investigations and contribute to a more just and secure society.[11,12]

Want to Learn More?

Forensic science is evolving fast, and AI is just one piece of the puzzle. If you're curious about what's next, here are some topics to explore:

- **AI Liability and Accountability: Who is Responsible When AI Makes a Harmful Decision?**
- **Sustainable AI: Balancing Tech and Ethics**
- **Unlocking the Future of Forensics**
- **Top 5 Technologies Reshaping Forensic Science**
- **Body Farms; An Overview of Their Purpose in Forensic Science**
- **How AI and 3D Imaging are Transforming Body Farm Research**

References for Further Reading

1. Becker, S., Heuschkel, M., Richter, S., & Labudde, D. (2022). COMBI: Artificial Intelligence for Computer-Based Forensic Analysis of Persons. KI - Künstliche Intelligenz, 36(2), 171–180. DOI:10.1007/s13218-022-00761-x
2. Lodhi, K., & Kassem, M. A. (2024). Revolutionizing Forensic Science: The Role of Artificial Intelligence and Machine Learning. International Journal of Data Science, 10–18. DOI:10.5147/ijds.vi.255
3. Ahmed Alaa El-Din, E. (2022). ARTIFICIAL INTELLIGENCE IN FORENSIC SCIENCE : INVASION OR REVOLUTION? Egyptian Society of Clinical Toxicology Journal, 10(2), 20–32.

DOI:10.21608/esctj.2022.158178.1012

4. Solanke, A. A., & Biasiotti, M. A. (2022). Digital Forensics AI: Evaluating, Standardizing and Optimizing Digital Evidence Mining Techniques. KI - Künstliche Intelligenz, 36. DOI:10.1007/s13218-022-00763-9
5. Ghezelbash, F., Hossein Eskandari, A., Robert-Lachaine, X., Cao, S., Pesteie, M., Qiao, Z., Shirazi-Adl, A., & Larivière, C. (2024). Machine learning applications in spine biomechanics. Journal of Biomechanics, 166, 111967. DOI:10.1016/j.jbiomech.2024.111967
6. Jarrett, A., & Choo, K. R. (2021). The impact of automation and artificial intelligence on digital forensics. WIREs Forensic Science, 3(6). DOI:10.1002/wfs2.1418
7. Khan, D. Z. A., & Rizvi, A. (2021). AI BASED FACIAL RECOGNITION TECHNOLOGY AND CRIMINAL JUSTICE: ISSUES AND CHALLENGES. Turkish Journal of Computer and Mathematics Education (TURCOMAT), 12(14), 3384–3392. DOI:10.17762/turcomat.v12i14.10923
8. Michael, K., Abbas, R., Jayashree, P., Bandara, R. J., & Aloudat, A. (2022). Biometrics and AI Bias. IEEE Transactions on Technology and Society, 3(1), 2–8. DOI:10.1109/tts.2022.3156405
9. Sessa, F., Esposito, M., Cocimano, G., Sablone, S., Ahmed, M., Chisari, M., Davide Giuseppe Albano, & Salerno, M. (2024). Artificial Intelligence and Forensic Genetics: Current Applications and Perspectives. Applied Sciences (Basel), 14(5), 2113–2113. DOI:10.3390/app14052113
10. Abirami Arthanari, Raj, S. S., & Ravindran, V. (2025). A Narrative Review in Application of Artificial Intelligence in Forensic Science: Enhancing Accuracy in Crime Scene Analysis and Evidence Interpretation. Journal of International Oral Health, 17(1), 15–22. DOI:10.4103/jioh.jioh_162_24
11. Wahengbam Upendra Singh, & Kh. Pradipkumar Singh. (2023). The transformative role of artificial intelligence in forensic medicine and toxicology. Journal of Medical Society, 37(3), 101–102. DOI:10.4103/jms.jms_54_24
12. Wickramasekara, A., Breitinger, F., & Scanlon, M. (2024). Exploring the Potential of Large Language Models for Improving Digital Forensic Investigation Efficiency. ArXiv.org. DOI:10.48550/arXiv.2402.19366

AI Tool for Forensic TBI Investigations

Researchers from the University of Oxford have created a cutting-edge AI-driven tool based on physics to support forensic and law enforcement traumatic brain injury (TBI) investigations. The results were published in *Communications Engineering*.

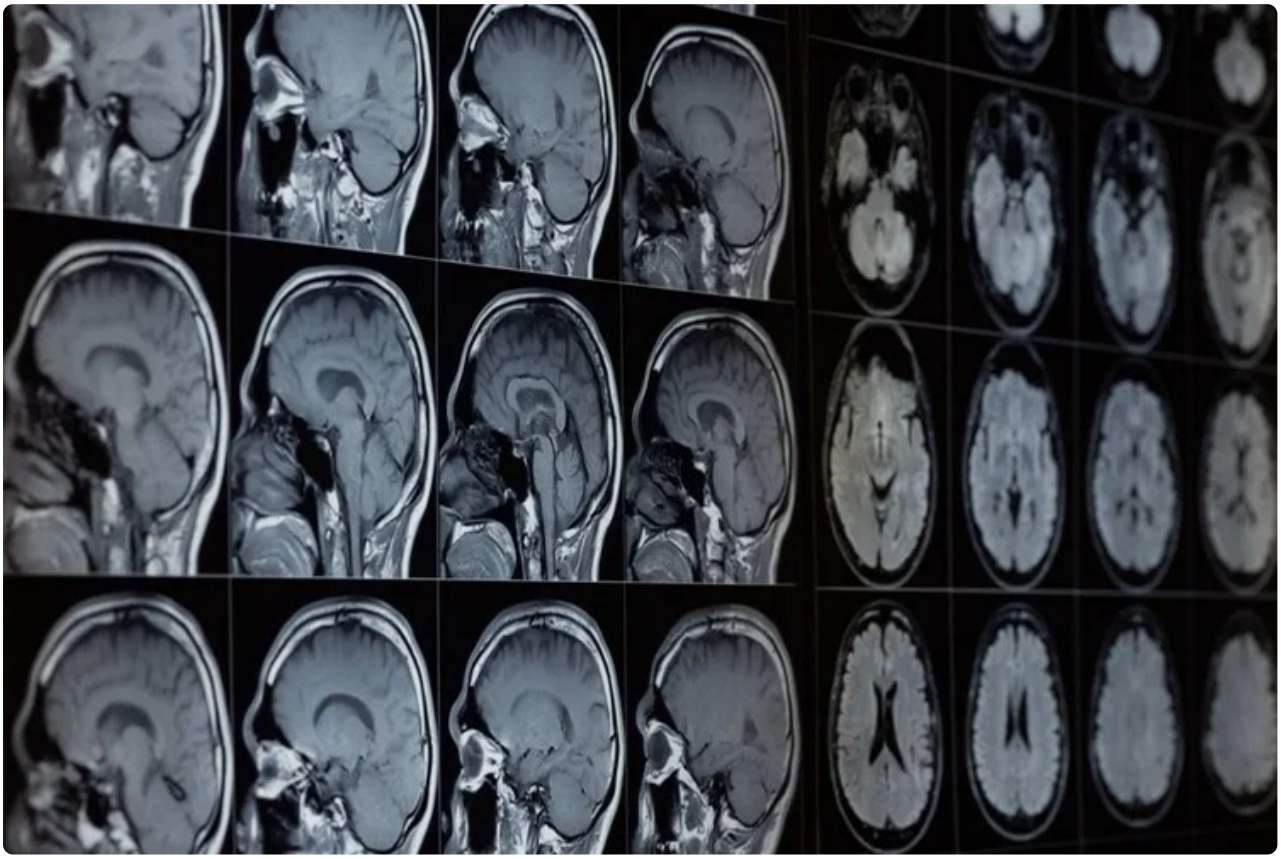


Image Credit: Teeradej/Shutterstock.com

TBI has serious, long-lasting neurological effects, making it a serious public health concern. Determining whether an impact might have caused a reported damage is essential for legal processes in forensic investigations, but there is not a standardized, quantitative method for doing so at the moment.

The latest study shows how machine learning methods informed by mechanistic simulations could produce evidence-based harm predictions. Based on recorded assault scenarios, this would assist law enforcement and forensic teams in making precise predictions about TBI consequences.

The study's AI framework demonstrated exceptional prediction accuracy for TBI-related

injuries after being trained on actual, anonymized police reports and forensic data:

- 94% accuracy for skull fractures
- 79% accuracy for loss of consciousness
- 79% accuracy for intracranial hemorrhage (bleeding within the skull)

The model demonstrated good sensitivity and specificity (a low rate of false positive and false negative outcomes) in every instance.

Using a broad computational mechanistic model, the framework simulates the effects of numerous impacts, including punches, slaps, and strikes against a flat surface, on different regions of the head and neck. This offers a simple forecast of the likelihood of tissue stress or deformation following an impact. Nevertheless, it cannot independently forecast any risk of harm. An upper AI layer combines this data with any other pertinent metadata, such as the victim's height and age, to provide a prognosis for a particular injury.

> *"This research represents a significant step forward in forensic biomechanics. By leveraging AI and physics-based simulations, we can provide law enforcement with an unprecedented tool to assess TBIs objectively.*
>
> *Antoine Jérusalem, Study Lead Researcher and Professor, Department of Engineering Science, University of Oxford*

The researchers trained the overall framework using 53 anonymized genuine police records of assault instances. Each report included information regarding various parameters that could influence the severity of the blow (for example, the victim's or offender's age, gender, and body type). This produced a model capable of combining mechanical biophysical data with forensic facts to forecast the risk of various injuries.

When the researchers determined which elements influenced the prediction value for each type of injury, the results were strikingly similar to medical findings. For example, when estimating the chance of skull fracture, the most relevant component was the maximum amount of force sustained by the scalp and skull during an impact. Similarly, brainstem stress measurements were the best predictor of loss of consciousness.

The research team cautions that the model is not meant to take the role of real forensic and clinical professionals in analyzing assault cases. Instead, the goal is to provide an objective

assessment of the likelihood that a documented assault was the genuine cause of a reported injury. The model could be used to identify high-risk situations, improve risk assessments, and devise preventive techniques for lowering the frequency and severity of head injuries.

> *"Understanding brain injuries using innovative technology to support a police investigation, previously reliant on limited information, will greatly enhance the interpretation required from a medical perspective to support prosecutions.*
>
> *Ms Sonya Baylis, Senior Manager at the National Crime Agency*

"Our framework will never be able to identify without doubt the culprit who caused an injury. All it can do is tell you whether the information provided to it is correlated with a certain outcome. Since the quality of the output depends on the quality of the information fed into the model, having detailed witness statements is still crucial," Jérusalem added.

Dr Michael Jones, Researcher at Cardiff University and Forensics Consultant, added, *"An "Achilles heel" of forensic medicine is the assessment of whether a witnessed or inferred mechanism of injury, often the force, matches the observed injuries. With the application of machine learning, each additional case contributes to the overall understanding of the association between the mechanism of cause, primary injury, pathophysiology and outcome."*

A multidisciplinary team of engineers, forensic specialists, and medical professionals from the University of Oxford, Thames Valley Police, the National Crime Agency, Cardiff University, Lurtis Ltd., the John Radcliffe Hospital, and other institutions collaborated on the study.

Journal Reference:

Wei, Y. *et. al.* (2025) A mechanics-informed machine learning framework for traumatic brain injury prediction in police and forensic investigations. *Communications Engineering*. doi.org/10.1038/s44172-025-00352-2

Source:

University of Oxford