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FORENSIC SCIENCE REVIEW

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Objectives and Scope

The discipline of forensic science has nurtured many publications oriented toward research and case reports, as well as broad-based formal treatises. Rapid advances in forensic science have created a need for a review journal to bridge the gap between research-oriented journals and reference volumes.

The goal of *Forensic Science Review* is to fill this void and provide a base for authors to extrapolate state-of-the-art information and to synthesize and translate it into readable review articles. The addition of this journal extends the spectrum of forensic science publications.

Articles bring into focus various narrowly defined topics whose literature has been widely scattered. Articles are presented to stimulate further research on one hand and worthwhile technological applications on the other. The publisher's aim is to provide forensic scientists with a forum enabling them to accomplish this goal.

Technological applications based on basic research are emphasized. Articles address techniques now widely used in forensic science as well as innovations holding promise for the future.

FORENSIC SCIENCE REVIEW

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Forensic Science Review (*http://www.forensicsciencereview.com*; ISSN 1042-7201; US Library of Congress Control No. 90649976; indexed and included in MEDLINE/PubMed) is a biannual review journal devoted to the timely publication of current topics in the field of forensic science. Both issues include two sections ("Professional Review and Commentary" and "Review Article") that are published in January and July of each year.

The journal, originally founded by Shih-Si Yen, President of the Central Police University (Taoyuan, Taiwan), is currently published by Forensic Science Review with executive editorial offices located in Arlington (Texas, US) and the Department of Criminal Justice, University of Alabama at Birmingham (Alabama, US).

Both professional review/commentary and review articles published in **Forensic Science Review** are mostly invited contributions. Review articles are peer-reviewed. The invitation process normally originates from the recommendations of the Editorial Board. Unsolicited articles from the general readership are also welcomed but should be preceded by a query letter to the Editor-in-Chief for presentation to the Editorial Board. Query letters and editorial correspondence should be addressed to: Editor-in-Chief, **Forensic Science Review**, P. O. Box 153034, Arlington, TX 76015, US or preferably through E-mail to rayliu@uab.edu. Honoraria are presented to authors and reviewers upon distribution of the issue in which the article appears. All published articles represent the opinions of the authors and do not represent the official policy of the publisher or the institution with which the author is affiliated, unless clearly specified.

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Professional Review and Commentary

Review Articles

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Review Articles (Continued)

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CSI/Forensic Science Experience Camp in Taiwan

Forensic Science in the [US] DOE National Laboratory Setting

Forensic Science in Ireland

Revealing the Web of Connections: Online Drug Sales, Financial Crimes, and Crypto Scams

The Wisdom of a Constant Blood/Breath Ratio of Alcohol in Law Enforcement

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Advances in the Examination of Fingerprint Evidence: A Review on Related Efforts

Drugs in Hair. Part II: Analysis of Hair in Workplace Drug Testing

Ethics in Forensic Science: An Overview

Nerium oleander Toxicity: A Comprehensive Review

Systematic Review on Forensic Craniofacial Reconstruction. II: Methodologies and Applications

Three-D Virtual Comparison Microscopic Examination of Firearm Evidence

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Forensic Science Review's Professional Review and Commentary (R&C) section highlights contemporary issues and events in the profession of forensic science. To contribute updates or commentary or to recommend books for review, please contact Ray Liu (rayliu@uab.edu).

[a]The views expressed are those of the authors and do not necessarily reflect the view, the position, or the policy of *Forensic Science Review* or members of its editorial board.

FORENSIC SCIENCE AROUND THE WORLD

Upcoming Events

2025 Online Forensic Symposium — Current Trends in Seized Drugs Analysis
(https://forensiceducation.brightspace.com/d2l/lor/viewer/view.d2l?ou=6658&loIdentId=329&emci=7f59a9c0-00ac-ef11-88cf-6045bdfe8d29&emdi=4a3330ba-d8ac-ef11-88cf-6045bdfe8d29&ceid=8113655)

Jan. 13–17, 2025; Virtual

International Medical Cannabis Conference
(*https://www.imccb.org/*)

Feb. 13–14, 2025; University of Bern
Bern, Switzerland

American Academy of Forensic Sciences — 77th Annual Meeting
(*https://www.aafs.org/annual-conference*)

Feb. 17–22, 2025; Baltimore Convention Center
Baltimore, MD, US

PITTCON Conference and Expo
(*https://pittcon.org*)

March 1–5, 2025; Boston Convention and Exhibition Center
Boston, MA, US

European Drugs Winter School 2025
(*https://ipps.iscte-iul.pt/en/*)

Mar. 10–21, 2025; Instituto Universitário de Lisboa
Lisba, Portugal

Society for Research on Nicotine and Tobacco Annual Meeting
(*https://srnt.joynmeeting.com/v2/*)

Mar. 12–15, 2025; Hilton New Orleans Riverside
New Orleans, LA, US

The SOT 64th Annual Meeting and ToxExpo
(*https://www.toxicology.org/events/am/AM2025/index.asp*)

Mar. 16–20, 2025; Orange County Convention Center
Orlando, FL, US

17th Annual BBC (Behavior, Biology, and Chemistry) Meeting: Translational Research in Substance Use Disorders
(*https://ww2.uthscsa.edu/artt/bbc/index.asp*)

Mar. 21–23, 2025; Embassy Landmark San Antonio
San Antonio, TX, US

ACS Spring National Meeting & Exposition 2025
(*https://www.showsbee.com/fairs/14149-ACS-National-Meeting-Exposition.html*)

Mar. 23–25, 2025; San Diego Convention Center
San Diego, CA, US

American Academy of Pain Medicine Annual Meeting
(*https://painconnect.org/*)

April 3–6, 2025; Austin Convention Center
Austin, TX, US

2025 American College of Medical Toxicology Annual Scientific Meeting
(*https://www.acmt.net/annualmeeting/*)

April 2–6, 2025; Fairmont Hotel
Vancouver, BC, Canada

American Society of Crime Laboratory Directors — 52nd Annual Symposium
(*https://www.ascld.org/ascld-annual-symposium/*)

April 4–8, 2025; Hyatt Regency Denver
Denver, CO, US

International Association of Chemical Testing — 2025 Annual Conference
(*http://iactonline.org/*)

April 6–11, 2025; Sahara Las Vegas
Las Vegas, NV, US

2025 Addiction Medicine Conference
(*http://addiction-medicine.org/spring-conference/*)

April 11–12, 2025; Renaissance Asheville Hotel
Asheville, NC, US

14th World Gene Convention (WGC 2025)
(*https://www.clocate.com/world-gene-convention-wgc/43385/*)

April 23–25, 2025; Nara Royal Hotel
Nara, Japan

California Association of Criminalists Seminar
(*https://www.cacnews.org/events/seminar/seminars.shtml*)

April 27–May 2, 2025; Lake Natoka Inn
Folsom, CA, US

Southern Association of Forensic Scientists — 2025 Annual Meeting
(*https://safs1966.org/annual-meeting/*)

May 5–9, 2025; Hyatt Regency Jacksonville Riverfront Jacksonville, FL, US

Mid-Atlantic Association of Forensic Scientists — 2025 Annual Meeting
(*https://www.maafs.org/annual-meeting*)

May 6–9, 2025; Richmond Marriott Downtown
Richmond, VA, US

The Association of Firearm and Tool Mark Examiners — 56th Annual Training Seminar
(*https://afte.org/meetings/annual-seminars*)

May 11–16, 2025; Marriott Anaheim
Anaheim, CA, US

American Psychiatric Association 2025 Annual Meeting
(*https://www.psychiatry.org/*)
May 17–21, 2025; Los Angeles Convention Center
Los Angeles, CA, US

2025 Association for Psychological Science Annual Convention
(*https://www.psychologicalscience.org/conventions/2025-aps-annual-convention*)
May 22–25, 2025; Washington Hilton Hotel
Washington, DC, US

The European Academy of Forensic Science (EAFS 2025) Annual Meeting of the European Network of Forensic Science Institutes (ENFSI)
(*https://eafs2025.org/*)
May 26–30, 2025; Convention Centre Dublin
Dublin, Ireland

West Coast Symposium on Addictive Disorders
(*https://hmpglobalevents.com/symposia-addictive-disorders*)
May 29–31, 2025; La Quinta Resort & Club
Palm Springs, CA, US

73rd ASMS Conference on Mass Spectrometry and Allied Topics
(*https://asms.org/conferences/annual-conference*)
June 1–5, 2025; Baltimore Convention Center
Baltimore, MD, US

BODE 2025 — 24th Annual Forensic DNA Conference
(*https://www.bodeconference.com*)
June 3–6, 2025; Hyatt Regency Long Beach
Long Beach, CA, US

The College on Problems of Drug Dependence Annual Meeting
(*https://cpdd.org/meetings/current-meeting/*)
June 14–18, 2025; Sheraton New Orleans
New Orleans, LA, US

24th International Council on Alcohol, Drugs and Traffic Safety Conference
(*https://t2025.org*)
June 15–18, 2025; The Conference Centre
Alcobaca, Portugal

Forensics Europe Expo
(*https://forensicseuropeexpo.com/*)
June 18–19, 2025; Excel London
London, UK

48th Annual RSA Scientific Meeting/ISBRA Congress
(*https://researchsocietyonalcohol.org/*)
June 21–25, 2025; Hyatt Regency New Orleans
New Orleans, LA, US

Forensic Analysis of Human DNA — Gordon Research Conference
(*https://www.grc.org/forensic-analysis-of-human-dna-conference/2025/#*)
June 22–27, 2025; Jordan Hotel at Sunday River
Newry, ME, US

European Drugs Summer School 2025
(*https://ipps.iscte-iul.pt/en/*)
June 23–July 4, 2025; Instituto Universitário de Lisboa
Lisbon, Portugal

The 10th International Conference on Behavioral Addictions
(*https://icba.issba.hu/*)
July 7–9, 2025; La Cité Nantes Congress Centre
Nantes, France

ADLM (Association for Diagnostics & Laboratory Medicine) 2025
(*https://meeting.myadlm.org/*)
July 27–31, 2025; McCormick Place Convention Center
Chicago, IL, US

IACP Impaired Driving and Traffic Safety Conference
(*https://www.theiacp.org/IDTSconference*)
Aug. 4–6, 2025; Not found
Chicago, IL, US

APA Annual Convention 2025 — American Psychological Association
(*https://convention.apa.org/*)
Aug. 7–9, 2025; Convention Center
Denver, CO, US

International Association for Identification — 109th Educational Conference
(*https://theiai.org/conference.php*)
Aug. 10–16, 2025; Rosen Shingle Creek Resort
Orlando, FL, US

ACS Fall National Meeting & Exposition 2025
(*https://www.acs.org/meeting/acs-meetings/future-meetings.html*)
Aug. 17–21, 2025; Walter E Washington Convention Center
Washington, DC, US

American Society of Questioned Document Examiners 83rd Annual Conference
(*https://asqde.org*)
Aug. 18–20, 2025; Harrah's Las Vegas
Las Vegas, NV, US

International Conference on Forensic Nursing Science & Practice
(*https://www.forensicnurses.org/page/FutureConferences/*)
Aug. 19–20, 2025; Convention Center
Omaha, NE, US

Midwestern Association of Forensic Scientists — 2025 Annual Meeting
(*https://mafs.net/page-18404*)

Aug. 24–29, 2025; Renaissance Columbus Downtown Hotel
Columbus, OH, US

18th Annual Alcohol Law & Policy Conference
(*https://www.centerforalcoholpolicy.org/law/*)

Aug. 25–27, 2025; Hyatt Centric Chicago Magnificent Mile
Chicago, IL, US

Cape Cod Symposium on Addictive Disorders
(*https://www.hmpglobalevents.com/symposia-addictive-disorders*)

Sept. 4–7, 2025; Cape Cod Village at the Emerald Resort
Hyannis, MA, US

59th Congress of the European Societies of Toxicology
(*https://www.eurotox2025.com/*)

Sept. 14–17, 2025; Megaron Athens International Conference Centre
Athens, Greece

International Society of Substance Use Professional Regional Conference on Drug Prevention, Treatment and Care
(*https://www.issup.net/about-issup/workshops/bali-2025*)

Sept. 15–19, 2025; Not found
Bali, Indonesia

23rd International Congress of Therapeutic Drug Monitoring & Clinical Toxicology
(*https://www.iatdmct2025.org/*)

Sept. 21–24, 2025; Grand Copthorne Waterfront Hotel
Singapore, Singapore

East Coast Symposium on Addictive Disorders
(*https://hmpglobalevents.com/symposia-addictive-disorders*)

Oct. 3–5, 2025; Sawgrass Marriott Golf Resort & Spa
West Palm Beach, FL, US

SCIX 2025 (Annual Meeting of the Federation of Analytical Chemistry and Spectroscopy Societies)
(*https://scixconference.org*)

Oct. 5–10, 2025; Northern Kentucky Convention Center
Covington, KY, US

NAADAC Annual Conference (The Association for Addiction Professionals)
(*https://www.naadac.org/annualconference*)

Oct. 11–13, 2025; Hyatt Regency Bellevue
Seattle, WA, US

ICT2025 (The 17th International Congress of Toxicology)
(*https://www.ict2025.com/en/web/index/*)

Oct. 15–18, 2025; Beijing Guoce International Conference and Exhibition Center
Beijing, China

Canadian Society of Addiction Medicine (CSAM-SMCA) Annual Meeting and Scientific Conference
(*https://csam-smca.org/*)

Oct. 16–18, 2025; Le Centre Sheraton Montreal
Montreal, ON, Canada

National Association of Medical Examiners
(*https://name.memberclicks.net/annual-meetings*)

Oct. 17–21, 2025; Louisville Marriott Downtown
Louisville, KY, US

International Association of Chiefs of Police 2025
(*https://www.theiacpconference.org/*)

Oct. 18–21, 2025; Colorado Convention Center
Denver, CO, US

GAB 2025 (6th Edition of Global Conference on Addiction Medicine, Behavioral Health and Psychiatry)
(*https://addiction-behavioral-conferences.magnusgroup.org*)

Oct. 20–22, 2025; Hilton Garden Inn Lake Buena Vista/Orlando
Orlando, FL, US

Northeastern Association of Forensic Scientists — Annual Meeting
(*https://www.neafs.org/neafs-annual-meeting*)

Oct. 20–24, 2025; Lancaster Marriott at Penn Square
Lancaster, PA, US

Society of Forensic Toxicologists — Annual Meeting
(*https://www.soft-tox.org/annual-meeting-information*)

Oct. 26–31, 2025; Oregon Convention Center
Portland, OR, US

ISHI 36: International Symposium on Human Identification
(*https://www.ishinews.com/attend/*)

Nov. 3–6, 2025; Palm Beach Convention Center
Palm Beach, FL, US

AMERSA Conference (Association for Multidisciplinary Education and Research in Substance Use and Addiction)
(*https://amersa.org/*)

Nov. 13–15, 2025; Hyatt Regency at the Oregon Convention Center
Portland, OR, US

62nd Annual Meeting of the International Association of Forensic Toxicologists
(*https://www.tiaft2025.com*)

Nov. 23–27, 2025; New Zealand Int. Convention Centre
Auckland, New Zealand

American Academy of Forensic Sciences — 78th Annual Meeting (*https://www.aafs.org/*)

Feb. 9–14, 2026; New Orleans Ernest N Morial Convention Center
New Orleans, LA, US

Forensic Sciences in the United States. III: Current Issues Facing Forensic Laboratories

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This is the final part of a three-article series on "Forensic Science in the United States". The first article [1] focused on the history and outlook for publicly funded and private forensic laboratories. The second part [2] focused on the US medical examiner system. This final article will focus on some of the current issues facing publicly funded forensic science laboratories in 2024, e.g., the increase in gun-related crime, supply chains, standardization, remote testimony, salaries, separation of forensic laboratories from law enforcement, and forensic science education.

Increase in Gun-Related Crimes

As gun-related crimes continue to increase throughout the country, the pressure on forensic services to provide instantaneous information on analyses does as well. In particular, forensic service providers (FSP) who perform firearms and toolmark analysis feel this pressure most acutely. With the release of the ATF's (Bureau of Alcohol, Tobacco, Firearms and Explosives) Minimum Required Operating Standards (MROS) in 2017 and implementation in 2018 [3], forensic laboratories in the US were suddenly mandated to achieve 24- to 48-hour turnaround times on nearly all cases, resulting in some laboratories to cease offering National Integrated Ballistics Information Network (NIBIN) services. FSPs who moved away from performing "confirmations" and toward "leads" (further described below) have been the most successful at achieving the once-impossible goal.

Lead Model vs. Full Microscopic Confirmation

In the "lead" model, a laboratory will receive fired cartridge casings from scenes of all types, ranging from discharging to homicide. A triage process is performed where a scientist will perform a visual examination and group the casings by gross characteristics. The best of each grouping is entered into the NIBIN database in the hope of creating links between different events. When leads are generated, a preliminary lead report is issued without microscopic confirmation. It is not until a case is charged and moves into the judicial phase that the full microscopic confirmation is performed, though some exceptions to this do occur. In the most efficient models, only those cases that reach this stage are microscopically examined and confirmed while those still under investigation remain in line. This new model has been shown to quickly reduce turnaround times, allowing the FSP to provide linkage information to investigators within a day or two after the event itself.

Conducting a full microscopic confirmation on a case involves a great deal of work. An analyst must review all casings for gross characteristics, group them, and, following any NIBIN [4] leads, microscopically compare each casing recovered to all of the casings in the newly matched case(s) [5]. This confirmation protocol was the schema used in many laboratories for years. Traditional analysis models typically required full microscopic comparative analysis on every questioned item prior to issuance of investigative leads. Due to staffing resource issues, this practice dragged firearms laboratory turnaround times into the range of several weeks to several months before critical probative information was released to detectives. Reported national average turnaround times for firearms full microscopic comparisons range from 10 to 130 days while firearms database (NIBIN) turnaround times are just 1–11 days, according to data from the 2023 FORESIGHT project report [6].

The transition from full comparison to the lead model is still a work in progress. The ATF reports that "For test-fires of recovered crime guns in 2023, 65% of NIBIN sites had an average lead generation time of less than 48 hours, meeting ATF's minimum standards. But, 20% of NIBIN sites had an average lead generation processing time of 2–7 days, and another 16% of sites had an average processing time of more than 1 week. For a handful of NIBIN sites, the average time between the test-fire of a recovered crime gun and the generation of a lead report was more than 100 days" [7].

Challenges

The challenges faced by FSPs who must improve their turnaround times to meet the ATF's MROS 24 to 48 hour rule can be significant. These can range from large-scale policy changes and stakeholder buy-in to simple logistics.

First, a provider must have the staff in place to conduct quick preliminary reviews of submitted cartridge casings. This often means trained and authorized firearms examiners or technicians skilled in the review of gross characteristics of fired cartridges. Depending on the volume of gun crime, this can be a very large undertaking or relatively small. When the volume is large, the time required to complete

this first step can be long. From the moment the casings hit the ground and/or arrive in the lab, the 48-hour max is ticking down.

Second, FSPs must have buy-in from the entity that authorizes charges, such as a state or district attorney's office, in the jurisdiction. The change in procedure from issuing charges with a court-ready microscopic confirmation to one in which a preliminary lead is issued can be insurmountable for some jurisdictions. The educational and outreach efforts required to make this change can prevent a provider from being able to move forward with the transition. Even after this has been worked out, delays can occur due to a lack of understanding or willingness of individuals who do not want to use leads.

Finally, the provider must convince their own staff to perform work in a very different way than they had been in the past. Buy-in isn't just about convincing external stakeholders to accept a different work product. One of the most difficult obstacles an FSP can face is convincing their own staff to perform work in a way different than "the way they've always done it". Without this critical piece of the puzzle, an FSP's plans to use the lead model can be stopped before they get started.

If a laboratory is unable to achieve these three tasks—and maybe even in instances where they are—the ATF will ask an FSP to use one of the NIBIN National Correlation and Training Centers (NNCTC). These centers perform the evaluation of the leads generated by labs across the country in one centralized location and return their decisions to the lab or even the investigator directly. They claim to report back all correlations within the required 24 to 48-hour window or sooner.

The NNCTC can be a game-changer for those laboratories who were not able to meet the ATF's MROS, but it may not be the boon that it seems. Laboratories who have been able to successfully integrate the requirements and issue leads quickly may find the diversion out to the NNCTC adds time to their otherwise quick turnarounds. The detour costs time for fast FSPs, a luxury the MROS itself does not provide for.

Lasting Effects of COVID

Supply Strains

COVID changed the way many forensic laboratories do business. Many FSPs rely on other public government agencies in order to be able to perform their critical functions. Purchasing, accounts payable, legal services, facilities, and more are often functions performed outside of an FSP. Depending on whether staff in these external government agencies were deemed to be essential service providers or not, the impact forensics experienced during the pandemic ranged from none to dramatic. In areas where purchasing and facilities were deemed to be essential, FSPs may have had little interruption in their ability to perform work. But where those services were stopped or slowed, the effect was very different. Local governments experienced budget cuts and staffing shortages nationwide, which had a direct effect on forensic science providers.

Telework

As a means to address staffing challenges, telework became commonplace as agencies tried to remain afloat and keep workers on the books. The concept of telework is a good one in many industries and the pandemic forced reluctant industries, like state and local governments, to find ways to make it work for them. Studies [8] have shown that workers are happy to have teleworking as an option, and when managed properly, productivity can be very high.

The global pandemic affected all industries and even governmental public service providers were forced to find ways to perform critical governmental functions remotely. Some services seem tailored to the work-from-home schema, like procurement. Purchasing items for use by other governmental agencies requires a computer and an uplink, and with these things can be performed from anywhere. On the other hand, services like facilities and building maintenance may be less so. These workers need to be physically on site in order to perform the majority of their work.

During the pandemic, many of the more administrative staff in police and other public agencies were working from home, and today many of them have yet to return. This has led to a slowdown in the effectiveness of their core functions and caused many governments and agencies to mandate a return to work to address this. These slowdowns can affect the work of FSPs by preventing quick action on such things as purchasing reagents and adopting contracts, and create logjams in hiring and recruitment. These slowdowns can often add up to very detrimental effects on the ability of an FSP to provide timely investigative information and reduce their backlogs.

As the pandemic dragged on, those agencies affected by slowdowns naturally began to prioritize who would receive sparsely available services and who would continue to wait in line. FSPs felt the pinch, especially when they were embedded within police agencies as police response is typically prioritized over FSP work. This meant that routine purchases like reagents and consumables would be delayed, causing FSPs to value-rank the delivery of their own services which resulted in increased backlogs and longer turnaround times. The trickle-down effect of the administrative slowdowns during the pandemic affected

the way FSPs did their work. Many are still digging out from the effects of this aspect of the pandemic today.

Improving Standardization

Standardization of training, education, and practices has been a long-sought goal in forensics. Starting in the 1980s, scientific/technical working groups (SWGs) were established to develop a consensus on best practices and standards in forensic science. Most were housed in a federal agency; the Scientific Working Group on DNA Analysis Methods (SWGDAM) was sponsored by the FBI and the Scientific Working Group for the Analysis of Seized Drugs (SWGDrug) was sponsored by the Drug Enforcement Administration. Approximately 20 SWGs were formed between 1988 and 2010.

In 2009, the National Academies of Science published a report on the status of forensic science in the United States, citing a lack of standardization in many areas of forensic science, including terminology, educational requirements, performance, accreditation, certification, and reporting [9]. To address these issues, the National Institute of Standards and Technology (NIST) has established the Organization of Scientific Area Committees (OSAC). The OSACs define discipline-specific requirements for best practices and standard protocols to produce analytical results that are reliable and reproducible [10]. The OSACs subsumed many SWGs [11]. One exception is SWGDAM, which continues to produce guidance documents on methods, protocols, training, and quality assurance standards for forensic DNA analysis [12].

OSAC members are volunteers from public and private FSPs, academics, and government. The OSACs also encourage conformation with recommendations through their voluntary OSAC Registry Implementation program. As of this writing, over 200 laboratories in the United States currently hold this title.

NIST provides access to the OSAC standards through standards developing organizations (SDO). An SDO is an accredited member-based organization responsible for developing and maintaining standards for their field. NIST has partnered with several SDOs, the most comprehensive being the American Academy of Forensic Sciences Academy Standards Board and ASTM International. The AAFS Academy Standards Board provides resources and training in the OSAC standards to increase awareness and adoption of the standards. Resources include standard factsheets and checklists to aid in summarizing and evaluating the implementation of a standard [13].

In addition to AAFS, NIST also works closely with ASTM International. ASTM has approved public access to standards relating to forensics, E30 ASTM. The standards can be accessed through the OSAC registry. Most recently, NIST has awarded $15 million to ASTM International for a Standardization Center of Excellence to focus on "international standardization of critical and emerging technologies (CETs)" [14].

Strides are also being made toward even higher levels of standardization through the recent creation of the National Association of Forensic Science Boards (NAFSB) and a push toward more legislation on forensic science topics such as forensic genetic genealogy and the processing of SAFE kits collected from sexual assault cases. The NAFSB is an association of state-level forensic science boards established to "disseminate and exchange best practices, research, expertise, data, and lessons learned" [15].

Expert Testimony and the Sixth Amendment

The Confrontation Clause of the Sixth Amendment of the United States Constitution establishes that a defendant has the right "to be confronted with the witnesses against him" [16]. In its review of *Smith v. Arizona*, the Constitution Annotated states, "The Supreme Court vacated and remanded the Arizona Court of Appeals' decision, holding that the Confrontation Clause prohibits a 'surrogate analyst' from introducing testimony from an absent forensic analyst even if those out-of-court statements are presented as 'the basis for his [own] expert opinion'" [15]. By finding a surrogate analyst ineligible to testify, this decision has the potential to significantly impact forensic laboratory operations as well as the length of a forensic scientist's obligation to provide expert testimony.

Forensic laboratories strive to provide the criminal justice system with the most accurate scientific information in the most efficient way possible. In order to accomplish this goal, laboratories prescribe to various case analysis workflows. When creating optimal workflows, laboratory management must consider significant contributing factors, e.g., budget, staffing, available technology, facility footprint, evidence handling and retention policy, state and local regulations. While there are commonalities among forensic laboratories, the uniqueness of the factors listed above to each laboratory prohibits a universal workflow.

Some basic steps in laboratory workflows include evidence transfer, instrument setup, sampling, preliminary testing, sample preparation, high throughput batching, confirmatory testing or verification, data interpretation, report writing, and testimony. The allocation of these responsibilities is heavily dependent on the number of staff. In smaller laboratories, it is commonplace for one individual to perform more than one of these roles. Conversely, larger laboratories have the capability to increase efficiency by

implementing an assembly-line-like workflow where an individual or group of individuals is assigned to only one of these roles.

In the example of a smaller laboratory, one individual may be responsible for evidence transfer, instrument setup, and preliminary testing. According to the Supreme Court's decision above, this one individual could be called to testify for each of these functions. In the example of the larger laboratory, one individual may be responsible for all sample preparation. Consequently, this individual could be called to testify in all cases for which they performed sample preparation. In both scenarios, when these individuals are called to testify, they are not performing their portion(s) of the workflow, thus decreasing the efficiency of testing results while increasing the burden of testimony on the laboratory.

Over the course of a forensic scientist's career, they could be involved in the analysis of thousands of cases. When a scientist separates from a forensic laboratory for whatever reason, e.g., a new employer or retirement, they are still eligible to be called to provide expert testimony for cases they previously analyzed. It is not practical for former forensic scientists to remain available and competent to testify indefinitely.

The Supreme Court ruling expressed that the *Smith v. Arizona* decision be remanded because of specific facts of the case and that the remand not be applied in such a way as to affect expert testimony more broadly [17]. However, the American Civil Liberties Union (ACLU) asserts that, "Trials are rare in today's practice in all jurisdictions, including in States that already follow the rule Petitioner seeks ... Stipulation and waiver reduce the prosecution's need to call the authoring analyst at trial ... Even if the prosecution's use of a substitute analyst who testifies as an expert might alleviate genuine burdens imposed by the judicial system, the Court should still resist weighing a 'bedrock procedural guarantee' against purported efficiencies" [18].

When forensic laboratory management is making decisions about workflows, evidence retention, and re-testing policies, they must include in their list of considerations how the decision will affect the laboratory's ability to afford a defendant their constitutional right as described in the Confrontation Clause without productively grinding to a halt.

Salaries, Retirement, and Retention

As the field of forensic science developed technical methods for analyzing evidence, regulations developed alongside to ensure unbiased and reliable results of analysis were provided to the criminal justice system. Though the field of forensic science has advanced dramatically over the past 50 years, antiquated job classifications/descriptions persist. These job descriptions oversimplify the modern role of the crime scene investigator and laboratory analyst.

By their nature, many forensic science positions are within law enforcement agencies. While many agencies are shifting to hiring professional staff for roles that do not require law enforcement capabilities, situations still exist where sworn members and professional staff are performing similiar job duties, but one is an underpaid scientist and one is a sworn member of the agency. Unions play a role in establishing benefits, salaries, and job descriptions, and typically law enforcement personnel are represented by long-standing and powerful unions, where the forensic scientist is grouped in with more general worker unions.

Since job descriptions have not changed, salaries in many agencies have also remained stagnant. With extensive background checks requisite for employment in the field of forensic science, hiring outside candidates is extremely time-consuming. A laboratory has made a significant investment in just hiring and onboarding an entry-level employee. Additionally, to meet accreditation standards, laboratories have internal training programs. The length of internal training programs can range from months to years. This adds even more time before employers see a return on their investment in an employee. Because of the resources needed to fully onboard an employee, retaining the employee is very important to a company/agency's fiscal responsibility.

While job descriptions have not changed, retirement planning has. Traditional retirement plans or defined benefit plans provide a fixed, pre-established benefit at retirement, such as a pension. With defined benefit plans, the employee is guaranteed a benefit for which the responsibility and liability lie with the employer. These types of retirement plan offerings have decreased significantly and, one expert says, may be gone in the next 15–20 years [19]. In lieu of defined benefit plans, employees are increasingly participating in defined contribution plans, e.g., 401(k), 403(b), 457, or profit sharing plans. The responsibility and liability of defined benefit plans lie with the employee, not the employer. When an employee with a defined benefit plan changes jobs, their retirement plan moves with them. With no effect on their retirement plan, employees are less incentivized than before to remain at one company for their entire career.

Employees are not ignorant to this and are "getting their foot in the door" at any agency for any position possible. From there they are applying to comparable positions and receiving contingent job offers. To avoid having to repeat the onboarding costs, agencies are willing to match these competitive offers. This creates inequity and compression within an agency and wasted resources between neighboring agencies.

Separation of Forensic Science from Law Enforcement Control

The mission of publicly funded FSPs is to utilize science technology to produce actionable results for law enforcement [20]. The FSPs' function is to aid law enforcement and the criminal justice system; however, it is also important for the laboratory to be independent of law enforcement oversight. The most cited justification for the autonomy of FSPs is to eliminate bias, removing the forensic scientist from pressure or information that could influence their conclusions regarding the scientific testing. Laboratory analysts should be blinded regarding evidence as even the submission form can contain race and sex. A less-cited reason is that policies and procedures are being decided by non-scientists whose priorities differ from those of a scientific laboratory. This can affect every level of the laboratory, from administration to operations, from funding and hiring procedures, to how evidence is collected [21].

While the 2009 NAS's report on crime recommended the removal of "all public forensic laboratories and facilities from the administrative control of law enforcement agencies or prosecutors' offices", recognizing the advantages of the separation of forensic science from law enforcement control is not a recent development. Some of the first state laboratories were established by legislative mandate, independent of law enforcement; for example, the Alabama Department of Forensic Sciences (ADFS) in 1935 and the Wisconsin State Crime Laboratories (WSCL) in 1937. However, most municipal laboratories are embedded within law enforcement.

Laboratories are moving to ISO/IEC 17025:2017, General requirements for the competence of testing and calibration laboratories, for their accrediting standards. Recent changes to ISO/IEC 17025:2017 clause 4.1 [22] on impartiality requires that conflicts of interest must be eliminated or managed to avoid negatively impacting the activities of the laboratory. Documenting conformity to 17025 adds an additional responsibility on FSPs associated with law enforcement [23].

The events leading to the creation of the Houston Forensic Science Center (HFSC) are an example of where management by law enforcement failed [24]. Years of unaddressed water damage caused the destruction of a large backlog of DNA evidence, followed by the execution of Cameron Todd Willingham, whose guilt was strongly questioned by the public [25]. An investigation revealed the absence of a quality assurance program, inadequate training, lack of meaningful administrative and technical reviews, and inadequately trained analysts across the laboratory. Causes were attributed to inadequate financial support and resources, ineffective management, lack of quality control and quality assurance, and isolation of the DNA section [26].

Separating the forensic laboratory from law enforcement was not the only step taken to improve forensic services in Houston. Reforms in several areas of the criminal justice system were required to ensure the integrity of forensic evidence. A Texas Forensic Science Commission was established whose membership consisted of five academic scientists, two forensic scientists, a district attorney, and a defense attorney. The Dallas County district attorney's office created Conviction Integrity Units to collaborate with the Innocence Project of Texas to review old cases. The Texas legislature established the Office of Capital and Forensic Writs in addition to enacting the Michael Morton Act and the "Junk Science" writ. The first established a state-wide open-file discovery policy to ensure defendants have access to exculpatory evidence. The second was a special writ of habeas corpus called to address forensic evidence later determined to be invalid. Finally, Texas law now requires that all biological evidence must be preserved for 40 years and all samples from sexual assault cases must be analyzed [25].

At the same time, there are advantages to coordination between laboratories and law enforcement agencies. Evidence collection, prioritization of exhibits for testing, case status updates, and status of a case can all aid in avoiding unnecessary testing [27].

Needs Related to Forensic Science Education

Internships

The training required before an entry-level employee is fully online can range from six months to three years, even for new hires with an advanced degree. Academic programs focus on teaching the foundational sciences on which forensic science is based. Graduates with degrees in chemistry, biology, or even forensic science do not have an understanding of the work environment in an FSP. Consequently, there is a disconnect between forensic science practice and forensic science education.

One existing vehicle providing laboratory exposure through academics is internships, and some universities offer internships as part of a forensic science degree. Examples include University of Nebraska–Lincoln and West Virginia University. However, students often have difficulties finding internships, and there are several difficulties in implementing internships in the laboratory. It is challenging to integrate interns into a working laboratory where casework is the focus. Laboratories such as the Kansas Bureau of Identification and the Baltimore Police Department also offer internships. These internships are

often considered a three-month job interview. The Alabama Department of Forensic Sciences and the University of Alabama at Birmingham have a unique paid trainee program for students in the graduate program that can last for the two years of the student's education. Many federal and state agencies and forensic professional organizations also offer internships, including the ATF [28] and the Center for Forensic Science Education and Research [29], while others are a resource for internships, including the International Association for Identification [30].

Difficulties for students include the limited number of laboratories within commuting distance. Most internships are unpaid, and an internship could extend the time to graduation. Regardless of the difficulties, internships are a valuable tool for bridging the gap between academics and forensic science practice.

Another solution recently proposed is a post-educational/pre-employment training. Currently focusing on DNA, a National DNA Training Institute is intended to serve as a transition between education and employment in a laboratory [31]. The goal is to offer hands-on experience with instrumentation and hands-on experience with case scenarios.

The Comparative Sciences

A second issue in forensic science education is the lack of graduate education in the comparative sciences. Comparative evidence ranks lower in the percentage of evidence submitted to FSPs. Of 3,346,000 evidence submissions in 2020, over 32% were controlled substances, DNA database 20%, toxicology 19%, forensic biology 10%, toolmarks 6.7%, and fingerprints 5.4% [32]. Nor do many academic programs place much emphasis on the comparison sciences: fingerprints, firearms and toolmarks, shoeprints, tiremarks, and fracture match. Even for accredited programs, only the undergraduate CSI track explicitly requires courses in the comparative sciences, and that is limited to latent prints and/or other pattern evidence [33]. At the MS level, the topics of pattern evidence and microscopy can be covered by a minimum of 9 hours of instruction in each.

This lack of emphasis may be partly due to the CSI effect in the early 2000s, glamorizing forensic science and creating a lot of interest among young adults. Universities and colleges responded by creating degrees in forensic science, often in chemistry, biology, or other natural science departments. Consequently, nearly 400 universities and colleges offer a degree or certificate in forensic science [34]. The programs tend to reflect the department they are housed in. A chemistry department will already be equipped with GC-MS and LC-MS, the essential equipment in forensic chemistry. Few science departments had existing expertise in the comparative sciences or comparison microscopes, the primary instrument in pattern evidence.

Loyola University Maryland has recently addressed this issue by offering a Master of Science in Forensic Pattern Analysis [35]. Designed in collaboration with practitioners, the coursework provides the knowledge and skills normally offered during the training period for an entry-level trainee in the comparative sciences. The goal is to reduce the training time to nine months. The program developed by the university's Department of Forensic Sciences is a model that could be applied to other areas of forensic science. If coursework is designed to cover the training materials used by the forensic laboratory, new employees can "test out" of training modules. The difficulty in this approach is that training in forensic laboratories is not standardized. However, much of the training material is universal. Greater collaboration between FSPs around training requirements could greatly enhance forensic science education and benefit laboratories in onboarding new employees.

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Forensics Unlocked: The Research Forensic Library

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Library website: https://forensiclibrary.org

The Research Forensic Library (RFL) was born to fill a critical void in the forensic science field: the lack of a centralized repository of published research. Despite the existence of forensic labs in the US since the 1920s, there was no specialized library to serve the entire forensic community. This century-long gap was finally met in 2022 with the launch of the RFL at FIU (Florida International University: Miami, FL), in partnership with the NIJ (US National Institute of Justice). With more than 7,400 articles, reports, and books, and more added every day, the RFL has become a valued and much-accessed resource for forensic scientists. Since its launch, this first-of-its-kind library has had visitors from 174 countries around the world.

A Serious Challenge for the Forensic Science Community

One of the biggest obstacles across scientific disciplines, including forensic science, is the inaccessibility of information. Paywalled journal articles limit scientists' and practitioners' ability to gather the material needed for casework, research, and courtroom preparation. The RFL's mission is to break down these barriers by providing open access and public domain materials, ensuring that no forensic professional is excluded due to cost or copyright restrictions.

The challenge of creating such a library goes beyond offering open access. Forensic science is not monolithic; crime scene analysts, for example, need expertise in a variety of disciplines, including bloodstain analysis, fingerprint analysis, DNA collection, proper evidence collection techniques, photography and scene documentation, and many more. Relevant information, however, isn't confined to a few forensic journals; it's scattered across countless sources, including specialized reports, trade publications, court transcripts, and even out-of-print historical documents. The RFL curates this diverse body of knowledge, bringing together material from hundreds of sources, which previously would have required forensic professionals to search far and wide.

Open Access for All

One of the RFL's most important contributions is its role in democratizing forensic knowledge. By eliminating the financial barriers associated with paywalled articles, the Library makes it possible for anyone, regardless of their own or their institution's funding limitations, to stay informed about the latest developments in their field. This is true not only for forensic scientists, but those in medical examiner offices, biomedical organizations, military research labs, students and faculty at universities, and anyone else interested in forensic science. This inclusivity fosters collaboration and innovation, which is critical for the future of forensic science as it continues to move into other areas such as psychology, veterinary sciences, and artificial intelligence. Ease of access is also facilitated by the Daily Digest (further illustrated in a later section), a curated list of articles emailed directly to subscriber inboxes.

The partnership with the NIJ lends additional credibility and strength to the Library. This collaboration ensures that the RFL's resources are tailored to meet the evolving needs of the forensic science community and the constituents they serve. It also exemplifies how academic institutions and government agencies can work together to drive progress in forensic research and practice.

In addition, the Library's dedication to the open access movement reinforces its mission of fostering collaboration. By ensuring that every resource is free of copyright restrictions, the RFL encourages knowledge sharing across the forensic community, allowing practitioners to work together more effectively to advance the field.

Beyond the Journal

The RFL's commitment to offering a wide range of materials, beyond just academic journals, acknowledges the interdisciplinary nature of forensic science. By including everything from trade newsletters to government reports to newly published drug information to accreditation standards

[a]The author is the forensic librarian and curator for Research Forensic Library.

to rare historical articles that trace the development of forensic science, the Library provides a unique resource that forensic professionals can rely on for all aspects of their work.

This wealth of freely available information not only supports scientists in their research but also plays a critical role in casework and court testimony. Forensic practitioners need access to accurate, reliable data when presenting their findings in legal settings. The RFL's expansive collection ensures that forensic experts have a solid foundation on which to build their arguments, thus improving the quality of forensic investigations and enhancing the integrity of the legal process. A forensic librarian is also available to assist with literature reviews and article requests.

Structure, Functionality, and Services of the Research Forensic Library

A. The library can be found online at: *https://forensiclibrary.org* (*see* **Figure 1** for partial view of the library home page).
B. The library can be searched in any of the following ways:

1. Search box (search by title, author, publication, year, keyword)
2. Search by any of the following categories via drop-down menu:

- Alcohol
- Anthropology
- Biometrics
- Bloodstain Pattern Analysis
- Cannabis and Cannabinoids
- Chemistry
- Crime Scene Investigation and Reconstruction
- Criminal Justice System
- Digital and Multimedia Analysis
- DNA and Biology
- Dogs and Sensors
- DREs, Traffic Safety Resource Prosecutor
- Entomology
- Fingerprints, Friction Ridge
- Fire Debris Analysis, Fire Investigation and Explosions
- Firearms and Toolmarks
- Footwear and Tire
- Forensic Pathology and Medicolegal Death Investigation
- Genetic Genealogy
- Laboratory Operations
- Odontology
- Photography, Video and Imaging Technology
- Questioned Documents

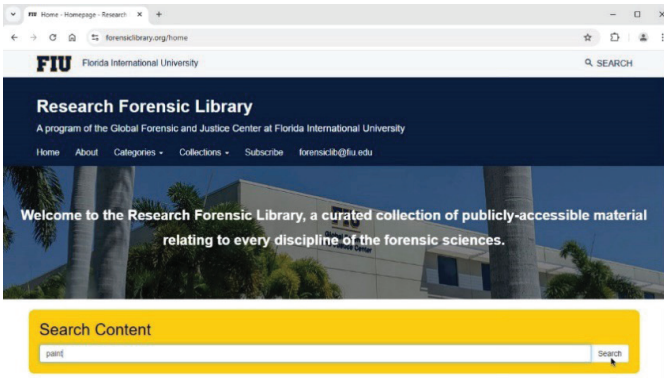


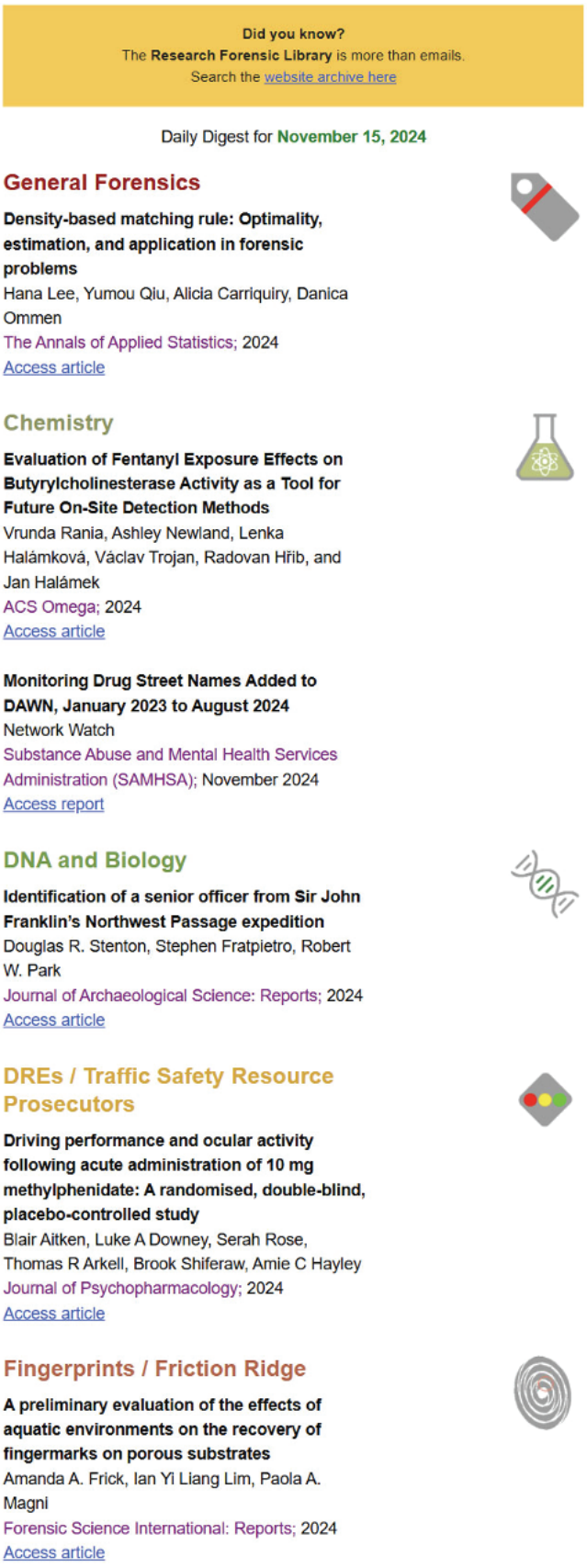
Figure 1. Partial view of library home page.

- Seized Drugs, Controlled Substances
- Sexual Assault, SANE
- Statistics and Data Analysis
- Toxicology
- Trace Evidence
- Veterinary Forensics
- Wildlife

3. Search by any of the following collections via drop-down menu:

- ANSI/ASB Standards
- Center for Forensic Science Research & Education
- Drug Enforcement Administration
- European Monitoring Centre for Drugs and Drug Addiction
- Historical
- International Narcotics Control Board
- Morbidity and Mortality Weekly Report
- National Academies Press
- National Highway Traffic Safety Administration
- National Institute of Justice
- National Institute of Standards and Technology
- The Organization of Scientific Area Committees for Forensic Science
- United Nations Office on Drugs and Crime

C. Literature searches and specific articles can be requested from the forensic librarian at forensiclib@fiu.edu (*note: response is dependent on time/work availability of the librarian*)
D. Subscribe to the Daily Digest at no cost (*see* **Figure 2** for a partial view of a typical Daily Digest). This is a library email sent out each business day that features links to 10 new articles and reports and offers an excellent way to stay current with newly published studies. Subscribe from the library's home page.



Did you know?
The **Research Forensic Library** is more than emails.
Search the website archive here

Daily Digest for **November 15, 2024**

General Forensics

Density-based matching rule: Optimality, estimation, and application in forensic problems
Hana Lee, Yumou Qiu, Alicia Carriquiry, Danica Ommen
The Annals of Applied Statistics; 2024
Access article

Chemistry

Evaluation of Fentanyl Exposure Effects on Butyrylcholinesterase Activity as a Tool for Future On-Site Detection Methods
Vrunda Rania, Ashley Newland, Lenka Halámková, Václav Trojan, Radovan Hřib, and Jan Halámek
ACS Omega; 2024
Access article

Monitoring Drug Street Names Added to DAWN, January 2023 to August 2024
Network Watch
Substance Abuse and Mental Health Services Administration (SAMHSA); November 2024
Access report

DNA and Biology

Identification of a senior officer from Sir John Franklin's Northwest Passage expedition
Douglas R. Stenton, Stephen Fratpietro, Robert W. Park
Journal of Archaeological Science: Reports; 2024
Access article

DREs / Traffic Safety Resource Prosecutors

Driving performance and ocular activity following acute administration of 10 mg methylphenidate: A randomised, double-blind, placebo-controlled study
Blair Aitken, Luke A Downey, Serah Rose, Thomas R Arkell, Brook Shiferaw, Amie C Hayley
Journal of Psychopharmacology; 2024
Access article

Fingerprints / Friction Ridge

A preliminary evaluation of the effects of aquatic environments on the recovery of fingermarks on porous substrates
Amanda A. Frick, Ian Yi Liang Lim, Paola A. Magni
Forensic Science International: Reports; 2024
Access article

Figure 2. Partial view of a typical Daily Digest.

Concluding Remarks

The forensic science community has been struggling with fragmented resources and restricted access to vital information, often hidden behind paywalls. Based on the thousands of requests for paywalled material that the author has received from forensic scientists over the years, it is clear that the current journal publishing model has made it more difficult for forensic practitioners to efficiently perform their casework analysis, conduct research for publications, and prepare for and deliver testimony in court. RFL aims to curate and provide a searchable archive of material that is accessible to anyone.

The establishment of RFL represents a major leap forward in forensic science. By creating a centralized, open access repository for forensic knowledge, it has addressed long-standing issues of accessibility and fragmentation. With its collaborative foundation and diverse range of materials, the RFL is not only an invaluable resource for forensic professionals but also a critical driver of the field's continued growth and innovation.

NEW BOOKS AND BOOK REVIEW

New Forensic Science Books

Advancements in Cyber Crime Investigations and Modern Data Analytics
S. K. Shandilya, D. Sujay, V. B. Gupta, Eds
CRC Press: Boca Raton, FL, US; Forthcoming

Advanced Techniques and Applications of Cybersecurity and Forensics
K. Kaushik, M. Ouaissa, A. Chaudhary, Eds
CRC Press: Boca Raton, FL, US; July, 2024

Advances in Analytical Techniques for Forensic Investigation
P. Chhabra, D. B. Tripathy, A. Gupta, S. Shukla, R. Kumar, K. Bhati, Eds
Wiley: Somerset, NJ, US; Aug., 2024

Advances in Forensic Human Identification
X. Mallett, T. Brythe, R. Berry, Eds
CRC Press: Boca Raton, FL, US; Oct., 2024

Advances in Forensic Taphonomy
W. D. Haglund, M. H. Sorg, Eds
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Wigmore on Alcohol: Courtroom Alcohol Toxicology for the Medicolegal Professional, 2nd ed

J. G. Wigmore
Irwin Inc.: Toronto, Canada; Sept., 2024

Book Review

Ethics and the Practice of Forensic Science

Robin T. Bowen
CRC Press: Boca Raton, FL, US; 2024

Reviewed by

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Ethics and the Practice of Forensic Science Third Edition is a revised edition of an established ethics text by Dr. Robin Bowen. Ethics is concurrently a simple and complex topic to attempt to cover. In some ways, ethics is very simple: "be nice, work hard, don't lie". In other ways, it is a profoundly complex and nuanced topic that reaches every aspect of practice.

Dr. Bowen and her contributors have done an excellent job of comprehensively updating the new edition. The text covers a wide-ranging discussion of ethics from foundational philosophy to a solid and comprehensive appendix of ethical misconduct. This is all written in a readable fashion.

For those who are new to this text and have not read or used the prior editions, this is a comprehensive ethics text. While it is more focused on forensic laboratory practice, it does include many aspects of other related practices such as forensic pathology, law enforcement overlaps, and adjudication.

It begins with philosophical and foundational discussions of ethics and ethics as more specific to a forensic setting. The next chapters consider forensic practice in the wider setting of law enforcement (where many labs reside) and the criminal justice setting. A chapter is dedicated to ethics in testimony particularly as it pertains to the scientific expert.

The last chapters are the most pragmatic, with examples of ethical misconduct as a chapter of more extensive discussions and an expanded appendix. Likewise, there is a chapter with detailed discussions of a variety of codes, and more codes with less discussion included as an appendix. This is a text that is applicable to students, graduate students, and practicing professionals at almost any level. It is perhaps too extensive for an annual ethics training, but does provide ample examples and sections that could be useful to a laboratory trying to keep ethical practice part of recurrent training for staff.

Some of the additions to this edition are perhaps the most interesting. A new chapter 11 provides a discussion of a large survey-based research study of laboratories and ethical perceptions and practices. For anyone running a laboratory, the perspective is invaluable.

Wigmore on Alcohol: Courtroom Alcohol Toxicology for the Medicolegal Professional, 2nd ed

James G. Wigmore

Irwin Inc.: Toronto, ON, Canada; 2024

Reviewed by

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For all the new psychoactive substances (NPS) and traditional drugs detected in forensic toxicological analysis, the most used and abused drug is still ethanol (alcohol). Alcohol is arguably the most studied drug in the world. For this reason, it can be difficult for medicolegal practitioners and lawyers to identify relevant literature on the forensic aspects of alcohol. This can be especially true during the heat of a trial or other legal situations, where unusual defences may be brought up. For this reason, the first edition of Wigmore on Alcohol was the perfect reference to have on hand and was rightly called the "alcohol bible". It has been for many years my go-to book when I needed to quickly and easily find references with regards to alcohol and its effects for my cases. I was therefore pleased to learn that after a 13-year wait a second edition was being published.

The second edition of Wigmore on Alcohol has significantly increased the number of references from ~700 in the first edition to over 1200 references in the second edition. As well as the print version it is also available electronically via the University of Toronto Press website. The significant advantage of this book over other books in this area is the way it is laid out. The book consists of nine chapters covering all of the areas you would expect:

1. Absorption, Distribution, and Elimination of Alcohol;
2. Blood Alcohol;
3. Breath Alcohol;
4. Urine, Saliva, Sweat, and Breast Milk Alcohol and Biomarkers of Alcohol Consumption;
5. Effects of Alcohol on Driving Ability;
6. Effects of Alcohol on Other Behavior;
7. Postmortem Alcohol;
8. Other Alcohols and Related Compounds; and
9. Addiction/Alcohol Use Disorders, Withdrawal, Health Risks, Fetal Alcohol Spectrum Disorder, and Public Safety Measures.

The chapters are then divided into subsections. For example, the chapter "Effects of Alcohol on Other Behavior" has subsections on topics as diverse as bicycling, recreational boating, flying, and snowmobiling. This layout allows the reader to quickly identify relevant literature with regards to the question they may have been asked. Each of the subsections is made up of a brief introduction giving an overview of what is currently known. This is followed by the relevant paper(s) in that subject area with a short abstract by the author of this book written in plain English that, where possible, avoids scientific jargon. This enables both expert and lay readers to identify the papers that may be relevant to their case quickly and easily, with each paper having its own reference number. This makes sure that a particular paper can be found quickly in the future.

The large number of references in this book means that all the salient literature you would expect are present. As always, no book can cover everything, especially in the fast-moving field of forensics. In the future, I look forward to the book covering more on the emerging areas of forensic alcohol research such as:

- The alcohol biomarker phosphatidylethanol (PEth), that has become more popular in recent years; and
- Coverage of standards/guidance that have been emerging around the world that are relevant to forensic alcohol, such as the ANSI/ASB 122 Best Practice Recommendation for Performing Alcohol Calculations in Forensic Toxicology (USA) and the UKIAFT Guidelines for alcohol calculations (UK).

Overall, this is a reference book that is a must-have for any forensic practitioner, forensic researcher, or lawyer working in the area of the forensic aspects of alcohol. it is still rightly the "alcohol bible" and will be for the foreseeable future.

TEITELBAUM'S COLUMN ON FORENSIC SCIENCE: HISTORICAL PERSPECTIVES

The Borkenstein Breathalyzer: Looking Back to the Beginning of Evidentiary Breath Alcohol Testing[a]

Jan Semenoff

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1954 *– Dr. Jonas Salk begins polio vaccinations of children. Elvis Presley's records are first broadcast in Memphis. Sports Illustrated is published for the first time (and future cover model Christie Brinkley is born). Radio is AM. Televisions are black and white and have tubes. By today's standards, the electronic technology of the day was in its infancy.*

Lieutenant Robert Borkenstein patents the Breathalyzer while working for the Indiana State Police as a crime scene photographer and technician. He received his bachelor's degree in forensic science four years later, while studying under Dr. Rolla Harger. For his life's work in traffic safety, he is ultimately awarded an honorary doctorate.

May 10, 2024, marked the 70th anniversary of the original Breathalyzer patented by Robert Borkenstein, an Indiana State Police crime lab supervisor and police photographer. It was one of the first portable devices utilized by law enforcement to measure the breath alcohol concentration (BrAC) of suspected drunk drivers. Although Dr. Rolla Harger's Drunkometer had been developed a few decades before (with Borkenstein), it was the Breathalyzer that was first able to precisely quantify the amount of exhaled breath delivered into the instrument, beyond the Drunkometer's simple "blow into the balloon" breath sample capture. The Breathalyzer also precisely measured the chemical reaction in the reagent solution to quantify the breath sample's alcohol content.

The Breathalyzer[b] (**Figure 1**) was "a photo-electric device capable of collecting a sample of deep lung air, analyzing it for alcohol, and expressing the value as a blood-alcohol concentration". So successful was the Breathalyzer, in fact, that the proper trade name, *Breathalyzer*®, became synonymous with breath alcohol testing and the detection of impaired drivers, and remains a term in our collective lexicon to this day. It was, simply, the most reliable breath alcohol testing instrument available at the time of its release.

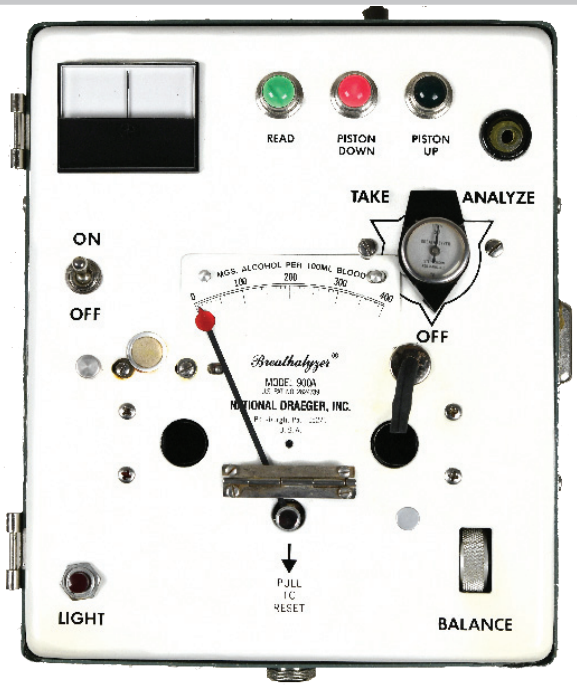

Figure 1. The Breathalyzer Model 900A.

Based on 1954 technology, the Breathalyzer was a breakthrough in its day. But there were technical limitations with the Breathalyzer. Although elegant in its design, the instrument required an open glass ampoule that contained a highly concentrated sulfuric acid solution. Spills and splatters were very messy, and sometimes caused the operator severe chemical burns.

Since the first truly empirical measurement instrument for impaired driving was Borkenstein's Breathalyzer, perhaps it would be valuable to examine how that instrument worked. The Breathalyzer, with its operational strengths and weaknesses, set the tone for much of the early case law with regard to breath alcohol testing, and more importantly, established some of the operational requirements for breath alcohol testing still used today.

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[a] All figures are the work of the author. Contact the author for all figure- and reference-related questions.

[b] The term "Breathalyzer" is a trademark presently used by the National Dräger Corporation. All references in this article to the "Breathalyzer" refer entirely to the original Borkenstein Breathalyzer, Stephenson Breathalyzer Model 900, and the later Smith & Wesson Breathalyzer Models 900 and 900A, and are *not* in any way to be construed as representative of any instruments currently manufactured by the National Dräger Corporation.

Components and Operation of the Breathalyzer

There were four main components in the Breathalyzer:

- The reagent solution;
- The optical bench (photometer assembly);
- The breath chamber (piston and cylinder assembly); and
- Cam & cam shaft linkage assembly (the BrAC scale)

The instrument itself used simple circuitry, a mechanical piston and gas delivery system to collect the sample of breath and relied upon the change in color of a chemical reagent solution when combined with ethanol.

The Reagent Solution (**Figure 2**)

The reagent solution was "apple-juice colored" and was stored in a tiny glass vial composed of the following chemicals:

- Potassium dichromate ($K_2Cr_2O_7$): 0.025% w/v (weight/volume);
- Sulfuric acid (H_2SO_4): 50% by volume;
- Silver nitrate ($AgNO_3$): 0.025% w/v; used as a catalyst; and
- Distilled water (H_2O): remainder.

The chemical reaction includes both oxidation of the ethanol and reduction of the potassium dichromate, a method described by Maurice Nicloux (1873–1945) in France in 1896 and 1900. A.W. Jones (1996) described the history of blood and breath forensic analysis, and I will refer you to that article for more details. [1] (**Figure 3**).

The presence of silver nitrate in the reagent solution served as a catalyst for the reaction to increase the rate of dichromate reduction but was otherwise not involved in the chemical equation.

Figure 2. The proprietary ampoule of reagent solution designed and manufactured specifically for the Breathalyzer.

The quantitative determination of alcohol concentrations using this potassium dichromate/sulfuric acid mixture as a reagent was used by scientists about ninety years before Borkenstein. Antoine Béchamp first used this oxidizing reaction in 1865 to test for the presence of alcohol in a solution. Dr. Francis Anstie also published research on this formula in England in 1874 [2]. The Cavett test, developed by J. W. Cavett in 1938 [3], also used this reaction, as did the Kozelka and Hine [4] method in 1941, so Borkenstein's adoption of this process was hardly "new science."

What *was* new was applying this reaction to a breath sample, as opposed to the blood and urine specimens previously being tested using this method. Additionally, the use of the silver nitrate catalyst allowed the reaction to occur quickly, within 90 seconds, and at room temperature (the formula required heating the solution slightly otherwise). Also, since other volatile chemicals such as acetone, isopropanol, and methanol would react differently within the 90-second window, a trained operator could identify potential interferent substances.

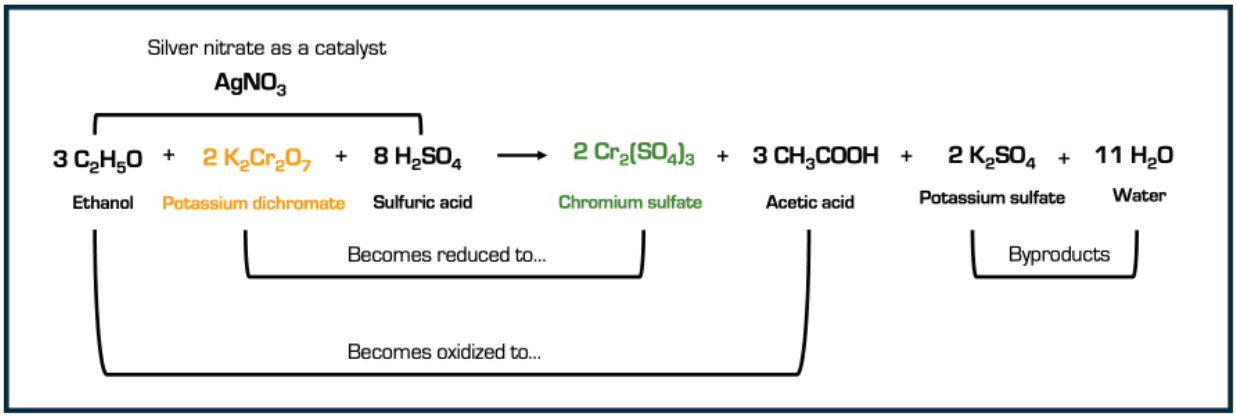

Figure 3. The chemical reaction that occurred inside the test ampoule's reagent solution. Ethanol was oxidized to acetic acid by the sulfuric acid. Potassium dichromate was reduced to chromium sulfate, changing its color in the process. Potassium sulfate and water were by-products of the reaction.

Reagent Ampoules (**Figure 4**)

When originally put into the Breathalyzer, the reagent ampoule first had to be checked visually to ensure it contained no visible impurities. It was also checked in a go/no-go gauge to ensure it was the correct diameter and had the correct volume of about 3.5 mL of reagent solution. The bottom of the meniscus of the solution had to just touch the level of the top of the gauge, as judged by the operator. The neck of this ampoule was then cracked off, a pipette (or bubbler) inserted and attached to the sample tube assembly, and the ampoule placed in the right-hand optical tray. The reagent ampoule was now referred to as the test ampoule.

The left-hand optical tray also contained a reference ampoule, one that had also been checked for impurities and gauged, but with the top left intact. It was imperative that both ampoules came from the same batch and had identical lot numbers. They needed to have identical color signatures for the Breathalyzer to be photometrically balanced. Once both ampoules were in place, they were optically balanced using two light meters built into the instrument.

The Optical Bench **(Figure 5)**

As with the chemical reagent solution, Borkenstein built upon previous work on alcohol determination using a "photometric colorimeter" (Gibson & Blotner, 1938) [5]. Their work also describes the potassium dichromate/sulfuric acid solution and measured the transmission of light through a blood or urine sample prepared with this reagent solution so that a blood alcohol concentration could be measured.

Between the two ampoules on the optical array was a light bulb. When switched on, it emitted light through both ampoules. On the other side of each of the ampoules was an electric selenium photocell similar to one found in simple cameras of the 1950s (with blue filters to increase

Figure 4. An ampoule in the "go" side of the go/no-go gauge.

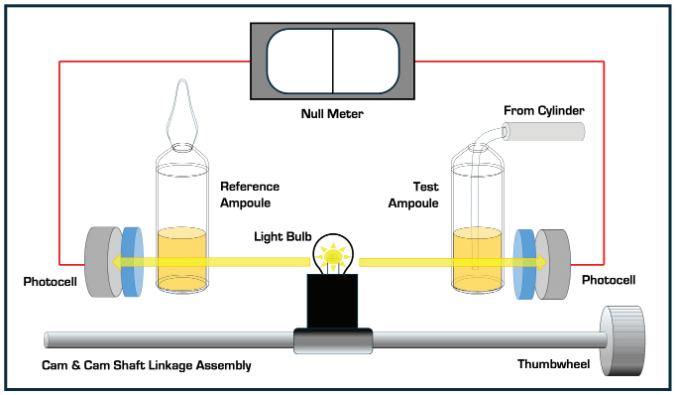

Figure 5. A diagram of the optical bench of the Breathalyzer Model 900A.

the contrast — the same filters describer by Gibson & Blotner). The light bulb was "balanced" by use of a thumbwheel connected to a cam shaft linkage system. As the thumbwheel was turned, the light bulb moved left and right between the ampoules until the amount of light hitting both photocells was identical.

The operator judged this by watching an electric ammeter on the top of the Breathalyzer. When the needle on the ammeter, referred to as the null meter (**Figure 6**), was centered, this indicated that the amount of light striking each photocell was the same. Each photocell was in turn producing an equal current. The optical array had been aligned. At this point, the BrAC arm was pulled back off the cam shaft linkage system and set to ZERO on the BrAC chart.

In order to ensure that no residual alcohol remained in the sample chamber or collection tubes from previous subjects, the Breathalyzer first had to be flushed, or purged, by the operator. This was accomplished by attaching an aspirator bulb to the sample collection tube and flushing room air through the system. This room air was, in essence, also measured to determine if any ambient interferents were present. A reading greater than 10 mg/100 mL (**Figure 7**) would result in a failed purge test. The entire test procedure would then have to be restarted with a fresh test ampoule.

Figure 6. The Breathalyzer's null meter, used to balance the optical array.

Figure 7. The Breathalyzer's BrAC scale. Note the start line to the left of the zero point. Subject tests began with the BAC pointer repositioned to the start line to negate or reduce the possibility of endogenous contamination affecting the reported BrAC results.

Following the first purge, the BrAC needle was pulled back to disengage it from the cam shaft linkage system again, then carefully positioned on the "START" line on the BrAC scale. The start line was slightly below the zero point on the BrAC chart at approximately the negative 5 mg/dL position. This was thought necessary to address the additive effect introduced by any endogenous oral interferent possibly contained on the subject's breath. The Breathalyzer was now purged and balanced, and ready to receive the breath sample from the subject.

The Breath Chamber Assembly **(Figure 8)**

The breath sample was captured by having the test subject exhale into a disposable mouthpiece connected to a plastic tube. The tube ran into the instrument, past a valve assembly, and from there, into a small stainless steel cylinder, which was wrapped with a heating blanket at 50±3 ºC to prevent condensation. The total internal volume of the cylinder was slightly more than a fifth of a cup (56.5 mL). As the subject exhaled, a stainless steel piston was pushed upward inside the cylinder, exposing two small vent holes. Once pushed up to the top of the cylinder by the exhaled breath of the subject, the piston was held in place by two magnets. The machining of the piston and cylinder were closely matched to very close tolerances in diameter to ensure no loss of breath sample volume occurred.

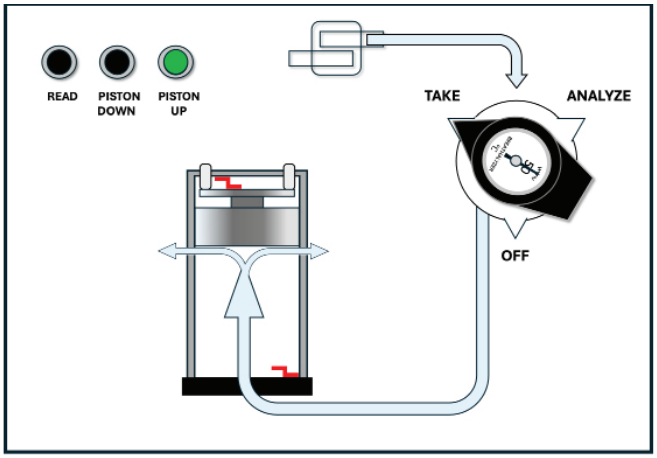

Figure 8. The Breathalyzer in the "take" position, accepting a breath sample.

Exhaled breath from the subject continued to flow out the vent holes and into the internal circuitry compartment of the Breathalyzer. When the subject stopped blowing at any time during provision of a sample, vertical play in the piston-magnet arrangement made it possible for the piston to fall back down slightly in the cylinder, just covering the vent holes, and trapping a known volume of exhaled breath — exactly 56.5 mL.

The challenge for the Breathalyzer operator was to capture a true sample of deep lung air. Remember, deep lung air was the target, because this is where the blood-to-breath ratio of alcohol is thought to be located. With the slight resistance that was offered by the tube and piston, an average person needed to blow for about 8–12 seconds before they visibly began to taper in their exhalation. But the decision as to when alveolar air was being provided rested entirely with the operators and their best judgment.

It was at that point that the prudent operator pinched off the breath sample tube to capture the sample (to prevent the subject "sucking back" some of the exhaled air in the cylinder, thereby lowering the alcohol analyzed in the sample). I've seen smaller subjects begin to taper their exhaled breath sample in as little as 4–5 seconds, and larger, more robust subjects blow for almost 20 seconds. The goal was to truly capture a sample of deep lung air — the gold standard at the time.

Once the breath sample was captured, a control knob on the top of the Breathalyzer was turned that disengaged the magnet holding the piston to the top of the cylinder. The knob also pinched off the collection tube in the valve assembly from the inside of the instrument and opened up another tube connected to the test ampoule. Exactly 52.5 mL of deep lung air began to bubble through this reagent vial through a small pipette. The rest, 4.0 mL, remained in the tube transfer system and valve assembly, and had to be purged out as residual contamination during subsequent stages of analysis.

Once the known-volume breath sample, collected from the subject and stored in the cylinder, began to bubble through the solution in the ampoule, the chemical reaction between the alcohol and the reagent solution occurred. The darker yellow potassium dichromate solution was converted by the ethanol to form a lighter yellow-green chromium sulfate solution (**Figure 9**). The silver nitrate in the solution was simply a catalyst — a substance that made the reaction go faster and at room temperature without participating in the reaction.

Figure 9. The reference ampoule, left, retains its original color while the test ampoule, right, has changed significantly.

The reaction took about 90 seconds to complete. During that time, a timing circuit was activated which prevented the light bulb from being turned on. This inhibited a reading from being obtained from an incomplete chemical reaction. After 90 seconds, the chemical reaction was complete, and the light bulb circuitry lock was released. All variables were known and controlled except the BrAC of the subject.

The rate of the chemical reaction became important when interferent substances other than ethanol were introduced into the reagent — the rate of the reaction being the only way for the operator to identify an interferent.

When the chemical reaction between the ethanol and the ampoule solution was complete, the color of the solution faded to more of a light green color. More alcohol in the reaction resulted in more potassium dichromate being reduced to chromium sulfate, and the solution became even lighter in color. I've tested subjects with BrACs so high that a single sample made the solution almost clear.

Any evidentiary breath test result greater than 210 mg/dL required the test ampoule to be changed for a new one, and the optical array to be rebalanced, before a second test was performed. The ampoule contained enough reagent in the solution to allow for a BrAC reading of about 650 mg/dL, and in common practice, a single ampoule could easily perform two evidentiary tests and an alcohol standard calibration check on a single subject.

When the light bulb was again switched on, light passed through both ampoules (**Figure 10**). Remember, the test ampoule in the right-hand array was now lighter in color due to the reaction with alcohol. More light was therefore able to pass through this test ampoule and strike the photocell. More current was then produced by this photocell, and the needle on the null meter would deflect towards the left. Again, I've

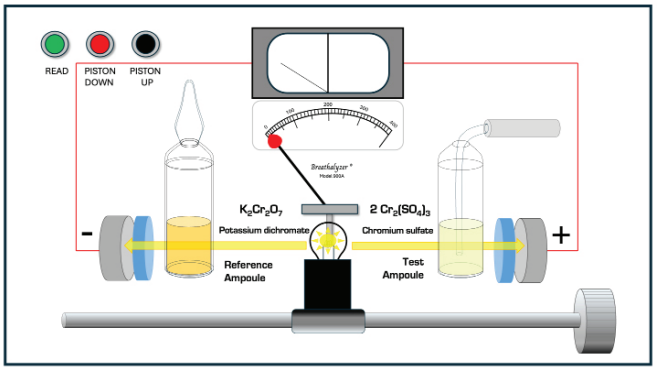

Figure 10. The test ampoule allows more light to pass through it to the photocell on the right side, producing more current by that photocell. This pushes the null meter towards the darker reference ampoule, whose photocell is producing less current.

seen readings so high that when the light was turned on, you could hear the needle "slap" against the side of the null meter. The optical array was no longer aligned.

Cam & Cam Shaft Linkage Assembly

To realign the optical array, the thumbwheel was again turned, moving the light bulb on the cam shaft linkage assembly towards the left-hand reference ampoule with the darker solution. The light bulb, now being closer to the ampoule with the darker colored solution, gave a greater intensity of light on that side of the array. The operator simply moved the light bulb towards the darker reference ampoule until the light striking both photocells was again the same, as indicated by a balanced null meter (**Figure 11**). The optical array was now rebalanced using the inverse-square law in optical physics.

Moving the cam shaft linkage assembly holding the light bulb had the further effect of causing the BrAC needle to pivot on the BAC scale (**Figure 12**). The pivoting BrAC needle moved in direct proportion to the movement of the light bulb on the cam shaft assembly. The greater the

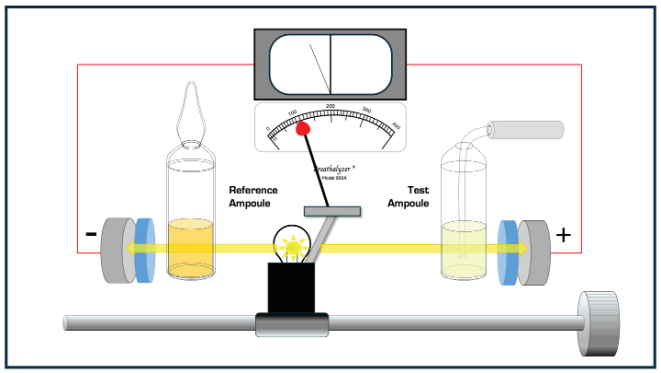

Figure 11. Moving the light bulb to the left brings it closer to the darker reference ampoule. The null meter was balanced when an equal current was produced by each photocell, indicated by a centered needle.

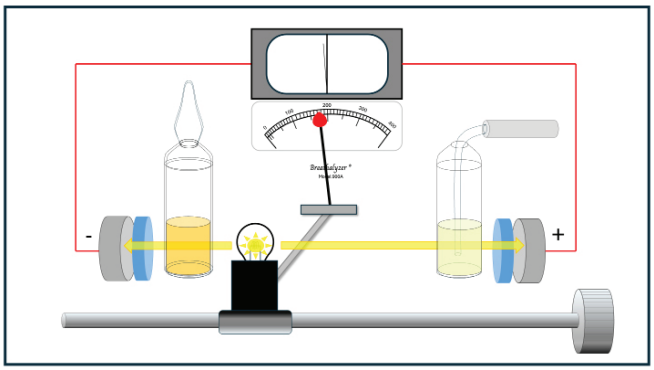

Figure 12. Moving the cam shaft assembly caused the linked BrAC needle to move proportionately. Notice the null meter is almost centered.

amount of alcohol in the subject's breath, the lighter the test ampoule became. The lighter the test ampoule, the closer the light bulb had to move towards the *darker* reference ampoule to photometrically rebalance the optical system.

More light bulb movement on the cam shaft linkage assembly moved the BrAC needle a greater distance. Once the null meter again indicated a rebalanced optical system, the movement of the BrAC needle indicated the breath alcohol content of the subject on a scale.

The Calibration Check Test

In many jurisdictions, the operator was required to verify the operation of the Breathalyzer against a known alcohol standard once during the testing sequence and using at least one test ampoule. The standard alcohol solution (SAS) was placed in a baby bottle arrangement called an equilibrator that had an aspirator bulb to pump room air through an aerator, generating sufficient force to lift the piston to the top of the cylinder to capture a test sample. The temperature of the room and the temperature of the SAS had to be identical, recorded to 0.1 ºC.

Truncation of Readings

It should be noted that the increments on all the scales were quite small (**Figure 13**). It was sometimes difficult to distinguish if the reading was 81 mg/dL or was still touching the 80 mg mark. This is one of the reasons that various jurisdictions adopted the notion of truncated readings. Readings between 81–89 mg/dL were *all* rounded down to 80 mg/dL.

In this way, operator inaccuracy and judgment of the readings were minimized. In order to be charged with having a BrAC in excess of 80 mg/dL, the subject would in essence need to provide a sample that was analyzed at 90 mg/dL or greater.

Figure 13. Increments on the BrAC scale were small, and their interpretation left to the judgement of the trained operator.

Issues with the Breathalyzer

Even though it was 1950s technology, the Breathalyzer still had some advantages over modern computerized devices:

1. Operating it was very much a hands-on situation. An experienced operator could tell if the device was working correctly by the response and feel of the moving parts. It was not the "black box" experience of today. However, the operator had to be fully competent in its use, and as such, the operators tended to be better trained than operators today, many of whom know little more than to push the start button.
2. The compliance of the subject exhaling properly was easily discernible. A smaller statured person could still provide a suitable sample where the newer instruments have minimum programmed algorithms for exhalation force and volume that may not otherwise be achieved. The operator could hear the "clunk" of the piston as it hit the top of the cylinder, indicating the test subject was blowing hard enough, and hear the air escaping out the cylinder vent holes, indicating that the subject was, in fact, exhaling. Any attempt by the test subject at "sucking back" would draw the piston back over the vent holes, and the sound of escaping air would stop, indicating the attempt at subverting the testing process.
3. If any of the individual components malfunctioned, either a reading was not obtained (as in a dead light bulb), or the reading was lowered due to leakage in the internal tubing (more on that below).
4. An experienced operator could identify non-specificity towards ethanol by the response of the test ampoule. Remember that the chemical reaction of ethanol with the *test ampoule's reagent solution* took 90 seconds to complete. With other interferent chemicals, the optical array would not balance during subsequent tests or give inordinate numerical results. Identifying specificity towards ethanol was a component of operator training that somehow disappeared when the new electronic units used a programmed algorithm to determine the presence of interferent chemicals.
5. The quickest a second breath sample could be obtained with a calibration check in between the samples was about 12 minutes (the blank and purge cycles were long and complicated). Therefore, the dissipation of any fresh mouth alcohol from oral contamination would be identified with the longer wait time. Newer instruments use a 2–3 minute wait period programmed between samples, and this is simply not enough time for oral contamination to dissipate.

Disadvantages

Of course, there were severe drawbacks with the Breathalyzer that newer technologies ultimately improved:

1. The Breathalyzer was extremely complicated to operate, with almost 100 steps on an Operational Check Sheet [6] that had to be correctly performed, in the specific order required, to obtain two breath samples with a calibration check. Newer technologies are simple push-to-start devices. This is a dual-edged sword compared to Advantage #1 above.
2. It took about two weeks to train an operator in this complicated-to-operate device and its procedures [7]. Today's operators are often trained in as little as 4–8 hours, but again, this is a dual-edged sword, as the newer operators often don't really understand how a suitable breath test sequence should be performed, or what to do under substandard testing conditions. Too often I hear operators in court testify that they understand very little about sample provision requirements and rely upon the programmed algorithm to determine when a suitable sample is obtained.
3. There was no independent analysis of the test protocol for an individual test subject. The operator could easily declare a person had whatever BrAC they wanted, hence the oft-used derisory term "dial-a-drunk". Almost every component of the testing sequence was discretionary on the part of the operator, with their own individual integrity serving as their guide.
4. The maximum reading obtained by the dial was 400 mg/dL. Operators were taught that with very high readings, they would dial the unit to 400, reset the pointer at 0.00, and keep balancing the optical array. The highest BrAC reading I ever received was 420 mg/dL. I did the test three times to make sure I hadn't made a mistake. All breath samples were analyzed the same at 420 mg/dL. We took the test subject to the emergency department for treatment for potential alcohol toxicity. His hospital blood draw came back at 470 mg/dL (with the whole blood conversion, this is about right).

A cautious and prudent operator of the Breathalyzer usually had little difficulty in obtaining a valid sample from a test subject. For the most part, any failure by the instrument itself would result in too *low* a reading, or the inability to complete the testing sequence. There are, however, a few issues to examine.

Specificity

In order for a substance to be considered an interferent chemical, that is to say, a substance other than ethanol that gives a false positive breath reading, a number of conditions must be present:

- First, the substance must be something that can exist in the body or on the breath of the subject in an amount that the Breathalyzer can detect.
- The substance cannot be poisonous or fatal in small doses.
- The substance must be chemically volatile.
- The substance must provide a reading that is interpreted by the instrument as being a reading of *ethanol.*

The reagent solution reacts differently if exposed to methanol, isopropanol, or substances containing endogenous ketones, as with certain diabetic conditions or severe diets. The oxygen-hydrogen group in an alcohol molecule will react with the reagent regardless of the alcohol type, albeit to a different extent than ethanol.

Isopropanol (isopropyl alcohol; rubbing alcohol; 2-propanol; $(CH_3)_2CHOH$)

Isopropanol produced relatively low BrAC readings compared to the often highly visible indicia of impairment. The chemical reaction of the reagent solution would complete well before the 90 seconds were up, but this would not, in general, be picked up by the operator under normal conditions, as there was no built-in indicator that identifies a chemical reaction that was too fast. The possibility of isopropanol interferent was identified by the combination of an extreme indicia of intoxication coupled with a low reported BrAC reading.

Methanol (methyl alcohol; wood alcohol; CH_3OH)

Methanol is the simplest form of alcohol and reacts strongly but slowly with the reagent. As with isopropanol, the operator would obtain a reading that may appear to be too low given the signs and symptoms of impairment. However, the reaction time between the methanol and the reagent solution was very slow. The operator would not be able to center the null meter needle at the end of the 90 seconds of reaction time, as the reaction would continue to occur. The null meter would continue to drift between breath tests and during the calibration check. The operator was typically trained to pick up on the discrepancy.

Acetone (dimethyl ketone; 2-propanone; CH_3COCH_3**)**

An area of concern is that of acetone inhalation, or substances containing acetone-like properties. Found in lacquer thinner, nail polish remover, and many lacquer paints, acetone is a commonly abused *inhalant*. Persons abusing acetone often display bizarre and aggressive behavior when confronted and appear sluggish and stuporous. They are unpredictable in nature, but their BrACs produce virtually no reading. Breathalyzer operators were therefore taught to identify bizarre drunken behavior with little or no appreciable reading (less than 20 mg/dL) as being a possible indicator of inhalant abuse or uncontrolled diabetes, and therefore a cause for medical intervention (*see* next section).

Ketosis and Ketoacidosis

These conditions result when the diabetic person suffers complete or partial insulin deficiency. The conditions may also be brought about by persons fasting on unregulated or extreme diets. These persons often present themselves with symptoms resembling impairment or intoxication, but with an added general appearance of being ill. Diabetics are often fully self-regulated in terms of their sugar/insulin balance and may self-identify their medical conditions. However, they can display bizarre and sometimes aggressive behavior and have a fruity, acetone-like (ketotic) odor on their breath. Occasionally they appear confused, potentially to the extreme.

Acetone and other ketone bodies (acetoacetate and b-hydroxybutyrate) are exhaled by the person in ketosis as a by-product of their medical condition. Both the ketones and the ketotic odor associated with ketosis and ketoacidosis would react with the reagent solution in the breathalyzer but produce a very low reading. Any reading obtained by the Breathalyzer was quite minor, if it was detectable at all, in comparison with the signs and symptoms of intoxication.

Additionally, and more importantly, the diabetic person's physical condition will deteriorate over time, while an intoxicated person will generally improve. Testing acetone on a Breathalyzer produced a reading less than 10–20 mg/dL. It was thought that setting the BrAC indicator on the BrAC scale to the "Start" line at -5 mg/dL would be more than enough to compensate for any ketone-like compounds produced by a person in ketosis or ketoacidosis.

Operational Considerations

Provision of Deep Lung Air

The volume determination of the breath sample was left entirely to the discretion of the operator. Given the technology of the day, this was understandable, but it could lead to issues. In order to get the desired blood-to-breath ratio, we need to get the subject to exhale fully into the instrument. At the point that they start to "taper off" in their exhalation, the sample of deep lung air is being produced. That is what the operator needed to capture.

For the most part, this was not too much of an issue, but certain medical conditions made this difficult to gauge. Some operators timed the samples being taken, while others did not. Some operators waited for taper to occur, while others took the sample at the 5, 8, or 10 second mark, to their personal preference. Too much variability existed in this regard.

Fresh Mouth Alcohol

During exhalation, the subject may intentionally or unintentionally burp, producing a false-positive reading of ethanol that comes from the stomach. There may also be fresh mouth alcohol from an unnoticed "micro-burp" (my term) that is not detected by the operator or even the subject. Not enough time may have elapsed between the last consumption of alcohol and the time the first sample is obtained. The reagent would then be exposed to an artificially inflated ethanol amount and would indicate a BrAC reading that was higher than the true BAC of the subject. The Breathalyzer had no means to determine mouth alcohol or oral pathway contamination. As such, an efficacious deprivation and observation period was warranted.

Temperature Control

The Breathalyzer required temperature control between the instrument, the room air, and the SAS solution used. The instrument itself had its internal temperature controlled at 50±3 ^{o}C by the warming pad around the cylinder and piston assembly. This was intended to reduce the condensation of breath inside the cylinder, and ensure the piston moved smoothly.

The temperature of the room was much more critical. Fluctuations would invariably occur, as it was difficult to prevent them, but it was imperative that the room temperature and the temperature of the SAS solution were identical. This was accomplished by storing the SAS solution in the test room and ensuring that the air temperature inside the room didn't fluctuate too much due to heating and cooling systems or other factors.

A chart was used to provide the expected reading of the SAS versus the measured ambient temperature of the room. As an example, using an SAS with a calibrated value of 100 mg/dL in a room with a temperature of 23.1 would yield an expected reading by the Breathalyzer of 123 mg/dL. Higher ambient temperatures produced higher SAS readings, and vice versa. An actual SAS obtained was considered accurate if its value fell within ±10 mg/dL of the expected reading based on the ambient temperature.

Reagent Solution

The reagent solution was highly regulated and controlled. Representative samples of the specially designed glass ampoules were often retained for independent analysis if requested by counsel. The problem with the reagent was not so much the manufacturing control as the inherent danger of using the solution. Splatters of acid and burns were commonplace. Chemical burns to the operator sometimes occurred. When the top of the test ampoule was snapped

off, the entire ampoule could sometimes shatter, spewing sulfuric acid and glass shards into the hands of the operator. I looked away and held my breath every time I carefully cracked open one of those test ampoules, even while the ampoule was wrapped in a large sheet of optical paper.

During my initial Breathalyzer Qualified Technician program in 1989 from the Royal Canadian Mounted Police, a carton of 25 ampoules was accidentally dropped onto a carpeted floor in the classroom, smashing all the ampoules. The mess was nearly impossible to neutralize and decontaminate. When we returned the next morning, we found a 4-foot-diameter hole in the carpet, not to mention the damage to the concrete floor underneath, which looked like a crater on the moon (nasty stuff, indeed).

The reagent solution vials were relatively expensive and were specifically designed for the Breathalyzer. At least one ampoule was used per breath test subject.

Standard Alcohol Solution (SAS)

Also highly controlled during its manufacture, the standard alcohol solution had an expiry or "best before" date. Solutions past their prime could not be used for evidentiary testing purposes, although from a chemical point of view they were probably relatively stable. For instructional purposes, I've used expired SAS extensively, and never had a reading that was outside the expected range. In fact, for this article, I used SAS solution that expired 40 years ago with no aberrant readings.

Representative samples of SAS were also retained for independent analysis if requested by counsel. Before being released for use, representative samples were typically verified by forensic alcohol technicians. Each bottle of SAS contained 3.38 milligrams of ethanol per l00 milliliters of solution to create the expected 100 mg/dL reading. A fresh bottle of SAS solution was used for each breath subject, resulting in increased expense for the police agency involved.

I once swished a bottle of SAS solution to see if it would provide a false positive reading, as they did contain ethanol. I was able to deliver a reading of 90 mg/dL, but only if I just delivered a mouthful of air into the cylinder. When I provided a "tapered, deep lung" breath sample, I was able to purge out most of the rich ethanol sample with air from my quite sober body and obtained a reading of about 50 mg/dL. We had been alerted by a circular that one subject had grabbed a bottle of SAS solution and downed it before the operator or arresting officer could stop him. He was attempting to disrupt the testing sequence.

Flooding of the Instrument by SAS Solution

An aspirator assembly was used to flush ethanol-laden air into the Breathalyzer when performing a reference test using the standard alcohol solution. A moment of inattention, or sometimes a vapor lock of the equilibrator, would result in an inadvertent flooding of the Breathalyzer test cylinder by the standard alcohol solution. The instrument had to then be immediately taken out of service, dismantled in its entirety, thoroughly cleaned, and re-assembled. This was a 2–3 hour procedure at best. [8]

If a previous operator, or the operator in question, accidentally flooded the instrument without being aware this occurred, they would be unable to center the null meter needle. Their air blank purges would always be highly elevated, and they would not receive two breath readings within the ±10 mg/dL range required. The SAS test was typically done between the first and second breath samples, as dictated by the Operational Check Sheet. A flooded instrument would be very easy for the operator to identify.

Operator Error

The operation of the Breathalyzer was sufficiently complex to warrant the use of an Operational Check Sheet. Quite frankly, the check sheet was nice to have at 3AM. Each stage of the testing process was well documented on the check sheet, and as long as it was followed, no major errors would typically occur.

Operator Input

The operator had control over the operation of the instrument at every point of the testing sequence. Whether you feel this was a good or bad situation depends upon your point of view. Proponents for operator control identified the need for sound judgment in determining when suitable samples are being obtained. The instrument, after all, was incapable of identifying this situation.

Opponents of the Breathalyzer were quick to point out that the operator was really the only person who ever knew what was truly happening in the breath testing sequence. *Was it possible that results were falsified? Could an extra turn of the balance wheel push an accused's reading just enough over the line to justify the charge?* I'm not prepared to say categorically that this situation never occurred. We were left with having to rely upon the honesty and integrity of the operator, with little corroboratory evidence as to instrument operations from the instrument itself.

Operator Judgment

The qualified operator was required to read, within a tenth of an increment, both the temperature of the room and the temperature of the SAS solution, plus the BrAC reading as provided by the pointer on the BAC scale. For the most part, this was an interpretative value, as the scales provided on the Breathalyzer or the thermometer in the

equilibrator were not that finely delineated. The operator, as previously discussed, also used their own judgment to determine when deep lung air has been provided by the subject.

Additionally, when centering the null meter, the operator had to use their judgment to determine when the needle was precisely centered. This became fairly critical when determining the difference between 79 mg/dL and 80 mg/dL, as a lot was riding on the outcome. I would note that interpreting the difference of 1 mg/dL with the rather thick pointer on a fairly small scale was often challenging.

Sticking of the Piston in the Cylinder

Sometimes, after receiving a great number of breath samples, the piston would begin to stick inside the cylinder. When this occurred, the time it took to drop the piston when the "Analyze" knob was turned would be greatly increased from its normal fall time of about 20–30 seconds. In fact, if the piston stuck totally, it would not fall to the bottom of the cylinder at all, and the 90-second timer switch would not activate. The "Piston Down" and "Read" lights would then not light. I made it a habit of timing the piston drop time and observing the bubbler pipette in the test ampoule to ensure that it was indeed bubbling the captured breath sample. A failure of this type was quite easy to spot and would result in less breath sample being analyzed, with a resulting lower BrAC obtained.

Burnt-Out Light Bulbs

These were rare, but they did occur. For whatever reason, an indicator light would just not come on. After troubleshooting the obvious problems, the operator would feel the light cover in question. Most of them were quite warm, as the lights were on a lot of the time, and the older style light bulbs generated a lot of heat. Once the burnt-out indicator was discovered, the testing process could continue with no change in the reading.

However, if the main light bulb in the optical array burnt out, it would require servicing by an authorized repair person. This technician had to align the light bulb in its array and check to make sure it would illuminate within factory specifications. This necessitated terminating the testing sequence on that instrument and moving to a backup instrument if one was available.

It was argued that the light bulb could "brown out"; however, if that situation occurred, both the test and reference ampoules would be affected equally. The light meters required a lot of light to get any sort of reading. A severely browned-out light bulb did not generate a sufficient amount of light to provide usable voltages for the balancing system.

Radio Frequency Interference

The Breathalyzer used a sensitive electric ammeter (null meter) to balance the optical array. The null meter was subject to radio frequency interference from the police handheld radios in use at the time. In 1995, I tested our then newly purchased Motorola MTX digital radios and discovered that the radio had to be placed in the immediate vicinity of the instrument, within 30 cm or less, and keyed to produce a radio transmission before radio frequency interference was generated.

Even then, the interference was transient and lasted only as long as the radio was keyed open in the transmit mode. The reading produced fluctuated the null meter with a ±50 mg/dL reading, depending upon the orientation of the radio to the instrument. During actual breath sampling, the radio had to be placed so close to the Breathalyzer that the operator would have to know that radio frequency interference was occurring.

Some Final Thoughts Concerning the Breathalyzer

I have discussed some of the issues that affected the Breathalyzer, but I don't want to leave you with a poor impression of the instrument. The bulk of my evidentiary testing as a Qualified Technician was done using a Breathalyzer Model 900A. In my view, a trained and competent professional breath test technician could operate the Breathalyzer and produce accurate and specific results.

The Breathalyzer was, in many ways, like driving a manual transmission vehicle or operating a manual camera. Perhaps it was more work to operate, but in many ways, it *felt* like you were interacting with the device. One complaint raised by senior Breathalyzer technicians when they converted to the then-new infrared devices was that the hands-on aspects of breath testing procedures were removed. We were relegated to "pushing the green button", and from there, the instrument did most of the work. The Intoxilyzer 5000, as an example, reduced the necessity of operator judgment in comparison to the Breathalyzer. As discussed in the sections on operator input and operator judgment, I leave it to you to decide if this was a positive or negative situation.

Regardless of the limitations of the instrument, I'm convinced the opportunity to use the Breathalyzer early in my career made me a better Qualified Technician. I had to rely upon my judgement, plus a complete understanding of the instrument and its limitations to determine the suitability of samples received and analyzed.

Apart from the historical significance of the device, keep in mind that it set the tone for breath testing, and many of the procedures we follow today were handed down, by

necessity, due to the limitations of the technology. And, as newer devices were introduced, they were compared to the "tried and true" Breathalyzer, and as a result many of the features and procedures of that device were ultimately part of what came after, and what still occurs today.

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COMMENTARY

Nicotine: The Neglected Forensic Drug*

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James Wigmore has been a practicing forensic toxicologist for over 35 years and has testified in over 700 criminal cases across Canada and in personal injury, wrongful death, and coroner cases. He continues his Commentary series, this time on nicotine. His book "Wigmore on Nicotine and Its Drug Delivery Systems" was published by Irwin Law (Toronto, Canada) in 2023; https://irwinlaw.com/product/wigmore-on-nicotine-and-its-drug-delivery-system/).

A more detailed biographical overview can be found in his previous Commentary on Cannabis [*Forensic Sci Rev* 35:74; 2023].

> "*Due to the widespread prevalence of smoking and therefore the frequency with which nicotine is detected by toxicological screening, there is the potential of its significance to be overlooked when present in overdose.*" [1]

When I was a junior forensic toxicologist in the 1980s and 90s, I remember being perplexed by the drug nicotine being detected numerous times, but it was ignored. I was told, "He was a smoker," "She was a smoker," "They were smokers," etc., and not to be concerned about it.

Soon after, I became deeply involved in blood alcohol analyses, and the breath alcohol program with the introduction of a new infrared (IR) instrument (Intoxilyzer 5000C) in Ontario. I seldom did drug screens after that. But I always wondered, even though nicotine is one of the most toxic and rapid-acting poisons, why did we ignore all positive nicotine results, almost as if it was an internal standard added to the analysis?

Forensic Toxicology of Nicotine

> "*Nicotine, which is found in tobacco, is one of the most toxic of all known poisons*." [2]

Nicotine is the major alkaloid of the tobacco leaf and acts as a botanical pesticide. It is a stimulant and weak base and is absorbed fastest at alkaline pH (i.e., >7.0). Smoking is the most effective form of drug administration as it enters the brain rapidly (within 20 seconds). Inhalation also avoids the first pass effect through the liver, which lowers drug concentrations. Nicotine is 95% water soluble and passes readily through all membranes in the body, including the skin and oral cavity. About 70 to 80% of the nicotine in the body is converted to cotinine and over 20 other metabolites by the liver. Binding of nicotine to the plasma proteins is less than 5% [3].

$C_{10}H_9N_2$

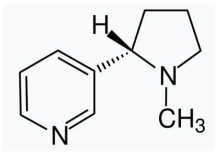

Figure 1. Nicotine chemical formula and structure.

Smoking a cigarette results in an uptake of about 2 mg of nicotine and produces an arterial plasma concentration of about 30 nanograms of nicotine per milliliter of serum (ng/mL). Early studies have indicated that an oral dose of 60 milligrams (mg) of nicotine could be fatal, but more recent studies indicate that a lethal dose of nicotine for an adult is between 500 to 1,000 mg, which results in a lethal blood nicotine concentration of 200 ng/mL [4]. A lethal dose of nicotine in children, however, may only be 19 mg [5].

Nicotine acts on the parasympathetic and sympathetic nervous systems and binds to the acetylcholine receptors. Low doses of nicotine cause stimulation (nausea, vomiting, increased salivation, dizziness, and headache) and high doses causes depressor effects (low blood pressure, slow heart rate, and unconsciousness). The most common mechanisms of death are respiratory failure, cardiovascular arrest, and seizures [6].

Safer Than Coffee?

> "*Indeed, a chemist at Philip Morris would have been amongst a select few in the country who could appreciate just how nasty nicotine really is. Many at the research center learned the hard way that merely leaving a bottle of the clear liquid open in a warm room brings a wave of coughing and gagging followed in short order by dizziness and nausea*." [7]

As the large international tobacco companies pivot from cigarettes to delivering nicotine via vapes, pouches, and dissolvable products, the toxic effects of nicotine are being downplayed. Numerous times when I posted about the science of nicotine and its risks on social media such as Reddit, I received numerous replies that nicotine is no more addictive and dangerous than caffeine (i.e., coffee).

There are approximately 100 to 200 milligrams of caffeine in a cup of coffee. The fatal dose of caffeine in adults is approximately 10,000 mg, which is at least 10 to 20X greater than the lethal dose of nicotine [8].

When I replied with the scientific literature that shows nicotine is much more addictive and toxic than coffee, I have had bots attached to the posts which automatically gave it a "thumbs down" every time a reader gave it a "thumbs up". I have also found that any post I write on nicotine receives many fewer views and engagements than my posts on alcohol, cannabis, or carbon monoxide.

Although Big Tobacco has lost in traditional media, it is winning on uncontrolled social media platforms and with social influencers, who scoff at the dangers of nicotine and cause a new generation of users to be addicted to this drug [9,10].

This downplaying of the adverse risks of nicotine may also cause investigative agencies and forensic and clinical laboratories to overlook the toxicity of nicotine as a cause of death.

Homicides (Figure 2)

> "*High doses of nicotine inhibit the central nervous system, inducing hypotension and bradycardia followed by coma and respiratory paralysis, leading to death by asphyxia*." [11]

The first recorded homicide using nicotine occurred in 1850. The Belgian Count Hyppolite Visart de Bocarme murdered his brother-in-law by poisoning him with nicotine that he had extracted from tobacco leaves. An autopsy was conducted on the victim and various tissue samples were collected and preserved in alcohol and vinegar. Three years earlier, Mateo Jose Bonaventura Orfila, the father of modern toxicology, stated that organic poisons such as nicotine could not be extracted from

Figure 2. First recorded homicide by nicotine poisoning in 1850; *https://en.wikipedia.org/wiki/Hippolyte_Visart_de_Bocarm%C3%A9#/media/File:Hippolyte_Visart_de_Bocarm%C3%A9_murders_Gustave_Fougnies.jpg.*

human organs and would be undetectable. Fortunately, J.S. Stas was able to identify nicotine in the deceased's organs via deproteinization with alcohol and diethyl ether extraction. Bocarme was found guilty of homicide after a court trial in May 1851 and was executed [12].

Over the years, nicotine was seldom used except in well-planned homicides, as extraction of the nicotine from tobacco products and administration of the poison was difficult for the layperson. But it was employed because it was thought by the perpetrator that forensic laboratories did not routinely conduct analysis for nicotine. And if they did, it may be dismissed as being due to the victim being a smoker [13].

With the advent of readily available high-nicotine e-liquids, potential homicides have become easier [14].

Suicides

> "*In this case, the deceased had ingested a lethal dose of nicotine and developed symptoms of poisoning, but because of the nonspecificity and a history of aortic dissection, death due to endogenous disease was initially suspected as the time of transport and poisoning was almost overlooked*." [15]

Two suicides in the UK due to the ingestion of nicotine extracted from tobacco using instructions from the Internet are reported in this study [1]. The instructions given on the website were to soak 150 grams of tobacco in water for several days and then slowly heat the liquid and let it simmer until it becomes a gooey residue, which is then added to a drink.

In one case, a 19-year-old male was found dead in the bedroom of his father's home. Empty tobacco packs and a saucepan with a brown gooey residue were found by his personal computer (PC). He had vomited and there were large quantities of feces surrounding the body.

An autopsy was conducted 4 days after death and the cause of death was not apparent. Initial toxicology results showed only a postmortem blood alcohol concentration of 43 mg/100 mL (0.043 g/100 mL). Several days later, the father was cleaning up his son's bedroom where the death had occurred and noticed that he had searched for "death" on his PC and had clicked on the instructions for the nicotine extract as a way of committing suicide.

Further special postmortem toxicological analyses were conducted, including a validated GC assay using nitrogen phosphorus detectors for nicotine and cotinine. His postmortem blood nicotine concentration (which was not detected in the initial toxicology screen) was 5,500 ng/mL and cotinine concentration was 2,500 ng/mL. Nicotine poisoning as a cause of death was initially overlooked in part due to the wide prevalence of smoking.

In a similar case, in the same study, a 32-year-old man obtained the nicotine extraction instructions and was found to have a fatal postmortem blood nicotine concentration of 1,000 ng/mL.

Other suicide/attempted suicide cases have involved the use of nicotine transdermal patches [11], nicotine chewing gum [16], and nicotine e-cigarette liquids [15,17–19].

In addition, e-liquids also contain multiple other chemicals such as propylene glycol, which may also contribute to the cardiac collapse caused by nicotine [20].

Drug-Related Deaths

> "Whereas the concomitant consumption of alcohol is frequently mentioned, the use of tobacco, which is present in nearly all cases, is almost completely ignored in forensic literature on drug problems. Even studies specifically dealing with the consumption of hashish and marijuana in drug addicts do not pay any particular attention to the consumption of tobacco, which is an integral part of smoking cannabis joints." [21]

Part of the problem in the detection of nicotine poisonings is that this drug is a common finding in forensic laboratories and so can be easily ignored by hard-pressed, understaffed facilities. Rates of smoking are 2 to 5X greater in people with psychiatric disorders [22]. Adolescents and young adults who experienced a sudden and unexpected death that resulted in an autopsy were found to have a positive nicotine finding in 75% of the cases, compared to a rate of about 20% in the general population. A majority of drug abusers were also nicotine users [23].

In a study of 100 consecutive drug deaths, a positive cotinine urine concentration, which indicates nicotine use, was found in 98 victims [21].

Organophosphates? Sarin? Russian Nerve Agent? No, E-Liquids!

> "*There may be deaths caused by fatal nicotine ingestion because suicide guides recommend this method, but nicotine poisonings are often not detected as such. Since ingestion of cigarettes does not result in death in most cases, the new preparations of nicotinic fluids may increase the risk of fatal nicotine ingestion*." [17]

The following case would not have occurred without easy access to high-nicotine e-cigarette liquids and may be a forerunner to further use of this poison. A man and his ex-wife agreed to meet in a busy park so that he could spend time with their two children in a public space. She felt it odd that he had brought water guns for the kids to play with. While she sat on the park bench, the man played with the children, squirting them with water.

He left for a short time to use the public bathroom. When he emerged, he sprayed his ex-wife with the water gun and splashed her with a sticky yellow liquid from a bottle. She began to feel sick almost immediately, started choking and vomiting, was dizzy and unable to stand up, and began to lose consciousness. After a 911 call she was transported to a hospital, where the doctors felt she was exposed to a nerve agent or organophosphate pesticide poison. Her condition deteriorated and she nearly died.

As such, a Hazmat team was called to the busy park to ensure the public was not exposed to possible toxic agents. A urine sample collected at the hospital from the woman showed a nicotine metabolite, cotinine, at a concentration of nearly 10X that found in heavy smokers. The doctors who treated her said they were not surprised as nicotine has symptoms similar to organophosphate poisoning.

The man was charged with second degree attempted murder and second degree assault using a poisonous substance. Unfortunately, during trial evidentiary issues arose and the charges were dismissed [24].

Concluding Remarks

Nicotine is one of our most lethal and toxic poisons, and yet millions of bottles of high-nicotine e-cigarette fluids, which are frequently candy flavored, are manufactured yearly having no or limited warning labels and with no child-resistant tops. It is as if this known pesticide is no more lethal than coffee.

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