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Advancements in Forensic DNA Analysis and Its Role in Sustainable Justice Systems (Exoneration of Wrongfully Convicted Suspects as an Example)

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الملخص.تبحث هذه الدراسة الشاملة في الدور والآثار الحاسمة لتحليل الحمض النووي الجنائي في أنظمة العدالة الجنائية الحديثة، مع التركيز على توافقه مع الهدف 16 من أهداف التنمية المستدامة للأمم المتحدة (السلام والعدالة والمؤسسات القوية). وتلعب أدلة الحمض النووي الجنائي دورًا محوريًا في تحديد هوية الجناة بدقة، وربط المشتبه بهم بمسارح الجريمة، وتبرئة الأبرياء المحتجزين ظلماً. ومن خلال الحد من الإدانات الخاطئة وحل الجرائم الخطيرة مثل السرقة والقتل والاعتداء الجنسي بكفاءة أكبر، تُعزز التطورات في مجال الطب الشرعي سيادة القانون وتُحسّن المساءلة المؤسسية. وتتضمن الدراسة رؤىً قائمة على البيانات، ومقارنات دولية، ودراسات حالة، مما يُبرز أهمية التقدم المستمر في علوم الطب العدلي. وتُولي الدراسة اهتمامًا خاصًا للأطر الأخلاقية وتوصيات السياسات التي تُوجه ممارسات الحمض النووي ضمن الأنظمة القانونية، مثل نظام إقليم كردستان.

Abstract. This comprehensive study examines the critical role and effects of forensic DNA analysis in modern criminal justice systems, emphasizing its alignment with UN Sustainable Development Goal 16 (Peace, Justice, and Strong Institutions). Forensic DNA evidence plays a pivotal role in accurately identifying perpetrators, linking

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suspects to crime scenes, and exonerating innocent individuals wrongfully detained. By reducing wrongful convictions and resolving serious crimes such as theft, murder, and sexual assault more efficiently, forensic advancements strengthen the rule of law and improve institutional accountability. The study incorporates data-driven insights, international comparisons, and case studies—highlighting the importance of continued progress in forensic science. Special attention is given to ethical frameworks and policy recommendations guiding DNA practices within legal systems like that of the Kurdistan Region.

Introduction:

The rise in violent crimes such as murder, rape, and armed robbery in the Kurdistan Region has intensified the demand for accurate and rapid criminal investigation techniques. Despite the Iraqi Penal Code's severe punishments and ongoing efforts, crime rates continue to rise, highlighting the critical need for reliable forensic tools. Forensic DNA technology has emerged as a cornerstone of modern forensic science, enabling authorities to solve complex cases with unprecedented precision and fairness . According to the Locard Exchange Principle, "every exposure at the crime scene leaves traces, including DNA, on the victim or the crime scene itself" (2020 - Locard). This scientific foundation underlines the importance of collecting and analyzing DNA evidence to either confirm or refute allegations against suspects. In the Kurdistan Region, systematic collection and storage of DNA samples—such as through civil status identification, driver's licenses, or passports, and from visitors—could significantly enhance the ability of forensic offices to match crime scene DNA with potential perpetrators. Our study emphasizes the importance of proactively storing DNA profiles of individuals in society before crimes occur. This proactive approach supports forensic medicine's role in improving the rationality and objectivity of criminal justice decision-making. Forensic scientists meticulously analyze evidence, making excuses or denials from the accused less impactful during trials. Without precise forensic analysis, wrongful punishments and miscarriages of justice become more likely due to misinterpretation or insufficient evidence . The profession of forensic expertise carries immense responsibility, as forensic experts assist judges by providing scientifically sound evidence essential to reaching the truth. After courts review forensic reports, this evidence becomes a vital component in the judicial balance of evidence to determine legal outcomes.

Therefore, integrating forensic science into the legal system not only strengthens the rule of law but also fosters justice and public trust—key elements for sustainable development and peace in society.

Research Problem:

In the Kurdistan Region, through the media, we often hear that a crime has been committed and the perpetrator is unknown, or people are detained on suspicion, so this study tries to present the important role of forensic medicine Innocent people should be extended by taking a DNA sample from every individual in the community, including citizens and guests, storing it in the forensic office, in the case of theft, rape, murder or any other crime innocent defendants .

The importance of research:

Every scientific research is naturally important and takes its place in the right place, because the goal of the researcher in writing research is to feel the existence of a gap, which can be filled in an appropriate field and taken into account (Mr. Mand-2020) However, the importance of this study is for the legislature and the authorities to consider its recommendations to create a progressive environment in the Kurdistan Region, because the processing of DNA from anyone without reason, or without a court decision. A DNA sample should be taken from it, so that it can be used in courts at any time, which will lead to faster investigation of criminal cases and protect the security of the country, in addition to making the Kurdistan Region become a leader in powerful countries.

Purpose of Research:

Our study aims to examine and demonstrate how advances in forensic DNA analysis have improved the process of criminal investigations, by facilitating more effective identification of suspects, while helping to exonerate those who have been wrongly detained, or charged. It also aims to highlight specific instances or cases where forensic DNA analysis has played an important role in both creating reasons to arrest the true perpetrators of crimes and in ensuring justice and releasing innocent individuals.

1. Part 1 Research Methodology DNA, forensic and suspect definitions:

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1.1. Definition:

Deoxyribonucleic acid (DNA) is the polymer that carries the genetic information of all living cells and many viruses (2015- Mama Janov) or deoxyribonucleic acid, a molecule that contains the genetic instructions for growth, function and reproduction of all organisms known organisms and many viruses. It consists of two long strands wrapped into two helices and consists of nucleotides, each containing a sugar, a phosphate group, and a nitrogenous base (adenine, thymine, cytosine, or guanine). Alberts-2002.

1.1.1. Definition of Forensics:

Forensics refers to the application of scientific principles and techniques to the investigation of crimes and legal matters. The term "judicial proceedings" is derived from the Latin word "forensic," meaning "in or before the forum" or "pertaining to public discussion or debate." In the context of criminal justice and legal proceedings, forensic science is the collection, examination and analysis of physical evidence to prove facts, resolve disputes and support the legal process (.James-2014) Forensic science includes various scientific disciplines, including : 1 .Forensic Biology: Analysis of biological evidence such as DNA, blood, saliva, hair, and other body fluids to identify individuals or make links between people and crime scenes . 2.Forensic Chemistry: The examination of chemicals, such as narcotics, toxins, and trace elements, to determine their composition and possible role in criminal activity.

1.1.2. Forensic Toxicology:

The study of the effect of drugs, chemicals, and toxins on the human body, often in the context of a criminal investigation or post-mortem examination.

1.1.3. Determination of cause of death:

Investigation of the cause and circumstances of death through autopsy and examination of human remains, with the aim of determining the manner and cause of death .

1.1.4. Forensic Anthropology:

Examination of human skeletal remains to determine the identity of individuals, assess trauma or injury, and give insight into the circumstances surrounding death .

1.2. Digital Forensics:

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Retrieve, analyze, and preserve electronic data from computers, mobile devices, and digital storage media to gather evidence related to cybercrime, fraud, or other digital crimes.

1.2.1. Medical dentist:

Examination of dental evidence, including bite marks and dental records, to identify individuals or provide insight into criminal cases 8 .Forensic science therefore plays a crucial role in criminal investigations, court proceedings and the administration of justice by providing objective and scientific methods for analyzing evidence, identifying suspects and establishing facts in legal cases Crime.(Azad-2023)

1.3. Definition of accused:

A person suspected of committing a crime that has not yet been proven and is under investigation, may be changed from accused to guilty due to the presence of evidence, or acquitted due to lack of evidence He is acquitted.

2. Part Two: Properties of DNA

2.1 DNA, or deoxyribonucleic acid, possesses several key properties that make it essential for the storage and transmission of genetic information in living organisms. Some of the basic properties of DNA are: 1. Storage of genetic information: DNA acts as the primary repository of genetic information in living organisms. Nucleotide sequences in DNA encode instructions for the creation and maintenance of organisms, 2. Regeneration: DNA is able to replicate itself, ensuring that genetic information is passed on accurately from one generation of cells to the next as cells divide. During DNA replication, the two strands of the DNA molecule are broken and each strand acts as a template to create a new complementary strand. This process allows for the transmission of genetic information. Altogether, these properties of DNA make it a fascinating molecule that plays a key role in the storage, transmission and expression of genetic information in all living organisms. (Michael and Simmons-2015) 3. Non-replication: , one person's DNA does not replicate with another person's DNA in the sense of joining or merging together. DNA replication refers to the process by which a cell makes an exact copy of its DNA before cell division, ensuring that each new cell receives an identical copy of the genetic information. Instead, during sexual reproduction, specialized cells called gametes (sperm and egg cells) from two different individuals combine during fertilization, resulting in a new organism with a

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unique mix of genetic material from both parents It shouldn't be. Each parent contributes half of the genetic material to the offspring, and the DNA of each parent remains separate and intact within the cells of the offspring. That is, throughout humanity, no human DNA is the same as another human being and each is distinguishable. (2008 -John and Hunt).

2.2 Presence of DNA in human sites: DNA is present in various body tissues and fluids, including saliva, hair, blood, sperm, and others. Here DNA can be found in these different biological materials: 1. Saliva: Contains the cells of the lining of the mouth, which is shed regularly. These cells contain DNA that can be extracted for genetic analysis. Saliva is commonly used for DNA testing in applications such as paternity testing and forensic identification. 2. Hair: Hair follicles contain cells with DNA in their nuclei. When a hair is pulled out, it often leaves a small amount of tissue from the follicle attached to the root. This tissue contains DNA that can be analyzed for identification purposes. 3. Blood: Contains a variety of cells including white blood cells (leukocytes) and red blood cells (erythrocytes). Specifically, white blood cells contain nuclei with DNA. Blood is a common source of DNA for medical diagnosis, forensic analysis, and genetic testing. 4. Sperm: Sperm cells carry DNA inside their nucleus, tightly packaged inside the sperm head. DNA from sperm can be analyzed for paternity testing, fertility assessment and genetic disorders. 5. Other body fluids: DNA can also be found in other body fluids, such as semen and other secretions such as vaginal discharge, urine, tears and sweat. These fluids may contain cells or cell fragments with DNA that can be extracted and analyzed. 6. Tissues and Organs: Virtually all body tissues and organs contain cells with DNA. Biopsies or specimens collected during surgery can provide DNA for diagnostic testing, research, or transplant purposes. In summary, DNA is present in various tissues and body fluids throughout the human body. These DNA sources can be used for a variety of applications, including medical diagnosis, forensic identification, paternity testing, and genetic research. (2024 - collaborators-yawang)

2.3 Lifetime of DNA after storage: The longevity of DNA samples stored in the laboratory depends on several factors, including storage conditions, the type of sample, and the DNA extraction and purification methods used, In general, under optimal storage conditions, DNA can remain stable and intact for many years or even decades. Here are some key considerations: 1. Temperature: DNA is most stable when stored at low temperatures, typically -20°C or lower. Storing DNA samples in ultra-low temperature freezers or

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freezers (-80°C) helps prevent degradation and preserves the integrity of DNA molecules. 2. Moisture Form: DNA samples should be stored in a dry environment so that moisture cannot cause degradation. Closed containers or tubes containing desiccants can help maintain low humidity levels and preserve DNA integrity. 3. Light exposure: Exposure to light, especially ultraviolet (UV) rays, causes DNA damage and degradation. DNA samples should be stored in opaque containers or wrapped in foil to protect them from light exposure. 4. Contamination: Contamination by microorganisms, enzymes, or other chemicals can damage DNA over time. Proper handling techniques, sterile conditions, and regular maintenance of laboratory equipment can help minimize contamination and maintain DNA integrity.

5. Sample type: The type of sample can also affect DNA stability. Purified DNA samples, such as those from blood or saliva, tend to be more stable than raw or complex samples, such as tissue biopsies or environmental samples. 6. Storage medium: The choice of storage medium can affect DNA stability. DNA is commonly stored in buffers or solutions that help protect it from degradation. Commercially available DNA storage buffers or preservatives can enhance long-term stability.

7. With appropriate storage conditions and proper handling, DNA samples stored in the laboratory can remain intact for many years. However, it is important to periodically monitor stored DNA samples for signs of degradation and to follow best practices for sample storage and management to ensure DNA integrity over time. (Smith and Jones)

Part three*:*

3.1 The role of DNA in identifying criminals and acquitting detainees

DNA evidence has played a significant role in identifying perpetrators in many criminal cases since its discovery. DNA profiling, also known as DNA fingerprinting, revolutionized forensic science by providing a highly accurate method of identifying individuals based on their unique genetic codes. Countless criminal cases have been solved using DNA evidence, from murder and rape to theft and other crimes. DNA evidence has been instrumental in convicting both the guilty and the innocent. In the United States, for example, the Exoneration Project has used DNA evidence to help exonerate large numbers of people wrongly convicted of crimes they did not commit. In these cases, DNA evidence not only identified the real perpetrators but also highlighted flaws in the criminal justice system, such as misidentification of witnesses or faulty forensic techniques . Overall, DNA evidence has become

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the cornerstone of modern criminal investigations and has contributed greatly to the identification and prosecution of offenders in a wide range of cases around the world (2011- Garrett)

3.2 Examples of wrongfully convicted cases In 1984, in Virginia, a defendant named Earl Washington, under torture and false testimony confessed to rape and murder, so the defendant was sentenced to death, but 17 years after receiving this sentence, DNA testing raised doubts about his conviction DNA tests showed that the semen on the clothes of the accused had nothing to do with the sperm of the accused. Therefore, after 17 years in prison, he was acquitted and immediately released . DNA tests have undermined confidence in the country's criminal justice system, leading to a review of dozens of other cases in the country, revealing that (250) other people who were wrongly convicted were acquitted by DNA tests. (Garrett-2011 ibid.). Therefore, according to the researcher, if a DNA sample is taken from each individual in society and stored in the forensic office, if necessary compared with the suspect, will serve the court and society, shortening the investigation and results easier to obtain .

3.3 Countries' support for DNA repositories The storage of DNA profiles or samples of individuals in forensic databases varies by country and it is not uncommon for some countries to maintain DNA databases for law enforcement purposes. Here are some examples : 1 .The US FBI administers the Combined DNA Index System (CODIS), which includes DNA profiles of convicted offenders, unsolved crime scene evidence, and profiles of missing persons and relatives. Additionally, its individual people have their own DNA database. (NATIONAL INSTITUTE OF JUSTICE -2016) 2.United Kingdom: The UK maintains the National DNA Database (NDNAD), managed by the Home Office's National DNA Database Unit (NDU). It contains DNA profiles of people convicted of certain offences, as well as profiles of crime scene evidence.(GOV.UK-2014) 3 .Canada: There is a national DNA data bank maintained by the Royal Canadian Police (RCMP). It includes DNA profiles of convicted criminals, as well as profiles of crime scene evidence. The National DNA Data Bank (NDDB) maintains a collection of more than half a million DNA profiles. These profiles help investigators across the country solve crimes and help identify human remains. Regardless of police jurisdiction, the primary purpose of the NDDB is to help support criminal and humanitarian investigations by : Helping identify suspects, so these national centers, when a crime occurs, DNA is stored at the scene, in a computer with data, anyone in this country when he wants to get government support for

employment or work, the DNA is compared. This is aimed at eliminating suspects where there is no match between a crime scene DNA profile and a convicted offender's DNA profile (Royal Canadian mounted police-2021) 4. EU: Some EU countries maintain DNA databases, and there are PROM decisions, which allow the exchange of DNA profiles and other forensic data between EU member states, in order to find and arrest fugitives Criminals arrested.(European councll-2017) 5. Other Countries: Many other countries in the world, including Australia, Japan, and various European countries, also have DNA databases for law enforcement purposes.(NPA-2022) It is very important to note that database establishment and management of DNA databases are subject to national laws and regulations, and privacy concerns are often carefully considered. Additionally, features of what types of individual DNA profiles are stored and in what circumstances they can be used.

Table .1: Notable DNA-Based Exoneration Cases in the United States

#	Name(s)	Year of Conviction	Year of Exoneration	Details	Source
1	Gary Dotson	1979	1989	First U.S. person exonerated by DNA. Convicted of rape; victim later recanted. DNA testing confirmed innocence.	Capital Punishment in Context
2	David Vasquez	1985	1989	Wrongfully convicted of rape and murder in Virginia. DNA testing excluded him.	National Registry of Exonerations
3	Kirk Bloodsworth	1985	1993	First death row inmate exonerated by DNA. Convicted of rape and murder of a young girl in Maryland.	Innocence Project

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#	Name(s)	Year of Conviction	Year of Exoneration	Details	Source
4	Ronald Cotton	1985	1995	Wrongfully convicted of rape in North Carolina based on eyewitness misidentification. DNA testing identified real perpetrator.	Innocence Project
5	Ray Krone	1992	2002	Convicted of murder in Arizona; spent time on death row. DNA proved he was not the killer.	Death Penalty Information Center
6	Frank Lee Smith	1986	2000 (posthumous)	Died of cancer on death row before DNA proved innocence in rape/murder case.	Innocence Project
7	Earl Washington Jr.	1984	2000	Mentally disabled man wrongfully confessed to rape/murder. DNA excluded him and identified the real perpetrator.	National Registry of Exonerations
8	Nicholas Yarris	1982	2003	Spent 21 years on death row in Pennsylvania. DNA proved innocence in rape/murder case.	Innocence Project
9	Curtis McCarty	1986	2007	Oklahoma man convicted of murder. DNA	Innocence Project

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#	Name(s)	Year of Conviction	Year of Exoneration	Details	Source
				testing and misconduct findings led to exoneration.	
10	Kennedy Brewer	1995	2008	Convicted of child murder and rape in Mississippi. DNA exonerated him; false forensic evidence involved.	Innocence Project
11	Michael Blair	1994	2008	Texas death row inmate wrongly convicted of child murder. DNA and further investigation cleared him.	National Registry of Exonerations
12	Thomas Haynesworth	1984	2011	Misidentified in multiple rape cases. DNA later showed another man committed the crimes.	Innocence Project
13	Michael Morton	1987	2011	Spent 25 years in Texas prison for wife's murder. DNA testing found real killer.	Innocence Project
14	Cornelius Dupree Jr.	1980	2011	Served 30 years for rape/robbery. DNA evidence proved innocence.	Innocence Project
15	Kerry Porter	1996	2011	Convicted of murder in	Kentucky Dept. of

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#	Name(s)	Year of Conviction	Year of Exoneration	Details	Source
				Kentucky. DNA evidence excluded him and pointed to actual perpetrator.	Public Advocacy
16	Derrick Williams	1993	2011	Florida man wrongfully convicted of kidnapping and rape. DNA on clothing proved innocence.	Innocence Project
17	James Bain	1974	2009	Served 35 years for child rape in Florida. DNA testing cleared him.	Innocence Project
18	Robert Lee Stinson	1985	2009	Wrongly convicted of murder based on bite-mark evidence. DNA disproved involvement.	Innocence Project
19	Beatrice Six	1989	2009	Six individuals convicted of rape/murder in Nebraska. DNA matched another man; confessions were coerced.	Innocence Project
20	Bintz Brothers (David & Robert)	1990*	2018	Wrongfully convicted of rape and murder in Wisconsin. DNA evidence and genetic genealogy cleared them.	Wisconsin Innocence Project

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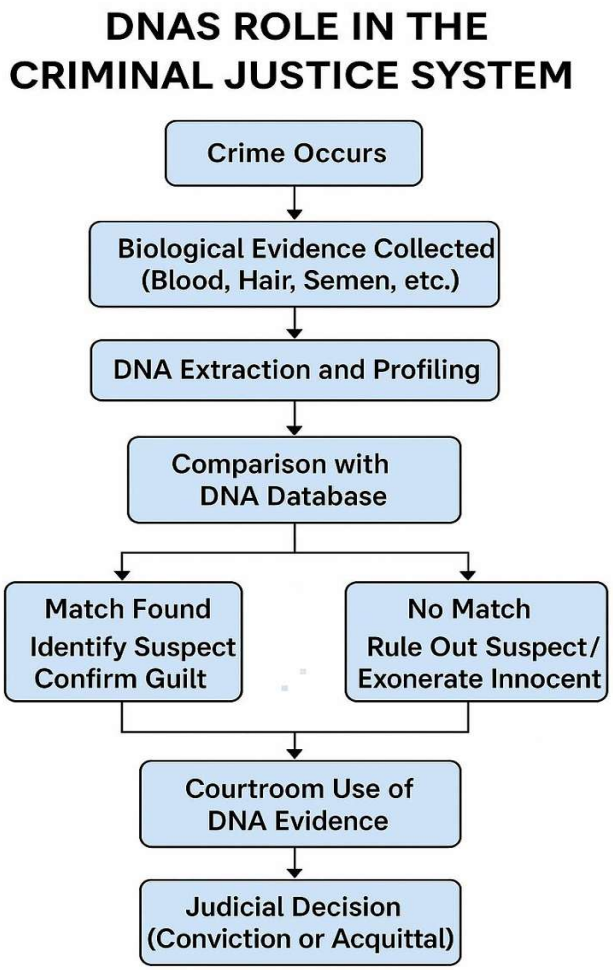

Figure 1. Role of DNA in the Criminal Justice System

Conclusion:

Our conclusion highlights the transformative effects of forensic DNA analysis on criminal investigations, emphasizing its potential to enhance accuracy, intended to facilitate the acquittal of wrongfully accused persons,

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and contribute to a more just justice system. Additionally, it recognizes the importance of addressing ethical considerations to ensure responsible use of DNA evidence, Finally, remarkable advances in forensic DNA analysis have revolutionized investigations, leading to both arrests of criminals and exoneration of wrongfully detained suspects. Using the power of science and technology, these developments have provided law enforcement with unprecedented tools, to ensure justice is served accurately and quickly, since the evolution of forensic DNA analysis has revolutionized criminal investigations by providing law enforcement with powerful tools to accurately identify and exonerate suspects. These developments have not only resulted in greater convictions of criminals but have also played a crucial role in exonerating those who have been wrongfully detained. Using techniques such as DNA profiling and next-generation sequencing, law enforcement agencies can establish links between suspects and crime scenes with unprecedented accuracy. Additionally, the implementation of family searches has expanded the pool of possible suspects, further helping to solve complex cases. In addition to the profound implications for investigations and the exoneration of the innocent, advances in forensic DNA analysis hold promise for the future of criminal justice. Through enhanced techniques and methodologies, we can anticipate greater accuracy and efficiency in identifying perpetrators and resolving cases where perpetrators remain unknown. This proactive approach not only strengthens our ability to arrest criminals but also acts as a deterrent, which causes fear, by those who intend to commit a crime, because they understand that they are easily arrested and easily identified. As we navigate the evolving landscapes of forensic science, continued investment in research, training, and collaboration will be critical to harnessing the full potential of DNA analysis in the pursuit of justice. Also, forensic DNA analysis remains the cornerstone of modern criminal justice. As we seek to harness the full potential of this powerful tool, we must be vigilant in maintaining its integrity and upholding the principles of fairness, accuracy and fairness for all. In conclusion, the steps involved in forensic DNA analysis represent a major turning point in modern criminal investigations, offering unparalleled potential in identifying the guilty and exonerating the wrongly accused. Through innovative techniques such as DNA profiling, sequencing, and the use of databases, law enforcement agencies around the world have significantly strengthened their investigative capabilities, resulting in more accurate identification and resolution of long term cases. Moreover, the impact extends beyond mere identification, with countless individuals wrongfully detained

finding justification through DNA evidence. These developments have not only restored faith in the justice system but also underscored the importance of continually pushing the boundaries of forensic science. We believe that if every individual in society, a sample of DNA is stored in the office of evidence and crime, as we have discussed in our study the survival power of DNA, which is stored in the right conditions will not be destroyed for decades. Recommendations: Based on Article 34, paragraph 3 of the Iraqi Permanent Constitution, which is also applicable in the Kurdistan Region, it says that the state shall encourage researchers and scientists to propose new sciences for the service of humanity. 1. Enact a law entitled (Protection and storage of DNA samples of every individual in society, including citizens and guests), with the aim of early access to criminals who commit crimes and compare them with DNA samples stored at the crime scene. 2. Establish an appropriate annual budget for the Office of Forensic Medicine in order to activate and promote this science. 3. After implementing the above two points (1 and 2), obliging every individual in society, citizens and foreigners, to take DNA samples from them, every (10) years, otherwise, impose severe punishment against them. Legal and Ethical Frameworks In Iraq and Kurdistan, the collection and storage of DNA are still in their infancy. Many countries like the U.S. (CODIS), U.K. (NDNAD), and Canada (NDDB) have developed national DNA databases with clear policies. These legal frameworks ensure data integrity and protect civil rights. The Iraqi Constitution (Art. 34, para 3) encourages the development of science for public welfare, providing a legal basis for DNA policy integration. DNA and Sustainable Development Goals Forensic DNA plays a direct role in SDG 16: -Promotes rule of law and equal access to justice. -Enhances institutional transparency and accountability. Challenges and Considerations Despite its benefits, challenges include: - Privacy concerns and potential data misuse. - Cost and technical infrastructure gaps.

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