

ADVANCE SOCIAL SCIENCE ARCHIVE JOURNAL

Available Online: <https://assajournal.com>

Vol. 04 No. 02. October-December 2025. Page# 4723-4737

Print ISSN: [3006-2497](#) Online ISSN: [3006-2500](#)Platform & Workflow by: [Open Journal Systems](#)**Forensic Science and Technology in Criminal Investigation: Legal and Ethical Challenges for Law Enforcement in Pakistan****Muhammad Umar**

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maryamarshad190102@gmail.com**Abstract**

Technological inventions have revolutionized detective work in the field of forensic science, and law enforcement agencies are now armed with state of the art tools and methods that may help crime investigation to become more efficient and effective. The adoption of numerous innovations like DNA profiling, digital forensics, artificial intelligence, and big data analytics has made criminal investigations much more precise and efficient. However, along with these developments, there are many legal challenges that must be addressed to ensure the ethical and legal use of forensic technologies. This paper covers the two sides of the advancement of technology in criminal investigation, because investigations have both gained benefits and suffered setbacks through advancements in technology which have brought with them legal issues that need to be addressed. The paper examines how modern forensic technologies augment the performance of law enforcement in finding essential evidence, speeding up investigations, and improving crime-solving rates. It also focuses on the legal and moral issues connected with privacy, information security, admissibility of evidence, and the potential for the misuse and overreliance on technology. It argues for a well-balanced strategy that combines technological progress with strong legal structures to safeguard individual rights while improving the efficiency of the criminal justice system. To optimize the advantages of forensic advancements and maintain the integrity of the legal system, law enforcement in Pakistan must confront these obstacles through legal reform, training, and institutional investment.

Keywords: Forensic Science, Digital Forensics, Criminal Investigation, Admissibility of Evidence, Legal and Ethical Challenges

1. Introduction

Forensic science is playing a vital role in the modern criminal justice system. Its earliest application originates from ancient Greek and Roman societies. Significant efforts were made in China in the 13th century in pathology and entomology to solve crimes, while 16th-century Europe saw medical practitioners making

further contributions to forensic medicine. By the 17th century, forensic science had begun to evolve into an important area of study. Later, the 18th and 19th centuries witnessed a breakthrough in the application of forensics in solving crimes via footprints, clothing fiber, fingerprints, ballistics, toxicology and DNA profiling. The 20th century saw law enforcement form special forensic teams for evidence-gathering and analysis, as crime scene investigation acquired a modern outlook. Studies demonstrate that forensic analysis of physical evidence enhances the efficiency of criminal investigation (Bradbury & Feist, 2005; Peterson, Mihajlovic, & Gilliland, 1984).

Forensic analysis, which involves careful consideration of each piece of evidence at the crime scene, is an essential part of police work today. The investigation is helped by recreating the scene of crime in multiple ways to connect the crime with suspects, assess motives, and identify the weapon used or the method employed to commit the crime. It not only helps in narrowing down the suspects but also in getting the real culprit convicted. Forensic science offers the scientific foundation for identifying criminals through evidence at the crime scene, including mobile phones, blood drops, hair, and fingerprints (Sanders, 1977). Advanced methods involve forensic anthropology, entomology, odontology, chemical analysis, criminal profiling, geographic profiling, document analysis, data analysis, and audio/video analysis. The purpose of utilizing forensic equipment is to connect the crime with the suspect and obtain a conviction after trial, and to this end there are two important aspects: the preservation and recording of the crime scene. Failure to accomplish these two crucial steps can jeopardise scientific evidence and end in the loss of forensic records. Forensic science has undergone tremendous development and has become a crucial part of police investigations in Punjab. Law enforcement agencies now have more tools at their disposal to collect, retrieve, and examine mobile devices as digital evidence for investigative purposes. Forensics allow investigators to access an extremely wide collection of digital evidence that could include call logs, text messages, emails, social media messages, geolocation data, internet browsing history, multimedia files, and use of apps (Yaqoob et al., 2019). Over the years, the skills and equipment involved in mobile device forensics have improved tremendously, enabling police to reenact actions and create a chronology that proves vital to detective work, circumvent security features, recover deleted information, and decipher encrypted data (Sharma & Geetha, 2016). The development of specialized software and methodologies has improved data integrity and the preservation of evidentiary standards, guaranteeing the admissibility of information gathered from mobile devices in legal proceedings (Umar, Riadi & Zamroni, 2018). But problems still exist, such as how quickly technology is developing and how security features on mobile devices are becoming more complex, necessitating ongoing innovation and adaptation in forensic techniques (Bennett, 2012).

Digital forensics, DNA profiling, and artificial intelligence, as some of the technological advances in forensics, have revolutionized criminal investigation systems in every part of the world. These technologies have enhanced the accuracy of evidence and the speed of investigation, and have also assisted in making case decisions more reliable and science-based. Even in Pakistan, police agencies are attempting to acquire modern forensic science tools, yet incoherent resources, training, and institutional coordination remain a challenge to such endeavours. A lot of legal and ethical complexities are also involved in these technological advances, to illustrate, when the confidentiality of personal information, the legality of the admissibility of evidence, and the possibility of violating human rights in the case of a wrong diagnosis are considered, a complex situation is created before the judicial and investigative system of Pakistan. Moreover, the lack of legislation or the unclear interpretation of the use of modern technology only puzzles law enforcement agencies, which might raise the probability of injustice. This paper investigates how police in Pakistan are

effectively using modern forensic technology, what legal and ethical challenges they face, and what policy reforms or technological improvements could mitigate these problems, in order to improve the quality of justice delivery in the country.

2. Literature Review

Over the years forensic science has greatly developed in Pakistan and it has been instrumental in criminal justice system. The history of forensic science dates back centuries, and such ancient methods as fingerprinting and handwriting analysis were the primer of the contemporary forensic activity (Barnett, 2016). The history of forensic science in the subcontinent, as explained by Butler (2015), traces to the colonial times when the British established forensic methods including those which are presently in Pakistan but the use of forensic methods was crude and immature during this era and the introduction of forensic laboratories and training institutes was a major development in this context. Azhar, Rizvi, and Asghar (2025) state that the Punjab Forensic Science Agency (PFSA) was established in 2011 and became one of the largest forensic institutions in the country that provides its services to the law enforcement agencies and the courts, and the evolution of the forensic science was related to the legal system of criminal investigations and trial in Pakistan, and such evidence is offered in the CrPC (1898) and the PPC (1860).

According to Saferstein (2011), the time-tested forensic techniques (trace evidence examination, ballistics and fingerprinting) have always been a part and parcel of criminal investigations; Ashbaugh (1999) has added that the old techniques are still a vital part of criminal investigations but they are increasingly becoming complemented and supplemented by novel technologies. As noted by Schwartz (2014), the introduction of the vast use of DNA sequencing technology is one of the biggest changes, as now forensic scientists can examine minute amounts of biological evidence with a level of accuracy that was never possible before. Williams and Johnson (2008) have shown that police investigation methodology has been enhanced due to the growing use of forensic technology in European countries, however, privacy, legal procedure, and the admissibility of evidence are also becoming problems with these innovations. According to Lynch (2013), forensic science is a kind of power arena that involves the state institutions using power via technology stating that forensic information like biometrics and genetic data provides police with supernormal powers to which civil liberties and privacy are questioned. Morgan and Bull (2007) highlighted the need of communication between police and forensic specialists, which they demonstrated as effective only under the condition of appropriate use, interpretation and analysis based on the judicial criteria, and that training and professionalism matter greatly in this sphere. In the case of miscarriages of justice, Naughton (2012) stated that poor analysis or misuse of forensic evidence can result in conviction of innocent individuals and that there should be a high level of care in the application of the scientific methods and that institution accountability should be encouraged by law system.

Cheema (2012) researching legal status of forensic evidence in Pakistani courts, explained that although scientific evidence is used by the court even in the Pakistani context, its scientific reliability has not been tested in front of the court, and has pointed out instances where the importance of DNA evidence has been overlooked or where the court has not been confident with the technicalities of the scientific evidence. Sheikh and Jilani (2019) found that Pakistani police, prosecution, and judiciary have the tools, but they could not be used effectively because they require cooperation and coordination among the three, and that the chain of custody is not met often, which impacts the legality of evidence. Raza and Hassan (2020) emphasized the issue of cyber forensics in Pakistan, where the rate of cyber crime is increasing rapidly, but there are no specialists, laboratories, and legal advice, which leads to the need to make modern amendments to the

forensic legislation.

3. History and Development of Forensic Science

Forensic science is a multidisciplinary field, which combines scientific knowledge and practices with the legal system, with its primary aim being to find out the truth, seek justice, and bring the justice nearer to the truth using evidence. The process of identification of criminals has been made more efficient over time, and the process of delivery of justice has been enhanced by a series of revolutionary changes and developments in forensic science.

3.1 Early Developments of the Nineteenth Century

The 19th century may be regarded as the century of the initial discoveries in the sphere of forensic science when such branches as forensic toxicology, fingerprinting, and document analysis appeared. The presence of arsenic was recognized through James Marsh well known Marsh test (1836) which formed the basis of forensic chemistry; it was adopted in the European courts very soon (Trestrail, 2007). In France, in 1890, the anthropometry System introduced by Alphonse Bertillon measured parts of the human body to identify criminals and was used in numerous European countries before fingerprinting, his work on analyzing handwriting as a forensic technique was pioneered (Hilton, 1993) and chemical analysis of ink gained importance (Hilton, 1993). Biological evidence was also significant: bloodstain analysis started in the 1860s, and in 1895 the Uhlenhuth Test was introduced, and it was able to differentiate between human and animal blood (Thorwald, 1966). Forensic psychology also started to evolve, as in the 1890s Hugo Munsterberg suggested that human perceptions and recollections are not always reliable and thus need psychological analysis of eyewitness accounts (Munsterberg, 1908), which would later on prove useful in evaluating the reliability of witnesses. Towards the end of the century, forensic laboratories were being opened in Europe and in 1892 an Argentine court for the first time convicted a person based on fingerprints, a victory of forensic science (Beavan, 2001).

In the subcontinent, scientific education and experimentation began largely through the British, who introduced Western medical sciences, including forensic medicine, when medical schools were established in Calcutta and Bombay (Arnold, 2000). The police in the subcontinent were organized after the Police Act of 1861, and British officers appointed specially trained "Investigating Officers" trained in evidence collection and rudimentary scientific methods, whose impact on the Pakistani judicial system was later significant (Anderson, 2004). The fingerprint system introduced by the Bengal Police in 1897, developed with the key contributions of local experts Azizul Haque and Hem Chandra Bose (though credited to British officer Edward Henry), was a revolutionary step in the subcontinent (Sodhi & Kaur, 2005). Although forensic science did not fully institutionalize in the subcontinent between 1800 and 1900, the introduction of fingerprints, toxicology analysis, post-mortems, and scientific principles into police investigation laid a foundation that proved to be a milestone for the institutionalization of forensic science in Pakistan after 1947 (Punjab laws, 2007).

3.2 The Twentieth Century: Institutionalization

Forensic science emerged as a fully-fledged scientific and legal discipline in the 20th century, a period that can be called the golden age of the formation of forensic sciences and their integration with legal institutions. The most revolutionary discovery of the century was DNA profiling, discovered in 1984 by British scientist Alec Jeffreys, who found that each person's DNA is unique, making it possible to identify any person (Jeffreys et al., 1985); the case of Colin Pitchfork in Leicestershire, England, in 1986 was the world's first criminal to be arrested on the basis of DNA evidence, ushering in a new era in forensic science (Jobling & Gill, 2004). Fingerprinting, first used in the late nineteenth century, was formally adopted by police and courts when Sir

Edward Henry introduced a fingerprint system for the London Metropolitan Police in 1901, which soon spread to the United States, Canada, and Europe (Henry, 1900). Modern chemical analysis methods such as chromatography and mass spectrometry were introduced into forensic toxicology, allowing detection not only of the presence of a poison but also its quantity and nature (Baselt, 2008). Forensic pathology was recognized as a formal discipline through cases such as the Crippen case (1910) (Burney & Pemberton, 2010), while Hugo Münsterberg's 1908 book *On the Witness Stand* paved the way for psychologists to be included as expert witnesses (Münsterberg, 1908). Calvin Goddard's invention of the comparison microscope made it possible to determine the relationship between bullet marks and weapons (Haag & Haag, 2006), and digital forensics emerged with the proliferation of computer crime in the 1980s and 1990s, when the FBI, Interpol, and Scotland Yard established specialized digital units capable of analyzing hard drives, emails, web traffic, and encrypted content (Casey, 2011). Courts came to accept forensic evidence as a central pillar, and the Daubert Standard (1993) became the standard for assessing the legality of scientific evidence in the United States, testing evidence for accuracy, reliability, and reputation before admission (Faigman et al., 2002).

In Pakistan, the foundations of forensic science are linked to the scientific, medical, and legal systems of the British era; after the establishment of Pakistan, the country faced the task of rebuilding the forensic system, and because state institutions were initially weak, the use of forensic science remained limited, though progress was made over time (Shah, 2022). At the time of the country's formation, there was no separate institution for forensic science; medico-legal departments in medical colleges such as King Edward Medical College, Lahore, and Dow Medical College, Karachi, performed these services and prepared post-mortem reports presented as evidence in court, while basic departments such as ballistics, serology, and fingerprint bureaus were established in major cities, often poorly trained and lacking modern methods, which weakened evidence in courts (Nawaz, 2021). Until the 1970s there were no formal forensic science education programmes in Pakistan; medical students were taught "forensic medicine" as a subject, with training usually provided by police training colleges under the supervision of senior officers (Nawaz, 2021). In the 1980s, Pakistan faced new challenges of drug trafficking and terrorism, and law enforcement agencies tried to improve ballistics, toxicology, and drug analysis, including laboratories set up in collaboration with the Anti-Narcotics Force, though most had poor facilities and outdated machinery, leading to poor quality investigations (Khan, 2018). The importance of forensic science in Pakistan was seriously realized after 1990, and the Punjab Forensic Science Agency (PFSA) was established in Lahore in 2009, laying the foundation for taking forensic science in Pakistan to international standards (Nawaz, 2021). PFSA's main areas include DNA and serology, forensic pathology, toxicology, questioned documents, firearms and tool marks, and polygraph testing, and it established a laboratory system based on the international ISO 17025 standard (Punjab laws, 2007). Since 2005, the High Court and Supreme Court have considered forensic evidence a decisive factor in several decisions, with DNA evidence in the well-known 2020 motorway case proving helpful in the delivery of justice.

3.3 The Twenty-First Century and the Digital Turn

The development of forensic science in the 21st century has not only transformed the criminal justice system but also reshaped the concept of investigation, judicial proceedings, and crime prevention. In the early 21st century, DNA forensics was rapidly incorporated into the judicial system in the West; the FBI modernized its CODIS (Combined DNA Index System), and the United Kingdom expanded the National DNA Database (NDNAD), which by 2020 remained one of the largest DNA databases in the world (McCartney, 2021), helping solve many old cases such as through the Innocence Project USA, which exonerated more than 375

wrongfully convicted people (Innocence Project, 2023). The internet, smartphones, and digital communication introduced new forms of crime, and in response digital forensics developed rapidly through units such as the FBI's Regional Computer Forensics Laboratories and the UK's National Cyber Crime Unit, while laws such as the GDPR gave legal protection to citizens' digital data and forced forensic experts to work within the legal framework (European Commission, 2018). Facial recognition, voice recognition, and biometrics were incorporated into forensic science, with the FBI integrating fingerprint, iris, and facial recognition into a single system under the Next Generation Identification (NGI) programme (FBI, 2020), though these techniques have also been criticized by human rights organizations such as the ACLU over concerns about racial discrimination in AI (Garvie, 2019). The decision in the European Court of Justice *S and Marper v UK* (2008) case in the UK made it clear that the retention of non-criminal data in the DNA databases constituted the abuse of human rights and the forensic technology has the potential to influence the civil liberties.

Law enforcement agencies of Punjab began to appreciate the value of digital evidence in criminal investigations at the start of the 2000s and started paying initial attention to computer forensics as mobile devices were not a primary focus at that time due to their limited capabilities (Shah and Hussain, 2021). The emergence of mobile technology led to the ubiquity of smartphones, which criminals began to use as a communication medium, a coordination tool, and to plan illegal activities, and Punjab policing has had to build its own forensics capabilities to include mobile devices when it is investigating a case (Umar, Riadi, and Zamroni, 2018). This prompted forensic professionals and law enforcement agencies in Punjab to come up with special software and hardware that specializes in mobile device forensics, which are designed to analyse, extract and interpret digital evidence on a wide variety of mobile devices (Mushtaque, Ahsan, and Umer, 2015), and courses and seminars were offered to educate investigators on the most recent developments in the area (Jahankhani and Hosseinian-far, 2014). With the emergence of forensics as an important part of investigations, legal and procedural reforms were necessary to allow the legal system of Punjab to allow the use of mobile phone-based digital evidence without violating its integrity and admissibility in the court (Leenen and Jansen, 2020). Encryption method dynamism and varying mobile devices are the two main challenges that keep on reoccurring and the law enforcers as well as forensic professionals must continue to keep up, innovate and improve in the area of mobile device forensics (Yaacoub et al., 2021).

4. Technology and its use in criminal investigation

Technology is an inevitable aspect of everyday living, and the increasing speed of technological advancements in the modern world in the form of smartphones and tablets has radically changed how individuals communicate, store data and transact their daily business, and the net effect is that mobile devices have become prolific in offering a plethora of potential digital evidence in judicial proceedings. The law enforcement agencies of Punjab have a plethora of problems with utilizing this evidence to investigate crimes and convict the criminals (Wilson and Chi, 2017). The increased levels of encryption and advanced security features on mobile devices pose a daunting obstacle to data retrieval and interception; in situations where law enforcement officers face encrypted messaging, locked phones, and encrypted data, retrieving important evidence can be challenging, and current forensic methods might fail to match up with the ever-evolving technology, yielding incorrect and timid outcomes (Tassone et al., 2013). Collecting and preserving digital evidence also raises critical ethical and procedural issues, since it is essential throughout an

investigation to follow legal guidelines and maintain the chain of custody and reliability of evidence (Eren, Morina, & Papajorgji, 2021).

Forensic analysis is the only way to complete criminal investigation that will go a long way to resolve heinous crimes and other types of violence; without practicing forensic science, it will be extremely hard to arrest any criminal unless someone was present when the crime occurred. Forensic science deals with the analysis of evidence to establish facts that are admissible in a court of law, and without its help, murderers, thieves, drug traffickers, and rapists would roam free, making it of utmost importance for police forces to keep pace with modern forensics in terms of training, equipment, and analytical tools (Khan, 2018). Due to the increased technology, forensic science has been transformed into a revolutionized discipline, providing investigators with efficient tools and skills that can be applied in the gathering, investigation, and analysis of evidence (Nawaz, 2021).

The art of retrieving and processing information in electronic gadgets, known as digital forensics, has now become a highly critical part of the investigation of crimes (Casey, 2011). Computer and mobile device forensics can extract and analyze digital evidence such as emails, text messages and internet browsing history to provide investigators with vital insights and leads in cases involving cybercrime, fraud and terrorist activities (Carrier and Spafford, 2003). Developments in imaging technology have also reinvented the ways investigating teams trace and record crime scenes: methods such as 3D scanning, photogrammetry, and drone imaging permit investigators to develop an accurate recreation of a crime scene, retaining key evidence and offering a solid visual presentation of information to jurors in court (Laycock et al., 2017). The potential of researchers and practitioners has also been enhanced by technology in the field of forensic anthropology, with computer tomography (CT) scanning and magnetic resonance imaging (MRI) making skeletal human remains much easier to study (Dirkmaat, 2012), and developments in the DNA analytic field making the possibility of identification of individuals using skeletal remains a possibility where classical methods cannot be used (Prinz et al., 2019). But these developments also introduce issues of data privacy, evidence integrity, and admissibility, which forensic investigators need to tackle (Rogers, 2016), and necessitate cooperation among forensic scientists, law enforcement agencies, lawmakers, and jurists.

Digital Evidence Management Systems (DEMS) have the significance in the global law-enforcement agencies, and Pakistan is not an exception. DEMS is a computer program designed to store, process, and analyze digital evidence, which can be in the form of videos, photographs, audio tapes, documents and other multimedia files related to a criminal case or a pending lawsuit (Casey, 2011). Under these systems, it is easy to gather and process all types of digital evidence, and due to the ever-increasing use of digital devices and technologies in criminal activities, there is an increased necessity for a solid system of digital evidence management in Pakistan, allowing investigators to quickly search and retrieve potential evidence, streamline case handling, and preserve digital evidence integrity throughout the process (Shah, 2022).

Crime analysis technologies make use of data analytics and geographic information systems (GIS) to determine crime time patterns, trends, and hotspots, while predictive policing algorithms utilize historical crime data to denote possible future criminal activity so that resources can be allocated to predict outcomes (Mohler et al., 2015). Biometric identification systems, as seen in facial recognition and fingerprint matching, aid law enforcement agencies in identifying individuals believed to be criminals through fast and accurate identification, with automated fingerprint identification systems scanning fingerprint images against massive databases to match suspects with criminal records (Jain et al., 2016), and facial recognition technologies designed to recognize individuals depicted in surveillance footage and photographs through facial feature

analysis (Ross et al., 2018).

Digital forensics is essential to isolate crime that involves electronic gadgets and cyber crimes; digital forensic examiners analyze not only retrieved files but also internet browsing history and other communications in order to recreate events and expose suspects (Carrier & Spafford, 2003; Casey, 2011). Digital forensics also allows law enforcement agencies to collect actionable intelligence that can help track criminal activity and assist prosecutions in court. The increasing debate on civil liberties and government surveillance is an issue related to the gathering and utilization of digital evidence, especially biometric and surveillance equipment (Lyon, 2020), and the fast pace of technological change means that law enforcement agencies must constantly modernize their equipment, train staff, and revise their policies and procedures to overcome new threats and opportunities (Nobles et al., 2019).

5. Legal Framework for Forensic Evidence in Pakistan

Forensic science, also termed the “Science of Justice,” offers the study of evidence for use in courts, and its importance has grown considerably in Pakistan, where the legal framework is currently governed by several legal regulations, particularly the newly introduced legislation, the Punjab Forensic Science Agency Act 2007. The legal system in Pakistan dates back to the British colonial system and was therefore especially focused on witness statements and testimony early on; nevertheless, the passage of time showed that a verdict could lead to the conviction of innocent individuals or acquittal of criminals when relying on a system of human observation or a verbal statement alone (Rehman & Zubairi, 2018), and forensic science had to be used to contain such risks.

The Punjab Forensic Science Agency (PFSA), whose legal basis is the Punjab Forensic Science Agency Act 2007, decides the structure and composition of the agency and the way forensic evidence should be presented practically in court (PFSA Act, 2007). The Act marks a milestone because forensic services were, for the first time in Pakistan, legally recognised: under it, the PFSA was set up with different departments including DNA, fingerprints, firearm analysis, digital forensics, and toxicology, primarily aimed at introducing serious scientific techniques into the entire process of investigation and trial to reduce errors and inaccuracy in solving crime (Khan & Hussain, 2020). Article 3 of the Act establishes the creation and structure of the agency; Article 4 sets out its responsibilities, including the interpretation of forensic evidence and expert opinion; Article 10 makes expert opinion admissible in court; and Article 12 gives the court a right to have forensic material re-analyzed where it believes there is sufficient reason. PFSA has been central to a number of high-profile cases; for example, its DNA analysis services assisted in the identification and conviction of the perpetrator in the 2018 murder case of Zainab Ansari in Kasur (Ali & Bukhari, 2017), and, in a case in the Multan region in 2017, PFSA’s DNA analysis services helped acquit an innocent person.

The relevance of scientific evidence is also embedded in the Code of Criminal Procedure 1898, whose primary goal is to act as a code of behaviour in investigation, arrests, evidence, and court proceedings (CrPC, 1898). Section 510 of the CrPC allows courts to accept the report of a medical or technical expert as admissible evidence without the expert’s presence in court, while Section 164 governs how the statement of an accused or a witness is recorded, so that where it is accompanied by scientific or technical evidence, the veracity of the statement is further strengthened. Thus, forensic evidence in the CrPC has a legally recognized status, provided it is obtained under proper procedures, and today forensic evidence is considered conclusive evidence in Pakistan’s judicial system, especially when it is properly collected and preserved in accordance with international norms (Khan & Rehman, 2019). The Supreme Court of Pakistan has itself emphasized the importance of scientific evidence in several decisions (PLD 2016 SC 951).

The Sindh government passed the Sindh Forensic Science Agency Act in 2017, aiming to promote forensic science facilities in that province; however, no full-fledged forensic laboratory has yet been established under this law, and the province continues to face a shortage of forensic experts, a lack of training facilities, and the non-availability of forensic laboratories, though efforts are underway to establish a forensic DNA testing laboratory at the University of Karachi (EJFS, 2018). Pakistan thus has several laws for the application of forensic science that have increased transparency and efficiency in the judicial system; however, further steps are needed for their full implementation, including training programmes, the establishment of laboratories, and public-awareness raising (Nawaz, 2021). Nevertheless, the application of forensic science in Pakistan faces a number of challenges, including the absence of trained personnel, flaws in evidence-preservation procedures, and difficulties in the proper comprehension of the legal meaning of scientific evidence in courts (Jamil, 2017); evidence retrieved at crime scenes is often not kept in a manner that renders it usable in court, and delayed release of forensic reports together with untrained investigating officers diminishes the value of scientific evidence. It is therefore high time for Pakistan to train its legal minds and lawyers in the area of forensic evidence so that they are able to evaluate scientific evidence correctly; international organizations such as the United Nations Office on Drugs and Crime (UNODC) have already provided technical assistance to enhance forensic capacity in the country (UNODC Report, 2020).

6. Legal, Ethical and Practical Challenges

6.1 Admissibility, Authentication, and Chain of Custody

The admissibility of technology-based evidence in court is a prominent feature of contemporary court proceedings, since technology has created new types of evidence and raised challenging legal issues concerning digital evidence, forensic science practices, and emerging technologies (Ahmed & Rehman, 2021). Under the principle of legality, law enforcement agencies are obligated to act within the limits of the law and constitutional and statutory stipulations when using technology in investigations, including obtaining warrants or court orders where required and observing procedural protections against unjustified surveillance or searches (Kerr, 2016; *United States v. Jones*, 2012). The principle of proportionality requires that the use of technology in investigation be proportional to the gravity of the offence or the legitimate purpose being pursued (*Riley v. California*, 2014), balancing effective crime prevention and detection against the right to privacy, freedom of expression, and immunity from arbitrary interference (Marx, 2019). Privacy protects individuals' personal autonomy against unreasonable government interference, and courts rely on standards such as the reasonable expectation of privacy and the minimization of data collection to assess the legality of surveillance and data-collection procedures (*Carpenter v. United States*, 2018; Lyon, 2020). Due process further requires transparency, accountability, and oversight to guard against the misuse of technological powers by law-enforcement institutions when evidence, surveillance, and data analysis interfere with the rights of individuals (Goldsmith & Woods, 2018).

Determining the authenticity and integrity of evidence is one of the main obstacles to legal admissibility. Evidence must be properly authenticated to warrant that it is indeed what it purports to be and has not been tampered with, which requires a transparent chain of custody documenting the storage and transfer of evidence to be presented in court; inadequate authentication can even result in the exclusion of evidence from proceedings (National Institute of Standards and Technology, 2016). Forensic evidence, especially, must endure rigorous tests of reliability and validity, which is difficult due to flawed test processes, the constraints of science, or conflicting expert viewpoints (*Kumho Tire Co. v. Carmichael*, 1999). The proliferation of digital technologies has also introduced new complications, and evidence (emails, social

media posts, electronic records) has raised special issues in areas like authentication, reliability, and interpretation, which are further complicated by the reality that technological development often outpaces law requirements (Casey, 2011; United States v. Jones, 2012; Khan, 2018).

6.2 Privacy and Ethical Consideration

The ethical considerations are critical in determining how technological innovations are applied in the field of law enforcement, especially regarding privacy; as technology keeps advancing, it is necessary to maintain ethical standards that put more emphasis on privacy, autonomy, and civil liberties, and have technology developers collaborate with law enforcement agencies and policymakers to ensure that the investigative practices are ethical in nature, rigorously supervised, and adherent to legal and moral values (Shah, 2022). Privacy rights and civil liberties are viewed as central values of democratic societies and are entrenched in the legal system of all countries as the rights to privacy of the personal life of people against surveillance, information accumulation, and sharing any personal data (Warren and Brandeis, 1890; Stone, 2008). All these technologies enable police to monitor locations, track the activities of citizens, and gather vast volumes of data without their consent (Lyon, 2020), which is questionable in terms of mass surveillance, profiling, and the chilling effect on the freedom of association and expression (Haggerty and Ericson, 2000); ethically speaking, surveillance technologies must be employed with legitimate law enforcement purposes and must be subject to high levels of oversight and accountability. The development of data mining and predictive analytics allow law enforcement agencies to comprehend patterns, trends, and deviation indicators that may indicate criminal activity through processing large amounts of data, yet this also leads to ethical concerns related to the sensitivity of the data, algorithmic bias, and discrimination (Gilliom and Monahan, 2013), as well as the issue of consent, transparency, and data protection (Lyon, 2018).

Emerging types of biometric identification, including DNA and facial recognition raise new ethical concerns since they are so intrusive and can be exploited and misused. Facial recognition technologies enable tracking and identification of individuals on a large scale by recognizing them using facial features, rendering the developments dubious when it comes to surveillance, profiling, and falsely identifying individuals (Garvie et al., 2016). The ethical concerns related to genetic privacy, data security, and genetic discrimination are even more worrisome when genetic information gathered about individuals finds its way into DNA databases identifying crime perpetrators (Rothstein and Talbott, 2006); the ethical consideration here is that biometric identification technology and DNA databases must be tightly regulated and should be accompanied by an informed-consent process, with heavy controls surrounding the privacy and autonomy of the individual (Ali and Bukhari, 2017).

6.3 Resource, Training and Institutional Constraints

One of the greatest obstacles to law enforcement is the complexity of technology because the majority of newer forensic techniques, computer analytics tools and collaboration systems cannot be utilized without specialized knowledge (Carrier, 2014); the rate of technological change means that law enforcement agencies have to continually invest in training and professional growth to keep pace with it (Kappeler et al., 2010). Another barrier is the adoption of new technological advances into existing systems and infrastructure, as police departments often use legacy systems and databases, which might not be compatible with new technology (Reaves, 2015), and adopting new technologies into existing workflows is often a costly and time-consuming task, which can require extensive investment in system upgrades and data migration (Makridakis, 2017).

Limitations of resources such as budgetary constraints and insufficient technological infrastructure is also a

significant issue in the implementation and integration of technological advances in law enforcement, as many agencies struggle with funding costly technology upgrades and infrastructure modernization (Kappeler et al., 2010), and underserved and rural populations might have less access to high-speed internet, digital materials, and technology infrastructure, further increasing the digital divide in technological adoption (Ferguson, 2017). Such limitations complicate the maximization of the gains of technological progress in law enforcement, and, in the context of Pakistan, specifically, resources, training, and institutional coordination are incongruent to bring the forensic capability modern.

7. Comparative Perspective: Forensic Practice in the United Kingdom

In the United Kingdom, scientists employed by the police maintain the crime scene and make sure that bloodstains, fingerprints, hair, or weapons are scientifically preserved and then passed on to a laboratory so that the identity, date, and possible perpetrator of a crime could be identified (FSS, 2018). A number of solved cases in the UK demonstrate how useful this method can be: the first time in the case of Colin Pitchfork, the case was solved based on DNA evidence that allowed identifying a criminal and convicting him (BBC News, 2004), and in the case of Stephen Lawrence, the criminals were found guilty many years later with the help of sophisticated forensic technology (The Guardian, 2012). The 21st century has seen artificial intelligence increasingly implemented in forensics within the UK, enabling evidence to be processed much faster and more accurately; the technology has been used to automatically process photographic data, fingerprints, facial recognition, and DNA profiles, and UK police and security agencies are also using AI to predict crime trends so that criminal can potentially be identified before they strike, with AI-based face detection of CCTV videos becoming a comparatively common practice in several cities, which is both more efficient and quicker and more transparent than the human eye.

The UK example demonstrates both the potential and the constraints of technological modernization: DNA and digital forensics have facilitated faster and more precise investigation and have enabled the reopening and resolution of cold cases, but the same technologies have brought about ongoing questioning of civil liberties, data retention, and algorithmic bias, most prominently in the ruling of the European Court of Justice in *S and Marper v UK* (2008) that non-criminal DNA data retention was a violation of human rights. This comparative experience is the point that is made throughout the body of this paper namely that technological progress in the field of forensic science should be, step by step, accompanied by an equally stringent legal and ethical framework in order to be of benefit, and not detriment, to the interests of justice.

8. Conclusion and Recommendations

The technological advances in the field of forensic science provide a tremendous benefit in the criminal investigation process, but they also come with a lot of legal and practical issues. To overcome such challenges, a very balanced approach that entails adjusting legal frameworks, ethical implementation, adequate training, and acquisition of the requisite resources is necessary, such that law enforcement agencies can harness the potential of these technologies to enhance the efficiency of criminal justice system. The increased use of forensic instruments, like DNA analysis, digital forensics, and biometrics by the law enforcement agencies should have been accompanied by the consideration of the legal and moral aspects of the circumstance; a solid legal framework and ethical guidelines should be implemented in relation to the privacy, admissibility of evidence, and the possibility of misuse. Most importantly, the use of technology should be introduced into the regular legal systems to prevent the abuse. On the one hand, the evolution of forensic science has aided to improve the investigation process, on the other hand, it is evident that ethics are the key factors in the correct utilization of technology and when these norms are not followed, the civil

rights of people will be infringed and trust in the courts will be lost.

Law enforcement agencies are urged to pay specific attention to the latest technological advancements and the training of human resources, where the officers are not only familiar with the use of modern equipment but also trained on when, where, and how to use it in a legal and ethical context. Another critical concern is the lack of resources and especially in the rural settings where the forensic facilities are not available; to close this gap the state needs to invest and increase budgets and be able to cooperate between institutions to deliver justice equally at each level. Interagency coordination, standard practices and secure data-access channels are also critical as information exchange between investigative agencies saves time and makes the process of investigation more transparent and expedited, which a central digital system might facilitate. With the appearance of new technologies, policymakers need to adopt a law, control its implementation, and update policies on a regular basis, as the technology will not be able to bring positive change until it will work in an open, safe, and fair system. The solution is to strike a balance between technological advancement and morality and the law, to achieve an effective and fair criminal justice system.

On this basis, the following recommendations are offered:

1. **Comprehensive specialized training programmes.** Specific training modules relating to particular technologies (e.g., DNA analysis, digital forensics) should be developed and instituted in initial police training as well as continuing professional development, to ensure officers remain well conversant with new forensic techniques and instruments.
2. **Interagency forensic task forces.** Specially trained task forces made up of officers from different agencies and laboratories dealing with law enforcement and forensics should meet frequently to exchange experience and cooperate on cases requiring multi-agency coordination, ensuring forensic information is shared effectively across jurisdictions.
3. **A centralized forensic database.** A national or regional centralized database of forensic information, accessible to authorized law enforcement and forensic professionals and protected by stringent access controls and data-protection procedures, would increase data sharing and improve the accuracy of forensic investigations by supplying high-quality, readily available data.
4. **Investment in rural and under-resourced departments.** Additional funds and grants should be directed toward rural or under-resourced law enforcement agencies to acquire vital forensic equipment and technologies, so that all departments can conduct forensic investigations to a comparable standard irrespective of budget.
5. **A digital chain-of-custody system.** A secure, blockchain-based digital chain-of-custody management system for forensic evidence should be designed and implemented, with officers trained in its use, to minimize the chances of tampering or loss and enhance the credibility of evidence in court.
6. **Regulatory oversight.** Independent monitoring bodies should be established to guide the use of forensic technologies by concerned departments and to conduct regular audits and reviews addressing misuse or non-compliance.
7. **Regular updating of legal standards.** A periodic review cycle, supported by a legal-technical advisory board, should be established to keep legal standards for forensic evidence aligned with technological change, so that forensic evidence remains admissible in courts and reliable in argument.
8. **Public awareness campaigns.** Awareness among citizens of their role and contribution to forensic science within the criminal justice system should be raised through social media, workshops, and

open seminars, developing public trust in forensic science and reducing misunderstanding or distrust of its application in solving criminal cases.

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