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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

VOLUME THIRTY-SIX ■ NUMBER ONE ■ JAN. 2024

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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 bi-annual 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, original founded by President Shih-Si Yen, President of the Central Police University (Taoyuan, Taiwan), is currently published by Forensic Science Review with executive editorial offices located in Vancouver (Washington, 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**, Department of Criminal Justice, University of Alabama at Birmingham, Birmingham, AL 35294, 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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Carbon Monoxide: An Ancient, Silent Enemy

Forensic Odontology in Latin America

Forensic Science in the United States. III — Strengths and Challenges and Future Directions

The History of Carbon Monoxide, Our Oldest Poison

Oral Fluid — A New Matrix for US Federal Workplace Drug Testing Programs Using Oral Fluid

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[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.

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Forensic Science in India

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History and Development of Forensic Science in India

India is the seventh largest and second most populated country. In India, around 1.4 billion people live in 3.287 million km². Even though the implementation of contemporary science and technology in criminal investigation to administer justice is not new, the approach has been mostly empirical, based on keen observation and experience. It is well known that Indians researched and studied the papillary ridges of fingers about a thousand years ago [1]. They also knew about poisoning and human and animal footprints. It is also believed that the persistence and the individual characteristics of fingerprints were known, which were then used as signatures. Due to the steep increase in the number and nature of crimes committed, the use of forensic science in investigations has gained utmost importance, utilizing the latest advances in science and technology, on par with international standards [2].

Modern Indian forensic science gradually evolved due to various steps initiated by the British during their rule, including the establishment of various laboratories and institutions, such as Chemical Examiner's Laboratories at Madras (now Chennai, 1849), Calcutta (now Kolkata, 1853), Agra (1864), and Bombay (now Mumbai, 1870); Anthropometric Bureau (1892); Fingerprint Bureau (1897); Inspectorate of Explosives (1898); Office of Government Handwriting Expert (1904); Serology Department (1910); Footprint Section (1915); Note Forgery Section (1917); and Ballistics Laboratory (1930). There are currently 28 Central Forensic Science Laboratories (CFSLs) and State Forensic Science Laboratories (SFSLs), as well as 32 Regional FSLs (RFSLs) and 144 Mobile FSLs (MFSLs), all of which are primarily affiliated with the respective home ministry or departments, either directly or through police establishments [3].

Categories of Forensic Science Institutions

Chemical Examiner's Laboratories. In the 19th century, several problems were faced by law enforcement agencies arising from deaths due to poisoning and physical assaults, which were generally examined by medical personnel in laboratories. This necessitated the establishment of Chemical Examiners' Laboratories in four cities by the central government.

Gradually, many states across India established their own State Chemical Examiner's Laboratories. For the establishment of strong, scientific support for the justice delivery system, considering the constraints of resources, the laboratories were set up to handle (a) toxicological analysis of viscera, biological analysis of blood, semen, and stains; and (b) chemical analysis of foods, drugs, and various excisable materials [1]. In the case of disputes, the Central Chemical Examiner's Laboratories had been assigned an appellate authority status.

Anthropometric Bureau. While there had been considerable improvement in the identification of drugs and poisons, reliable methods to identify persons were not available, particularly for criminals. Along with the rest of the world, India adopted Bertillon's anthropometric personnel identification system after its development in 1878. Hence, an anthropometric bureau was established at Calcutta in 1892 to keep records of criminals and offenders.

Fingerprint Bureau. The credit for establishing the world's first fingerprint bureau goes to India. One of the earliest proponents of using fingerprints to identify criminal offenders was Sir William Herschel, a British civil servant in India. To combat widespread rejections due to forgeries of signatures, in 1858 he introduced the use of thumbprints as a security feature on documents and papers. Sir Francis Galton, a distinguished English scientist, formulated the fundamental theories of uniqueness and permanence in fingerprints based on the theories of Herschel and Faulds. The anthropometric system of identification was then abandoned when Sir Edward Richard Henry (who at the time was the Inspector General of Police, Bengal), with the skillful assistance of two Indian officers, Khan Bahadur Azizul Haque and Rai Bahadur Hemchandra Bose, came together to develop a system for the classification of fingerprints. In 1897, the Writer's Building in Calcutta housed the world's first ever Fingerprint Bureau [4].

Explosives Department. It was thought necessary to identify the reasons for explosions, accidental or deliberate, after the usage of explosives for disruptive operations became widespread. Major C. A. Myspratt Williams assumed leadership as the first Chief Inspector of Explosives with independent authority on September 9, 1898, at his headquarters in Nagpur (First Annual Report, Department of Explosives, 1900). The Superintendent and Assistant Superintendent of the Ordnance Factories at Ishapur and Kirkee initially supported the Chief Inspector of Explosives. Later, subordinate offices were established in Calcutta, Bombay, Agra, Madras, and Gwalior, along with three sub-offices at Shivkashi, Gomia, and Asansol, for improved operations. Presently, the Department of Explosives, under the Ministry of Industry, is headed by the Chief Controller of Explosives, along with a full-fledged laboratory based in Nagpur. Almost every state has an office of the Controller of Explosives. Apart from investigating the explosions, the department is a licensing authority as well and looks after safety aspects. Across the country, the analysis of explosives and explosion residues is carried out in the forensic science laboratory.

Government Examiner of Questioned Documents. Due to the need to identify the handwriting on the documents related to the Indian independence movement, the then British Government of Bengal created a post – that of the Government Handwriting Expert of Bengal. The then-Superintendent of the Bengal Accountant General's office, Mr. C. R. Hardless, was appointed to this position in 1904. In 1906, this setup was moved to Shimla and brought under the direction of the Director, Criminal Investigation Department (CID), Mr. C. R. Hardless, who was assigned to the position of handwriting expert for the government in Shimla. He was later replaced by Mr. F. Brewster. In 1920, Mr. R. Stott was appointed Assistant Government Examiner of Questioned Documents. The three Central Government Examiners of Questioned Documents, which were functioning independently, merged with the CFSLs in 2011. Thus the CFSLs as well as SFSLs have divisions for document examination in their respective laboratories.

Footprint and Ballistics. In 1915, identifying criminals became possible by examining the footprints observed and collected from the crime scene with the help of the footprint unit, which was set up under the Criminal Investigation Department of the Government of Bengal. In 1930, the first Ballistics Laboratory was set up along with the arms expert under the police department of Calcutta [5].

Structured Forensic Science Institutions

Central Forensic Science Laboratories. In 1956, the Chemical Examiner's Laboratory, Calcutta, was taken over by the Intelligence Bureau for renaming and established as the first CSFL. In 1967, as the workload increased, another CFSL was established in Hyderabad. Simultaneously, in 1968, after the establishment of the Central Bureau of Investigation (CBI), one more CFSL was established in Delhi to exclusively cater to the needs of the CBI. When Chandigarh became a union territory in 1966, the old Punjab State Laboratory was re-designated as a CFSL. Now there are seven CFSLs, as further detailed later.

All the CFSLs provide expert services in scientific examination and analysis of evidential materials referred by the central government/CBI/state governments. They perform forensic analyses and investigations using the current state-of-the-art forensic technologies and to provide reports to respective forwarding authorities. These laboratories are also treated as appellate authorities in forensic cases of dispute. Scientists appear in the courts of law if and when they are summoned. As per the Indian Criminal Procedure Code, forensic experts need not appear in the courts for each and every case. Only when defence attorneys insist and the judges approve do forensic experts have to appear in court to give their testimonies. However, in most cases of document examination, the experts are invariably called to court to give testimony, as document examination is considered a subjective examination.

After the establishment of the first CFSL in Calcutta in 1956, the government advised all the states to set up their forensic science laboratories (FSLs) by taking over their own Chemical Examiner's Laboratories, wherever applicable, for which the Ministry of Home Affairs (MHA) would provide the financial assistance, technical support, and training facilities through CFSLs and Government Examiners of Questioned Documents (GEsQD). Currently, only one Chemical Examiner's Laboratory, which did not merge with FSL and examines all the toxicology-related cases of the state, exists in Thiruvananthapuram, Kerala.

As of now, there are seven CFSLs, located in Hyderabad (Telangana), Kolkata (West Bengal), Chandigarh (Union Territory), New Delhi (Union Territory), Guwahati (Assam), Bhopal (Madhya Pradesh), and Pune (Maharastra). The locations of these seven CFSLs and other laboratories are shown in **Table 1** and **Figure 1**.

Directorate of Forensic Science Services. In 2002, MHA established an independent Directorate of Forensic Science Services (DFSS), with a directorate in Delhi, while taking

Table 1. Distribution and number of central/state/regional/mobile forensic science laboratories (CFSL/SFSL/RFSL/MFSL) and educational institutions in India

No.	State/ Union Territory	Laboratory[a] CFSL	SFSL	RFSL	MFSL	Educational institution
1	Nagaland		1			
2	Mizoram		1			
3	A & N Islands		1	(+1[b])	1	
4	Puducherry		1		1	
5	Meghalaya		1		1	
6	Andhra Pradesh		1	5	13	1
7	Rajasthan		1	6	34	3
8	Arunachal Pradesh		1		9	
9	Uttarakhand		1	1	2	
10	Goa		1		2	2
11	Assam	1	1	5	7	
12	Manipur		1		2	
13	Himachal Pradesh		1	2	3	1
14	Jammu & Kashmir		1		20	
15	Madhya Pradesh	1	1	4	50	1
16	Tripura		1		5	2
17	Punjab		1	3	19	2
18	Sikkim		1		1	
19	Gujarat		1	6	46 (+4[b])	3
20	Bihar		1	2 (+9[b])	38	1
21	Chhattisgarh		1	3	9	2
22	Haryana		1	4	4	
23	Jharkhand		1		18	1
24	Karnataka		1	5	15	7
25	Maharashtra	1	1	7	50	5
26	Orissa		1	3	36	3
27	Kerala		1	3	19	3
28	Tamil Nadu		1	10	38	4
29	Uttar Pradesh		1	4	75	5
30	West Bengal	1	1	1	5	1
31	Delhi[c]	1	1	1	6	3
32	Telangana	1	1	5		1
33	Chandigarh	1				
	Total	**7**	**32**	**80 (+10)**	**529 (+4[b])**	**52**

[a] Abbreviations: CFSL = Central Forensic Science Laboratory; SFSL = State Forensic Science Laboratory; RFSL = Regional Forensic Science Laboratory; MFSL = Mobile Forensic Science Laboratory;
[b] Number of laboratory under the process of establishment.
[c] National Capital Territory of Delhi.

over the three CFSLs in Kolkata, Hyderabad, and Chandigarh, as well as the three GEsQD in Hyderabad, Kolkata, and Shimla. In 2011, three more CFSLs were established in Bhopal, Gauhati, and Pune. The DFS is headed by the Director-cum-Chief Forensic Scientist. The three independent GEsQD were merged with their respective CFSLs in 2011. The organization chart of DFSS is shown in **Figure 2**.

The mission of DFSS is to provide high quality and credible forensic services of international standard, backed by the National Accreditation Board (NABL) for forensic laboratories, for law enforcement agencies and the criminal justice system. Various roles shared by the DFSS include:

- Supporting the justice delivery system;
- Providing the latest technical knowledge;
- Carrying out research and development in forensic sciences;
- Maintaining contacts and interactions with the international forensic community;
- Regulating and providing technical and financial support to the SFSLs; and
- Supporting the organization of seminars, symposia, conferences, workshops, and training programs on forensic science for professionals across the country [6].

State and Regional Forensic Science Laboratories. State Forensic Science Laboratories are functional systems similar to the CFSLs. The Central Forensic Science Advisory Committee encouraged governments to create fully functional laboratories which numerous Indian states acknowledged. Some jurisdictions converted the scientific divisions of the CID units and the then-existing Chemical Examiner's Laboratories into forensic science laboratories. Across India, there are 32 SFSLs (Table 1). However, currently, in some of the larger states, self-governing departments under the authority of the state home departments and in many other cases, the SFSLs, are governed by the respective state police departments [7,8].

Most of the SFSLs have a couple of RFSLs, keeping in mind the high workload and vast distances in large states. Most of the RFSLs have the infrastructure to cater to the routine, simple cases of work in forensic biology, toxicology, and documents, which do not require high-end technologies. There are 80 RFSLs across the country [4,8] (Table 1).

The typical organization of State and Regional Science Laboratories is shown in **Figure 3**.

Mobile Forensic Science Laboratories. Many of the larger states, especially in metropolitan cities, have MFSLs, whose members are meant to reach the crime scene, collect all the physical evidence and carry out fingerprint examination, photography, crime scene mapping, and some presumptive tests at the crime scene itself. There are 529 MFSLs working across the country (Table 1).

A typical MFSL is headed by a Senior Scientific Officer, who is a crime scene expert with a team of three scientific assistants (biological, chemical, and physical sciences), a photographer, a fingerprint expert, two junior laboratory assistants, and a driver.

Forensic Science Education in India

With the development of forensic science in India, the need for forensic science training and education was felt. The first step the government took was to establish Police Training Schools (PTS), which gave basic forensic education with the help of experienced police personnel and scientists. Each of the states had PTSs even before

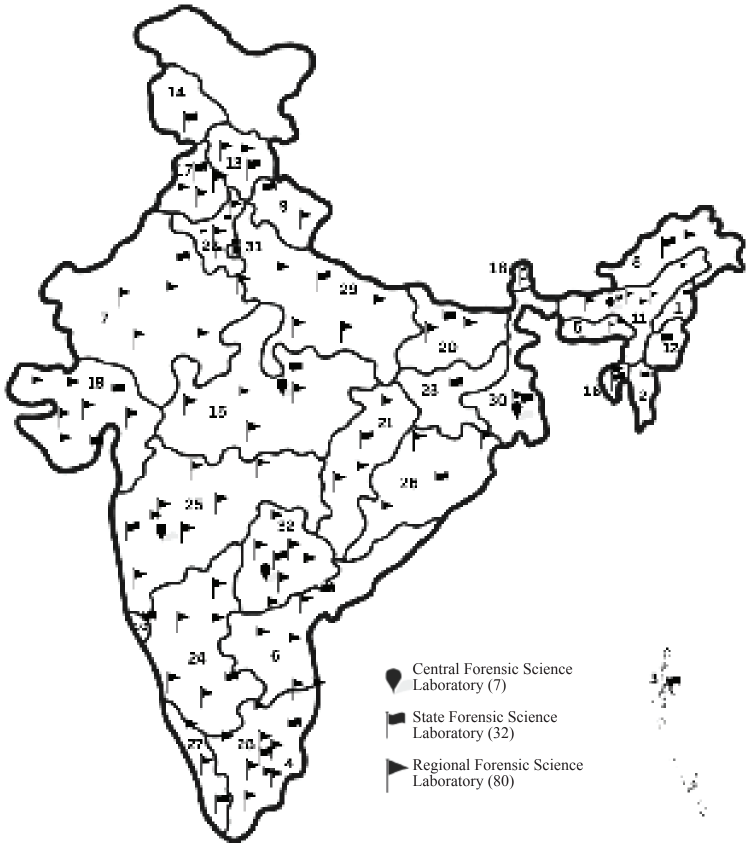

Figure 1. Distribution chart of forensic science laboratories across India (*See* Table 1 for the names of respective geological areas as represented by the numerical numbers).

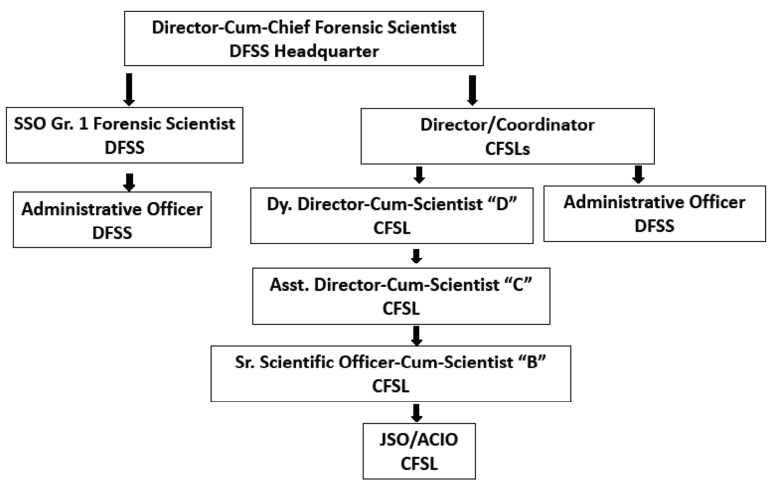

Figure 2. Organisational chart of Directorate of Forensic Science Services (DFSS). Abbreviations: SSO = Senior Scientific Officer; CFSL = Central Forensic Science Laboratory; JSO = Junior Scientific Officer; ACIO = Assistant Central Intelligence Officer.

independence to provide induction training as well as periodic, upgraded training for the police personnel in service. For senior-level police officers, State Police Academies were established, which gave exposure to forensic science at a higher level both to induction trainees as well as periodical in-service officers.

The government established the Central Police Training College in Mount Abu, Rajasthan, on September 15, 1948. This institution was renamed National Police Academy in 1967. As a befitting token to the memory of Sardar Vallabhbhai Patel, the Iron Man of India, the Academy was named after him in 1974 after it was moved to Hyderabad to train senior-level police personnel. The police are borne on the central cadre but allotted to various states across India at the induction level and later for periodic, in-service, and advanced training.

The central government opened three Central Detective Training Schools (CDTS) under the Central Intelligence

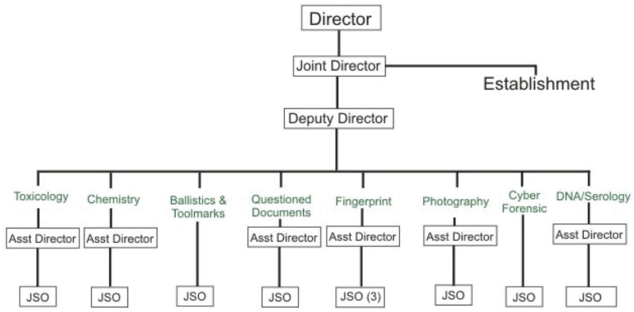

Figure 3. Organisational chart of a typical forensic science laboratory (JSO: Junior Scientific Officer).

Bureau (CIB) in Calcutta (1956), Hyderabad (1968), and Chandigarh (1973). Later, these three CDTSs were taken over by the Bureau of Police Research and Development (BPR&D). Two more CDTSs were opened in Ghaziabad (1970) and Jaipur (2012). The five CDTSs provide training in scientific methods of crime investigation with the help of forensic science for mid-level police officers and other law enforcement agencies. The forensic scientists of the CFSLs and SFSLs are involved as guest faculty at e-training programs, giving live demonstrations.

Sauger University, now Hari Singh Gour Sagar University, in Madhya Pradesh was the first state university that offered undergraduate, postgraduate, and doctoral-level courses in criminology and forensic science (1959). Later, Karnataka University (Dharwad, Karnataka; 1969) and Punjabi University (Patiala, Punjab; 1974) were two more state universities that offered courses in criminology and forensic science.

The Lok Nayak Jayaprakash National Institute of Criminology and Forensic Science (LNJN NICFS) was started by the government in 1974 as a major training institution for in-service forensic scientists, police officers, and the judiciary. They have been organizing long-term and short-term training programs, seminars, and conferences. Around 2004, they started regular postgraduate courses in forensic science, in collaboration with the Guru Gobind Singh Indraprastha University, formerly Indraprastha University in Delhi.

Over the last two decades, there has been a great increase in teaching forensic science in India. Many state and private universities have started imparting education in forensic science. Notable institutes are the Gujarat Forensic Science University (Gandhinagr, Gujarat), Osmania University (Hyderabad, Telangana), Amity University (Noida, Uttar Pradesh), Jain University (Bangalore, Karnataka), Guru Ghasidas Vishwavidyalaya, (Bilaspur, Chhattisgarh), Galgotia University (Greater Noida, Uttar Pradesh), and Christ University (Bangalore, Karnataka). As per one source [8] there are 80 universities and colleges imparting education in forensic science.

Recently, the central government took over the Gujarat Forensic Science University, named it the National Forensic Science University (NFSU), and designated it as an institution of national importance [9]. It is solely dedicated to forensic and investigative science [2].

Advanced research is being carried out in some of these CFSLs, SFSLs, and universities in collaboration with each other and with other institutions, such as Indian Institutes of Technology (IITs), the Defence Research and Development Organisation (DRDO), Bhabha Atomic Research Centre (BARC), University Grants Commission, and Council of Scientific and Industrial Research to carry out interdisciplinary research. There has been an increase in research publications in national and international journals.

The distribution of these educational institutions in the nation is shown in **Figure 4**.

Operation and Effectiveness of the Current System

The details of crime scene examinations are noted in minute detail in a prescribed format called the Forwarding Note, with details of the crime, evidence exhibits, persons under custody, nature of the forensic examination required, and a certificate of authority. All the exhibits are packed and sealed as per the SOP and sent to the forensic laboratory along with a sealed Forwarding Note and a specimen seal. A forensic report is prepared during an investigation into an alleged offense by a person with specialized knowledge or training, setting out the results of a forensic examination in the form of facts, opinions, or a combination of both. A legally defensible forensics report includes a title page, table of contents, matching of seals, reason for the investigation, signature page, the evidence examined, description of the investigation, and details of findings, following the chain of custody rules, and everything is documented. The Central and State Forensic Laboratories use the prescribed forms and have all the above details. The Forwarding Note and details of analytical procedures are recorded during the laboratory examination. They are maintained in a register or file, which can be submitted to the court on demand.

The documentation includes notes, photographs, sketches, and videos, generally prepared by the specially trained investigating police officer. In some cases where specialized expertise is needed, the services of forensic experts are sought at the crime scene. Note-taking is one of the most critical parts of processing the crime scene. The three most common methods of recording a crime scene are note-taking, sketching, and photography. A detailed record of the crime scene and the actions taken during the search are noted in the file/register, which helps the crime scene specialist accurately recall events and identify items of evidence later in a court of law.

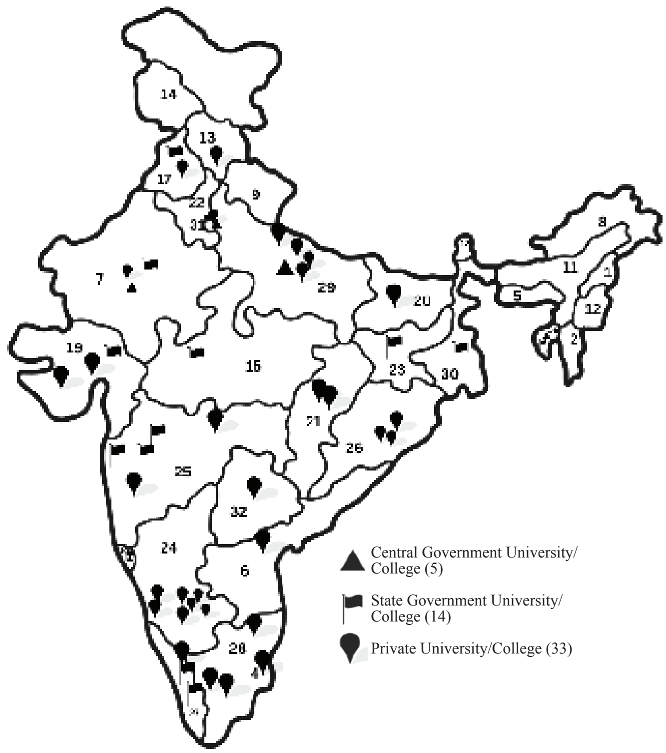

Figure 4. Distribution chart of Indian colleges and universities offering forensic science educational programs (*See* Table 1 for the names of respective geological areas as represented by the numerical numbers).

Failure to secure a crime scene until a full investigation has been carried out by both the investigating police and the forensic experts, reaching the crime scene late, not following the prescribed rules of search and seizure, or a failure to keep crime scene samples separate at all times from reference samples from the victim(s) and possible suspects would result in the miscarriage of justice.

The reasons for miscarriage of justice could be someone's negligence, an error of judgement, or the result of a witness fabricating a complaint or other evidence, deliberately lying, or making a simple mistake and not following the protocols of prescribed procedures. Errors in forensic science and other expert evidence have led to a significant number of miscarriages of justice in recent years across the world, and India is no exception. Different checking and cross-checking safeguard mechanisms are built into the system to minimize the miscarriage of justice. However, in rare cases where a miscarriage of justice proves beyond reasonable doubt (through a new or newly discovered fact) that the person is innocent of the crime for which they were convicted, they are compensated suitably by the courts.

The above protocols and mechanisms are effective in forensic investigation/examination. However, since forensic analysis in the criminal justice system is a dynamic process, steps are constantly taken to improve justice delivery without any loopholes or pitfalls.

Effectiveness

Unlike many other jurisdictions, India does not have a comprehensive legal framework to govern the use of forensic science within its criminal justice system. The absence of clear and consistent standards to evaluate expert evidence across cases adversely impacts judicial scrutiny of the foundational validity of forensic techniques and the forensic analysis conducted in a particular case. As a result, many obsolete and unscientific forensic methods continue to be admitted as evidence in Indian courts. Further, the Code of Criminal Procedure exempts specific categories of government scientific experts from testifying in court.

Although courts technically have the power to summon the expert as a witness, they often elect not to. There are also no standards for documentation to be provided to the opposing party or for the judge to enable an independent evaluation of forensic analyses, nor are there standards to evaluate the expertise of an expert witness. In the absence of clear legal standards, courts tend to accept or reject forensic reports without critically assessing the reliability of the results. An evidentiary framework to admit or weigh forensic evidence has a detrimental effect on the quality of forensic analyses in individual cases. The quality of forensic analyses is also impacted by the gap in legislation to govern the functioning of forensic science laboratories across the country.

Further, there is no overall regulator to govern the Indian forensic science system and set scientific and quality standards for laboratories. The DFSS in the MHA controls the functioning of the central laboratories but lacks statutory powers. The state and regional laboratories, which carry out the bulk of forensic examinations in the country, are outside its purview. Without a legal or regulatory requirement for quality management, most forensic laboratories in India do not have an efficient quality management system. As part of the quality control and quality assurance mechanisms, laboratories should create their own working procedure manual for each division based on the internal validation of techniques. Yet, most Indian laboratories do not internally validate the methods routinely used in their casework, instead depending on external manuals for their operation. The staff within laboratories do not undergo proficiency testing to assess their competence, and laboratories need systems for technical and administrative review of individual casework. The procedures for forwarding evidence and reporting forensic results are also not standardized, leading to high variance across laboratories, states, and courts.

Besides the need for a regulatory or legal requirement for quality management, forensic laboratories' administrative and functional challenges also contribute to the absence of quality management systems. Indian laboratories face various challenges concerning finances, personnel, case pendency, and infrastructure, which impact their day-to-day functioning and impede their ability to invest resources and personnel towards building quality management systems. Without quality management, there is no assurance that scientific procedures have been reliably followed in every case, making forensic analysis in individual cases susceptible to doubt.

Wrongful Prosecution/Conviction and Remedy

Herein, the ambit of wrongful prosecution would include:

- Malicious prosecutions; and
- Prosecutions instituted without good faith [10].

The compensation claim can be brought by:

- The accused person so injured;
- Any agent duly authorized by the accused person; or
- Where the accused person died after the termination of the wrongful prosecution, by all or any of the heirs or legal representatives of the deceased.

In Ramesh Harijan v. State of Uttar Pradesh [11], the Supreme Court overturned an acquittal order, noting undue importance given to "insignificant discrepancies and inconsistencies" by the trial court. The Supreme Court observed that such a course is equivalent to the miscarriage of justice, and preventing the same is of paramount importance. Further, in Allarakha K Mansuri v. State of Gujarat [12], the Supreme Court held that in a case where the trial court has taken a view based upon conjectures and hypotheses and not on the legal evidence, a duty is cast upon the appellate court to reappraise the evidence in an appeal to ascertain whether the accused has committed any offense. These judicial pronouncements discuss a broad view of the expression "miscarriage of justice." The cases mentioned above are among a few where the accused was not guilty of the offense, and the police and the prosecution engaged in some form of misconduct in investigating, thereby prosecuting the wrong person. In Gandhi v. Union of India [13], the Supreme Court gave a dynamic interpretation of Article 21, resulting in a new orientation to the concept of personal liberty. One of the important offshoots of the proceeding was that the courts started to consider awarding compensation in cases of undue detention and bodily harm.

In Mohd. Jalees Ansari v. Central Bureau of Investigation [14], the victim's brother filed a petition for compensation, saying that they were financially and mentally drained and had no will to fight another dubious legal battle, sacrificing everything to get their brother acquitted. In Rudal Shah v. State of Bihar [15], the court awarded compensation for the first time to the wrongfully convicted victims whose fundamental rights were violated by such conviction. The petitioner was unlawfully detained for 14 years. The Supreme Court awarded Rs. 30,000 as compensation and, in doing so, held that the scope of Article 32 of the Constitution is sufficiently broad enough to include the power to grant compensation for infringing upon rights. In Ram Lakhan Singh v. State of UP [16], an amount of Rs. 10 Lakhs was given to the victim, who was wrongfully accused and put in jail for 11 days. In S. Nambi Narayan v. State of Kerala, the Supreme Court awarded Rs. 50 Lakhs as compensation to an ISRO scientist who was wrongfully accused of espionage after a long battle of 24 years ended in acquittal. The fact that Rudul Shah was granted compensation in the amount of Rs. 30,000 after being imprisoned for 14 years and Ram Lakhan Singh was granted compensation in the amount of Rs. 15 Lakhs after being imprisoned for 11 days reflects the lack of consistency of the Judiciary's approach to these cases, thereby highlighting the need for a uniform compensation legislative framework.

The Effects of Wrongful Conviction and Prosecution

There have already been several cases in which an innocent person is prosecuted and later found not guilty in India. However, still, no proper approach has been adopted by the Indian criminal justice system to resolve or prevent such events. Some of the landmark cases are given below.

In the case of Hussainara Khatoon and Others v. Home Assistant State of Bihar [15], in the state of Bihar, the disturbing conditions for under-trial prisoners were highlighted after filing a habeas corpus writ petition before the Supreme Court. In this case, the Supreme Court has confirmed that the right to a speedy trial is a significant part of our criminal justice system in all states, as mentioned by the apex court. Subsequently, in the case of State v. Saqib Rehman and Others [16], the Supreme Court held that the victim was wrongfully prosecuted because of the police officer who framed an innocent person with false evidence. But no compensation was awarded to such innocent and even the police were not punished for fabricating false evidence. Assam's Madhubala Mondal's case, again, is an example of negligence or fault on the part of the police who mistook the identity of the accused, due to which an innocent victim, a 59-year-old woman, was wrongfully arrested for three years for an offense she did not commit [17].

All of this demonstrates how a mistake on the part of state officials may wreck an innocent person's whole life, restricting not only their liberty and privacy but also subjecting their family to shame and condemnation in society. Because of the aforementioned cases, there is a greater need for the state to rectify or overturn the wrong done to somebody like this by assisting them with rehabilitating and integrating into society after their release, as well as providing adequate financial compensation to them as well as their family members.

Remedy Accessible Under India's Constitution

In instances of wrongful prosecution of a victim, the Indian Constitution provides the following remedies in the event of a miscarriage of justice. Article 21 [18] of the Indian Constitution guarantees the right to life and personal liberty, and Article 22 [19] gives protection against arbitrary arrest and illegal detention. So, to vindicate such rights, the person aggrieved by the act of wrongful prosecution may approach the High Court or the Supreme Court of India by filing a writ petition under Articles 226 [20] and 32 [21], respectively.

In the case of Bhim Singh, MLA v. State of Jammu & Kashmir and Others [22], the court was unable to determine an adequate compensation mechanism for the innocent. This case is a sheer violation of Articles 21 and 22(2) of the Indian Constitution. An MLA was illegally arrested and detained, and further, he was prevented from joining the session of the legislative assembly, and all this was done by police authorities. The court awarded Rs. 50,000 as compensation to the MLA. Further, the court also held that: “When a person comes to us with the complaint that he has been arrested and imprisoned with malicious or mischievous intent and that his constitutional and legal rights were invaded, the mischief or malice and the invasion may not be washed away by his being set free. In inappropriate cases, we have the jurisdiction to compensate the victim by awarding suitable monetary compensation.” There is a plethora of cases in which courts have taken the view in favor of the victim and awarded adequate compensation to them, such as Khatri v. State of Bihar [23], Boma Chara Oraon v. State of Bihar [24], A Woman’s Resources Center and Others v. Commissioner of Police, Delhi [25].

In all the above cases, the court held the police or the state authorities liable for their negligence. But apart from the above issues, the court has restricted its viewpoint and tried to curb the power to award compensation for violations of the right to life and personal liberty.

In the Sube Singh v. State of Haryana case [26], it was held that monetary compensation shall not be provided in all cases of violation of the “right to life and personal liberty” [18]. The Supreme Court refused to award monetary compensation to the victims because the court was not satisfied with the evidence produced, which was inadequate to prove that the petitioners were illegally detained or were victims of custodial torture and harassment.

The National Judicial Grid (NJDG) shows that 26.55% of the appeals are against convictions that have been pending before high courts for more than ten years. The number of cases is increasing gradually due to a lack of knowledge, awareness, literacy, and proper legal aid being provided to these victims. Since many of these victims are not provided with appropriate legal assistance, they are generally unaware of any alternative remedy available to them for a speedy trial in cases of wrongful prosecution. The years that pass and the toll on the victim’s family cannot be undone by the compensation that is provided to them. The person alone is not the victim here, but also the people whose lives are dependent on them.

As is clear from the above discussion, awarding compensation is solely based on the court’s discretion. But due to this exclusive power of the court, there is still no set or standard framework for providing monetary compensation to victims of wrongful conviction. Even though the law commission recommended various guidelines, not all of its suggestions were implemented. The problem arises because this remedy is to be provided depending on the facts and circumstances of the case, as this remedy is merely declaratory.

Concluding Remarks

India has always kept pace with development in forensic science by transferring and developing technology. With the fast progress of India from a developing to a developed country, there has been a substantial advancement in recent years in the utilisation of advanced forensic science for law enforcement agencies and the criminal justice system. With almost one-fifth of the population involved in crime and an increasing crime rate, India is putting all its efforts into fighting lawlessness, especially those that use advanced science and technology. Currently, India has 120 functional forensic science laboratories with about 5,000 scientific personnel practising to help the country’s law enforcement agencies and criminal justice system. Most of the major forensic science laboratories are equipped with state-of-the-art technology, as good as anywhere in the world.

Unlike in the US and some other countries, a complete toxicological examination is carried out in forensic laboratories in India to assist forensic medicine professionals. The significant laboratories have divisions for chemistry, physics, ballistics, biology, DNA, serology, explosives, narcotics, polygraphy, questioned documents, crime scene management, and cyber forensics. The government is helping the scientists to keep pace with international advancement by providing the appropriate infrastructure and training. As per the statistics provided by the National Crime Record Bureau, in 2021 there were 60, 96,310 cognizable crimes reported in India. Assuming that only 40% of cases have exhibits sent to the forensic science laboratories, the number of referred cases would be 24, 38, 524 with about 12,192,620 exhibits (assuming an average of five exhibits per case). Population-wise as well as case-wise, 120 forensic laboratories are too few to handle the huge workload. The government of India is also considering increasing the number of laboratories, as the present number is too small to cater to the needs of a population of 1.4 billion. The government is aware of the situation and in the coming years it is planning to increase the laboratory network and the recruitment of trained scientists threefold.

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The Role of Forensic Science in Overturning Wrongful Convictions in Taiwan

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While using new science to exonerate individuals in wrongful conviction cases is not a novel concept, the practices of this concept around the world are not necessarily universal and may take different forms depending on local context, such as their own landscapes and judicial, social, cultural, and political structures.

In 1992, Barry Scheck and Peter Neufeld founded the Innocence Project (IP) in New York [1], aiming to use science, especially DNA testing, to exonerate the wrongfully convicted. Since then, hundreds of people in the US have been exonerated through post-conviction DNA testing, analysis, and/or interpretation [2]. Over the past few decades, many were inspired by the IP in the US and started to build their own innocence organizations, including the Taiwan Innocence Project (TIP). Since its foundation in 2012, TIP has successfully exonerated 14 clients by utilizing new scientific findings, methods, and professional opinions [3]. However, when comparing the rescue strategies and the trajectories toward exonerations of TIP, a unique characteristic emerges: there are actually very few DNA exoneration cases in Taiwan; in fact, 13 of the 14 TIP's exonerations are non-DNA cases [4].

Undoubtedly, DNA testing and analysis have become vital to solving crimes and exonerating innocent people in the US. Why, then, does DNA testing not appear to be the most effective strategy when it comes to overturning wrongful convictions in Taiwan? If DNA evidence does not work, what other strategies do? What role does forensic science (and scientists) play in the process of correcting wrongful convictions in Taiwan?

This paper aims to provide insight into the role of science in the innocence movements, with a focus on the context of Taiwan [5]. TIP places emphasis on the following two strategies:

- Seeking new sciences to conduct new tests; and
- Bringing in new experts to review existing evidence.

For each strategy, two cases will be presented as examples to illustrate the roles of new sciences/scientists. Lastly, we will emphasize that factors beyond sciences — e.g., the lack of post-conviction evidence preservation — greatly influence how innocence organizations and the courts perceive the role of sciences in the courtroom.

New Sciences and New Technologies

As mentioned earlier, while the development of DNA tests has become one of the main ways to prove the innocence of the wrongfully convicted in the US, biological evidence is not available in most of TIP's cases. Instead, in the cases of Mr. Huang (黃先生)[a] and Mr. Jin-Guei Lin (林金貴), our primary approach involved the introduction of new technologies that were not available at the time of their convictions. We utilized new scientific tests to generate new evidence.

The Case of Mr. Huang: A Self-Conducted Human Experiment

In 2016, TIP client Mr. Huang, then 21 years old, was arrested for consuming Category 1 narcotics while serving in the army. His urinalysis result was positive for codeine and morphine. Huang disputed the charges. He stated that he had a cold at the time of the urine test and claimed that the result was affected by the prescribed cough syrup he was taking (Liquid Brown Mixture, containing glycyrrhiza extract, opium tincture, and antimony potassium tartrate). However, the court dismissed Huang based on a report from the US National Institute of Drug Abuse (NIDA), stating that if the amount of morphine was more than twice the amount of codeine in one's body, the substance ingested was heroin rather than cough syrup. Huang's morphine/codeine ratio was 6:1.

It is worth noting that the court, while citing scientific literature as a basis, actually misapplied it in different contexts. In the literature cited in the original trial, the subjects were actually directly administered codeine and then tested for the concentration and ratio of codeine and its main metabolite, morphine. This is entirely different from taking the Brown Mixture, which has both morphine and codeine within the opium tincture. Since the composition and fundamentals are different, the experimental data can only be used as a reference and should not be directly cited as a standard for determining drug use. In Taiwan's judicial practice, another frequently cited standard is a 2006 study which selected eight commercially available licorice compound drugs in Taiwan (including tablets and liquids) and tested the levels of morphine and codeine in the subjects' urine [6]. However, in other judgments that cited this domestic study, issues such as taking quotes out of context, incorrect applications, and disputes from the research team about misinterpretation have arisen.

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[a]The first name is not presented to protect the client's identity.

During the legal proceedings, Huang underwent genetic testing at a hospital. The results of the test revealed that Huang had a genetic abnormality (specifically in the genes CYP2C9, CYP2C19, and CYP2D6) affecting his metabolism of codeine. This abnormality led to a faster metabolism of codeine in his body, resulting in a higher production of morphine compared to an average person. Despite this evidence, the court dismissed it, and as a result, Huang was admitted to a rehabilitation institution for a period of 42 days [7].

To prove his innocence, after leaving the institution, Huang signed himself up for a rigorous medical experiment to make a stronger case. He was administered cough syrup under medical supervision for two days. The experiment (conducted by the team of Clinical Toxicology and Occupational Medicine, Taipei Veterans General Hospital) controlled the frequency and the quantity of doses — simulating the scenario during the military service — and documented Huang's urine test results by hour. In essence, the experiment sought to recreate the scenario that led to the urine test and the subsequent report that formed the basis of his wrongful conviction.

One hour after consuming the cough syrup, Huang's urinalysis showed a morphine concentration of 9,690 ng/mL and a codeine concentration of 4,720 ng/mL. The next day, Huang's morphine concentration reached 22,050 ng/mL and his codeine concentration reached 7,910 ng/mL. In a normal context, these levels would strongly imply the use of heroin. At the same time, Huang was negative for 6-acetlymorphine, an exclusive metabolite for heroin, ruling out his possibility of consuming heroin. In summary, due to his genetic abnormality and the specific circumstances of taking the medication, the consumption of cough syrup by Huang led to a urinalysis result that closely resembles that of a heroin user. The results of the experiment strongly affirmed what Huang had steadfastly maintained all along: he was not a heroin user but rather a patient who had been taking the prescribed syrup to alleviate his cold symptoms.

Huang contacted TIP with this convincing new test result, and we immediately filed for a retrial on his behalf. It is with this new evidence that the court granted a retrial, which later led to overruling the prosecutor's petition for Huang's admission to rehabilitation [8,9]. The genetic testing and medical experiment Huang undertook helped clear his name [10].

The Case of Jin-Guei Lin: 3D Facial Recognition Technology

On May 9, 2007, a taxi driver was shot dead in Fengshan County, Kaohsiung. Five months later, the police arrested Jin-Guei Lin and believed he was involved in this incident. The prosecutor relied primarily on the identifications made by the two male witnesses and a confidential teenage witness, as well as the testimony of a masseuse who was not at the crime scene. The masseuse identified Lin from the monitor screen during the investigation by the police. The murder weapon was not found, and the fingerprints in the car were not Lin's. Lin also passed the polygraph test. After being arrested, Lin claimed his innocence and alleged that he had never fired a gun or committed homicide. However, in 2010, the court still found Lin guilty of the murder and sentenced him to life imprisonment [11].

Taking on this case in 2014, TIP started working to find new evidence to reopen the case. One of the key witnesses, the masseuse, only identified Lin from surveillance footage. According to the monitor screen, the suspect's hair was long enough to touch his shoulder; however, Lin's sister found a photo of Lin two months before the incident, which showed Lin had short hair above his ears. With the surveillance footage (shoulder-length hair) and the headshot (hair above the ears), the question then became whether it is possible, scientifically, for one's hair to grow over 14 centimeters within a two-month period. TIP consulted a dermatologist from the Hospital of National Taiwan University (NTU), who provided academic literature indicating that the average speed of hair growth for an adult man is 1.5 centimeters per month. This response was reaffirmed by another dermatologist consulted, with two other specific literature as reference [12]. In other words, it is scientifically unlikely for hair to grow 14 centimeters in two months.

Worrying that the hair evidence might not be strong enough, TIP sought out experts specializing in computer vision and 3D facial recognition. They aimed to leverage this emerging technology to conduct a comparative analysis between the facial features of the individual in the original surveillance footage and those of Jin-Guei Lin, in order to establish the extent to which they might match, and thus ascertain if they belonged to the same person. According to the analysis, after converting the 2D images of the man from the surveillance footage and Jin-Guei Lin's headshot into 3D models and comparing these two models, the result indicated a 68% probability that they did not represent the same person.

In 2016, the defense team filed a motion for a retrial with the newly found headshot photo and the two expert opinions on the hair growth rate and on 3D facial recognition analysis. Finally, on April 18, 2017, the Kaohsiung High Court ruled in favor of a retrial and ordered that Lin be released [13]. He was fully exonerated in January 2023, becoming the first exoneration with a life imprisonment sentence in the history of Taiwan [14].

Conclusion

New technology and methods enabled TIP to present new evidence to the court as grounds to reopen the trial. In both cases, conducting new tests and creating new pieces of evidence helped to reconstruct the facts so that the court could reconsider an innocence claim. Despite the possibility of flaws in forensic examination, its role is crucial in criminal cases as science and technology provide objective insight that forms the grounds for the court to consider whether a defendant is guilty.

Fresh Eyes on Existing Evidence

The extensive body of literature on the fallibility of forensic sciences, as well as the numerous exonerations worldwide, vividly illustrate how human factors such as confirmation bias and tunnel vision can tragically result in the wrongful conviction of innocent individuals [15–17]. In some instances, it is not the limitations of a specific scientific method but rather the seemingly credible opinions, assertions, or conclusions of forensic science experts that led to these wrongful convictions [18–20]. In essence, what is required in these cases is not a more advanced or technically sophisticated scientific breakthrough, but rather a fresh, impartial, and professional perspective to reevaluate the evidence.

In this section, we would like to highlight the second strategy for TIP to exonerate the wrongfully convicted: having the original evidence "reviewed" by new experts. We use the examples of two of our death row exonerations, Mr. Hsing-Tse Cheng (鄭性澤) and Mr. Chih-Hung Hsieh (謝志宏), to illustrate how and when new experts' opinions on existing evidence can bring new insights and paths to difficult cases, particularly for capital cases[b].

The Case of Hsing-Tse Cheng: The Plausible "Two-Stage Shooting Theory"

Hsing-Tse Cheng is not only the sixth exoneree from death row in the history of Taiwanese jurisprudence, but also the first death row inmate to have a prosecutorial motion for retrial initiated on his behalf in Taiwan. The main impetus prompting this unprecedented act was a scientific forensic examination report conducted by the Department of Forensic Medicine at National Taiwan University at the request of the Taichung Branch of the Taiwan High Prosecutors' Office. It is worth noting that the prosecutor who later filed a motion for a retrial admitted that the reason the prosecution was willing to request experts for reexamination was due to their awareness of the strong public concern about Cheng's case and the compelling theory built by the rescue team. In sum, it was civic society that had indirectly prompted the prosecutor's involvement in this case.

The initial gunfight unfolded rapidly within a karaoke room on January 6, 2002, resulting in two injuries (including Cheng) and two fatalities, including the initial gunman and the police officer who first stormed in. Cheng was later convicted of murdering the police officer and was sentenced to death in 2006 [21]. The police tortured Cheng and extracted a false confession; the false confession would later be rejected during the retrial. The main basis for Cheng's conviction was a forensic expert opinion provided at the time. After examining the positions and angles of the gunshot wounds and the fact that only one gun was fired, the forensic expert asserted that the shooter must have opened fire from "two different spots". Although this "two-stage shooting theory" did not align with the location of the gun or the shell casings and bullets found at the scene, it was embraced by the courts until March 2016, when the new scientific forensic report was released. The report was produced by a team led by the Forensic Medicine Department of NTU. It is worth noting that the building of the original crime scene had long since been demolished, so NTU's team primarily relied on the photos, videos, reports, data, measurements, and records derived from the collected physical evidence at the time. The team reconstructed the crime scene based on the available data, reevaluated the gunshot wounds, the ballistic trajectories, the gunpowder residue analysis, and introduced new academic literature on the Glock pistol's casing ejection pattern [22], refuting the original plausible assumption that casings never eject "to the left side of the shooter". In conclusion, they determined that all the gunshot wounds on the victim were the result of a single gun fired from the same location, thus completely debunking the previous "two-stage shooting theory".

This new scientific opinion not only significantly bolstered the arguments put forth by the defense team, but it also compelled the prosecutor to file a motion for a retrial on Cheng's behalf in March 2016. The Taichung High Court granted the motion on May 3, 2016 and decided to release Cheng from the Taichung Detention Center, where he had awaited execution for 14 years [23].

The new conclusions presented by the NTU team did not enter the court without challenges. During the trial, the prosecution also called upon another firearm forensic expert from the Department of Forensic Science, Central Police University, to testify and provide insights into the gunshot wounds, bloodstains, and bullet trajectory in order to confirm the possible shooter's position. While this expert's opinion on the shooter's likely location did not

[b]Except for a brief three-year suspension (2006–2009), Taiwan is a country with capital sentences and is still executing people. The most recent execution took place in 2020.

align entirely with the NTU's, both experts did concur that the gunshot wounds on the victim were the result of the same person using the same firearm to fire consecutive shots. Cheng was acquitted on October 26, 2017 [24].

The Case of Chih-Hung Hsieh: The Arbitrary "Blood Groove Assumption"

Following Cheng's exoneration in 2017, Mr. Chih-Hung Hsieh became Taiwan's seventh exoneree from death row and the second case where a prosecutor filed a motion for retrial on behalf of a death row inmate. Similar to Cheng's case, the prosecutorial intervention of Hsieh's case did not appear out of thin air. The prosecutor who filed the motion for a retrial was assigned to the case after the Control Yuan (the highest ombudsman in the country that exercises the powers of impeachment, censure, and audits) issued an investigatory report in 2018 upon TIP's petition explicitly suggesting that the prosecutor's office act [25]. The prosecutor put in charge then discovered evidence hidden by the police during his investigation. Among all the new evidence to support the necessity to reopen Hsieh's case, one piece of evidence presented by TIP is particularly worth noting here: the new expert opinion regarding the murder weapon issued by the Institute of Forensic Medicine (IFM), Ministry of Justice.

The case involved a double homicide that took place on June 24, 2000. Hsieh was convicted of murdering the two victims along with another man, Mr. Chun-Wei Kuo. The court asserted that they had jointly committed the murders, taking turns using the single murder weapon, a butterfly knife. The main basis of this assertion originated from a tenuous assumption regarding the design of the so-called "blood groove". A blood groove, or a "fuller", is a rounded or beveled longitudinal slot along the flat side of a blade. While the design is usually described as merely a decoration or at most serves to lighten and stiffen the blade, the court insisted that it serves as a strength-saving design; the absence of this design would make deep stabbing the female victim 11 times a too-tiring task for one person to execute alone. The court found that Hsieh was part of the double homicide and sentenced to death alongside Kuo. His conviction and his capital punishment became finalized in 2011 [26].

Besides the false confession Hsieh gave to the police and the testimony of Kuo against him, this "blood groove assumption" was considered the strongest "scientific-ish" inculpatory opinion of Hsieh. However, the whole assumption, either of the effort-saving function of the blood groove, or of the "too tiring for one man" task, had no scientific basis. It thus became the defense team's challenge to argue against a scientific myth.

During the review process of the case, TIP found an article online that aims to debunk the myth of the effort-saving effect of blood grooves [27]. Though not strong and solid enough, TIP included it in the list of new evidence for the motion for a retrial filed in 2018. The Tainan High Court decided to ask the opinion of new experts on this matter from the IFM, who responded explicitly that "the design purpose of the grooves is typically to reduce the weight of the blade without compromising its strength. However, there is currently no available literature or research regarding whether these grooves on a blade would affect the force required to insert and withdraw the blade from a body."

Once the blood groove assumption was debunked, Hsieh's involvement in the double homicide could not be assumed. With other compelling new evidence of the case at hand, especially the new evidence discovered by the prosecutor, the Tainan High Court granted the motion for retrial on March 19, 2019, freeing Hsieh from the Tainan Detention Center after 19 years of unjust imprisonment [28]. With both the defense and the prosecution claiming his innocence, Hsieh was acquitted on May 15, 2020 [29].

Conclusion

As shown in the above two death penalty cases, TIP adopted a different strategy in terms of using forensic sciences to exonerate wrongfully convicted people. Instead of conducting a new test or using high-end technology — which implies that the original opinion was not "wrong" but was "just not advanced enough" — the second strategy is to have new experts review the seemingly plausible or sometimes arbitrary opinions that supported the conviction. This is a strategy especially suitable in cases that were built upon erroneous assumptions. Take the blood groove as an example; the whole assumption essentially appeared out of thin air, leaving nothing to be subjected to a "new test".

However, it can be easily imagined that this strategy, which directly challenges the previous expert opinions or courts' assumptions, may lead to higher levels of conflict compared to the first strategy. Consequently, it is not an easy approach to implement. Forensic experts themselves are not always fond of challenging and reviewing their peers publicly. In addition, courts, contrary to general impressions, do not always appreciate new experts' opinions, since getting contradictory scientific opinions can only further complicate the already messy facts. In fact, literature has documented how the reluctance of courts to entertain "bigger and better experts" can be a danger for the parties seeking new trials [30]. With this "danger" looming, it appears to be somewhat irrational for the defense team to employ an oppositional approach, as opposed to seeking newer and more advanced technologies to retest or to obtain new test results. The explanation for this seeming irrationality is related to the absence of post-conviction preservation regulation in Taiwan.

Bricks Without Straw: Lacking Post-Conviction Evidence Preservation in Taiwan and Its Impacts

Currently, there is no law on evidence preservation after conviction in Taiwan. Since most of the evidence in Taiwan shall be processed "in a timely manner" after conviction under the existing regulations [31], conducting new tests on existing evidence collected from the crime scene or even samples is often not feasible at all [32]. This is even true in DNA-related cases. Inspired by the post-conviction DNA testing statutes in the US, TIP successfully lobbied the legislature to pass Taiwan's version of such a law in 2016 [33]. But without the proper regulation on evidence preservation, based on the review five years after the act was enacted, no person has had his or her conviction overturned [34]. In other words, obtaining exculpatory results via retesting is like making bricks without straw. Consequently, incorporating new experts to review (not to retest) and form new opinions sometimes is the "only possible" way to generate new evidence.

While it is obvious that there is an urgent need to reform and advocate for post-conviction evidence preservation regulation in Taiwan, it is also important to recognize that it takes more than the advance of techno-sciences per se to exonerate the wrongfully convicted. Factors beyond sciences should also be taken into account [35,36].

The lack of post-conviction evidence preservation regulation has created a systemic barrier for the innocence movement in Taiwan. On one hand, it explains why there are still very few DNA exoneration cases in Taiwan, despite the fact that DNA has emerged as a powerful tool to overturn wrongful convictions since the 1990s. On the other hand, it has become a unique factor shaping the landscape of the innocence movement in Taiwan.

Concluding Remarks

In a system where focusing solely on DNA cases and prioritizing post-conviction DNA testing does not offer the best chance of success, seeking new sciences to conduct new tests and having new experts review previous statements have instead become the most effective and distinctive strategies to overturn wrongful convictions in Taiwan. This finding indeed reminds us that the tendency to consider new scientific advancements to be the only way to exonerate might prompt people to seek only "newer and more advanced" technologies, thus neglecting the effectiveness of examining the plausible, the untested, or the invalid "scientific" statements that serve to support wrongful convictions from the beginning.

By exploring how and why TIP adopts certain strategies under certain institutional constraints, this paper emphasizes the importance of taking local context into account, even for sciences that appear to be neutral, objective, and universal. As this paper reveals, though the general notion of exonerating innocent people with sciences seems universal, innocence movements in different countries could develop diverse practices and strategies to utilize, interpret, or invalidate sciences in the courtrooms based on their own landscapes and judicial, social, cultural, and political structures. The experience in Taiwan suggests furthermore that the tendency to regard new scientific advancements as the exclusive or primary strategy to correct wrongful convictions might prompt people to neglect pursuing practices that invalidate "scientific" statements underpinning wrongful convictions. Both strategies have proven effective in TIP's work in Taiwan.

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Upcoming Events

Medical Device Registration — Strategies to Place Your Devices in the EU, UK, and US (*https://bio-academy.co/courses/medical-device-registration/*)

Jan. 16, 2024; Online Training Course
rosemarle@bio-academy.co

American Academy of Forensic Sciences — 76th Annual Meeting (*https://www.aafs.org/*)

Feb. 19–24, 2024; Colorado Convention Center
Denver, CO, US

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

Feb. 24–28, 2024; San Diego Convention Center
San Diego, CA, US

ACS Spring National Meeting & Exposition 2024
(*https://www.showsbee.com/fairs/14149-ACS-National-Meeting-Exposition-2004.html*)

Mar. 17–21, 2024; Ernest N. Morial Convention Center
New Orleans, LA, US

2024 ACMT Annual Scientific Meeting & Symposia
(*https://www.acmt.net/annualmeeting/*)

April 10–14, 2024; Omni Shoreham Hotel
Washington, DC, US

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

April 15–19, 2024; Los Angeles Police Department
Los Angeles, CA, US

IFDAT 2024 — International Forum for Drug & Alcohol Testing
(*https://ifdat.com/*)

April 17–19, 2024; Tampa Convention Centre
Tampa, FL, US

International Association of Chemical Testing — 2024 Annual Conference
(*http://iactonline.org/*)

April 21–26, 2024;
La Jolla, CA, US

Southern Association of Forensic Scientists — 2024 Annual Meeting
(*https://safs1966.org/annual-meeting/*)

April 23–26, 2024; The Chattanoogan Hotel, a Hilton Hotel
Chattanooga, TN, US

American Society of Forensic Laboratory Directors — 51st Annual Symposium
(*https://www.ascld.org/ascld-annual-symposium/*)

April 28–May 2, 2024; Sheraton Birmingham Hotel
Birmingham, AL, US

American Psychiatric Association 2024 Annual Meeting
(*https://www.psychiatry.org/psychiatrists/meetings/annual-meeting*)

May 4–8, 2024;
New York, NY, US

Mid-Atlantic Association of Forensic Scientists — 2024 Annual Meeting
(*https://www.maafs.org/annual-meeting*)

May 6–10, 2024; Sheraton Station Square
Pittsburgh, PA, US

The Association of Firearm and Tool Mark Examiners — 55th Annual Training Seminar
(*https://afte.org/meetings/annual-seminars*)

May 26–31, 2024; Hilton Downtown Anchorage
Anchorage, AK, US

72nd ASMS Conference on Mass Spectrometry and Allied Topics
(*https://asms.org/conferences/annual-conference*)

June 2–6, 2024; Anaheim Convention Center
Anaheim, CA, US

15th European Network of Forensic Handwriting Experts Conference
(*https://enfsi.eu/agenda/15th-enfhex-conference-in-stockholm-save-the-date/*)

June 17–20, 2023; Langholmen Hotel
Stockholm, Sweden

Forensics Europe Expo
(*https://forensicseuropeexpo.com*)

June 19–20, 2024; ExCeL Exhibition Centre
London, UK

ADLM (Association for Diagnostics & Laboratory Medicine) 2024
(*https://meeting.aacc.org/about*)

July 28–Aug. 1, 2024; McCormick Place Convention Center
Chicago, IL, US

APA Annual Convention 2024 — American Psychological Association
(*https://convention.apa.org/*)

Aug. 8–11, 2024; TBA[a]
Seattle, WA, US

International Association for Identification — 108th Educational Conference
(*https://theiai.org/conference.php*)

Aug. 11–17, 2024; Peppermill Resort
Reno, NV, US

IACP Impaired Driving & Traffic Safety Conference
(*https://www.theiacp.org/IDTSconference*)

Aug. 16–18, 2024; TBA[a]
Washington, DC, US

ACS Fall National Meeting & Exposition 2024
(*https://www.acs.org/meeting/acs-meetings/future-meeting.html*)
Aug. 18–22, 2024; Colorado Convention Center
Denver, CO, US

American Society of Questioned Document Examiners 82nd Annual Conference
(*https://asqde.org*)
Aug. 26–28, 2024; Grand Hyatt Atlanta
Atlanta, GA, US

International Association of Forensic Nurses Conference 2024
(*https://www.forensicnurses.org/page/IAFN/*)
Aug. 27–29, 2024; TBA[a]
Denver, CO, US

TIAFT 61st Annual Meeting of the International Association of Forensic Toxicologists
(*https://www.tiaft.org/tiaft-annual-meeting.html*)
Sept. 2–6, 2024; Congress Centre
St. Gallen, Switzerland

58th Congress of the European Societies of Toxicology
(*https://www.eurotox2024.com/*)
Sept. 8–11, 2024; The Tivoli Congress Center
Copenhagen, Denmark

Midwestern Association of Forensic Scientists — 2023 Annual Meeting
(*https://mafs.net/page-18404*)
Sept. 8–13, 2024; InterContinental Kansas City at the Plaza
Kansas City, MO, US

International Congress of Therapeutical Drug Monitoring and Clinical Toxicology 2024 Congress
(*https://www.iatdmct.org/events/iatdmct-congress.html*)
Sept. 15–18, 2024; Centre for Arts and Creativity
Banff, Alberta, Canada

National Association of Medical Examiners
(*https://name.memberclicks.net/annual-meetings*)
Sept. 19–23, 2024; Hyatt Regency Denver at Colorado Convention Center
Denver, CO, US

Toxi2024 — 3rd Global Summit on Toxicology and Applied Pharmacology
(*https://www.thescientistt.com/2024/toxicology*)
Sept. 23–25, 2024; TBA[a]
Dubai, UAE

ISHI 35: International Symposium on Human Identification
(*https://www.ishinews.com/upcoming-meeting-locations/*)
Sept. 23–26, 2024; JW Marriott Hill County
San Antonio, TX, US

International Association of Chiefs of Police 2024
(*https://www.theiacpconference.org/*)
Oct. 19–22, 2024; Boston Convention & Exhibition Center
Boston, MA, US

SCIX 2024 — Annual Meeting of the Federation of Analytical Chemistry and Spectroscopy Societies
(*https://scixconference.org*)
Oct. 20–25, 2024; Raleigh Conference Center
Raleigh, NC, US

Northeastern Association of Forensic Scientists — Annual Conference
(*https://www.neafs.org/additional-annual-meetings*)
Oct. 21–25, 2024; Mystic Marriott
Atlantic City, NJ, US

Society of Forensic Toxicologists — Annual Meeting
(*https://soft-tox.org/soft-2024*)
Oct. 27–Nov. 2, 2024; Union Station
St. Louis, MO, US

Northwest Association of Forensic Scientists — 2023 Annual Conference
(*http://nwafs.org/wordpress/fall-meeting/*)
Sept. TBA[a], 2024; TBA[a]
TBA[a], US

Southwestern Association of Forensic Scientists — 45th Annual Conference (*http://swafs.us/*)
Oct. 6–10, 2024; Double Tree by Hilton
Little Rock, AR, US

American Academy of Forensic Sciences — 77th Annual Meeting (*https://www.aafs.org/*)
Feb. 17–22, 2025; Baltimore Convention Center
Baltimore, MD, US

[a]TBA: To be announced.

ADVANCING THE PRACTICE OF FORENSIC SCIENCE IN THE US

Navigating Common Nonconformities in Forensic Testing and Inspection Accreditation

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The International Organization for Standardization (ISO) has been responsible for developing and publishing international standards for conformity assessment bodies (CABs), including ISO/IEC 17025 for testing laboratories and ISO/IEC 17020 for inspection bodies.

Each standard details requirements for the organizational structure, process, and management system of the CAB and promotes confidence in the results provided by these organizations by requiring CABs to demonstrate competency and consistency in the activities being performed. The processes that are developed are intended to interact and build upon one another to promote a more efficient, competent conformity assessment organization. Many such organizations seek independent confirmation of compliance with these standards by working with third-party organizations, known as accreditation bodies (ABs). ABs evaluate the laboratories and inspection bodies by assessing each organization's management system activities, technical resources, and technical competence against the standardized criteria published in ISO/IEC 17025 and ISO/IEC 17020. Assessments are completed through a combination of real-time observation, interviews with staff, and reviews of documentation and records. These assessments also cover any additional requirements the CAB is expected to meet, such as contractual requirements with customers or government agencies.

As with many quality assurance standards, ISO/IEC 17025 and ISO/IEC 17020 encourage and contribute to a preventative, risk-based mindset. Both standards require CABs to enact policies and procedures intended to help mitigate risks commonly faced by laboratories and inspection bodies. The international standards do the heavy lifting of mitigating high-risk areas by requiring procedures for these areas; however, the rest is left up to the CAB to determine the measures they will take in order to maintain conformity.

Common Nonconformities

A nonconformity is defined as any deviation from a requirement; in other words, instances where a policy or process is not followed or properly implemented [1]. ISO/IEC 17025 is made up of 8 sections with 28 auditable subsections [2], whereas ISO/IEC 17020 is made up of 8 sections with 20 auditable subsections [3]. Each section contains clauses describing requirements and criteria for topics ranging from organizational impartiality to measurement traceability and proficiency testing.

An analysis was completed by A2LA on nonconformities cited during assessments of forensic CABs carried out between July 1, 2021 and June 30, 2023. For simplicity, the following nonconformities are grouped based on their respective sections. For the ISO/IEC 17025 standard, 221 nonconformities were cited across 24 assessments. For ISO/IEC 17020 assessments, there were 60 nonconformities cited across 9 assessments. The most frequently cited nonconformities are identified and addressed (*see* **Table 1** and **Table 2**) within this review.

Table 1. Top areas cited for ISO/IEC 17025 assessments of forensic CABs over a two-year (July 1, 2021 to June 30, 2023) period

Section	No. of instances	Percentage of total (%)
Management Reviews	41	19
Equipment	25	11
Nonconforming Work	22	10
Reports	18	8
Document Control	15	7
Personnel	15	7
Corrective Actions	14	6
Technical Records	14	6
Suppliers/Service Providers	13	6
Internal Audit	9	4
Other	36	16
Total	**221**	**100%**

Table 2. Top areas cited for ISO/IEC 17020 assessments of forensic CABs over a two-year (July 1, 2021 to June 30, 2023) period

Section	No. of instances	Percentage of total (%)
Equipment	13	22
Personnel	10	17
Preventative Actions	8	13
Document Control	7	12
Corrective Actions	6	10
Management Reviews	5	8
Internal Audits	4	7
Reports	2	3
Complaints	2	3
Other	3	5
Total	**60**	**100%**

Management Reviews. For the purposes of continual improvement, both testing and inspection forensic CABs are required to conduct management reviews per the requirements of ISO/IEC 17025 and ISO/IEC 17020, respectively. Management reviews are comprehensive, covering each facet of a CAB's management system and technical activities. Both standards list required inputs and outputs that must be examined and discussed as part of the management review process. Flexibility is given to CABs to add additional discussion topics that may be relevant to their management system. Inputs cover areas such as feedback from customers, changes in volume of work, management system changes, adequacy of resources, and results of audits. The outputs of the management review are actions or decisions that are intended to improve their overall management system and meet organizational objectives.

As part of this analysis, it was noted that CABs were typically cited for missing inputs or outputs related to the management review, or for not completing the review according to their own schedule. It is not uncommon for CABs to overcomplicate the management review process by going beyond the standard requirements or by requiring their management review to be performed as often as every quarter or each month. Successful CABs keep the process simple and perform management reviews once a year. To avoid missed inputs or outputs, CABs often adopt a specific template or format for recording management review inputs and outputs that assures all elements are included in the activity. In addition, they take detailed minutes during these discussions that are utilized to improve their overall processes within their organization.

Equipment. ISO/IEC 17025 and ISO/IEC 17020 both contain requirements for any instruments, materials, or software used in the measurement and data acquisition process. Forensic CABs are typically cited for either not utilizing calibrated equipment or lacking sufficient records related to their equipment, such as software and firmware versions or the period of validity. In addition, many organizations make the mistake of assuming that requirements for measurement traceability, validation, and asset records only apply to measurement instruments, making this section another frequently cited area of both standards. This may also involve issues like the handling and storage of instruments and materials, facilities requirements, and ongoing maintenance of test equipment. Such failures often necessitate costly nonconforming work investigations that raise serious concerns regarding the validity of results reported.

To avoid these potential nonconformities, best practice would be to maintain equipment records through a master list. Typically, these are maintained on a spreadsheet, where the rows document required information such as calibration dates and due dates, storage locations, firmware and software versions, and identification. By doing so, the record requirements of the standards are met, and the equipment's period of validity can be tracked.

Personnel. Personnel competency is a key pillar for demonstrating the validity of an organization's results. Each standard requires CABs to define the competency requirements of any position related to their activities. The competency requirements cover education, training, technical knowledge, skills, experience, and qualifications (ISO/IEC 17025 only). In addition, the CAB shall maintain procedures and records for the selection, supervising (ISO/IEC 17025 only), training, authorization, and monitoring of personnel.

Throughout this review, it will become evident that a robust training program is crucial to the success of a CAB. By prioritizing the competency of personnel, it will lead to fewer oversights regarding the different processes in place. Fewer oversights lead to less nonconforming work investigations, corrective actions, complaints, and so on. It is also recommended that the training program is frequently included in the agenda of the internal audits performed, as opportunities for improvements or gaps in competencies can be identified. Finally, CABs may want to consider including their respective standard requirements within their training program. By increasing personnel's understanding, diligent attention will be paid to the activities being performed as they will better understand the intent behind the processes in place.

Document Control. Managing internal and external documentation is crucial for both testing and inspection CABs. The intent of document control is to ensure that all documents used by the organization are reviewed and authorized by appropriate staff, and that documents are centrally located where personnel have access to the latest version of each document. One notable difference between the standards is that ISO/IEC 17020 requires CABs to maintain a document control procedure, while ISO/IEC 17025 does not. Nevertheless, both standards have similar requirements for document control, such as control of both internal and external documents, approval of documents before publication, periodic reviews of documents, maintenance of a revision status, and prevention of the unintended use of obsolete documents.

The nonconformities reviewed as part of this analysis suggest that document control errors are distributed evenly across document control requirements. Forensic CABs that are successful in maintaining their document control process tend to incorporate it into their management review and internal audits. Other organizations may utilize dedicated software for quality management systems. These software providers are familiar with the requirements of ISO/IEC 17025 and ISO/IEC 17020 and set up the platform to allow for easy monitoring. By maintaining an effective document control process, forensic CABs will mitigate the risk of having inconsistent implementation of processes, such as use of obsolete procedures, test data sheets, and report templates which may lead to costly errors and the need for repeated testing.

Corrective Actions. When a CAB encounters a nonconformity, both ISO/IEC 17025 and ISO/IEC 17020 require them to initiate their corrective action process. Both standards are similar in the requirements for performing corrective actions; however, inspection bodies are required to maintain a procedure whereas laboratories are simply required to carry out corrective actions according to standard requirements. The corrective action process begins by determining the cause(s) of a nonconformity or what we have referred to as "root cause analysis." Once the causes are identified, remedial actions are taken as necessary to address the issue and prevent similar issues from recurring in the future. Once the actions are taken, CABs are also required to review their corrective action's effectiveness and verify that the actions were appropriate for preventing recurrence of the original nonconformity. Assuming the corrective action was successful in preventing recurrence, the issue can be considered closed.

The forensic CABs cited for this area either lack a procedure (ISO/IEC 17020 only), or were found to be missing information within the corrective action records (e.g., missing root cause analysis or verification plan). CABs can avoid these oversights by using a documented template or workflow for their corrective actions that includes each step of the corrective action process as included in the standards. A predefined corrective action format may have an area to document the cause analysis, the actions to be taken, when the actions were performed, and the results of the effectiveness review.

In addition, many CABs overlook the effectiveness review component of corrective actions since this verification is intended to be performed later as a means of testing the success of the corrective action plan. To counteract this, CABs should implement mechanisms that remind them to review the effectiveness of their corrective actions at a later date. These same mechanisms can also include criteria for confirming the effectiveness of a corrective action and recording what was observed to determine that a corrective action was indeed effective. It is not uncommon for organizations to perform effectiveness verification as part of their management review activities. Both standards allow CABs to determine what implementation best suits them.

Lastly, consideration of risks and opportunities should be taken when performing a corrective action. Risks and opportunities are two sides of the same coin; where there is a risk, there is an opportunity, and vice versa. When a nonconformance occurs, considering the two sides will result in a more robust approach to the corrective action plan. For example, a CAB receives a nonconformance for not preventing the use of an obsolete test report template. A risk from this situation would be that a report would be released with missing information, which could potentially lead to a complaint. An opportunity would be to identify other documents that may be obsolete and remove them before personnel use them. Through this mindset, the CAB is not only focused on the specific issue that occurred, but taking a systematic approach to ensure all facets are covered.

Nonconforming Work. The requirement for initiating a nonconforming work investigation is exclusive to ISO/IEC 17025. For instances where the CAB does not conform to standard criteria or other relevant requirements (e.g., internal processes, customer-stated criteria), the CAB shall initiate a nonconforming work process that investigates the circumstances surrounding and leading up to the nonconformity and understanding the degree to which the nonconformity may or may not have affected the validity of previous test results. If the investigation finds that results were affected, the CAB shall act accordingly and perform actions such as notifying their customers and recalling work.

Forensic CABs are typically cited for not conducting nonconforming work investigations or lacking records showing that they followed their process when nonconforming incidents occur. Surprisingly, many organizations respond by claiming not to understand the significance of nonconforming work criteria or the purpose it is intended to play in day-to-day lab activities. For example, if a forensic laboratory sends a piece of equipment out for calibration and its report comes back indicating that the device was found out of tolerance, concerns should be raised about the validity of results provided to customers in the period since the equipment was last checked. If the lab chooses not to conduct a nonconforming work investigation and continues working as normal, the impact could lead to major oversights and measurement error. In the forensic world, this may result in significant consequences to individuals and cases such as wrongful convictions.

This leads to further discussion about performing a corrective action as a result of the nonconforming work investigation, something an accredited forensic lab is required to consider. For the example described above, they must consider what may have led to the equipment going out of tolerance, such as misuse, damage, or out-of-spec environmental conditions. One mitigation may include increasing the frequency of intermediate checks for their equipment to more closely monitor possible degradation. By doing so, the lab may successfully decrease the risk of having to recall previous results and results in the future.

Reports. The report section has the longest set of requirements in ISO/IEC 17025. It covers general requirements for reporting, in addition to requirements specific for testing, calibration, sampling, statements of conformity, opinions, and interpretations, and also covers requirements for amending reports. Due to the extent of the requirements, the likelihood of a nonconformity occurring evidently increases. Forensic testing CABs tend to mitigate this by utilizing templates that cover all the requirements laid out by ISO/IEC 17025; however, issues with staff training can still lead to findings in this area. ISO/IEC 17020 has a much shorter section for reporting, but the general criteria is similar to its counterpart.

The majority of nonconformities cited for reports involve missing information. From the perspective of a forensic CAB, this can be damaging. The incomplete information provided to the customer could result in accusations regarding the integrity of the chain of custody or inaccurate results. While the standard does give flexibility as to what a report shall contain, the omission of elements required by the standards shall be agreed upon with the customer prior to release of the report.

The easiest way to maintain compliance with each standards report requirement is to utilize report templates. Required fields can be implemented to prevent information from being missed. In addition, CABs can include and emphasize the report criteria in staff training programs and monitoring activities.

Internal Audit. Internal audits are one of the most effective ways by which a CAB can confirm its compliance with standard requirements and other relevant criteria. An internal audit's purpose is to review the requirements that apply to an organization's activities and verify that the work performed meets all specified criteria. ISO/IEC 17025 and ISO/IEC 17020 both require CABs to perform internal audits against relevant normative criteria. This involves both a review of policies and procedures as well as an investigation into the methodologies of the actual conformity assessment activities being performed. CABs have some flexibility in developing their internal audit plans and deciding which areas or activities to emphasize during the audit process; however, the audit plan needs to be justifiable and appropriate to the needs and activities of the organization. ISO/IEC 17025 also allows test labs to determine the frequency of their internal audits, whereas ISO/IEC 17020 requires that internal audits be conducted within a 12-month period.

For forensic testing and inspection CABs, we most often see organizations cited for deficiencies for not completing internal audits according to the schedule specified in their own procedures. In other cases, deficiencies may be cited for underdeveloped audit plans or for overlooking required audit elements without sound justification. When developing the audit plan, consideration shall be taken regarding the CAB's activities, any changes to the organization, and results of previous audits. In other words, CABs should be considering areas such as any new equipment, corrective actions performed, management review outputs, and complaints received.

Having a rigorous internal program can help prevent future complaints, raise awareness about nonconforming work investigations, and strengthen support processes such as supplier verification, report writing, and records retention. Since internal audits have the intent of confirming compliance, they are great tools to ensure CABs are finding issues before their customers do. For example, having a rigorous internal audit program may prevent future complaints, nonconforming work investigations, and corrective actions. As such, it is important to take internal audits seriously, as opposed to checking off a list.

Technical Records. In comparison to reports, the technical records section is one of the shortest sections in ISO/IEC 17025, making up two clauses. The first clause requires technical records to contain information sufficient for allowing the activity to be replicated as well as identifying any factors contributing to the uncertainty of the measurements taken. The second clause requires the date the test was performed and the identity of the personnel responsible for performing the testing, as well as the personnel responsible for reviewing the data and results.

For forensic CABs, findings typically involve incomplete test data or other missing information that must be documented per the test method. Many CABs consider these errors to be simple oversights or due to insufficient awareness. Considering the ramifications of forensic testing and inspection activities, record integrity is crucial specifically as it relates to chain of custody for test and inspection samples. Failure to observe proper protocols for technical records may result in challenges to the chain of custody and invalidation of test results.

It is important that forensic testing laboratories have the foresight to prevent oversight and lack of understanding when it comes to the requirements of technical records. Forensic labs can overcome such errors through initial and ongoing training activities that emphasize record integrity, peer check processes, and staff awareness of document control principles.

Although not a common nonconformity area, ISO/IEC 17020 has a similar section called Inspection Records. The concept and importance mirrors ISO/IEC 17025.

External Suppliers and Service Providers. The procurement of resources and outsourcing of activities is covered under a single section in ISO/IEC 17025. The section requires both procedures and records for developing the criteria for the products and services and how they evaluate, select, and monitor their suppliers and service providers. If the evaluation or monitoring activities present issues regarding the supplier or service provider, the CAB shall take action following a procedure. When a product or service is provided, CABs shall also verify that the product or service meets their pre-defined criteria.

It is important to note that ISO/IEC 17025 requires these items because it is the CAB's responsibility to ensure that products and services provided are meeting the requirements of the standard. For example, a CAB may be cited for not having the correct calibration for their measuring instrument. The CAB may direct blame to the calibration laboratory for not providing the correct information; however, it is still the responsibility of the CAB to do their due diligence to confirm that their calibration met their acceptance criteria. As such, it is crucial that the criteria for the product or service are communicated effectively, e.g., through a purchase order, and that there is a process in place to check the product and service against acceptance criteria once received.

For forensic inspection CABs, this is not a common nonconformance; however, ISO/IEC 17020 does touch upon external suppliers and service providers. As such, the information noted above can be applicable to inspection agencies.

Preventative Actions. A precursor to the risk-based approach, preventative actions were a staple in the ISO/IEC 17000 series of standards. It should be mentioned that with recent updates to these standards, the preventative actions requirement has been made obsolete; however, the current version of ISO/IEC 17020 still references and requires a preventive action process. Preventive actions act in the same manner as corrective actions; however, they are intended to proactively intervene and prevent nonconformities from occurring rather than responding to them after a nonconforming event has occurred. The standard requires CABs to maintain procedures on how they will identify potential nonconformities handled via preventive action processes, as well as what actions shall be taken and how they will be documented.

When reviewing the audit records, it was found that forensic inspection CABs are typically cited for not having implemented a preventive action process at the time of the assessment. This is often the case for all types of CABs regardless of field or discipline. Many organizations have difficulty with maintaining a preventive organizational culture and having more bandwidth to take action to resolve known problems as opposed to potential nonconformities. With the pending revision of ISO/IEC 17020, the preventative actions requirement will be eliminated; nevertheless, a preventive mindset will remain in the form of increased awareness of risks and opportunities particularly as they concern changes to organizations, methods, and resources.

Complaints. A complaint is defined as an expression of dissatisfaction by any person or organization to a CAB, relating to the activities or results of that CAB, where a response is expected from the CAB [1]. Both ISO/IEC 17025 and ISO/IEC 17020 require a documented process for handling complaints and stipulate the actions a CAB must take throughout the complaint handling process. For instance, upon receipt of a complaint, the CAB must first determine whether the complaint is valid and related to the specific conformity assessment activities of the CAB. If valid, the CAB is then required to acknowledge the complaint and resolve it by taking "appropriate action." Once resolved, the complainant is notified of the outcome of the investigation, where possible.

Due to the nature of their work, forensic CABs may experience more complaints as compared to other industries. Records reviewed during assessments suggest that many complaints involve slow turnaround times and customer service issues, but many also describe allegations of inaccurate or incompetent testing. Depending on the severity of the complaint, it can cause damage to an organization's reputation.

Many organizations benefit from a detailed complaint handling process that familiarizes their staff with the types of complaints a forensic organization may be more likely to receive. In turn, mitigation plans can be implemented to reduce these risks and internal audit activities can be conducted to identify the sorts of inefficiencies or oversights most likely to lead to such feedback. Depending on the complaint received, a CAB may also need to initiate a nonconforming work investigation or implement a corrective action in order to adequately resolve the complaint. CABs should use this opportunity to determine areas of improvement within their processes to prevent recurrence.

Conclusion

ISO/IEC 17025 and ISO/IEC 17020 act as great tools for managing the risks inherent in testing and inspections and ensuring that the reported results provided are both repeatable and trustworthy. By being proactive and forward-thinking, forensic organizations can prevent issues before they arise, and make consistent improvements to their processes. It is critical to remember that the standards and their requirements are intended to work systemically and in unison, such that the cumulative effect of their processes and mechanisms reduce risk to manageable levels. Both standards offer a roadmap to forensic organizations for managing risk, demonstrating competency, and assuring repeatable results.

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NEW BOOKS AND BOOK REVIEW

New Forensic Science Books

Advancements in Cybercrime Investigation and Digital Forensics
A. Harisha, A. Mishra, C. Singh
CRC Press: Boca Raton, FL, US; Oct. 2023

Animal Abuse and Interpersonal Violence: A Psycho-Criminological Understanding
H. C. (Oliver) Chan, R. W. Y. Wong, Eds
John Wiley and Sons: Hoboken, NJ, US; Sept. 2023

The Art of Investigation Revisited: Practical Tips from the Experts
C. A. Binns, B. Sackman, Eds
CRC Press: Boca Raton, FL, US; Sept. 2023

Artificial Intelligence (AI) in Forensic Science
Z. Geradts, K. Franke, Eds
John Wiley and Sons: Hoboken, NJ, US; Aug. 2023

A Blueprint for Implementing Best Practice Procedures in a Digital Forensic Laboratory, 2nd ed
D. L. Watson, A. Jones
Elsevier (Academic Press): San Diego, CA, US; July 2023

Burnt Human Remains: Recovery, Analysis, and Interpretation
S. Ellingham, J. Adserias-Garriga, S. C. Zapico, D. H. Ubelaker, Eds
John Wiley and Sons: Hoboken, NJ, US; May 2023

Chemical Analysis for Forensic Evidence
A. van Asten
Elsevier: London, UK; Nov. 2022

A Companion to Biological Anthropology, 2nd ed
C. S. Larsen, Ed
John Wiley and Sons: Hoboken, NJ, US; March 2023

Criminal Psychology: Forensic Examination Protocols
B. E. Turvey, A. C. Mares
Elsevier (Academic Press): San Diego, CA, US; June 2022

Forensic Law Casebook: Judicial Reasoning and the Application of Forensic Science in Criminal Cases
C. P. Nemeth
CRC Press: Boca Raton, FL, US; Dec. 2023

Modern Forensic Tools and Devices: Trends in Crime Investigation
D. Rawtani, C. M. Hussain, Eds
Wiley (Scrivener Publishing): Beverly, MA; May 2023

Investigating Animal Abuse Crime Scenes: A Field Guide
V. M. Maxwell, M. Smith-Blackmore
CRC Press: Boca Raton, FL, US; July 2023

Methodological and Technological Advances in Death Investigations
A. H. Ross, J. H. Byrd, Eds
Elsevier (Academic Press): San Diego, CA, US; July 2023

The Mindful Interview Method: Retrieving Cognitive Evidence
Z. Zamora
CRC Press: Boca Raton, FL, US; July 2023

No-Body Homicide Cases: A Practical Guide to Investigating, Prosecuting, and Winning Cases When the Victim Is Missing, 2nd ed
T. A. (Tad) DiBiase
CRC Press: Boca Raton, FL, US; Nov. 2023

Reading the Skull: Advanced 2D Reconstruction
N. Murry
CRC Press: Boca Raton, FL, US; Sept. 2023

The Path of Flames: Understanding and Responding to Fatal Wildfires
A. Kendell, A. Galloway, C. Milligan, Eds
CRC Press: Boca Raton, FL, US; Sept. 2023

Book Review

Death Investigation: A Field Guide, 2nd ed
Scott A. Wagner
CRC Press: Boca Raton, FL, US; 2023

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This is the second edition of the book *Death Investigation: A Field Guide* written by Scott A. Wagner, M.D. Andrea Terrell, Ph.D. is listed as a contributor. The book is written for professionals and students involved in the various phases of death investigation from the initial scene investigation to postmortem examination and death certification. The 305-page book with color photographs emphasizes a methodical approach to each of the phases that characterize adequate death investigation. It is not meant to be exhaustive, but more of a field guide, providing accessible and pertinent information to the many commonly encountered scenarios.

This is not to say that even the most experienced experts cannot find much value by having a copy of this guidebook close by. Dr. Wagner does an excellent job of crafting a well-organized, concise, yet thorough presentation of best practices in good death investigation. The book is organized into thirteen chapters, briefly described here.

Chapter one provides an overview of the philosophy and general approach to death investigation. Dr. Wagner clarifies the role of the death investigator and the forensic pathologist and outlines some of the principles that dictate which cases are reported to medical examiners and coroners. Finally, the general process and steps of scene investigation are outlined.

Chapters two through four focus on the investigation of the body at the scene. Chapter two describes pronouncement of death, the importance of scene security, and appropriate documentation of the body via photographs and diagrams. Dr. Wagner provides sound reasoning for the approaches he suggests and skillfully adds pearls derived from his extensive real-world experience. For example, he warns against the dangers of committing to opinions developed too early in an investigation, asserting to his readers to "be suspicious but objective" and the importance of emphasizing to others that "all opinions are working opinions." Chapter three focuses on the initial examination of the body at the scene, to include "first impressions" regarding the presence of blood and vomitus and how scene findings can help an investigator assess time of death. Overviews of livor mortis, rigor mortis, and algor mortis are provided, as are overviews of postmortem decompositional changes. Chapter four concludes the section on examining the body at the scene by providing a thorough description on the significance of specific examination findings (general findings like livor distribution, pupil size, and dentition, skin findings like jaundice and ecchymoses, extremity findings like asymmetrical calves and ankle swelling, and trunk findings like gynecomastia and chest shape).

Chapter five covers the importance of medical records and other investigative reports in assisting in adequate death investigation. The importance of this cannot be understated; the Office with whom I am employed has a relationship with a large academic medical center, and we find access to medical records of immense value in accurately determining cause and manner of death. Dr. Wagner describes how medical records are commonly obtained, how clues from the scene can help investigators know where to find medical records, and specifically how information in medical records can be used to provide information in both natural and nonnatural deaths.

Chapter six shifts from scene investigation to more specific medical aspects of death investigation. Chapter six focuses on findings in deaths due to natural disease. Common cardiovascular conditions associated with death are discussed, as are common respiratory and gastrointestinal conditions. A special section on findings in COVID-19 deaths include color gross and microscopic photographs. A section on central nervous system disorders describes findings in deaths from epilepsy, subarachnoid hemorrhage, strokes, and meningitis.

Chapter seven tackles the vast subject of traumatic injuries. General categories of traumatic wounds are discussed including blunt force injuries, sharp force injuries, and gunshot wounds, and more specialized categories of trauma are also discussed like hanging, strangulation, electrocution, and fire deaths. Dr. Wagner provides relevant color photographs for most of these descriptions.

Chapters eight through ten are narrow in their focus. Chapter eight provides an overview of identification methods. This is important because one of the main functions of a medical examiner's office apart from determining cause and manner of death is, first, accurately identifying an individual. Again, color photographs complement the narrative. Chapter nine discusses findings that can be observed from cardiopulmonary resuscitation. While brief, this chapter introduces an extremely important topic that often arises in difficult medicolegal cases. Chapter ten provides an example body diagram from an individual with previous surgeries and procedures.

Chapter eleven is the longest chapter in the book and covers the topic of the autopsy. The chapter begins by addressing the purpose of performing autopsies and some of the misconceptions regarding the procedure; Dr. Wagner's real-world experience shines through as he emphasizes the importance of thoughtful communication to families. The chapter describes the approach to the external examination followed by the internal examination. Dr. Wagner describes the appearance and examination of specific organs. The chapter is written from the perspective of the pathologist performing the actual autopsy, a prescribed sequence of maneuvers meant to minimize the possibility of missing something.

Chapters twelve covers basic toxicological methods and the approach to interpretation. Chapter thirteen briefly covers the different kinds of forensic experts other than forensic pathologists. The book concludes with a series of appendices covering basic medical terminology and classes of drugs.

In conclusion, Dr. Wagner's book *Death Investigation a Field Guide,* 2nd ed, serves as a useful introduction to death investigation for a student but also serves as a handy book to have around for a seasoned professional. The chapters are well-written, easy to understand, and provide the right amount of detail to serve as references for issues that may arise in day-to-day practice. I enthusiastically recommend this book to trainees and professional alike.

TEITELBAUM'S COLUMN ON FORENSIC SCIENCE: HISTORICAL PERSPECTIVES

Origin of the First Handheld Breath Alcohol Analyzer Incorporating an Electrochemical Sensor

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ABSTRACT: Historical events leading to the development of the first handheld instrument for breath alcohol analysis using an electrochemical sensor are reviewed. The first prototype instrument, known as the Alcolmeter Pocket Model, became available in 1972 and weighed only 180 g and was about the size of a cellphone. By the mid-1970s, the Alcolmeter instrument was used by police forces in several countries as a preliminary roadside test of driver sobriety. Positive results in a roadside breath test were considered sufficient evidence to arrest a suspect for further evaluation and testing. This might entail an evidential-quality breath alcohol test or taking a sample of the driver's blood for analysis at a forensic laboratory. The main advantages of breath testing over blood testing are the non-invasive nature of the sampling procedure compared with sticking a needle in a vein to draw blood, and obtaining immediate information whether or not a person is in breach of the drunk driving legislation.

Keywords: Alcolmeter, analysis, breath, drunk driving, law enforcement, roadside screening test, traffic safety.

The Breathalyzer instrument was invented by Robert F. Borkenstein (1912–2001) in 1954, almost exactly seventy years ago. This represented an important contribution to road traffic safety by furnishing the police with a rapid and reliable test of driver sobriety [1]. By the 1960s, Breathalyzer results were accepted as evidence for the prosecution of traffic offenders in the USA, Canada, and Australia [2]. The first report of the Breathalyzer instrument appeared in a 1954 traffic safety digest [3], and a US patent was granted to Professor Borkenstein in 1958 [4]. More detailed information about the Breathalyzer and its applications in forensic and legal medicine appeared in a 1961 publication by Borkenstein and Smith [5].

Traffic safety facts, from various sources, reveal that between 20–50% of drivers killed in road traffic crashes had consumed alcohol before driving [6,7]. Their blood alcohol concentration (BAC) at autopsy exceeded the statutory limits for driving, which vary from 20–80 mg% (0.02–0.08 g%) in different countries [8]. Most alcohol-impaired drivers killed in road traffic crashes are aged 18 to 35 years, in the prime of life [9]. According to a recent report from the United States Department of Transportation [10];

> "Every day, about 37 people in the United States die in drunk-driving crashes — that's one person every 39 minutes. In 2021, 13,384 people died in alcohol-impaired driving traffic deaths — a 14% increase from 2020. These deaths were all preventable."

Efforts to lower the incidence of drunk driving are high on the agenda for government action and preventative measures are urgently needed [11]. Much might be gained if the police made more frequent traffic stops and tested motorists with handheld breath alcohol analyzers [12]. In some countries, the police are allowed to stop and test drivers at random, without any suspicion of any alcohol consumption [13,14]. Road traffic safety would also benefit if the vehicles owned by repeat offenders were fitted with ignition interlocks [15]. These devices require a negative breath alcohol test before a driver can start the vehicle; this strategy has been successful in lowering recidivism rates [16,17].

This article describes the research and development work leading to the first handheld instrument for breath alcohol analysis that incorporated an electrochemical sensor [18]. This contribution to road traffic safety was the result of good collaboration between scientists at the University of Wales Institute of Science and Technology (UWIST) in Cardiff (UK), the Medical Research Council in London, and Lion Laboratories in Barry, South Wales.

Background

The British Road Traffic Act (RTA) of 1967 introduced a statutory BAC limit for driving of 80 mg% (0.08 g%), above which it was a criminal offense to drive or be in charge of a motor vehicle [19]. Hitherto, the evidence used to prosecute traffic offenders rested heavily on the results of a medical examination of a suspect, done by a forensic physician (police surgeon), who had to document typical clinical signs and symptoms of drunkenness [20]. After the 1967 RTA, the concentration of ethanol in a sample of the driver's blood, and whether this exceeded 80 mg%, became the deciding factor for a successful prosecution [21].

To help enforce the 1967 RTA, the UK police were equipped with a chemical tube and bag device, known as Alcotest tubes, which were used as a roadside screening test of alcohol influence. The chemicals in the tube consisted of a mixture of potassium dichromate and sulfuric acid on silica gel, and if these changed color from yellow to green up to a mark on the tube, this was sufficient evidence to arrest the driver for further testing. This meant transporting the suspect to a nearby police station where samples of blood and/or urine were collected for later analysis at a forensic laboratory [21].

Collaboration Between University and Industry

Shortly after the 1967 RTA came into force, Mr. William Ducie (1921–1977), an electrical engineer and entrepreneur, felt that the general public should have the opportunity to test their own breath for alcohol after an evening at a pub or restaurant. With this in mind, Mr. Ducie contacted the Department of Chemistry at UWIST and there he met Dr. TP Jones (1935–2013), a lecturer in inorganic chemistry. Together they started a company called Lion Laboratories, with Ducie as managing director. Within a few years, Lion Labs were manufacturing and selling a chemical detector tube test for the analysis of alcohol in breath called Alcolyser, which was similar in design and construction to the Alcotest tubes [22], manufactured by a German company (Dräeger Ltd: Lübeck, Germany).

The chemicals in the Alcolyser and Alcotest tubes were corrosive and needed to be carefully disposed of each time a test was administered. Furthermore, there was a considerable resistance to blowing through the tubes and some people, especially elderly ladies, heavy smokers, and those with pulmonary dysfunction, were unable to provide the required breath sample.

A number of evaluation studies done with the chemical tube and bag device showed large numbers of false positive and false negative results close to the statutory BAC limit for driving of 80 mg% [23]. A comprehensive evaluation of the then-available chemical tube tests was done in the USA in 1971, a project funded by the Insurance Institute for Highway Safety (Arlington, VA). The published report of the study recommended the development of a more reliable preliminary roadside test for alcohol influence [24].

Breath Alcohol Research for PhD Degree

After completion of a BSc degree in chemistry in 1969, AW Jones began studies towards a PhD degree in the chemistry department at UWIST. The topic of his thesis was suggested by Dr. TP Jones and involved development and evaluation of methods for the analysis of ethanol in blood and breath and studies of physiological factors influencing the blood/breath concentration ratio of alcohol. This project was funded by the Science Research Council and Dr. TP Jones was one of AW Jones's thesis advisers. The other was Dr. BM Wright (1912–2001), who was a respiratory physiologist and bioengineer employed by the Medical Research Council in London. Wright was an expert in respiratory physiology and had invented equipment for measuring lung function in health and disease [25,26]. Between 1969 and 1972, he made many visits to Cardiff to discuss progress and suggest new lines of research.

In the early 1960s, Wright collaborated with a scientist from Japan (Professor Kitagawa) and together they developed a breath alcohol analyzer for use by police to test drunk drivers known as the Kitagawa-Wright (K-W) instrument [27]. However, despite studies showing a good agreement with Breathalyzer results, the K-W analyzer failed to gain acceptance by the UK government [28]. The main reason for this was that gas chromatographic methods for quantitative analysis of ethanol in blood and urine were already accepted by the courts as evidence for prosecution in drunk driving cases [29].

Nevertheless, Wright was a strong advocate for the continued use of breath alcohol testing as a rapid and non-intrusive way to assess driver sobriety [30]. Furthermore, he had established good contacts with scientists in the USA who were involved with research on breath alcohol analysis, and Wright bequeathed several pieces of equipment and a large collection of scientific reprints to the PhD project of AW Jones.

Reviewing the Scientific Literature

Before the internet, keeping up to date with the scientific literature meant making regular visits to the university library and browsing through the latest scientific journals on display. On one such occasion, AW Jones noticed an article published in a journal called *Chromatographia* [31]. Although the article was written in German, it contained an English title and abstract and the figure legends were also in both languages.

The authors of the article were Cremer, Gruber and Huck from the Department of Physical Chemistry at the University of Innsbruck in Austria, and they described an electrochemical sensor for use as a detector for gas chromatographic (GC) analysis of low molecular aldehydes and alcohols. The senior author of the article was Professor Erika Cremer (1900–1996), who was a pioneer in gas chromatography, especially using different types of GC detectors [32,33].

It occurred to AW Jones that because ethanol was the only alcohol present in the breath after drinking alcoholic beverages, the bulky chromatography part of the instrument was unnecessary. Furthermore, a sample of the person's breath could be passed directly into the electrochemical sensor for oxidation without any major concerns about cross-reactivity with interfering substances.

The electrochemical sensor consisted of a small porous plastic polymer material coated on each side with a platinum oxide catalyst (platinum black) and impregnated with an acidic electrolyte. Platinum wires connect each side of the cell, forming an electrical circuit. The electrons released during the oxidation of ethanol were amplified, and the resulting signal was displayed on a galvanometer or other processing device. A sample of breath (~1 mL) was aspirated into the electrochemical cell as the person blew through a plastic tube connected to the instrument.

After further review and discussion of the *Chromatographia* article, Dr. TP Jones traveled to Innsbruck to meet with Professor Cremer and when he returned he had with him one of the electrochemical sensors and instructions on how to make them by electrolysis. At first this was easier said than done, because coating the porous discs with platinum catalyst was difficult to reproduce from batch to batch. Furthermore, the amount and concentration of phosphoric acid electrolyte turned out to be a critical variable.

First Prototype Instrument

During spring term 1971, a BSc student was assigned a project to investigate the response of the electrochemical sensor under in vitro conditions with increasing air-alcohol vapor concentrations. A gas-tight syringe was used to introduce the samples for analysis and the response showed good linearity over a wide range of air-ethanol concentrations. Ethanol was oxidized at the platinum surface of the cell and the signal displayed on a galvanometer in real time. These first tests with the electrochemical sensor also showed that it did not react to acetone, a physiological volatile exhaled in breath in people on starvation diets or in poorly treated diabetics.

In October 1971, PM Williams was recruited to continue this line of research with a main focus on developing the electrochemical sensor to determine alcohol in exhaled breath and this project was supported by a grant from Lion Laboratories. This eventually resulted in both MSc [34] and PhD degrees for PM Williams, who was later employed by Lion Laboratories and worked there his entire career [35].

On one of BM Wright's visits to Cardiff, mainly to discuss progress with research on physiological aspects of breath testing, he was shown a newly constructed device that incorporated an electrochemical for breath alcohol analysis. Before returning to London, Wright asked if he could take one of the sensors with him to "play around with", as he put it. A few months later, he returned to Cardiff and had with him the first prototype Alcolmeter Pocket Model instrument (*see* **Figure 1**), about the size of a cellphone and weighing only 180 g. As a test subject blew through a plastic mouthpiece tube attached to the instrument (*see* Figure 1), a sample of the person's breath was aspirated into the electrochemical sensor for oxidation of ethanol.

Operating the Alcolmeter Pocket Model

The first version of the Alcolmeter was powered with a small dry battery (22.5 volt), although after making certain modifications to the electronics it was possible to use a 9-volt PP3 type battery, which was much more practical and convenient. The electronic circuits for the Alcolmeter were designed by two other lecturers at UWIST, Graham Harris (1931–2019) and Gwyn Pearce.

The instrument shown in Figure 1 had dimensions of 11.5 cm × 6.0 cm × 2.5 cm. Pressing the SET button on the front side of the instrument activated the breath sampling valve, and pressing the READ button as a person was blowing through the breath sampling tube aspirated the required sample for analysis. It was important that the READ button was pressed while the subject was still blowing through the plastic mouthpiece tube attached to the top of the instrument. Pressing and holding down the READ button gave the final result, which appeared after about 20–30 s depending on the concentration of ethanol in the breath sample analyzed.

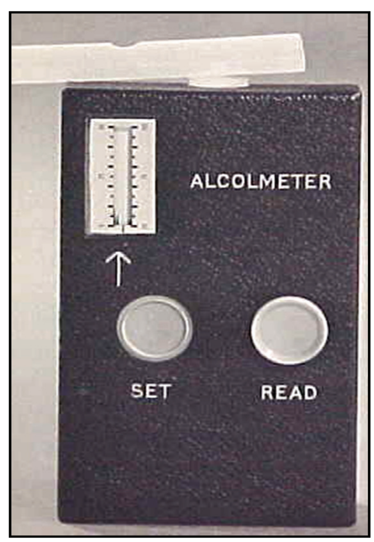

Figure 1. First prototype Alcolmeter Pocket Model (from 1972) fitted with plastic disposable mouthpiece tube and displaying results on a revolving drum galvanometer. Pressing the SET button primes the device for sampling breath and pressing the READ button captures a sample of breath for analysis by electrochemical oxidation.

Later Developments

The revolving drum galvanometer on the Alcolmeter was later replaced with an analog scale (**Figure 2A**), and afterwards a digital display (**Figure 2B**). This latter model, named S-D2, became very successful and was used by police forces worldwide. More recent versions of the Alcolmeter were fitted with microprocessors, which allowed automated sampling of breath after a minimum volume had been discharged and after blowing at a certain flow rate for a fixed time. The date and time of the breath test were recorded and the results were stored in an internal memory for quality assurance purposes (**Figures 2C** and **2D**) and could also be transmitted to a printer.

In January 1973, AW Jones moved from Cardiff to Sweden after being awarded a 12-month scholarship by the British Council for post-doctoral studies abroad. Jones's PhD thesis was awarded by the University of Wales in 1974 [36]. During his time in Sweden, AW Jones worked at the Karolinska Institute in Stockholm, Department of Experimental Alcohol Research, headed by Professor Leonard Goldberg (1911–2010) [37]. In 1974, the Swedish police authorities expressed an interest in replacing the chemical tube and bag device they were using to test driver sobriety at the roadside with a more modern and reusable instrument. The National Swedish Police Board awarded a research grant to Professor Leonard Goldberg to evaluate the available instruments for breath alcohol analysis and AW Jones was appointed to lead this project, hence extending his stay in Sweden.

The statutory BAC limit for driving in Sweden was 50 mg% at the time, and the small size and portability of the Alcolmeter Pocket Model made it a strong contender for use as a roadside screening test for alcohol influence. Moreover, the results of breath alcohol testing using the Alcolmeter instrument were particularly reliable at low BAC and many people could be tested before any re-calibration of the instrument was necessary.

Another instrument evaluated was the Alcohol Screening Device (ASD), which had been developed in the USA by the National Highway Traffic Safety Administration [38]. Although larger than the Alcolmeter, the ASD also incorporated an electrochemical sensor for alcohol analysis; however, it tended to give low positive results even with breath samples collected from people who had not consumed alcohol.

A paper published in the journal *Nature* in 1972 also described an electrochemical detector for the analysis of ethanol in air-vapor samples [39], which was later incorporated into a breath alcohol analyzer known as the Alco-Limiter [40]. However, this was not a handheld instrument and was therefore much less practical for testing drivers at the roadside compared to the Alcolmeter.

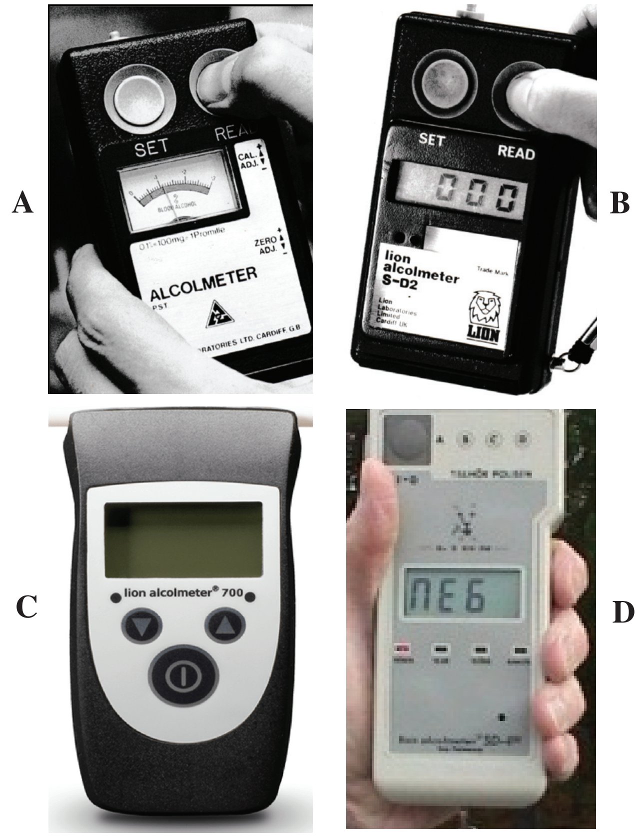

Figure 2. Later versions of the Alcolmeter Pocket Model; (A) fitted with analog scale and (B) with digital display, both of which required manually sampling breath by pressing the READ button. More recent versions of the Alcolmeter (C) and (D) were fitted with microprocessors that enabled auto-sampling of breath, recording date and time of the test, and storage of results in computer memory.

Between 1974 and 1977, extensive studies were made of the accuracy, precision, and specificity of the Alcolmeter Pocket Model using experiments in vitro [41] and human alcohol dosing studies in vivo [42]. This testing protocol began with laboratory studies under controlled conditions and a second stage involved experiments away from the laboratory with policemen operating the instruments [43]. The final phase of the testing program included actual roadside tests with apprehended drivers, which therefore allowed evaluating the performance of the Alcolmeter over a much wider range of BAC [44].

Discussion

Many factors are responsible for road traffic crashes, including human error, problems with the vehicle (brakes, tires, steering), the environment, dangerous roads, adverse weather conditions (rain, snow, ice), as well as age, infirmity, eyesight, and driving experience [45,46]. One of the most preventable causes of such crashes is driving impairment caused by over-consumption of alcohol and/or the use of other psychoactive drugs [47,48].

Handheld breath alcohol analyzers, such as the Alcolmeter Pocket Model, furnish the police with a quick and effective way to monitor driver sobriety at the curbside, thus serving as a preliminary screening test of alcohol influence [18]. The British police preferred the S-L2 model of the Alcolmeter, which had green, amber, and red colored light diodes as the display option. The green light indicated insignificant amounts of alcohol (<5 mg%), the amber light came on when BAC was >6 mg% but <70 mg%, amber and red at 70–79 mg%, and red only above a BAC of 80 mg%. Police forces in most other nations preferred a version of the Alcolmeter with a digital display of the results.

The traffic police in Nordic countries, Australia, Canada, and New Zealand, are permitted to stop drivers at random and request that they provide a breath alcohol test [49]. Mass screening of drivers is possible after prearranged traffic stops, and without any suspicion that the person had consumed alcohol. Expecting a driver to provide a breath alcohol test without having any suspicion that they had consumed alcohol is not considered a breach of integrity or human rights, considering the number of lives saved by removing alcohol-impaired drivers from the roads. Such a roadside breath test only takes a few minutes to complete and can be done with the driver sitting behind the steering wheel. The inconvenience caused to traffic flow is manageable and random breath testing is an effective way to enforce drunk driving legislation, and it also acts as a deterrent for some motorists [50].

The main advantages of measuring alcohol in breath for legal purposes are the non-intrusive nature of the sampling procedure and the fact that immediate results are obtained. There is no need to stick a needle into a vein to draw blood and then having to wait a week or more before the analytical results are obtained. Information as to whether a driver is in breach of the law allows the police to enforce various sanctions, such as confiscating the driving permit and/or the car keys and holding the suspect in custody until he or she sobers up.

In 1983, the British government approved the use of evidential breath alcohol testing, and suspects were transported to a police station where larger and more sophisticated breath alcohol instruments were available. The statutory BrAC limit for driving was set at 35 µg% breath, and this operated in parallel with the already existing statutory BAC limit of 80 mg% [51]. The threshold limit of 35 µg% in breath was derived from the limit of 80 mg% in blood by assuming a population average blood-breath alcohol ratio of 2300:1 [52]. This avoided the need to translate the measured BrAC into the coexisting BAC, a necessary requirement when the Breathalyzer instrument was used [5].

Electrochemical oxidation is a highly selective method for the identification of ethanol, and other endogenous volatiles in breath, such as acetone, are not oxidized at the same electrode potential [53]. However, methanol and isopropanol, if these are present in blood and breath, are oxidized, although at different rates of reaction [53]. Luckily, these more toxic alcohols are rarely encountered in the blood of apprehended drivers, so this cross-reactivity does not compromise the use of the Alcolmeter as a roadside screening test.

The Alcolmeter Pocket Model was marketed in the USA in the mid-1970s, although the name was changed to Alco-Sensor (Intoximeters Inc., St. Louis, MO). Lion Laboratories celebrated its 50th anniversary in 2017, although in 1990 the company was acquired by a US organization called MPD Inc.,Owensboro, KY, who were already manufacturing the Intoxilyzer range of breath alcohol instruments.

In conclusion, this historical perspective describes events leading to the development of the first handheld electronic instrument for breath alcohol analysis that incorporated an electrochemical sensor. This became possible thanks to a good collaboration between university and industry and the efforts of several enthusiastic PhD students.

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COMMENTARY

Non-Alcohol Drugs and Traffic Safety

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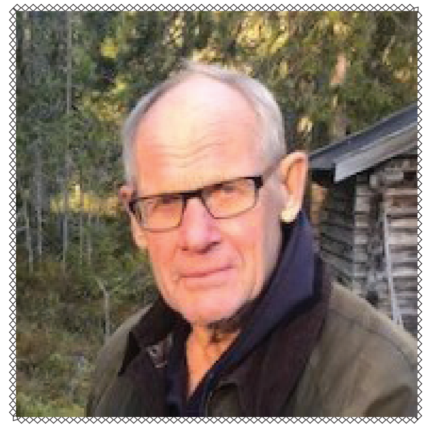

Jørg Mørland, MD, PhD is a specialist in clinical pharmacology. His career in forensic science started in 1980 when he left his position at the University of Tromsø, Norway as professor of pharmacology to be appointed as head of the Norwegian Institute of Forensic Toxicology. In 2002, he became the director of the Division of Forensic Toxicology, and later of the Division of Forensic Medicine at the Norwegian Institute of Public Health (NIPH). He retired from that position in 2012, and has since worked as a senior researcher at NIPH. He has been a professor at the University of Oslo since 1989, and professor emeritus since 2012.

Dr. Mørland's main research interest in recent years has been pharmacological studies of active metabolites of opioid drugs like morphine and heroin. He has supervised more than 30 MDs and scientists to a PhD, authored about 450 scientific articles in peer-reviewed journals with more than 11,000 citations, and cowritten a textbook on drugs of abuse (in Norwegian) for MDs and psychologists.

Dr. Mørland headed a group of MDs and scientists working for the Norwegian Department of Transportation to define guidelines for legal limits of concentrations in blood of non-alcohol drugs. He has made several hundred court appearances in Norway and Sweden as an expert witness in criminal cases. He was a member of the Norwegian Board of Forensic Science until 2023. In 2012, he received the Royal Norwegian Order of St. Olav for his achievements in clinical pharmacology and forensic toxicology.

Road traffic crashes are a major cause of lost lives, and according to WHO (2018) about 1.3 million people die each year as result of road traffic accidents. With respect to disability-adjusted life-years (DALYs) globally, road injuries were ranked as cause number seven in 2019 for all ages, representing close to 74 million DALYs [1]. In the 10–49 age group, road injuries were ranked as cause number one.

Reckless driving and vehicle crashes ultimately result from driver behavior. Thus, enhancing traffic safety entails improving driver behavior, in addition to a focus on making advancements in cars and roads. Even the best driver education can, however, be spoiled by using alcohol and drugs.

We have limited knowledge of the importance of alcohol- and drug-impaired driving in this global road injury pandemic, but data from high-income industrialized countries indicate that 30–50% of crashes with serious injury or fatal outcomes involve drivers who have used alcohol and/or drugs [2].

How Do We Know That Substance Use Decreases Road Traffic Safety?

The accident risk of drivers who have taken alcohol or drugs can be studied by different epidemiological research methods. The main types are pharmaco-epidemiological methods, case crossover studies, case control studies, and responsibility studies. The strengths and weaknesses of these methods are presented and discussed in a recent review in this journal [3]. For all methods there will be bias problems with respect to selection of drivers and information on substance exposure. In addition, several covariates such as time of day, day of the week, driver's age and experience, and various confounders might influence the outcome of any epidemiological study.

For alcohol, there is abundant research demonstrating increased crash risk ([4,5] and others in [3]). The increased risk is blood alcohol concentration (BAC) dependent and increases with a BAC above 0.04%. The estimated odds ratio (OR) for involvement in traffic accidents at a certain BAC, however, varies between studies, indicating the effects of different confounders such as the prevalence of measurable BACs in the general driving population [6].

Several epidemiological studies of road traffic accidents linked to non-alcohol drugs have been discussed and summarized in this journal [7]. The most comprehensive and well-designed studies have been part of the European DRUID (Driving Under the Influence of Drugs, Alcohol, and Medicines) project [8,9]. The highest risks for severe injury or deadly outcomes in the DRUID project were among drivers who had a BAC above 0.12% or alcohol and drugs in combination, with still high, but somewhat lower risks found for drivers with a BAC between 0.08 and 0.12%, or with multiple drugs or amphetamine in the blood [2]. A summary of 72 analytical epidemiological studies [7] concluded that the highest risk for involvement in road crashes was intake of alcohol or amphetamines (drug combinations were not included in that summary). Increased risk was also found to be well documented for drivers who had taken cocaine, cannabis, benzodiazepines, z-hypnotics, opioids, or some antidepressants.

A large epidemiological culpability (responsibility) study of about 5000 drivers injured and hospitalized because of a road traffic crash has recently been published [10]. The study reported an increased OR of culpability with increasing BAC levels, and with increasing concentrations of THC (the major psychoactive component of cannabis). The highest OR was found for a BAC above 0.15% (OR: 73), amphetamines (OR: 14–19), and THC above 10 ng/mL blood (>about 16 ng/mL plasma) (OR: 10). Alcohol and drugs used in combination showed ORs of 12–14.

In general, it appears that the highest crash risk is connected to the use of alcohol by the driver, and that this risk increases with increasing BAC. With the use of non-alcohol drugs there are also enhanced crash risks, but to a lesser degree than alcohol. Problems with obtaining a sufficient sample size and with selection and information bias are probably greater with studies on non-alcohol drugs than on alcohol. This makes quantification of risk increases from non-alcohol drugs more uncertain.

Legal Aspects

Driving under the influence (DUI) legislation can be divided in two principally different approaches: (a) based on an individual evaluation of the driver's performance or (b) based on the presence of a certain substance concentration in blood, or so-called per se legislation. In practice, punishment according to (a) will depend on an evaluation of a driver who has the substance in their system (preferentially in blood), supported by the results of a field sobriety test, a clinical examination, or similar. In (b) punishment is only dependent on the substance concentration (preferentially in blood) being higher than the legal limit for the actual substance. Besides (a) and (b), punishment according to so-called zero tolerance laws is another option. These laws require only the presence of the drug, sometimes its metabolites in blood or another body fluid. Being convicted under zero tolerance laws will thus not necessarily imply that the driver is impaired by a substance or poses a traffic safety problem.

Alcohol vs. Non-Alcohol Drugs

Alcohol Legislation

Alcohol legislation started according to principle (a) as described in [11]. The handling of suspected drunk driving cases required considerable resources (witnesses, medical expertise, court procedures). After semi-experimental studies of the relationship between BAC and performance [12] together with the development of a reliable method of blood alcohol analysis [13], Norway was the first country in the world to introduce a per se limit for alcohol at 0.05% in 1936, followed by Sweden in 1941. A series of countries and jurisdictions have since then introduced per se limits for BAC or breath alcohol concentrations (BrAC).

Experimental Research on Performance Decrements Caused by Alcohol

As it would be difficult to determine per se limits based on results from epidemiological studies alone, controlled experimental research on the effects of alcohol on driving performance has developed over the years. In such studies, volunteer subjects drink certain amounts of alcohol and the effects on driving performance are studied by different psychomotor tests, tests of neurocognitive function, and functional tests in driving simulators or on the road in relation to simultaneously measured BACs. Since such tests are also highly relevant for non-alcohol drugs, a closer look at the outcome of these experimental studies on alcohol may be warranted.

A major theoretical background for many experimental studies is that driving can be seen as one aspect of human behavior, and therefore linked to models of information processing in the human brain [14]. Information processing can be classified as one of the following steps or behavioral areas: active sensory search, sensory perception, feature extraction, processing, decision, reaction planning, and motor output. For each of these steps or areas, there will be tasks that can be tested experimentally for impairment.

Systematic reviews and meta-analyses of hundreds of experimental studies have demonstrated impairment of various tasks after alcohol intake. When summarized, the alcohol-induced reductions in performance are featured by an increasing fraction of tests demonstrating significant negative effects with increasing BAC levels [15,16]. There are, however, large differences between the sensitivity of different tests to a certain BAC level, as some tests are affected already at very low BACs, while others (e.g., simple reaction time) are more resistant and only markedly change at quite high BAC levels (around 0.1%). At a BAC around 0.05%, more than 50% of the tests of the different behavioral areas were not affected [16], and the same was the case for cognitive tasks, psychomotor skills, and choice reaction time in the US study [15] Some of the tests for these behavioral areas, however, showed significant deterioration at a BAC below 0.03%. At a BAC of 0.12%, 80–90% of all tests of performance were significantly impaired [16].

A systematic review and meta-analysis of 50 articles on the effects of alcohol on simulated driving [17] found that increasing BAC levels were associated with increasingly larger performance decrements. The study, however, also showed that the performance change at the individual level from a certain increase of BAC varied considerably. Ogden and Moskowitz [18] stated that "The variation in individual performance at BACs below 0.10% is sufficiently broad that uncertainties must attach to any prediction of the precise effects of a given quantity of alcohol on an individual" and that "Individual human performance abilities vary at the no-alcohol baseline, so that viewing an individual behavior (test) at low BAC can give only limited information about the BAC". An implication of this is that a legal BAC limit is unlikely to have the same relation to a certain reduced performance level in all drivers, in particular at low BAC levels.

Non-Alcohol Drugs Legislation

Until recently, most cases appear to have been handled according to principle (a) by individual performance evaluation, or in some countries and jurisdictions by zero tolerance laws if the drug was illegal. Over the last two decades, legislation according to principle (b), per se limits, have been introduced in several countries and jurisdictions for illicit drugs and sometimes also for medicinal drugs used without a prescription [11]. Gjerde and Strand [19] have recently published an overview of the existing legal limits for illicit drugs and found large variations between jurisdictions. Such variations call for a closer look at the experimental studies on non-alcohol drug use and human performance.

Experimental Research on Performance Decrements Caused by Non-Alcohol Drugs

Controlled experimental testing of subjects without health problems has been regarded as an important supplement to the epidemiological studies of non-alcohol drugs.

Several experimental studies have been performed and summarized in an article in this journal [20]. This research demonstrated dose-related impairing effects of benzodiazepines and similar drugs (z-hypnotics), cannabis and GHB (gamma-hydroxybutyric acid), moderate impairing effects of opioids with no clear dose relation, and variable results for cocaine, amphetamine, and MDMA. The studies included in the summary had largely adhered to the guidelines for experimental studies on drugged driving [21]. These guidelines are close to those recommended for similar research on alcohol, pointing at the importance of placebo groups, the use of alcohol as a reference (verum), and frequent measurements of blood drug concentrations (as a proxy of brain drug concentrations). While the ethanol concentration in the water phase in blood and brain are almost similar, this could be quite different for non-alcohol drugs. However, after drug distribution is attained, there will be a quite constant relationship between drug concentrations in blood and brain.

Most experimental studies on non-alcohol drugs have been performed with cannabis. I will therefore focus on this drug in the following, since there is also an ongoing debate on legal limits for THC impairment.

A summary of the outcome of behavioral psychomotor tests in 87 different experimental studies as a function of THC concentration in plasma after intake of cannabis [22,23] showed that about 10% of the psychomotor tests showed performance decrements at THC concentrations of 2 ng/mL plasma. Reduced performance in about 70% of the tests was found at THC concentrations of 10 ng/mL plasma or higher. For comparison, alcohol-induced decrements were found in about 10% of the psychomotor tests at a BAC of 0.02%, and 70% at a BAC of 0.1% [16]. After smoking about 33 mg, THC concentrations of 10 ng/mL and 2 ng/mL plasma have been measured after 1.5–2 h and about 6 h, respectively [24].

In another study [25], meta-analyses of data from a large number of experimental studies on the effects of alcohol and THC on driving-related performance were compared. At a BAC level of 0.04%, about 30% of the test results on performance (n = 846) were significantly reduced, and a similar reduction in 30% of the tests (n = 464) was found at THC serum concentrations of 4–5 ng/mL. Because of some differences between alcohol and THC on the performance of different tasks, the authors concluded that a THC serum concentration (equivalent to concentration in plasma) of 7–10 ng/mL was correlated with an impairment comparable to that caused by a BAC of 0.05%.

In a study [26] aiming to find a limit of impairment for THC concentrations in serum, effects on different cognitive and psychomotor functions were compared after smoking by recreational cannabis smokers. For all functions studied, there was a concentration-dependent increase in observations showing impaired performance. The most sensitive was tracking performance showing impairment at THC concentrations between 2 and 5 ng/mL serum. At THC concentrations above 30 ng/mL plasma, all subjects demonstrated performance decrements in all tests.

The DRUID project has given recommendations regarding legal limits for driving after intake of illicit drugs. Lower effect limits were defined as the blood concentration of a drug that was accompanied by effects comparable to those of BAC at 0.02%, and risk threshold concentrations as blood drug concentrations accompanied by effects comparable to those of BAC at 0.05% [2]. Based on a comprehensive meta-analysis of empirical studies concerning the effects of medicines and illegal drugs including pharmacokinetics [27], a risk threshold for THC concentrations (comparable to BAC 0.05%) of 3.8 ng/mL serum was recommended.

In a crossover trial, 17 healthy subjects who were infrequent cannabis smokers with no use for a least the last month before the trial were studied [28]. THC dose- and concentration-dependent reductions in tests of cognitive and psychomotor function were observed. The most pronounced impairment occurred 1–2 hours after smoking at THC concentrations of 1–2 ng/mL blood (i.e., 1.6–3.2 ng/mL plasma). After 3 to 4 hours, THC could no longer be detected in blood, but observed cognitive and psychomotor impairments persisted for up to 6 hours.

In almost all the experimental studies mentioned above, measured performance decrements increased with increasing THC concentrations in plasma/serum/blood. Some decline in performance occurred at very low THC concentrations. The THC concentration which was comparable with a BAC of 0.05% with respect to deterioration of performance differed between the studies that tried to make this comparison.

The Relation Between THC Concentrations in Blood and THC-Induced Impairment

There is a large number of studies showing a correlation between THC concentrations in blood and the presence and magnitude of THC-induced impairment in various tests of traffic relevance as mentioned above. But it has been questioned whether a THC level measured is a reliable marker of individual impairment, based on the poor relationship between plasma THC level and SDLP in a simulated driving study [29]. A meta-analysis of 28 placebo-controlled experimental studies of behavioral and cognitive "skills" after cannabis consumption by smoking or per orally found that higher blood THC concentrations were weakly associated with increased impairment in occasional cannabis users [30]. No such association was found in regular cannabis users. On the other hand, several studies have found a correlation between individual THC concentrations and impairment in some psychomotor and cognitive domains [26,31–33].

Several explanations have been put forth to elucidate these apparent controversies. One set of explanations is related to THC pharmacokinetics. Shortly after smoking, THC levels in blood reach a maximum, but it may take about 30–40 min before THC and the psychoactive metabolite 11-hydroxy-Δ9-tetrahydocannabinol (11-OH-THC) are in distribution equilibrium over the blood-brain barrier [34]. Oral administration of THC, e.g., in cannabis brownies, did not give rise to high blood THC concentrations shortly after intake, but the concentration peaked after 2–4 hours at concentrations in blood about 2 ng/mL (3.2 ng/mL plasma) after intake of about 25–50 mg THC. This rather low THC concentration was accompanied by clear reductions in cognitive and psychomotor performance [35]. 11-OH-THC was present at similar concentrations as THC, i.e., at higher levels than after smoking. THC has a long distribution phase of several hours [36]. During that extended phase, ongoing distribution to parts of the brain is a possibility if results from an experiment in rodents are considered [37]. That study reported an increasing ratio between concentrations in brain and plasma for the first 4 hours after intramuscular THC administration.

In addition to the pharmacokinetic factors mentioned, different sensitivity between individuals to the impairing effects of THC has been discussed. These pharmacodynamic differences can be innate, but also represent acquired tolerance by frequent cannabis use. A systematic review of 36 studies published through 2018 [38] concluded that several effects of THC on cognitive function were less pronounced and even absent in regular cannabis users compared to non-regular users. A controlled experimental study comparing occasional and daily cannabis users who smoked or vaporized their own cannabis ad libitum before simulator driving was recently published [39]. The THC concentration after driving was about five times higher in the daily users, but the change of SDLP from before smoking was similar in the two groups. The authors concluded that the study did not conclusively establish that occasional users exhibit more driving impairment than daily users when both smoke cannabis ad libitum. Similar findings were also reported [40,41], although there was some tolerance to psychomotor impairment in frequent users compared to occasional users. In another driving simulator study [42], both daily users and occasional users smoked the same amount of THC. Driving performance and vigilance were decreased in both groups, but most pronounced in occasional users.

Mechanisms behind individual differences and tolerance to the response to a certain THC concentration in the brain are most likely associated with the neuropharmacological mechanisms of action of THC.

In general, psychoactive drugs interact with receptors and other drug-specific targets in the brain to exert concentration-dependent effects. The signaling pathways from these effects at the primary sites of action to registrable neuropharmacological responses ranging from sensory to executive impairment are often only fragmentarily known, but likely subject to genetic or acquired intra-individual variation. It is mostly unknown which primary effect or combination of effects is most important to the increased crash risk accompanying drug use. THC has a complex mode of action as a partial agonist at the CB_1 —cannabinoid receptor, which is the most abundant G-protein coupled receptor in the brain [43]. After smoking, THC is present at similar levels as the endocannabinoid agonist anandamide [44,45]. THC might thus interfere with endocannabinoid signaling, mainly affecting GABA and glutamate synapses with outcomes depending on synaptic activity and endocannabinoid levels. Indirectly, this could lead to increased dopaminergic transmission in several neuronal networks [46]. Dopaminergic activity in the basal ganglia, prefrontal cortex, and gyrus cinguli will generally influence behavioral decision making and action selection [47–50], which also could apply to decisions made by drivers.

The studies mentioned above, as well as several others, may when considered together suggest that there is a correlation between blood THC concentration and THC-induced impairment, but that the relationship is probably more dependent on pharmacokinetic variables, as it also will be for other non-alcohol drugs, rendering time after intake an important variable compared to alcohol which has more straightforward absorption and distribution pharmacokinetics. With respect to neuropharmacological pharmacodynamic effects, alcohol interferes with series of receptors and other targets, partially different from those affected by THC and other non-alcohol drugs, but also with some common neurobiological consequences; e.g., increased dopaminergic transmission in the basal ganglia and prefrontal cortex [51,52].

Challenges of Legal Limits for THC

The discussion on the individual variation on performance variables by the same concentration of THC has led to the questioning of the usefulness of per se limits to detect THC-impaired driving. In this debate it might be useful to also include the individual variation of performance caused by alcohol. This can be approached by comparing the effects of alcohol and THC on the same performance tests in the same individuals, as has been done in the following publications.

In a study of occasional cannabis users [31], both THC-concentration-dependent and BAC-dependent changes in simulator driving performance were demonstrated. The principal effect studied was changes in car lateral control measured as a standard deviation of the lateral position (SDLP), a measure of considerable validity with respect to crash risk [53]. In the study [31], increases of SDLP were observed at the lowest concentrations measured, i.e., at THC 1 ng/mL in blood and at a BAC of 0.01%. Approximately the same increases of SDLP were measured at 7 ng/mL THC in blood (about 11 ng/mL plasma) and at a BAC of 0.05%, respectively.

Another study by the same authors [54] on the same subjects investigated the effect of THC and alcohol on driving speed in the driving simulator. THC reduced speed in a concentration-dependent manner in the concentration range from 1 ng/mL to 20 ng/mL plasma, while alcohol intake increased speed with increasing BrAC.

A recent paper [55] has compared the effects of alcohol and/or THC intake on SDLP in simulator driving. The design was a within-subjects, double-blind, double-dummy, placebo-controlled, randomized clinical trial. Other results from this study are also published elsewhere [56,57]. THC at a median concentration of 5 ng/mL blood (8 ng/mL plasma) was accompanied by similar increases of SDLP at a BAC of about 0.085–0.090%. No clear relationship between individual blood concentrations of neither alcohol nor THC and SDLP was observed. By splitting the results observed after cannabis administration in those above and below a concentration of 5 ng/mL blood (8 ng/mL plasma), it was found, however, that the increase of SDLP in the former group was significantly more pronounced than in the latter. The authors suggested that specified thresholds for THC in blood may be able to detect driving impairment, but that future studies are needed.

How to Proceed?

There are few obvious solutions on how to handle THC impairment in roadside traffic. If per se limits are to be used, when set at low THC concentrations they will give society increased protection against impaired driving, but on the other hand punish drivers who are marginally affected by THC. If the limits are set at a high THC level, the protection of safety on the roads could be diminished since an appreciable amount of impaired driving will be unpunished, while only those most severely impaired would face punishment. Perhaps in the future, with more knowledge about the effects of THC on all aspects of driving, it may be possible to find a limit that balances the interest of society and fairness to the driver. But an additional problem is that it would be difficult for the driver to know whether he or she was above the limit since the relationship between the self-experienced THC impairment and the THC-induced reduction of performance can be weak [58].

Individual evaluation of driver performance in addition to detection of THC in the blood has been suggested as a procedure which could be elaborated. Field sobriety tests and clinical examinations are, however, of limited help [59,60]. Other tests, e.g., computer-based approaches (independent of variable skills among examiners), have been suggested [61], but with variable inter-individual results. The problem with evaluations based on individual performance will probably always be the large inter-individual differences that exist between different drivers in a sober state. These inter-individual differences will most likely also be present when subjects are influenced by drugs [62].

Concluding Remarks

There are no obvious and easy ways to create a legislation which yields protection to society and at the same time fairness to the user of non-alcohol drugs in traffic, as exemplified by this commentary on THC. Future research on the acute impairing effects of non-alcohol drugs should probably include alcohol in the same study used to investigate the non-alcohol drug, as done in recent studies from Canada [55-57]. Such studies could also collect information on the individual variations of impairment at a certain drug level in comparison with the individual variations of impairment at a comparable alcohol level. If acquired tolerance caused by frequent use of a non-alcohol drug is considered of importance, it could be compared to the tolerance acquired by daily drinkers who were not alcohol dependent. Taken together, such studies could give some guidance on possible legal limit legislation for non-alcohol drugs in comparison to the existing legislation for alcohol with respect to the protection of society and fairness toward the driver.

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