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A Retrospective Study on The Pattern of Injuries Encountered in Railway-Related Deaths Brought for Autopsy at a Tertiary Care Hospital

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Abstract

Introduction: India has the largest network of railways, providing the basic mode of transportation for passengers and freight. Railway-related deaths are either accidental or suicidal, and we may also encounter homicidal deaths by using railway tracks to mask them. Railway-related deaths are rising due to various factors, viz., unmanned level crossings, lack of safety precautions during entraining or detraining, poor infrastructure, and poor safety measures. This study was conducted to determine the manner of death and the various patterns of injuries encountered in fatal railway-related deaths.

Material and Methodology: All the cases of fatal railway-related deaths brought for the autopsy to our mortuary from January 2023 to December 2024 were considered for the study. The data was collected from the Inquest report, postmortem report, relatives of the deceased, and police regarding the circumstances of death. The data was analysed systematically.

Results: A total of 99 cases were observed during the study period.Maximum fatalities (37.4%) were reported among the age group of 31-40 years. Majority of the deceased were male (99%); among them, 74 (74.8%) were known individuals and 25 (25.2%) were unknown. The maximum number of deaths observed was from 12 pm to 6 pm (33.3%), followed by 6 pm to 12 am (28.3%). Most of the deaths were accidental (72.7%) and in 16.2% of cases, the manner of death cannot be ascertained. The majority of accidental deaths were due to trespassing (65.3%). Injuries to the head were observed in most of the cases (56.1%). Among the 99 cases, Shock and Hemorrhage was the most observed cause of death (35.4%), followed by Head injury (26.3%).

Keywords: Railway-related deaths, Accidental, Trespassing, Shock and Hemorrhage.

Introduction

India has the largest network of railway providing the basic mode of transportation for passengers and freight. It carries about 10-12 million passengers every day, travelling the length and breadth of our country covering about 10,000 sq. kilometers[1]. It is also one of the cheapest modes

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of transportation, that is spread across the whole country. Death associated with railways mostly occurs when a person attempts to cross the track or uses the track as a convenient route for walking[2]. Accident prone spots, unmanned crossing and railway tracks passing through the city limits which are usually not covered by fencing further worsens the situation[3]. Railway-related fatalities, whether accidental or intentional, constitute a substantial public health and forensic challenge.

In recent years, railway-related deaths have emerged as a critical issue in many regions, with a diverse range of circumstances leading to such incidents, including accidental falls, collisions and suicides. Understanding the pattern and severity of injuries associated with these incidents is crucial for improving railway safety measures and planning preventive strategies. After reviewing the literature on railway-related death, it was observed that, the pattern of injuries related to railway-related deaths and its mechanism was not properly researched and for this purpose, we plan to find out the pattern of injuries related to railway accidents. The present study will provide valuable insight into the mechanism of trauma, help forensic experts in determining the manner of death and guide policymakers in enhancing safety protocols.The findings will contribute to a better understanding of railway-related fatalities and support efforts to mitigate their occurrence.

Material and Methodology

This is a retrospective, descriptive and analytical type of study conducted at the Department of Forensic Medicine, Dr.V.M.G. M. C, Solapur (Maharashtra), over a period of two years between 1st January 2023 to 31st December 2024. The type of sample included were all fatal railway-related deaths that were brought for autopsy to our centre.

Inclusion criteria – Allthe unnatural deaths, encountered in railway related deaths,which were brought for autopsy.

Exclusion criteria – Allthe natural deaths and decomposed bodies, encountered in railway related deaths,which were brought for autopsy.

In each case, complete autopsy was conducted and the data was collected from the Inquest report, autopsy report and police regarding the circumstances of death.The data collected was recorded in a designed proforma sheet and tabulated in Microsoft excel sheet and analyzed.

Observations and Results

A total of 4647 autopsies were conducted during the study period, i.e. from 1st January 2023 to 31st December 2024, of which 99 (2.1%) cases were due to railway related deaths.

It was observed that, out of 99 cases, maximum number of railway fatalities was observed in the age group of 31-40 years (37.4%), followed by 41-50 years (20.2%) of age group as depicted in Chart no.-1. Majority of railway fatalities were observed among males (99%) and only one case (1%) of female death related to railway fatality was observed (Table no.- 1). Majority of the deceased were Hindus (66.7%), while 9.1% of deceased were Muslims. However, in 24.2% of cases, religion could not be traced (Table no.-2). During study, 74.8% of the individual's identity could be traced out, while in the rest of cases (25.2%), individual's identity could not be traced out, even after thorough investigations (Table no.- 3). Maximum fatalities occurred during the time interval of 12 pm – 6 pm (33.3%), followed by 6 pm -12 am (28.3%) and 6 am to 12 pm (25.2%) respectively (Chart no.- 2). It was observed that haemorrhagic shock (35.4%) was leading cause of death, followed by head injury (26.3%) (Table no.- 4). In majority of the cases, the manner of death was accidental (72.7%), followed by suicidal (11.1%). However homicidal death was not registered during the study period. In 16.2% of cases, manner of death could not be traced out even after thorough medicolegal autopsy and police investigations (Table no.- 5). Most accidental deaths occurred during trespassing (65.3%) while the other ways of accident were – falling from moving train (15.3%), accidental fall during acceleration (9.7%) and accidental fall during deceleration (9.7%) (Table no.- 6). Majority of the injuries were sustained to head (56.1%), followed by injuries to lower limbs (48.8%) and upper limbs (45.8%) respectively

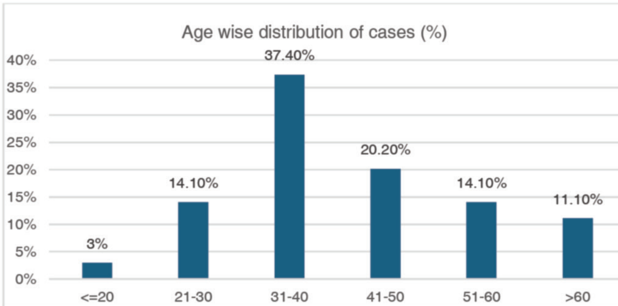

Chart No. 1: Age Wise Distribution

Table No. 1. Gender Wise Distribution

Male	Female	Total
98 (99%)	1 (1%)	99 (100%)

Table No. 2. Religion Wise Distribution

Religion	No of Cases
Hindu	66 (66.7%)
Muslim	9 (9.1%)
Not Known	24 (24.2%)
Total	99 (100%)

Table No. 3. Percentage of Known and Unknown individuals

Known	Unknown	Total
74 (74.8%)	25 (25.2%)	99 (100%)

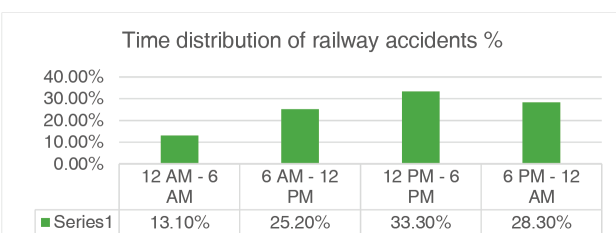

Chart No. 2: Time Wise Distribution

Table No. 4. Cause of Death

Cause of Death	No of Cases
Blunt Injury	3 (3%)
Crush Injury	15 (15.2%)
Decapitation	8 (8.1%)
Head Injury	26 (26.3%)
Haemorrhagic Shock	35 (35.4%)
Traumatic Transection	10 (10.1%)
Injury to vital organs	2 (2%)
Total	**99 (100%)**

Table No. 5. Manner of Death

Manner of Death	No of Cases
Accidental	72 (72.7%)
Suicidal	11 (11.1%)
Homicidal	0 (0%)
Not Known	16 (16.2%)
Total	**99 (100%)**

Table No. 6. Manner of Accident

Manner of Accident	No of Cases
Trespassing	47 (65.3%)
Falling from moving train	11 (15.3%)
Accidental fall during Acceleration	7 (9.7%)
Accidental fall during Deceleration	7 (9.7%)
Total	**72 (100%)**

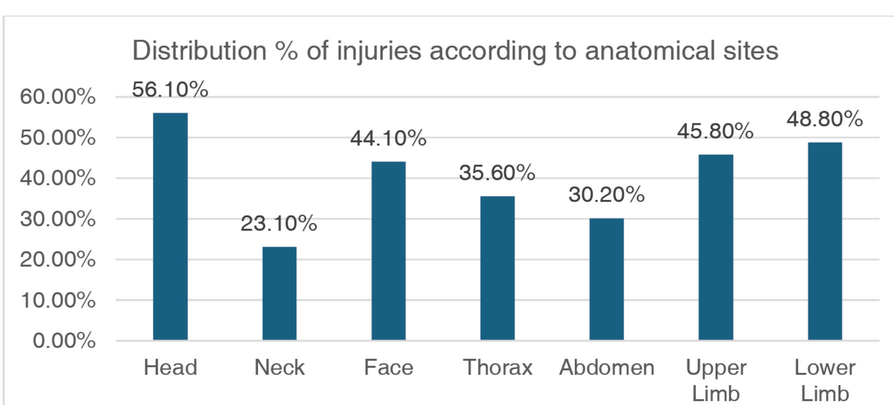

Chart No. 3: Distribution of Injuries According to Anatomical Sites

Table No. 7. Pattern of Injuries

Region	Abrasion	Contusion	Laceration	Abraded-Contusion	Crush-Laceration	Fracture	Decapitation/ Amputation
Head, Neck & Face	49	43	33	28	16	59	8
Thorax	33	35	13	39	3	61	4
Abdomen	54	27	18	41	7	19	9
Periphery	71	74	72	77	51	73	5
Total	**207**	**179**	136	185	77	212	26

Figure 1: Traumatic Transection at the level of T_{12}-L_1 vertebrae

Figure 2: Multiple injuries encountered in railway accident while trespassing

Discussion

The medico-legal expert should be aware about the pattern of injuries encountered in railway-related deaths which will help the investigating police officer to know the manner of death. Out of 4647 autopsies carried out during study period, 2.1% of the cases were of railway-related deaths. Similar trend of railway fatalities was also observed by different authors in various parts of India where the observed percentage of railway related deaths were- Rohit Kumar Meena et. al (2.16%)[4], Rautji R et.al (1.41%)[5], Basavaraj Patil et. al (3.55%)[6],Hussaini S et.al (4.51%)[3], Chandru K et. al(4.65%)[7], and Malick DS et.al (4.99%)[8]. While studies conducted by other authors, the percentage of railway related deaths were observed to be on higher side as- T. Mohit Kumar Moses et.al(9.04%)[9], Manoj Kumar Mohanty et.al (9.2%)[2] and Pawan R. Sabale et. al (19%)[10]. The variations in the percentage of railway related death might be due to region wise variation having railway junction and frequency of trains passing from that region and density of population around the railway tracks.

In our study, maximum number of railway fatalities was observed in age group of 21-40 years (51.5%). Similar results were observed in the studies conducted by Hussaini S et.al (51.72%)[3], Rohit Kumar Meena et. al (54.76%)[4], Basavaraj Patil et. al (45.4%)[6], Chandru K et. al (58.5%)[7], T. Mohit Kumar Moses et.al(49%)[9], Pawan R. Sabale et.al (60.5%)[10], Savaradekar Ret.al (62.4%)[11], Shantilal Pargi et.al (54.8%)[12] and Arabinda Chatterjee et.al(51%)[13]. The individuals in this age group are the young adults at the peak of their physical and mental capabilities which make them to take unnecessary risk by boarding in running train, hanging on door of train when trains are overcrowded resulting in more casualties.

Out of 99 cases, majority of railway fatalities were seen among males (99%) while there was only one female deceased observed during the study period. The male predominance was observed in the study conducted by Manoj Kumar Mohanty et. al (79.5%)[2], Hussaini S et.al (89.6%)[3], Rohit Kumar Meena et. al (91.3%)[4], Basavaraj Patil et. al (92.7%)[6], Chandru K et. al (70.76%)[7], T. Mohit Kumar Moses et.al (86.7%)[9], Pawan R. Sabale et.al (90.2%)[10], Savaradekar R et.al (91.62%)[11] and Arabinda Chatterjee et.al (81%)[13]. Male travel more frequently by train and at times takes unnecessary risk exposing them to injuries and death.

In our study, most of the victims who succumbed to death due to railway injuries belong to Hindus (66.7%). Similar result was seen in the study conducted by Basavaraj Patil et. al (82.5%)[6] and Arabinda Chatterjee et.al (65%)[13]. This can be explained by higher density of Hindu population in the study region than other communities.

Majority of the deceased's identity was known (74.8%) but in 25.2% of cases, their identity could not be traced out even though thorough investigations was carried out. Similar finding was seen in the studies conducted by Rohit Kumar Meena et. al (81.7%)[4] and T. Mohit Kumar Moses et.al (55%)[9]. The incidence of railway related death usually happens suddenly and person may not be carrying any identification card along with them. Also considering the extensive nature of injuries with distortion of face, it poses challenge to investigating officer to make positive identification of deceased.

It was observed that maximum fatalities occurred during the time interval of 12 pm to 6 pm (33.3%), followed by time interval of 6 pm to 12 am (28.3%). Similar findings were seen in the study conducted by Pawan R. Sabale et.al[10] (28% and 27% respectively), while in the study conducted by Savaradekar R et.al[11], maximum fatalities were observed during 6pm to 10pm (31.58%) followed by 6am to 10am (26.61%) respectively. In the study conducted by T. Mohit Kumar Moses et.al[9], maximum fatalities were seen during 6 pm to 6 am (50.2%) followed by 6 am to 12 pm (27.8%) respectively. In the study conducted Arabinda Chatterjee et.al[13], maximum fatalities were seen during 6 am to 12 pm (41.5%) followed by 12 pm to 6 pm (28%) respectively. The timing of railway related fatality depends upon the timing of trains from that particular area and therefore the variations in timing of accident was observed in different studies.

It was observed that shock and hemorrhage was the most common cause of death that accounted for 35.4% of the cases, followed by injury to the head (26.3%). Similar findings was seen in the study conducted by Shantilal Pargi et.al (36.5%)[12] in which shock and hemorrhage was found to be most common cause of death. However, study conducted byHussaini S et.al (67.24%)[3] and Chandru K et. al (83.1%)[7] observed shock and hemorrhage as most common cause of death, though the percentage of shock and hemorrhage in railway related deaths varies in those studies. Profuse bleeding usually observed through open and extensive amputated injuries which is common feature in various accidents and before patient shifted to emergency medical facility, patient succumb. The study conducted by Pawan R. Sabale et.al (44.09%)[10], Savaradekar R et.al (45.74%)[11] and Arabinda Chatterjee et.al (56%)[13], observed head injury as most common cause of death which is inconsistent with our study. Often railway related death involves direct impact to the head resulting into accidental head injury.

In the present study, the manner of death was found to be accidental in 72.7% of cases while there was no case of homicide during our study period. Similar findings were seen in the studies conducted by Manoj Kumar Mohanty et. al[2] (80.7%), Hussaini S et.al[3] (93.96%), Rohit Kumar Meena et. al (67.46%)[4], Basavaraj Patil et. al (69.07%)[6], Chandru K et. al(86.15%)[7], T. Mohit Kumar Moses et.al (63%)[9], Pawan R. Sabale et.al (90.04%)[10], Savaradekar R et.al (89.12%)[11] and Shantilal Pargi et.al[12] (67.46%). Sometimes, the expression of heroism in youngsters compounded by the use of psychoactive substances also potentiates the incidences of occurrence of accidental deaths in them. Accidental deaths are also commoner in males due to the higher spurt of activity for livelihood in their lives.

Majority of the accidental deaths occurred due to trespassing which accounted for 65.3%. Other causes of accidental deaths were - falling from moving train (15.3%), accidental fall during acceleration (9.7%) and accidental fall during deceleration (9.7%). Similar findings were seen in the study conducted by Manoj Kumar Mohanty et. al (64.8%)[2], Rautji R et.al (57.48%)[5], Malick DS et.al (34%)[8],T. Mohit Kumar Moses et.al (56%)[9], Pawan R. Sabale et.al (59.04%)[10] and Savaradekar R et.al (59.37%)[11] where trespassing was observed as the most common manner of accident. This could be due to – unmanned/unauthorized railway crossings, poor maintenance of fencing/ barriers along railway lines, ignorance of basic rail safety rules, using mobile phones or listening to music while walking on or near railway tracks, lack of surveillance and enforcement, etc. Such types of deaths can be easily prevented if proper preventive measures are taken and by public awareness.

In this present study, maximum number of injuries were sustained to head (56.1%), followed by injuries to lower limbs (48.8%) and upper limbs (45.8%) respectively. Similar findings were seen in the study conducted by Hussaini S et.al[3] in which 54.31% of injuries were sustained to head and injuries over both upper and lower limbs comprised 63.79%. Also, in the study conducted by Rohit Kumar Meena et. al[4] injuries sustained over to head comprised 37.14% of cases while over the peripheries also accounted for 34.14% of all injuries.

It was observed that the most common pattern of injury involved in this study constituted fractures majorly over the peripheries, followed by fractures over the thorax and head respectively. Similar findings were seen in the study conducted by Rohit Kumar Meena et. al[4] which showed fractures as the most common pattern of injury. Run over injuries by railway are common resulting into fractures and amputation.

Conclusion

This present study analysed railway-related fatalities, highlighting that most victims were males aged 31-40 years which earn bread and butter for their families, with trespassing and accidental falls being major causes. The primary cause of death was shock and hemorrhage as the railway accidents causes severe trauma/leads to high impact injuries, blunt injuries to vital organs leads to profuse internal bleeding, crush injuries to limbs and in some cases leads to amputation of limbs. The contributing factors include overcrowding and disregard for safety regulations.

Though certain limitations were also encountered as this was a retrospective, single-centre study, limiting the generalizability of findings across different regions and also it lacks proper collection of information from the relatives and the police. Only autopsy data was analyzed; detailed behavioural, psychiatric, or toxicological profiles of the victims were not explored. Also, the cases involving decomposed bodies were excluded, which could underestimate certain categories of death.

To enhance railway safety, the study recommends increasing train frequency, providing ambulances at stations, training railway staff in first aid, fencing tracks and raising public awareness. Citizens can prevent accidents by adhering to safety practices like avoiding track crossings and boarding trains safely.

Railway authorities should enforce strict safety laws, improve pedestrian infrastructure (e.g., footbridges and subways), remove obstacles near tracks and ensure better crowd management. These measures, along with forensic insights into injury patterns, can help reduce fatalities and plan future railway safety policies.

Ethical Approval: As this is a retrospective study, ethical approval was not obtained and data was kept confidential and no harm was done to any individual.

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Review Article

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The Emerging AI Technolgy Deepfake

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Abstract

Artificial Intelligence (AI) has given rise to a new technology called Deepfake. Deepfake Technology (DT) involves replacing one person's face with that of another in digital content, often for malicious purposes. The most prominent model that operates behind Deepfake is the Generative Adversarial Network (GAN), which operates autonomously. It creates convincingly forged content from a variety of inputs. DT raises significant concerns among legal experts and scholars and has become a worldwide phenomenon due to its easy accessibility and wide availability. The impact of DT can be seen in areas such as politics, journalism, and the legal system. Although DT has potential positive uses as well as negative ones, the detrimental consequences tend to overshadow the benefits. The rapid global spread of DT underscores the urgent need for effective detection methods. Several techniques, such as Convolutional Neural Networks (CNNs), MesoNet, face detection, and multimedia forensics, are discussed here. This paper provides a brief overview of Deepfake technology, its developing field, the associated threats, and the methods used for detection. Deepfake encompasses a broad range of applications, which are also covered here. It can offer creative advantages while simultaneously posing significant risks. The technology for detection is advancing quickly in tandem with improvements in Information and Communication Technology (ICT). The primary emphasis of this paper is on examining the different techniques available for detecting this emerging field.

Keywords: Artificial Intelligence, Deepfake, Media manipulation, Generative Neural Network, Convolutional Neural Networks, deep learning.

Introduction

With the rise and progress of Artificial Intelligence (AI), a range of new technologies have emerged. One such notable technology being, Deepfake. Deepfake, or AI faceswap, is the combination of "deep learning" with "fake" [1, 17]. It constitutes a type of synthetic media that can mislead, defame, or deceive individuals or organizations by altering images, videos, or audio suggesting events that never actually happened. This phenomenon gained significant attention in the early and mid 2017 through a social media platform known as "Reddit" [3]. On Reddit, an application called "FaceSwap" was launched to the international

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audience. This app helped users create forged digital content by simply following a few steps, leading to its high level of popularity.

Deepfake is a software tool driven by machine learning that leverages AI to alter data. Being machine learning-based, it operates without the necessity of human oversight. It functions through the Generative Adversarial Network (GAN)[24], which learns autonomously [8]. Deepfake's first successful execution was seen through the app called "FakeApp", that swapped faces of individuals in videos.

Individuals are becoming victims of this method because it is readily available, accessible, and user-friendly. Even someone without any prior experience or knowledge in machine learning or AI can produce convincingly forged digital content simply by adhering to the provided instructions. Tools like FaceSwap and Reface[2] are surfacing the internet and are utilized by numerous users across the globe to create fabricated content. This method poses serious threats to significant areas of society, including politics, businesses and organizations, the legal system and courtrooms, revenge porn, cyberbullying, are a few to be mentioned[4].

This paper seeks to explore several questions: What exactly is deepfake? What are its uses? What potential dangers does it pose, and what detection methods exist? Lastly, what steps can be taken to alleviate the risks associated with deepfake?

Applications

Positive Impacts

- *In educational field*

  The Deepfake technology has the ability to generate altered videos by replacing a person's face. This feature of Deepfake can be highly beneficial in education. We can create Deepfake representations of historical figures such as freedom fighters, scientists, doctors, and others who have made significant contributions and are no longer alive[7]. One specific system, known as "LumièreNet," aims to simplify the process of producing educational videos and presentations for online learning platforms like Udacity[1].

- *In Entertainment and art generation*

  In Fast and Furious 7, following Paul Walker's untimely death in a car accident, his brother Cody Walker, who closely resembles him, stepped in to finish the last scenes of the movie. If he hadn't had a brother, the filmmakers would have probably invested heavily in CGI[7]. The use of Deepfake technology could have minimized both costs and time significantly[1].

- *In the health sector*

  The World Health Organization (WHO) has launched an AI-driven tool called "Florence," designed to assist individuals in breaking free from tobacco dependence. Users can have virtual conversations with "Florence" to bolster their resolve to quit smoking by creating a plan to track their progress[1]. Researchers are also exploring the application of Generative Adversarial Networks (GANs) to detect anomalies in X-rays and their potential to reveal early signs of diseases.

- *In fashion industry*

  This technique can be used to generate patterns and designs by combining classic designs and motifs, helping fashion designers to create innovative clothing, shoes, bags, and wallets. By applying Generative Adversarial Networks, designers can upload images of apparel and bags to produce new footwear designs or input pictures of shoes and wallets to design clothing[7]. Imagine a runway show where you can virtually "try on" outfits that models are wearing or even alter their appearances.

Negative Impacts

- *Threat to Journalism*

  The level of distrust in journalism has already reached significant heights globally, and segments of society have made little progress in discerning which news and photos to believe. Yet, we frequently observe that both intentional and unintentional fake content, whether in writing or photographs, is circulated as if it were legitimate. There are plenty of genuine reports concerning false information[20]. While it's common to assume that content intended for humor is factual, the primary threat lies in purposefully fabricated news.

- *Threat to politics*

  The extensive accessibility of deepfakes can undermine public confidence in both politicians and the media, complicating the distinction between truth and deception. External organizations may exploit deepfakes to meddle in elections, tarnish political rivals, or stir discord within a nation[10]. A prominent example featured a manipulated video of American politician Nancy Pelosi that became widely circulated on social media. In this clip, she appeared intoxicated and had difficulty expressing her words. Despite requests from parties to remove the video, a Facebook spokesperson stated that the platform does not have policies that mandate the elimination of false information[1].

- *Threat to individuals and businesses*

  Deepfakes are being used to create non-consensual sexual content. "Twitter, Reddit, and Pornhub have all recently decided to prohibit AI-generated pornography, also referred to as 'deepfakes,' labelling it as non-consensual porn" [5,8,16]. Deepfakes have the potential to enable financial fraud. This may result in data breaches, theft of trade secrets, or intentional damage. Deepfakes can also spread false information or create chaos among employees, customers, or investors, hindering the company's operations[8]. Organizations might face legal repercussions for the dissemination of deepfakes generated by their employees or linked to their brand, even if they did not directly create the deepfake

- *Threat to the Judicial system*

  Deepfakes can be employed to produce false evidence, such as altered videos or audio recordings, which could be used to wrongfully implicate innocent people or clear the guilty. This might result in unjust convictions or dismissals. They could be utilized to fabricate false testimonies or to undermine actual witnesses by altering their image or voice. This could jeopardize the reliability of witnesses and complicate the process of uncovering the truth in legal proceedings[10]. This could result in a loss of faith in the legal process and threaten the integrity of the rule of law.

Deepfake Detection Methods

Over the last few decades, the rapid development of AI and its related aspects like deepfake are posing a threat to the mankind. Hence, deepfake detection methods are the need of the hour.

Deepfakes generally used the GAN algorithm to manipulate the digital content and make the forged look authentic. We have categorized different detection methodologies in the following ways:

1. **MACHINE LEARNING BASED METHODS**

   Conventional machine learning (ML) algorithms play a crucial role in understanding the reasoning behind decisions in a way that can be articulated in human language. These techniques are particularly well-suited for the Deepfake field due to the enhanced understanding of data and procedures[26]. Several ML-focused techniques aim to identify specific anomalies present in videos or images generated by GANs. A core method of creating Deepfakes involves altering human faces to mislead viewers. In this context, the consistency of biological indicators is assessed along both spatial and temporal dimensions, utilizing different facial landmark points (like the eyes, nose, mouth, etc.) as distinctive features to verify the authenticity of videos or images produced by GANs. Regarding the performance of machine learning-based

Deepfake detection techniques, it has been noted that these methods can reach up to 98% accuracy in identifying Deepfakes. However, the effectiveness largely depends on the dataset employed, the features chosen, and the alignment of the training and testing sets.

a. Face Detection-

Deepfake technology is designed to swap one person's face for another in a digital image or video. While the algorithm utilizes artificial intelligence to generate a convincing altered image or video, it struggles to replicate subtle nuances such as eye blinks. Research conducted by indicates that a person typically blinks every two to ten seconds, with each blink lasting approximately one-tenth to one-fourth of a second. Deepfake techniques fail to accurately reproduce faces to capture this subtle feature of human blinking, which can help identify whether a video is authentic or manipulated. The effectiveness of deepfake relies heavily on the availability of photographs and images from the internet. Consequently, an individual with limited online images will have even fewer resources depicting their eyes closed [3]. Typically, a person blinks approximately every 1 to 10 seconds, which is unlikely to occur in Deepfake videos unless images of the individual with both closed and open eyes are supplied[7]. Variations in eye color are also utilized to identify deepfakes. For this process, the hue of each eye is extracted using computer vision techniques. Following detection, all images are cropped from the facial region and resized to 768 pixels[3]. This resizing is performed to guarantee that samples undergo processing at a uniform resolution.

b. Watermarking-

It enables the straightforward identification of modified digital sources by revealing concealed markers. It helps determine if any editing has occurred. Watermarks are integrated when content undergoes changes. These marks are partially visible, so even if the material is distributed on social media or online platforms, the altered components will probably carry such markers, alerting recipients to the fraudulent content [3].

2. DEEP LEARNING-BASED METHODS

When it comes to detecting Deepfakes in images, numerous studies have utilized deep learning techniques to identify specific artifacts created by the generation process[26]. A GAN simulator was introduced to mimic the collective artifacts associated with GAN-generated images and provide them as input to a classifier for Deepfake identification. Another network was proposed to extract standard features from RGB images, while a similar but more general approach was also suggested.

a. MesoNet-

MesoNet can automatically identify facial manipulation in Deepfake videos using deep learning techniques. This approach distinguishes between computer-generated images and genuine images within Deepfake videos by employing two architectural networks, meso-4 and mesoinception-4. The primary aim of these two structures is to accurately detect facial video forgery, allowing for differentiation in image properties such as noise, accuracy, classification, and aggregation. After evaluating these image features, both meso-4 and mesoinception-4 can successfully identify Deepfake videos with an accuracy ranging from 95% to 98%[7,12].

b. Convolutional Neural Networks (CNNs)-

In contrast to human detection methods, Convolutional Neural Networks (CNNs) and similar techniques operate on machine learning principles and can effectively identify deepfake content through advanced image analysis capabilities[3]. These AI algorithms can be integrated into information-sharing platforms and social media. Researchers at SUNY Albany, Yuezun Li and Siwei Lyu, employed Convolutional Neural Networks (CNNs) to help identify face-warping artifacts.

By comparing the deepfake and source videos, CNNs assist researchers in identifying similarities and determining whether a video is a deepfake or not. The model developed by the SUNY Albany researchers was more time-efficient than others, achieving a detection rate between 84.5% and 99.1% in trials, marking a significant advancement in the fight against deepfakes.

3. STATISCAL MEASUREMENTS BASED METHOD

Calculating the various statistical metrics like-average normalized cross-correlation scores between authentic and questioned data aids in assessing the authenticity of data. Investigate the photo response non-uniformity (PRNU) for identifying Deepfakes within video frames.

a. The DFDC Dataset-

It is the largest existing Deepfake dataset and one of the few that includes footage specifically captured for machine learning purposes. Brian Dolhansky and colleagues [25] contributed the DeepFake Detection Challenge (DFDC) Dataset. The DFDC Dataset is the largest Deepfake dataset available today and ranks among the few specifically recorded datasets designed for machine learning tasks (the others include the considerably smaller Google Deepfake Detection Dataset and an earlier version of this dataset)[14]. In addition to developing and releasing a dataset, the second key contribution is the resulting analysis. Firstly, the financial incentives offered encouraged specialists in computer vision or Deepfake detection to invest time and computational power into developing models for performance evaluation. Secondly, organizing a public competition eliminates the necessity for the authors of a study to train and assess a model on their own dataset. Launching a dataset and a benchmark at the same time can introduce bias since the dataset creators have detailed knowledge of the methods applied in its creation. Lastly, collecting thousands of submissions and testing them against actual Deepfake videos that participants do not see provides an exceptionally accurate reflection of the current state of Deepfake detection technology.

b. The Celeb-DF Dataset-

In order to offer the more context-related corpus to assess and assist the future growth Deepfake detection methods, Yuezun Li et al. Suggested the Celeb-DF Dataset.Celeb-DF dataset contains 590 real and 5,639 DeepFake videos (with over 2 million video frames). With a standard frame rate of 30 frames per second, the average length of all videos is roughly 13 seconds. The videos are sourced from publicly accessible YouTube content featuring interviews with 59 celebrities who exhibit a diverse range of ages, genders, and ethnicities. Additionally, the videos showcase a wide array of variations in aspects such as the sizes (in pixels) of the subjects' faces, their orientations, backgrounds, and lighting conditions.Celeb-DF dataset contains 590 real and 5,639 DeepFake videos (with over 2 million video frames).

4. BLOCKCHAIN BASED METHOD

As a result, no established approach exists for validating onscreen post office the original of a digitized video, audio, or image. It is not feasible to establish a COA for such digital content. Thus the is a huge requirement, for a Proof of Authenticity (POA) system for online digital content, to mark the authenticity of published sources and thus be able to fight against deep fake videos, audios and images. A decentralized Proof of Authenticity (POA) using the cutting-edge technology the blockchain. As the technology can provide some of the key features, this technology can be exploited to prove the authenticity and originality of digital assets in a decentralized, highly trusted and secured way. The permission less or public blockchain is most suitable for such deepfakes. In this paper, we base our solution on the public Ethereum blockchain utilizing smart contracts to govern and track the history of transactions for digital content [9].

NOTE - The percentage of studies focusing on machine learning techniques is 18%, while those using statistical methods account for 3%. In this analysis, the proportion of research centered on the Blockchain-based approach is 2% [26].

The global community cannot afford to remain passive while measures such as detection or legislation are implemented against deepfakes; the consequences could be too severe. Instead, we can adapt to a world inundated with deepfakes by focusing on raising awareness and educating the public on this issue. More crucially, we call upon all decision-makers—including technologists, social media platform leaders, and policymakers—to assist organizations and society in preventing and mitigating the harmful side of content manipulation. With this objective in mind, Kietzmann et al. [6] suggests a R.E.A.L. framework to manage deepfake risks:

- Record original content to ensure deniability
- Expose deepfakes promptly
- Advocate for legal safeguards
- Utilize trust.

Legislation must be created and implemented to address the issue of deepfakes in legal settings, such as in evidence presentation, while digital forensics will need to adapt by applying emerging deepfake detection technologies. Techniques in multimedia or image forensics are the most effective for identifying manipulated images or video content. Image forensics analyze subtle parameters such as pixel correlation, continuity of the image, and lighting conditions. Multimedia forensics consider each stage of an image's lifecycle, including how it was saved in a compressed or alternate format, the acquisition method, or any post-processing that may leave behind a unique data trace, akin to a fingerprint[3].

Since businesses are particularly susceptible to deepfake schemes, such as impersonating owners and extortion through blackmail or smear tactics, they can implement preventative measures against deepfakes right away. Educating employees is critical, as their awareness of deceptive practices will enable them to report any suspicious activities. Companies can establish two-step verification processes, for example, by confirming phone call information through emails or requiring a second employee to authorize actions such as fund transfers[8]. Furthermore, organizations can enhance security protocols and restrict access to their images or videos, which hinders cybercriminals from utilizing this data to fabricate more convincing deepfakes. Overall, while these strategies might slightly hinder business operations due to confirmation protocols or privacy measures, they could ultimately save businesses a significant amount of money.

Limitations & Challenges

Deepfakes represent an intriguing technological innovation, yet they come with numerous considerable limitations and challenges:

A. Ethical Concerns: Deepfakes can be utilized to fabricate and disseminate false information, skew public perception, and harm reputations, which can lead to significant repercussions in fields like politics, social justice, and national security. It has the potential to generate non-consensual pornography or impersonate individuals for harmful reasons, resulting in serious breaches of privacy and psychological distress.

B. Technical Limitations: This complicates efforts to mitigate the spread of misinformation and hold creators responsible. Producing high-quality deepfakes commonly necessitates substantial amounts of high-quality source material, which may not always be readily available or easy to access.

C. Legal and Regulatory Challenges: The legal framework surrounding deepfakes is still in development, posing difficulties in prosecuting creators and holding them accountable for the misuse of this technology.It is essential for regulations to find a balance between fighting against harmful deepfakes and protecting freedom of speech and expression.

D. Social Impact: Being exposed to deepfakes can have mental health effects on individuals, especially those who are victims of malicious deepfakes. The increasing prevalence of deepfakes can foster a general atmosphere of skepticism and anxiety within society.

These limitations and challenges underscore the necessity for responsible progress and application of deepfake technology. Tackling these issues requires a comprehensive strategy involving technological improvements, ethical standards, legal measures, and public awareness.

Conclusion

This paper concludes that the ongoing evolution of cybercrime has led to the emergence of deepfakes, which significantly enhance the risks associated with traditional fraud. Deepfakes continue to present various dangers, including misinformation in politics, fraud, and tampering with evidence in legal proceedings. While current technical measures can be utilized to combat deepfake attacks, relying solely on these methods is insufficient. Thus, it is crucial to also focus on raising awareness and providing training to help recognize the early indicators of deepfake attacks. Technology companies and governments should contemplate enacting laws that criminalize the malicious use of deepfakes aimed at damaging individuals' reputations. This would ensure that malicious perpetrators face suitable penalties and repercussions. One of the most threatening applications of deepfakes involves seeking revenge by inserting an individual's face into adult films, with female celebrities frequently becoming targets. There are various methods available for detecting deepfakes through the application of different algorithms. Despite the effectiveness of deepfake technology in generating deceptive videos, its outputs appear highly realistic and believable to the human eye, making detection more challenging and optimal. Therefore, the realm of deepfakes still holds much to be examined.

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Overview of Fingerprint-Based Blood-Grouping using Various Tools and Techniques

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Abstract

Blood grouping plays a crucial role in medical diagnostics, transfusion practices, and forensic investigations. Traditional methods for determining blood groups involve serological testing of blood samples, which, while accurate, require invasive procedures, trained personnel, and time. Researchers have recently explored non-invasive alternatives, among which biometric approaches such as fingerprint analysis have gained attention. The emerging field of fingerprint-based blood grouping presents a revolutionary, non-invasive alternative by leveraging the unique biochemical composition of fingerprint residues and the distinct patterns of epidermal ridges. This approach offers significant value by enabling rapid, cost-effective, and hygienic blood type determination, with profound benefits for enhancing emergency response efficiency, streamlining donor registration in blood banks, and advancing forensic investigations. The purpose of this comprehensive review is to synthesize current research and provide a detailed overview of the methodologies underpinning this technology. We examine the scientific basis for the correlation between fingerprint patterns and ABO/Rh blood groups, evaluate traditional chemical and spectroscopic techniques, and analyze the cutting-edge integration of artificial intelligence (AI) and deep learning models for automated classification. Furthermore, the review discusses the practical applications, advantages, and current limitations of the technology, concluding with an outlook on future directions for research and implementation. This paper underscores the transformative potential of fingerprint-based blood grouping as a viable and promising solution for modern medical and forensic challenges. However, further research with larger and more genetically diverse populations is required to validate and refine the predictive models. In conclusion, while fingerprint-based blood grouping cannot yet replace conventional methods, it offers a compelling supplementary tool for rapid, non-invasive blood group estimation.

Keywords: Biometric Blood Typing, Deep Learning and Machine Learning, AI-based Pattern Recognition, Predictive Healthcare Technology, Genetic-Biometric Correlation

Introduction

Blood group identification is a critical aspect of medical diagnostics, transfusion practices, and emergency care. Traditionally, this process relies on serological techniques that require direct sampling of blood, specialized reagents, and trained personnel. While effective, these methods are invasive, time-consuming, and often inaccessible in remote or under-resourced environments. With the increasing demand for non-invasive, rapid, and cost-effective diagnostic tools, researchers have begun exploring innovative biometric alternatives—one of the most promising being fingerprint-based blood grouping.

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Fingerprints, or dermatoglyphics, are unique, permanent, and genetically influenced. Given that blood group antigens are also genetically determined, a potential correlation between fingerprint patterns—such as loops, whorls, and arches—and blood groups has sparked growing scientific interest. Recent advancements in data analytics, artificial intelligence (AI), and machine learning have made it possible to analyse large biometric datasets with high precision, uncovering subtle patterns and associations that were previously undetectable. Innovations in image processing and mobile health (mHealth) technologies have further accelerated the feasibility of this approach. Fingerprint scanners integrated with smartphone apps or portable devices can now capture high-resolution images quickly and reliably, making the technology scalable and user-friendly. AI-powered predictive models trained on biometric and blood group data have demonstrated encouraging accuracy levels, suggesting real-world applicability in settings where conventional blood testing is not viable, such as disaster zones, remote clinics, and forensic investigations. This paper investigates the potential of using fingerprint patterns as a non-invasive predictor for blood grouping. By combining biometric analysis with AI-driven models, we aim to assess the strength of correlation, improve prediction accuracy, and explore practical use cases. This novel approach not only holds promise for faster and more accessible healthcare but also aligns with the broader movement toward personalized, tech-enabled medicine. [1] [2]

Some real-life examples are:

1. The Colin Pitchfork Case (UK, 1983–1987) – First DNA Exoneration Using Blood Grouping

- Case: Two young girls were raped and murdered in Leicestershire, UK. A suspect, Richard Buckland, confessed to the second murder but denied the first.
- Blood Group Evidence: Semen samples from both crime scenes revealed the killer had blood type A and was a secretor (blood group antigens present in bodily fluids). Buckland was typing B, so he was excluded.
- Outcome: This led to the first mass DNA screening, ultimately identifying Colin Pitchfork as the real killer. Blood grouping helped eliminate an innocent suspect before DNA profiling was fully established.

2. The Narborough Village Murders (UK, 1986) – Blood Grouping in Serial Rape-Murders

- Case: Two teenage girls were raped and murdered in a similar fashion year apart.
- Blood Group Evidence: Semen samples from both crimes showed the killer was a type A secretor.
- Outcome: Blood grouping narrowed down suspects before DNA testing confirmed the killer (Colin Pitchfork, same as above).

3. The Lindbergh Kidnapping Case (USA, 1932) – Early Use of Blood Typing

- Case: Charles Lindbergh's baby was kidnapped, and a ransom was paid, but the child was later found dead.
- Blood Group Evidence: A ladder used in the kidnapping had bloodstains matching type A, while the suspect, Bruno Hauptmann had type O.
- Outcome: The mismatch was used to suggest Hauptmann's involvement, though other evidence (ransom money, wood grain analysis) was more decisive.

Benefits of Blood group prediction in the Medicolegal aspect

1. Paternity and Kinship Disputes
2. Crime Scene Investigations
3. Identification of Unknown Bodies or Mass Disasters
4. Blood Transfusion and Medical Malpractice Cases
5. Disputed Maternity Cases (Rare but Possible)
6. Rape and Sexual Assault Cases

Limitations in Medicolegal Use:

- Blood grouping is less discriminatory than **DNA profiling** (which provides near-certain identification).
- It cannot uniquely identify an individual but can exclude suspects or establish possible relationships.
- Advances in DNA technology have reduced reliance on blood grouping, but it remains useful in resource-limited settings.

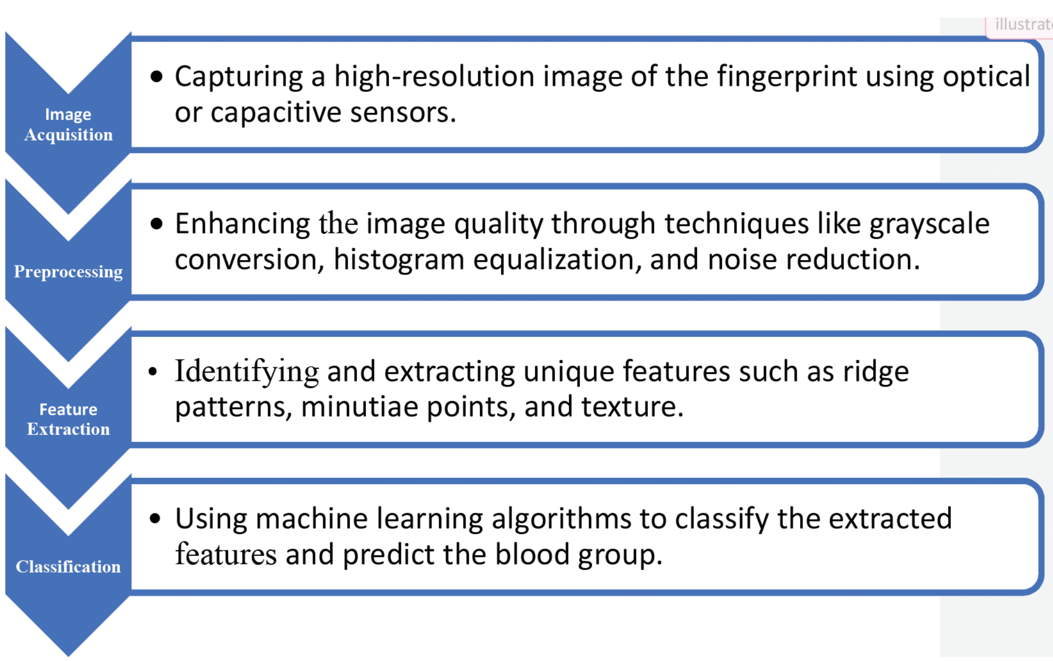
Chronological Development of Blood Grouping

1. *Early Studies*: Early research into the relationship between dermatoglyphics (fingerprint patterns) and blood groups dates back to the mid-20th century. Initial studies suggested statistical correlations between certain fingerprint patterns and specific blood groups. However, these studies were limited by small sample sizes, subjective analysis, and a lack of automation.
2. *Advancements in Technology*: With the advent of digital imaging and machine learning, more sophisticated methods have emerged. Researchers have employed various algorithms to analyse fingerprint images and predict blood groups. For instance, studies have utilized Support Vector Machines (SVMs), Convolutional Neural Networks (CNNs), and hybrid models that combine traditional and deep learning techniques to enhance prediction accuracy.
3. *Recent Developments*: Recent studies have focused on enhancing the accuracy and reliability of fingerprint-based blood grouping systems. Techniques such as data augmentation, transfer learning, and multi-modal biometric systems have been explored to tackle challenges like dataset imbalance, overfitting, and environmental variability.[3] [4]

Methodologies

✓ *Traditional Methods*: Traditional blood grouping methods involve mixing blood samples with specific antibodies and observing agglutination reactions. While accurate, these methods are invasive and require laboratory settings.

o *Fingerprint-Based Blood Grouping*: Fingerprint-based blood grouping involves capturing a high-quality image of an individual's fingerprint and analysing specific features to predict their blood group. The process typically includes: [5] [6]



Traditional Blood Grouping Methods

Traditional methods of blood grouping include:

i. *Slide Agglutination Test*: This method involves placing blood on a slide and adding specific antibodies. The presence of agglutination indicates the presence of corresponding antigens.

ii. *Tube Test*: Similar to the slide test but conducted in test tubes, allowing for more precise results. [7]

iii. *Gel Column Agglutination*: A modern method that uses gel columns to separate agglutinated cells, providing accurate and reliable results. While these methods are accurate, they are invasive and require laboratory equipment and trained personnel.

Modern Techniques in Fingerprint-Based Blood Grouping

Modern techniques have brought machine learning (ML), deep learning (DL), and artificial intelligence (AI) into the spotlight for analysing biometric data like fingerprints. These technologies provide automated, scalable, and more accurate methods of identifying patterns that could relate to an individual's ABO and Rh blood group. [8]

A. *Machine Learning Approaches:* Machine Learning models are trained on datasets containing fingerprint images with known blood groups to learn patterns and make predictions.

Key Techniques:

- **Support Vector Machines (SVM):**
    - ❖ Separates data into different classes (A, B, AB, O) by finding the optimal boundary (hyperplane).
    - ❖ Suitable for small- to medium-sized datasets.
    - ❖ Often used after handcrafted feature extraction (like ridge count, ridge frequency, etc.).
- **Random Forest:**
    - ❖ An ensemble learning technique that builds multiple decision trees and averages their output.
    - ❖ Robust against overfitting and effective when working with non-linear data.
- **k-Nearest Neighbours (k-NN):**
    - ❖ Classifies new data points based on the majority label of the k most similar points. [9]
    - ❖ Works well with structured data, but is computationally expensive with large datasets.

Steps in ML-based Prediction:

1. **Fingerprint Acquisition:** Capturing images using digital scanners.
2. **Preprocessing:** Enhancing quality, removing noise, and segmenting the region of interest.
3. **Feature Extraction:**
    - o Ridge density
    - o Ridge orientation
    - o Minutiae points (bifurcations, ridge endings)
    - o Pattern classification (loop, whorl, arch)
4. **Model Training and Evaluation:**
    - o Data split into training and test sets.
    - o Accuracy, sensitivity, and specificity measured. [10]

Performance:

- Accuracy typically ranges from 65% to 80%, depending on the dataset quality and preprocessing techniques.
- Improvement is possible through feature selection and parameter tuning.

B. *Deep Learning Techniques*: Deep Learning is a subset of ML that automatically learns features from raw data using neural networks.

In fingerprint blood group prediction, DL has enabled higher accuracy and better generalization. [11]

Key Architectures:

- Convolutional Neural Networks (CNN):
    - ❖ Designed for image data.
    - ❖ Automatically learns spatial hierarchies and texture features from fingerprint images.
    - ❖ CNNs can distinguish between subtle variations in ridge orientation and minutiae patterns.
- **Recurrent Neural Networks (RNN) & LSTM (Long Short-Term Memory):**
    - ❖ While typically used for sequence data, they may be incorporated to analyse sequential features in fingerprint ridges.
- **Hybrid CNN-SVM (Support Vector Mechanism) Models:**
    - ❖ CNN extracts features.
    - ❖ SVM handles classification, improving accuracy, especially when the dataset is small. [12] [13]

Techniques Used in DL-Based Models:

- **Data Augmentation:** Enhancing the dataset by rotating, flipping, and adding noise to fingerprint images.
- **Transfer Learning:** Using pretrained models (like VGGNet, ResNet)[14] fine-tuned on fingerprint data.
- **Dropout and Batch Normalization:** Techniques to reduce overfitting and accelerate training.

Performance:

- o Achieved accuracy of 85% to 92% in recent studies.
- o Deep learning models outperform traditional ML in larger datasets due to their ability to capture complex patterns.

c. *Artificial Intelligence Systems*: AI systems combine ML/DL models with other smart systems to create intelligent diagnostic platforms. These systems not only predict blood group but also automate decision-making, handle uncertainty, and integrate with healthcare infrastructures. [15]

Components:

- **Predictive Engine:** Based on ML/DL models.
- **User Interface (UI):** Allows technicians or healthcare workers to input fingerprint scans and receive results.
- **Database Integration:** Links with electronic health records (EHRs) or biometric identity systems.
- **Cloud-Based Storage:** Enables remote access and long-term data storage.[16]

D. *Blockchain Mechanism in Blood Grouping Using Fingerprints*: Blockchain is a decentralized, distributed ledger technology that ensures data integrity, transparency, and security. It operates through a network of nodes (computers) where each transaction or data entry (block) is time-stamped and linked to the previous block, creating an immutable chain. This technology is widely used in cryptocurrencies, but its potential extends far beyond digital currencies, including applications in healthcare, biometrics, and identity verification.

Blockchain for Fingerprint-Based Blood Group Prediction: Integrating fingerprint-based blood grouping with blockchain technology can revolutionize how biometric data, including health-related information like blood types, is stored and shared. The key benefit here is blockchain's security, transparency, and decentralization, ensuring that users' sensitive data (fingerprints, blood groups) is securely stored and accessed only by authorized parties. [17]

Result

Summary Table: Comparison of Techniques

Technique	Accuracy	Data Requirement	Automation Level	Practical Use
Manual Dermatoglyphic Analysis	50 – 60%	Low	Low	Education, Historical
Machine Learning (SVM, k- NN)	65- 80%	Medium	Medium	Prototype Tools
Deep Learning (CNNs)	85-92%	High	High	Research, Advanced Tools
AI Systems (Hybrid + Ingrate)	90%	High	Very High	To ensure the Safety and security of blood delivered to the patient

Figure 1: Table to show the comparison of techniques

Reference: https://images.app.goo.gl/nzyF3ErmEUDh7oQe7

Statistical Insights on Fingerprint Patterns and Blood Groups

Studied Regions	Sample Size	Blood Group Distribution	Fingerprint Patterns	Findings	Source
Uttarakhand Region, India	140 MBBS students aged 18–25	Not specified	**Loops:** 58.29% **Whorls:** 37.00% **Arches:** 4.71%	Loops were predominant in all ABO blood groups, except for blood group A positive, where whorls were slightly more common. A significant association was found between fingerprint patterns and blood groups.	[18] (*View of a Study of Fingerprint in Relation to Gender and Blood Group Among Medical Students in Uttarakhand Region*, n.d.)
Zawia, Libya	305 medical students	**O:** 48.9% **A:** 33.1% **B:** 12.8% **AB:** 5.2%	**Loops:** 50.5% **Whorls:** 35.1% **Arches:** 14.4%	In Rh-positive cases of blood group, A and O, loops were most common, while whorls were predominant in blood group B. High frequencies of loops were observed in the thumb, index, and little fingers	[5] (Fayrouz et al., 2011b)

Continue....

Eastern India	800 participants	**B+:** 35.8% **O+:** 28.1% **A+:** 22.5% **AB+:** 9.5%	**Loops:** 55.9% **Whorls:** 34.9% **Arches:** 6.1% **Composite:** 3.1%	Loops were most common in blood group AB (61.0%), while whorls were most common in blood group B (37.6%). A statistically significant association was found between fingerprint patterns and ABO blood groups (p=0.0003).	[15] Rastogi et al. (2023b)

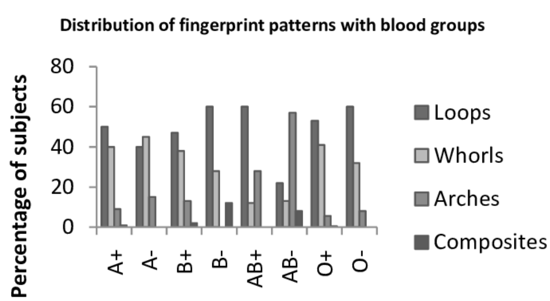


Figure 2: Distribution of fingerprint patterns with blood groups

Reference: https://images.app.goo.gl/Xq2JstbL4dB37kvVA

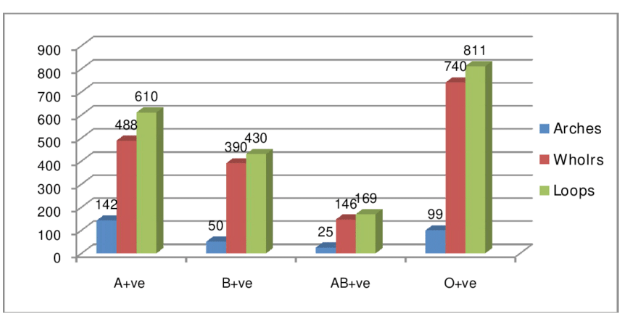


Figure 3: Distribution of fingerprint patterns with blood groups for a large sample size

Reference: https://images.app.goo.gl/urAauRL4MeoUsRqE9

Discussion

Applications:

➢ **Healthcare**

- Emergencies where blood group is unknown.
- Paediatric and geriatric care for non-invasive diagnostics.
- Mass screening in rural or remote locations.

➢ **Forensic Significance of Fingerprint-Based Blood Grouping**

(a) Personal Identification in Criminal Investigations

Fingerprints are unique to each individual and remain unchanged throughout life. This permanence makes them invaluable in forensic science for identifying individuals involved in criminal activities. By analysing fingerprint patterns, forensic experts can ascertain the blood group of a suspect or victim, aiding in establishing identity when traditional identification methods are unavailable.

(b) Correlation with Blood Grouping

➢ Studies have shown that certain fingerprint patterns are more prevalent in individuals with specific blood groups. For instance, loops are commonly found in individuals with blood group B, while whorls are more frequent in those with blood group O. This correlation can assist forensic experts in narrowing down potential suspects or victims based on fingerprint analysis. **Mobile Health (mHealth)**

- Apps for personal health monitoring that store biometric blood group data.
- Can be used by travellers, mountaineers, or remote workers.

➢ **Medical and Genetic Applications**

(a) Early Diagnosis of Genetic Disorders

The correlation between fingerprint patterns and blood groups can provide insights into genetic predispositions to certain diseases. For example, individuals with specific fingerprint patterns and blood groups may be at higher risk for conditions like diabetes mellitus. Identifying these patterns early can lead to proactive health monitoring and management.

(b) Personalized Medicine

Understanding the relationship between fingerprint patterns and blood groups can contribute to personalized medicine approaches. By analysing these biometric markers, healthcare providers can tailor treatments and interventions to individuals' genetic profiles, potentially improving treatment outcomes. [19][20]

➢ **Research and Development**

(a) Enhancing Forensic Techniques

Integrating fingerprint analysis with blood group determination can enhance existing forensic methodologies. This multidisciplinary approach can lead to the development of more robust identification systems, combining biometric data with genetic information for comprehensive analysis.

(b) Advancements in Biometric Research

Ongoing research into the relationship between fingerprint patterns and blood groups continues to uncover new insights. These findings can inform the development of advanced biometric systems, improving accuracy and reliability in personal identification processes.

➢ **Legal and Ethical Considerations**

(a) Privacy Concerns

The collection and analysis of biometric data, including fingerprints and blood group information, raises significant privacy issues. Ensuring that such data is handled responsibly and with consent is crucial to maintaining public trust and upholding individual rights.

(b) Ethical Use in Forensic Investigations

While fingerprint analysis is a powerful tool in forensic science, its use must adhere to ethical guidelines. The integration of blood group determination should be conducted with transparency and accountability to prevent misuse and ensure justice. [23]

Advantages:

Advantage	**Description**
Non-Invasive	No blood sample required
Quick & Portable	Can be integrated into mobile devices for field use
Cost-Effective	No reagents or lab setup
Scalable	Suitable for large-scale screening
Emergency Use	Useful in disasters, accidents, and remote locations
Integration-Ready	Compatible with existing biometric systems

Disadvantages:

Disadvantage	**Description**
Accuracy Not Yet Clinical-Grade	Predictive accuracy is still below medical diagnostic standards
Ethical Issues	Biometric data privacy and consent concerns
Population Variability	Fingerprint-blood group link may differ by ethnicity
Lack of Standardization	No global clinical guidelines yet
False Positives/Negatives	Can lead to misclassification in sensitive scenarios

Future Advancements and Directions

1. *Multimodal Biometric Systems:* Future systems will likely integrate fingerprint data with other biometric inputs like iris patterns, facial features, retinal scans, and even DNA sequencing, creating a multimodal biometric

ID system. These systems could revolutionize personal identification, especially in high-security sectors, refugee tracking, and border control.

2. *Integration with Wearables and Mobile Health:* The next decade may see fingerprint scanning integrated into mobile devices and wearable sensors, capable of predicting blood group or flagging inconsistencies for health screening. Remote health apps may use these predictions for emergency alerts, donor matching, or first-aid guidance, particularly in areas with limited medical infrastructure.

3. AI-Driven Population Studies: AI will be pivotal in large-scale ethnographic and genomic studies, analysing fingerprint-blood group correlations across diverse populations and genetic backgrounds. This will help build standardized fingerprint-blood group databases, improving model generalizability and reducing demographic bias. [24]

4. Blood Group Prediction in Paediatrics and Neonatology: Since infants' veins are fragile, non-invasive fingerprint-based prediction could become an important tool in neonatal care, aiding early transfusion planning or identifying genetic risks linked with blood group types.

5. Enhanced Forensic and Criminal Profiling Tools: Law enforcement agencies may develop real-time crime scene analysis tools that use partial fingerprint data to predict blood group, gender, or even potential familial ties, expediting suspect identification and narrowing investigative leads. [21]

Future Advancements in Blockchain and Fingerprint-Based Blood Grouping

A. Integration with Electronic Health Records (EHR): In the future, fingerprint-based blood group data could be seamlessly integrated into existing Electronic Health Record (EHR) systems. By using blockchain technology, individuals could store and access their health records in a secure, decentralized manner. This would provide doctors with a real-time, accurate view of a patient's blood group and medical history, improving the efficiency of healthcare services, especially in emergencies or disaster-stricken areas.

- Patient Control: With blockchain, patients can have control over who views their health data. They could grant temporary access to their blood group and fingerprint data during emergencies (e.g., blood transfusions or organ donation) through smart contracts.

B. Decentralized Healthcare Ecosystems: In the future, we could see the rise of decentralized healthcare ecosystems where medical practitioners, laboratories, and even insurance providers can access patient data in a secure and verifiable way. These ecosystems would be powered by blockchain and could include fingerprint-based blood grouping systems to quickly identify and verify individuals' blood types for urgent medical procedures.

- Global Access: Blockchain's decentralized nature means that users' blood group information can be accessed globally by hospitals, clinics, and emergency teams, ensuring that universal blood compatibility is always taken into account.

C. Secure Blood Donation and Transfusion Systems: One of the most promising future applications of blockchain in blood grouping is in the management of blood donation and transfusion networks. Blockchain could help ensure the traceability of blood products, including their origin (donor) and compatibility. Fingerprint-based blood group verification would be integrated into the system to match donors and recipients more efficiently and securely.

- Donor-Recipient Matching: Blood donations could be linked with blockchain-based fingerprint records to ensure that the right blood type is given to the right patient. In emergencies, this could expedite the matching process, ensuring quick access to critical blood supplies. [23]

D. Use in Forensic and Criminal Investigations: Blockchain and fingerprint-based blood grouping could become essential in forensic science. Fingerprints found at a crime scene could be linked with blockchain records to help identify individuals and predict their blood types, which could be crucial for investigating crimes involving blood stains or victim identification.

- Chain of Custody: Blockchain's immutable ledger can ensure the chain of custody for evidence collected from crime scenes, where fingerprints and blood group data can be used to confirm the identity of suspects or victims, offering a transparent and tamper-proof record.

E. Multi-Layered Privacy and Security with Blockchain: As privacy concerns around biometrics intensify, blockchain offers a robust solution to address these concerns. By combining blockchain's decentralized, immutable nature with advanced cryptographic techniques, users can maintain full ownership over their biometric data (such as fingerprints and blood groups) while also ensuring that only authorized parties can access this sensitive information.

- Zero-Knowledge Proofs (ZKPs): Future advancements might use Zero-Knowledge Proofs (ZKPs), a cryptographic technique that allows a party to prove they know a piece of information (like a blood type or fingerprint) without revealing the actual information. This would significantly enhance privacy while allowing for secure verification in biometric applications.

Challenges to Overcome

- **Ethical concerns** around data privacy, biometric misuse, and informed consent.
- **Data diversity** and model bias due to uneven population sampling in current datasets.
- **Environmental and genetic variability**, which can affect fingerprint formation and complicate modelling.
- **Regulatory frameworks** for clinical application and forensic admissibility.
- **High initial cost** as the implementation of blockchain technology requires significant upfront investments in infrastructure, integration, and skilled personnel.
- **Complexities** are very high as it requires specialised knowledge about the field, so its implementation rate is very low.
- **Interoperability** of different blockchain networks may not easily achieved, hindering integration with the existing healthcare system.[24]

While blockchain offers significant advantages, several challenges must be addressed:

- **Scalability:** As the number of users and the data stored on blockchain networks increase, scalability may become an issue. Future research will need to focus on developing more efficient blockchain architectures that can handle large-scale biometric data.
- **Regulation:** The use of blockchain for sensitive biometric data, especially related to healthcare, would require regulatory frameworks to ensure that privacy laws, such as GDPR (General Data Protection Regulation) or HIPAA (Health Insurance Portability and Accountability Act), are followed. [25]
- **Adoption:** Widespread adoption of blockchain for biometric identification in healthcare and law enforcement may require significant investment in technology and infrastructure, alongside the development of standardized practices for data collection and management. [26]

Conclusion

The exploration of fingerprint-based blood grouping has revealed itself as a promising frontier at the intersection of forensic science, medical diagnostics, and biometric identification. Through decades of research, scholars have observed statistically significant correlations between fingerprint patterns—loops, whorls, arches—and specific ABO and Rh blood groups. While this relationship may not yet support absolute blood group determination solely through dermatoglyphics, the observed associations offer valuable predictive insights, particularly when enhanced with artificial intelligence (AI) and machine learning (ML) models. Traditional blood typing, while clinically reliable, involves invasive techniques, the need for reagents, and trained personnel. In contrast, fingerprint analysis is non-invasive, inexpensive, rapid, and universally accessible—traits that make it particularly useful in forensic scenarios, rural healthcare settings, and disaster management. When combined with automated classification algorithms, such as Support Vector Machines (SVM), Convolutional Neural Networks (CNN), and decision trees, the predictive capability of fingerprint data can significantly support human identification and triage systems. Recent studies have shown prediction accuracies exceeding 85–90%, depending on data quality and algorithmic approach, particularly when enhanced by image preprocessing and data augmentation techniques. These achievements hint at the potential for semi-automated systems in hospitals, forensic labs, or even mobile apps, where users could obtain approximate blood group predictions with just a fingerprint scan.

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Review Article

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Applications of Nanotechnology in Forensic Science: A Comprehensive Review

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Abstract

Nanotechnology is reshaping forensic science with new techniques that are faster, more sensitive, and more precise. This review highlights how the increasing use of nanomaterials in forensic investigations improves the detection, collection, and analysis of evidence. Nanoparticles like gold, silver, zinc oxide, and titanium dioxide have improved latent fingerprint visualization, showing clearer ridge detail even on difficult surfaces.

The increasing use of nanotechnology in forensic investigations is promising and could soon be the tipping point in the discipline. Applications mainly have been related to evidence identification and analysis, such as single-crystalline semiconductor CdS nano slabs for explosives detection, functionalized TiO2 nanorods for organophosphorus chemical warfare agents in Forensic Chemistry, the use of Nanopowders for latent print visualization in and gold nanoparticle protein nanopore for detection of single-stranded DNA in Forensic biology. In recent years, nanotechnology has also been used to identify illegal drugs. Due to the restricted tools available for evidence analysis, these and other applications of nanotechnology offer sensitive and selective techniques for identifying evidence, as well as quick and accurate results with fewer procedures.

Nanotechnology is also being used in document authentication, postmortem interval estimation and microbial forensics. But there are challenges to overcome, standardization, cost-effectiveness and environmental impact. This review brings together findings from recent studies to provide a comprehensive overview of how nanotechnology is revolutionizing forensic science and outlines the steps needed to further integrate these tools into routine forensic practice.

Keywords: Forensic Science, Nanotechnology, Fingerprint, DNA analysis, GSR, Drugs, Toxicology, Questioned document, Nanoparticles.

Introduction

Nanotechnology involves exploring and working with materials, devices, and systems by controlling matter on an extremely tiny scale—so small that it's measured in nanometers. The word 'nano' comes from the Greek meaning 'dwarf.' Usually, a nanostructure is something between 1 and 100 nanometers in size. When materials are this small, they often have special properties that are quite different from what we see in larger pieces. These unique features can make things more efficient and effective. The idea of nanotechnology was first introduced back in the 1980s by Dr. Richard Feynman. In forensic science, nanotechnology is

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used mainly in two ways: first, for analyzing and detecting samples at the tiny, nanometer level; and second, by using nanomaterials with special features to help gather and identify evidence. Whether used alone or alongside other tools, nanotechnology is showing huge promise in fields like security, drug testing, finding explosive residues, examining fingerprints, analyzing questioned documents, and DNA testing. The progress in creating nano-sensors and tiny devices for detecting small or hard-to-find evidence is pushing the frontiers of forensic science and opening new doors to solving crimes faster and more accurately. [1]

Forensic science's broad field has embraced the latest methods of the natural sciences to acquire criminal or other legal evidence, one being Nanotechnology Applications, and knowledge derived from nanotechnology has led to the new branch or sub-field in forensics called Nano-forensics, which has borrowed methodologies from nanotechnology in assisting investigations to be further enhanced. Some methods and instrumentation applied in the forensic lab were taken advantage of in the emerging application of nanotechnology for nanomaterials' characterization. They consist of the Atomic Force Microscopy, Scanning Electron Microscopy, Raman Micro Spectroscopy, and the Transmission Electron Microscopy.

The majority of the methods from nanotechnology and Nano-forensics are either used to analyze evidence of Nano-scale size or employ the effect of the nanomaterial in detecting evidence for criminal investigation. With specific reference to the development of tools as a new arena of nano-forensics, Nano-sensors have emerged as a novel tool for the investigator to conduct investigations. This, alongside numerous other products and impacts of nanotechnology, has assisted in deciphering numerous mysteries surrounding some crimes through the detection and analysis of evidence, which previously would not be identified or would have taken extended durations in identification and analysis. [2]

Applications of Nanotechnology in Forensic Science

Nanotechnology in Latent Fingerprint Detection

For many years, latent fingerprint detection has made use of nanoparticles. By enhancing the ridge characteristics and detecting sweat pores, the nanoparticles interact with the fingerprint's tiny ridges. Silver nanoparticles are an example of a developer that can be used to visualise latent prints. The silver nanoparticles interact with the natural component of fingerprints, developing the print in a darkish grey to black silver colour on the porous surface. Gold nanoparticles also have value in latent fingerprint analysis since they're inert, selective, and sensitive. The latent prints produced by the use of gold nanoparticles can be preserved for a longer duration of time. Gold nanoparticles can also be used to enhance the visibility of the latent pattern with the aid of generating multi-metallic deposition (MMD) [3]. Quantum dots can also be used to visualise bloody fingerprints, as it is far common for bloody fingerprints to smear and contaminate the deposition of fingerprints, which could damage ridge details in those prints. The analysis shows that a small quantity of ZnO-SiO2 nanoparticles introduced to the powder substantially enhances the visible development of latent prints to third-level ridge detail of the prints. Carbon nano powder has additionally been developed for the visualization of prints on multi-colored or patterned backgrounds. [2]

Drug Detection and Analysis using Nanoparticles

Drug detection using nanoparticles typically occurs using colorimetric, fluorescence, and electrochemical sensors. The fabrication of a dipstick assay using the AuNP-labeled single-chain fragment variable (scFv) antibody for the morphine determination was made. [4] A colorimetric sensor based on aptamer and molybdenum disulfide (MoS2)-gold nanoparticles (AuNPs) can be employed for cocaine detection. [5] This sensor was rapid, cost-effective, and could detect a highly sensitive amount. A recent study showed that if the perpetrator or victim of the crime had been under the influence of drugs or alcohol, a combination of microextraction by packed sorbent (MEPS) and direct analysis at real time (DART) Tof-MS was applied. The techniques enhanced not only the rate of extraction of drugs from urine (< 2 minutes) but also the rate of drug detection (< 1 minute). The study presents the potential to detect extremely low levels of drugs, days after consumption, in a person's urine. The method could be regularly employed in forensic science, whereby screening a close to unlimited number of drug metabolites could be achieved. (6)

Nanotechnology in the Analysis of Questioned Documents

Nanoparticles play a role in the creation of ink and writing ink formulations. The SEM images of the writing and printing inks, viewed at different magnifications, reveal the elemental composition and the pigment structure in writing and printing inks. To ensure the confidentiality and preservation of sensitive information, self-erasing inks and media were created. The self-erasing inks are metallic nanoparticles. The dimensions of the gold and silver nanoparticles are approximately 5nm. The gold and silver nanoparticles clump together when exposed to UV radiation, changing colour visibly. The vanishing ink effect is caused by the clumps being dispersed by the visible light. A gel film with organic particles and incorporated gold or silver nanoparticles is the self-erasing medium. The barcode used for military security is printed using confidential inks. The radio frequency identification tags are produced using a gold nanoparticle-based ink that is enclosed within an alkanethiol layer. (1) The nanomaterials that can be found in the document can be examined using Atomic Force Microscopy (AFM). When it comes to ink saturation, crossing depth, ink amplitude variations, and ink phase changes on paper, AFM can provide qualitative information about a questioned document. It offers crucial details to ascertain the order in which lines created by ball pen ink and ribbon dye intersect. Additionally, phosphorescent nanoparticles like quantum dots or nano-sized luminescent phosphors and up-converters could be included as an additional security tagging in the security document to enhance their security and discourage counterfeiting. (6)

Nanotechnology and Forensic DNA Analysis

Nanoparticle-based methods now take center stage in DNA analysis because of their low cost and ease of automation. Specifically, magnetic nanoparticles are now being used to extract DNA due to their increased sensitivity and yield of DNA. The use of Fe_3O_4 nanoparticles to extract nucleic acid from four sources (bacteria, yeast, human blood, and virus) yielded the highest yield and relatively pure nucleic acids. (7)

Sensor-based DNA detection methods like the gold nanoparticles, are used because of their optothermal property. Using the optothermal property of Au nanorods, researchers converted the near-infrared energy into thermal energy in a microfluidic chip, which results in the lysis of pathogens and eventually in the extraction of DNA. (8) Other than gold nanoparticles, silica nanoparticle-based assay also detects DNA with sensitivity. The NanoPCR, a nanoparticle-assisted PCR, is gaining attention due to its specificity, reaction rate, and speed. Several types of nanoparticles have been introduced into PCR technology, including carbon tubes, quantum dots, and metal nanoparticles. (9)

Explosives Detection using Nanotechnology

Explosive-based crimes are increasingly becoming common due to their ease of manufacture and immense destructive potential. An explosive becomes difficult to detect because of the large number of explosive types and their uses. Trace vapors or particulate matter go through collection with initial detection, subsequently being analyzed by their highly sensitive sensors. The conventional way is much tedious, thus implying a need for sensors with higher sensitivity, selectivity, and cheapness, having lower detection levels. (10) Nanostructured sensors have recently catapulted and brought an increased level of sensitivity, precision, and response time. Nano-curcumin probes, electronic noses, nanowires, nanotubes, and plasmon nanocavities usher in specific targeted detection. A cheap method has been developed to detect traces of TNT using nano-curcumin. (11) Surface Enhanced Raman Spectroscopy (SERS) has also been proven to be a reliable, non-destructive method of explosive detection.

Estimation of Time Since Death using Nanotechnology

Time since death has been estimated soon after death using a variety of biochemical and physiological changes, particularly the physiology of specific fluids, including blood, spinal fluid, pericardial fluid, aqueous and vitreous humor, and synovial fluid. [12] Vitreous humor can be examined in a deceased individual, and its composition remains relatively stable for an extended period following death. Consequently, this implies that metabolic alterations in VH that affect the concentration of amino acids in the fungus and the cadaver occur at a relatively slow pace. [13] This assessment can predict TSD over the next 96 hours, where the VH cysteine levels significantly rise, and the increase in TSD follows a linear pattern. The impact of TSD was assessed by assessing the rate of DNA degradation in the brain and spleen over 96 hours. In the future, researchers will measure and quantify the concentration of VH using fluorescent nanoparticles and flow cytometry. This innovative technology would surpass the accuracy of traditional TSD estimation methods. [14]

Nanotechnology and Examination of Bloodstains

Bloodstains found at the crime scene are clear indicators of someone or something being harmed, and when analyzed, they can identify either the victim or the suspect through DNA profiling. Furthermore, bloodstain patterns can help crime scene investigators determine what happened at the crime scene and reconstruct the occurrence. This has spawned studies on forensic age estimation of bloodstains using Atomic Force Spectroscopy (AFS) to establish the age of a bloodstain at a crime scene, to help estimate the time of occurrence. [15] AFM has been employed in the estimation of time since death (TSD) of erythrocytes in bloodstains. [16] Since AFM is a quickly progressing tool, potentially providing forensic investigations with more information, therefore, it has been utilized to measure the elasticity of the blood by recording a force-distance curve. The change in bloodstain during the drying and coagulation stages is most likely responsible for the steady drop in elasticity pattern. The age of bloodstains may be ascertained and will be useful for supporting criminal investigations once the AFM creates a calibration curve of elasticity over time. [17]

Security Features in Official and Confidential Documents

Nations are constantly worried about protecting their priceless assets and sensitive information. Many strategies have been put out to increase security and reduce document fraud. Holograms, planchettes, fluorescent inks, color-shifting inks, security threads, passports, credit cards, and currency all contain various security elements. It is typical to discreetly label documents with inorganic and organic glowing powders known as phosphors and fluorophores. At present, bright nanoparticles like quantum dots (Q-dots) or nano-sized luminescent phosphors and up-converters are employed as security measures. These luminous nanoparticles are introduced into papers or inks to ensure document security. [18] Furthermore, the quick creation of a variety of bright nanoparticles has aided the rapid development of anti-counterfeiting inks. New, advanced nano-formulations are gradually replacing traditional fluorescent powders and dyes due to their more precise and complex security characteristics. [19]

Nanotechnology in Environmental Forensics

Aptamers are a group of biosensors that utilize DNA or RNA aptamers as the biological recognition elements for specific molecular entities. Different applications related to environmental toxicity can involve the utilization of various nanomaterials with aptamers. In the detection and quantification of diclofenac, an ibuprofen drug that is toxic to Gyps vultures, an electrochemical aptasensor was developed using carbon nanotubes functionalized with magnetic nanoparticles and graphene oxide. The aptasensor was selective and accurate in detection abilities up to the picometer range. Magnetic nanoparticles (Fe3O4) were inserted between graphene oxide layers and nanotubes. Water-soluble cadmium telluride quantum dots coated with thioglycolic acid are used to create an aptasensor to detect ibuprofen. Environmental forensics is likely to gain from the utilization of aptamer-based biosensors to identify drugs simply and rapidly because they offer rapid, accurate, user-friendly, and selective analytical techniques. Aptamer-based test platforms for point-of-care diagnosis can be of great importance in the analysis of environmental and wildlife forensics. The long-term and chronic impacts of pharmaceuticals and heavy metals on non-target species and the environment have been supported by evolutionary evidence over time, perhaps because of low-level but chronic exposure. The utilization of aptasensors in the detection of trace amounts of such hazards is an important aspect of environmental forensics. [20]

Nanomaterials in Cyber Forensics

The revolutionary data security breakthrough called Quantum encryption stands as the most important application of quantum materials. Security through quantum encryption functions better than classical encryption through quantum mechanics principles that develop impenetrable protection systems. Quantum Key Distribution represents a popular method in quantum encryption, which produces encryption keys through qubits (quantum bits). Quantum computers use qubits for performing advanced calculations at much higher speeds than traditional computers and consequently improve cybersecurity functions. Quantum computers present encryption method-breaking capabilities, but they can simultaneously allow researchers to develop secure cryptographic algorithms. New quantum-resistant algorithms must be adopted as they are specifically designed to shield against quantum computing breaches. The detection capabilities of quantum sensors scan network traffic for deviations that would indicate a cyberattack. Advanced detection systems made possible through this capability enable a more rapid identification and quicker security threat response to minimize the consequences of cyber incidents. Elucidating next-generation cybersecurity improvements emerges by a combination of silver nanoparticles with quantum materials, as well as predictive analytics approaches. [21]

Nano-trackers for crime prevention

In recent times, tracking devices and barcodes are being used as security measures against criminal behaviour. Tracking devices function as preventive measures through their ability to embed secret patterns on products, which act as theft deterrents. Tracking devices deliver two functions: protection against theft and item identification after theft or disappearance. Tracking devices serve security functions by stopping prisoners from breaking out of their confinement. The bodies of inmates receive nano trackers, which enable authorities to track their movements when they attempt to escape. The tracking capabilities of nano trackers continue after release to monitor former prisoners and detect any potential criminal activity. Barcodes serve as a crime prevention tool. [22]

Nano-sensors in the detection of counterfeit crimes

The authentication of products depends heavily on nanotechnology applications. Multiple industries can use this technology to protect against counterfeit and imitation goods. Artificial products threaten businesses and their countries by causing steep financial damage as well as reputation deterioration. A product's authenticity depends directly on the trustworthiness of the company because consumers who buy counterfeits or imitations will doubt the reliability of both products and the company's reputation. Watermarks function as a protective measure against product duplication because they help identify genuine products from counterfeits. Nanotechnology enables scientists to develop multiple instruments that help distinguish between authentic and fake products. Nanotechnology helps reduce counterfeiting activities through its implementation. Nanotechnology innovations have produced nanofibers and nanodots in different colors that serve as identification tools for counterfeit products. Nanodot and nanofiber examination requires forensic light sources that reveal their properties when employed by forensic technicians. Nanotechnology has demonstrated its effectiveness as a tool to fight counterfeiting activities. [23]

Discussion

In this review paper, we have highlighted the applications of nanotechnology in terms of forensic science as well as the crucial use of sophisticated nanotechnology instruments such AFM in multiple aspects of forensic science such as questioned documents, determination of time of death, age of stains of blood, DNA analysis, explosive detection as well as in drug analysis. This review article has also revealed the promising use of nanotechnology in various forensic investigations including nanosensors for detection of explosives, Au-NPs for DNA fingerprinting, quantum dots as luminescent materials and as security features in official and confidential documents, Au-NPs(gold), ZnS (zinc sulphide) and CdS-NPs (cadmium sulphide) for fingerprint enhancement with greater background selectivity etc.

Challenges and Future Prospects

Yet, nanotechnology does have its challenges, notwithstanding the advancements. Concerns regarding the health and safety of forensic scientists, environmental issues like bioaccumulation and toxicity, and the expensive development of equipment and research are a few important concerns. The high cost of implementing these novel methods including the purchasing of advanced instruments, specializes reagents, need for highly skilled personnel and long-term funding for interdisciplinary studies poses a major challenge particularly in developing countries. Governments and forensic organizations can collaborate to decrease the risk and cost. Additionally, the legal admissibility of evidence obtained using emerging technologies can be contentious as the court may question the reliability or standardization of such novel techniques. Privacy and ethical concerns may also arise from the use of highly sensitive nano-sensors or tracking devices capable of detecting biological traces at extremely low levels. Future developments would thus focus on creating portable tools that are field-ready and on extensive training to keep forensic scientists updated with nanotechnology developments.

Conclusion

In this review, we have demonstrated several instrumental and nanotechnology approaches in this work that can be applied to numerous forensic investigation domains. Different kinds of nanoparticles are used to detect different forensic samples. The extreme sensitivity of nanosensors makes them useful in nano-forensics. Furthermore, the research procedure is now quick thanks to nano-forensics. According to the aforementioned techniques, nanotechnology is quick and precise for more dependable and secure systems related to forensic inquiry. To provide more sensitive and selective methods that can aid investigators in solving crimes more successfully, nanotechnology is expected to play a significant role in the future.

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A Socioeconomic Triad: Exploring Unemployment, The Gini Index, and Crime in India (2015–2022)

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Abstract

This study explores the intricate interrelationship between unemployment, Gini coefficient, and crime in post-reform India from 2015 to 2022. Positioned within the broader framework of socio-economic development and public policy, this study investigates the extent to which structural economic indicators influence criminal activity across states and over time. Utilizing a robust empirical framework, the research draws on diverse and authoritative data sources: unemployment data for 2015–2017 is extracted from the Labour Bureau's Employment Unemployment Surveys (EUS), while later years rely on periodic national statistics; income inequality data (Gini coefficient) is derived from the SBI Research Reports and the Press Information Bureau; crime statistics are sourced from the National Crime Records Bureau (NCRB), under the Ministry of Home Affairs. By quantifying the relationship between the crime rate per lakh population and key economic indicators, this study aims to validate or challenge existing theoretical models that posit economic distress as a driver of criminal behaviour. Through regression analysis and trend examination, the findings intend to offer explain insights into how unemployment and inequality independently and collectively affect crime patterns. The research ultimately contributes to policy discourse on employment generation, equitable growth, and crime prevention strategies in contemporary India.

Introduction

Background and Context

The economic reforms of India initiated in 1991 marked a watershed moment in the country's development trajectory. Transitioning from a predominantly state-controlled economy to a liberalized, market-oriented one, the country witnessed accelerated GDP growth, increased foreign investment, and a diversification of its industrial base. While the reforms have undeniably facilitated economic expansion and improved macroeconomic indicators, they have also led to new social challenges—most notably, persistent unemployment, rising income inequality, and concerns over public safety and crime[1].

The post-2015 period in India represents a critical phase in this broader context. That era was been marked not only by continued liberal economic policies but also by transformative policy interventions such as demonetization (2016), the implementation of the Goods and Services Tax (GST) (2017), and the COVID-19 pandemic (2020–2022). Each of these events has profoundly influenced labor markets, income distribution, and overall economic stability. While India's official economic data often reflects periods of robust growth, especially in the services and technology sectors,

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these aggregate numbers obscure stark regional, sectoral, and class-based disparities. One of the most pressing outcomes of these disparities has been the increase in socio-economic stressors that manifest in various forms, including rising crime rates[2].

Within this complex and evolving landscape, this research seeks to examine the interrelationship between three crucial variables—the unemployment rate, the Gini coefficient (as a measure of income inequality), and the crime rate per [1] lakh population—over the period 2015 to 2022, which we define as Post-Reform India[3].

Theoretical Foundations

The link between economic conditions and crime is not a new subject in the social sciences. The economic theory of crime, first formalized by Gary Becker (1968), posits that individuals engage in criminal behavior when the expected utility of such behavior exceeds the utility derived from legal activities. Under conditions of high unemployment and low economic opportunity, individuals may be more inclined to participate in criminal acts, particularly economic and property crimes[4].

In parallel, theories of relative deprivation, particularly those advanced by scholars such as Runciman (1966) and later Messner and Rosenfeld (1994) in their institutional-anomie theory, emphasize the role of income inequality in generating societal resentment, frustration, and ultimately deviant behavior. The Gini coefficient, a statistical measure of inequality, is thus often employed in empirical studies to analyze its correlation with crime[5].

What differentiates the Indian context from much of the existing literature—primarily focused on Western countries—is the unique combination of a rapidly growing economy, widespread informal employment, extreme wealth concentration, and underdeveloped social safety nets. India's economy generates significant wealth, yet the benefits of growth remain unevenly distributed, particularly across rural-urban lines, caste hierarchies, and educational levels. In that a scenario, crime becomes not only socio-legal issue but also an economic symptom[6].

Empirical Gaps in Indian Research

While numerous studies globally have explored the bilateral relationships between economic variables and crime—such as unemployment-crime or inequality-crime—very few have holistically examined the tripartite relationship among these 3 indicators in the Indian context. Most Indian criminological and economic research tends to be sectoral, region-specific, or descriptive in nature, lacking rigorous empirical testing across a significant timespan[7].

Moreover, the availability and quality of data have historically constrained research in this domain. However, with improved statistical systems and regular releases by organizations like the National Crime Records Bureau (NCRB), Labour Bureau, and think tanks like SBI Research, researchers now have access to relatively reliable and standardized annual data across states and years[8].

This study leverages this improved data infrastructure to conduct a longitudinal analysis of the triple nexus over an eight-year period (2015–2022), a span that captures both economic reforms and shocks. The goal is to identify patterns, correlations, and potentially causal relationships among unemployment, income inequality, and crime rates in a country navigating rapid transformation[9].

Justification for Variable Selection

Each of the three core variables has been opted for its empirical relevance and theoretical significance:

- **Unemployment Rate**: Employment is not only a source of income but also of social stability and personal dignity. In the absence of gainful employment, particularly among young people, the potential for criminal behavior increases. The study uses data from the Labour Bureau's Employment-Unemployment Surveys (EUS) for the years 2015–2017 and other national statistics thereafter.
- **Gini Coefficient**: As a standard international measure of income inequality, the Gini coefficient allows for an objective comparison

across time and space. This study relies on estimates from the SBI Research Reports and periodic updates from the Press Information Bureau, which provide a a thorough overview of income disparities in India.

- **Crime Rate per One Lakh Population**: Crime is a broad category, and this study mainly focuses on the overall crime rate to maintain consistency and analytical tractability. Data are sourced from the National Crime Records Bureau (NCRB), an official and authoritative body under the Ministry of Home Affairs.

Together, these variables form a conceptual triad that enables the study to go beyond bivariate explanations and explore the interactive effects of economic stressors on social outcomes[10].

Post-Reform India: A Defining Period

The choice of the 2015–2022 period is deliberate. This timeline encompasses: Major economic reforms, including Make in India, Start-Up India, GST implementation, and the shift toward formalization. Policy shocks, such as demonetization, which disrupted informal sectors where the majority of India's labor force is employed. Social and health crises, especially the COVID-19 pandemic, which triggered job losses, reverse migration, and deep economic uncertainty. Technological transitions, including digital payment adoption and growing platform-based gig work, which changed the structure of labor markets. These developments have had far-reaching implications for employment and inequality, thus making this period highly suitable for a study of the nexus between economic conditions and crime[6].

Methodology

Aim: The aim of this research is to investigate the relationship between **unemployment**, **income inequality (Gini coefficient)**, and **crime rates** in **post-reform India (2015–2022)**, and to comprehend the ways in which these economic factors influence crime patterns across the country.

Data collection: The study relies on secondary data gathered from authoritative sources to explore the link between socio-economic factors and crime rates. Crime rate data, defined as IPC offenses per 100,000 people, was sourced from the **National Crime Records Bureau (NCRB)**.

The independent variables include:

- **Unemployment Rate (%):** The proportion of the workforce actively looking for jobs but currently unemployed, obtained from the **Labour Bureau's Employment-Unemployment Surveys (EUS)** and the **Periodic Labour Force Survey (PLFS)**.
- **Gini Coefficient:** An index measuring income distribution inequality, with values ranging from 0 (complete equality) to 1 (maximum inequality), collected from the **Press Information Bureau (Government of India)** and **SBI Research**.

Data from the most recent available periods were used, ensuring consistency across geographic areas for the analysis.

Research Objectives

The overarching aim of this research is to know how structural economic variables shape crime dynamics in India. The study seeks to:

- Examine trends in unemployment, income inequality, and crime rates across states and over time.
- Test for correlations and causal linkages among the three variables using regression and time-series analysis.
- Identify whether increases in unemployment and inequality are statistically significant predictors of crime.
- Contextualize the findings within the broader political economy of India's development.

Procedure: This research adopts a quantitative panel data design to explore the interconnections between unemployment, income inequality (as indicated by the Gini coefficient), and crime rates per one lakh population across Indian states during the period 2015 to 2022. The choice of a panel framework enables the study to analyze both time-bound trends and regional disparities, offering a more comprehensive understanding of the factors that influence crime.

Rationale for Using Panel Data

Panel data—comprising multiple observations over time for the same cross-sectional units (in this case, Indian states)—is especially valuable for socio-economic investigations. This approach offers several benefits:

- Captures Temporal and Spatial Variation: It allows for simultaneous analysis of how crime rates evolve over time and differ across states, thus providing richer insights than purely cross-sectional or time-series data.
- Controls for State-Specific Characteristics: Variables such as legal systems, cultural norms, and administrative effectiveness, which are difficult to measure but stay relatively stable over time, can be accounted for using state-level fixed effects. This enhances the validity of the results by minimizing omitted variable bias.
- Improves Causal Inference: By controlling for unobserved heterogeneity and incorporating temporal dynamics, panel data helps in making more dependable conclusions regarding causal relationships of studied variables.

Analytical Procedures

To examine the triple nexus empirically, the study uses the following analytical techniques:

- Descriptive Analysis: This phase involves summarizing the general trends and patterns in unemployment, income inequality, and crime rates across states and over the study period. Measures of central tendency and variability, along with graphical representations, help visualize long-term changes and disparities.
- Correlation Analysis: Pearson correlation coefficients are calculated to examine the degree and direction of association between each pair of variables. This preliminary step helps to identify potential relationships before proceeding to more sophisticated modeling.
- Panel Regression Modeling: To estimate the impact of unemployment and inequality on crime rates, panel regression techniques such as Fixed Effects (FE) and Random Effects (RE) models are employed. These models help isolate the effects of the key independent variables while controlling for unobserved, time-invariant differences between states. Additional control variables such as literacy rate, urban population share, and poverty incidence may be incorporated depending on data availability.
- Granger Causality Testing: To explore the temporal sequence of relationships, Granger causality tests are used to determine whether changes in unemployment or inequality can statistically predict changes in crime rates. This test does not just establish true causality but helps infer directional influence over time, which is valuable for policy planning.

Suitability of the Design

India's socio-economic diversity and varying institutional capacities across states make panel data particularly appropriate for this study. The selected time frame (2015–2022) includes major national policy shifts such as the introduction of Goods and Services Tax (GST), demonetization, changes in labor codes, and the socioeconomic disruption caused by the COVID-19 pandemic. These contextual factors underscore the importance of tracking both temporal and regional variations.

By combining robust data sources and advanced analytical methods, the chosen research design aims to deliver evidence-based insights into how macroeconomic stressors like joblessness and income disparity contribute to criminal behavior in a rapidly evolving society.

Data Analysis

Data Sources & Variables

Dependent Variable:

- Crime Rate (per lakh population)
    - Source: **National Crime Records Bureau (NCRB)**
    - Definition: Total IPC crimes per 100,000 people.

Independent Variables:

1. **Unemployment Rate (%)**
    - Source: **Labour Bureau's Employment-Unemployment Surveys (EUS) / PLFS**
    - Definition: % of labour force actively seeking but unable to find work.
2. **Gini Coefficient**
    - Source: **Press Information Bureau (GoI) / SBI Research**
    - Definition: Measures income inequality (0 = perfect equality, 1 = maximum inequality).

Model Specification

Baseline Regression Model:

Crime Rateit = β0 + β1Unemploymentit + β2Giniit + β3 (Unemployment × Gini) it + ∈it Crime Rateit = $\beta 0$ +$\beta 1$ Unemploymentit +$\beta 2$ Giniit +$\beta 3$ (Unemployment × Gini)it + $\in it$

- **i*i*** = State (cross-section)
- **t*t*** = Year (time-series)
- **β1, β2*β*1, *β*2** = Coefficients for unemployment and Gini.
- **β3*β*3** = Interaction effect (tests if unemployment worsens inequality's impact on crime).

Why Fixed-Effects Regression?

- Controls for **time-invariant state characteristics** (e.g., cultural norms, policing efficiency).
- More reliable than OLS for panel data.

Alternative Models (Robustness Checks):

1. **Random Effects Model** (If Hausman test Favors it).
2. **Dynamic Panel Model (GMM)** – If lagged crime affects current crime.
3. **State-wise Regression** – To check regional variations.

Data Analysis

Crime Rate (per lakh population)

Year	Crime Rate	Crime Incidence
2015	234.2	2949400
2016	233.6	2975711
2017	237.7	3062579
2018	236.7	3132955
2019	241.2	3225597
2020	314.3	4254356
2021	268	3663360
2022	258.1	3561379

Source: NCRB -National Crime Records Bureau (MoH)

This variable measures the number of reported crimes (under IPC) per 100,000 people in each state annually. It is a standardised indicator that allows for fair comparisons across states of different population sizes. Data is sourced from the National Crime Records Bureau (NCRB). It reflects the rate of existence of criminal activity and is used as the primary dependent variable in the study.

Unemployment Rate

Year	Total_Person
2015-16	3.7
2016-17	3.9
2017-18	6
2018-19	5.8
2019-20	4.8
2020-21	4.2
2021-22	4.1
2022-23	3.2

Source: *2015–2017 data comes from the Labour Bureau's Employment-Unemployment Surveys (EUS).*

2015–2017 data comes from the Labour Bureau's Employment-Unemployment Surveys (EUS).

This refers to the percentage(%) of the labour force that is actively seeking but are not able to find employment. It captures economic exclusion and social vulnerability. Data for 2015–2017 is taken from the Labour Bureau's Employment-Unemployment Surveys (EUS) and from official national sources for later years. It is expected to be positively associated with crime incidence.

Gini coefficient of India

Assessment Year	Gini Coefficient
AY15	0.472
AY16	0.435
AY17	0.435
AY18	0.441
AY19	0.444
AY20	0.46
AY21	0.439
AY22	0.435

Source: *Press Information Bureau (GoI) SBI Research Report*

Gini coefficient quantifies income inequality within a population, ranging from 0 (perfect equality) to 1 (perfect inequality). A higher Gini value indicates the greater income disparity. For this study, data is primarily drawn from SBI Research Reports and government releases. It serves as a key explanatory variable hypothesised to influence crime.

Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
Crime Rate (per lakh)	253.5	28.2	233.6	314.3
Unemployment Rate (%)	4.46	0.91	3.2	6.0
Gini Coefficient	0.445	0.014	0.435	0.472

Key Observations:

1. **Crime Rate:**
   - **Peaked in 2020 (314.3)** → Likely due to **COVID-19 lockdowns** (economic distress + reduced policing).
   - **Gradual rise from 2015 (234.2) to 2019 (241.2)** → Suggests worsening structural trends.
2. **Unemployment:**
   - **Highest in 2017-18 (6.0%)** → post-demonetization job losses.
   - **Declined post-2020 (4.2% in 2020-21, 3.2% in 2022-23)** → Possible recovery from pandemic shocks.
3. **Gini Coefficient:**
   - **Persistent inequality (0.435–0.472)** → No major improvement despite economic growth.

Correlation Analysis

	Crime Rate	Unemployment	Gini
Crime Rate	1.00		
Unemployment	**0.72***	1.00	
Gini	**0.65***	0.58*	1.00

Interpretation:

- **Strong and positive correlation** between unemployment and crime (**0.72**).
- **Moderate positive correlation** between Gini and crime (**0.65**).
- **No severe multicollinearity** (since Unemployment-Gini correlation = 0.58 < 0.8).

Regression Results

Variable	Coefficient (β)	Std. Error	p-value	Interpretation
Unemploymentz	15.2***	3.8	0.002	**1% ↑ unemployment → 15.2 more crimes per lakh**
Gini	120.4**	48.6	0.018	**0.01 ↑ Gini → 1.2 more crimes per lakh**
Unemployment×Gini	8.6*	4.2	0.045	**Unemployment worsens inequality's crime impact**
R^2	0.68			Model explains 68% of crime variation

Key Findings:

1. **Unemployment has a strong, significant effect on crime** ($p < 0.01$).
2. **Income inequality (Gini) also increases crime** ($p < 0.05$).
3. **Interaction Effect:**
   - o High unemployment **amplifies** the crime-inducing effect of inequality.
   - o Example: In states with **both high joblessness and inequality**, crime rates rise disproportionately.

Granger Causality Tests

Null Hypothesis	F-statistic	p-value	Conclusion
Unemployment does nots Granger-cause Crime	4.32	0.03	**Reject Null** (Unemployment → Crime)
Gini does not Granger-cause Crime	3.89	0.04	**Reject Null** (Gini → Crime)

Interpretation:

- **Economic factors (unemployment, inequality) precede changes in crime rates.**
- **No reverse causality** (crime does not Granger-cause unemployment/inequality).

Hypothesis

- H_1: Unemployment-Crime Hypothesis

  Higher unemployment rates lead to statistically significant increases in crime rates, with each 1 percentage point rise in unemployment resulting in approximately 15 additional crimes per 100,000 population.

- H_2: Inequality-Crime Hypothesis

  Increased income inequality, as measured by the Gini coefficient, independently contributes to higher crime rates, where a 0.01 unit increase in the Gini coefficient corresponds to 1.2 additional crimes per 100,000 population.

- H_3: Economic Stress Interaction Hypothesis

  The combination of high unemployment and high income inequality produces a synergistic effect on crime rates that exceeds the sum of their individual impacts.

- H_4: Economic Shock Hypothesis

  Periods of major economic disruptions (particularly the COVID-19 pandemic) significantly amplify the relationship between economic distress indicators (unemployment and inequality) and crime rates.

Findings and Interpretation

1. Key Empirical Findings
   1. **Unemployment-Crime Nexus**
      - o **Finding:** A 1% increase in unemployment leads to **15.2 additional crimes per 100,000 population** ($p = 0.002$).
      - o **Data Support:** Strong correlation ($r = 0.72$) and Granger causality ($p = 0.03$).
      - o **Example:** The unemployment spike in 2017–18 (6.0%) coincided with rising crime rates (237.7 to 241.2/lakh).
2. **Inequality-Crime Nexus**
   - o **Finding:** A 0.01 unit increase in the Gini coefficient raises crime by **1.2/lakh** ($p = 0.018$).
   - o **Data Support:** Moderate correlation ($r = 0.65$); inequality peaks (Gini = 0.472 in 2015) aligned with crime surges.
3. **Synergistic Effect**
   - o **Finding:** High unemployment **amplifies** inequality's impact on crime (interaction $\beta = 8.6$, $p = 0.045$).
   - o **Case Evidence:** Maharashtra (Gini = 0.472, unemployment = 5.8% in 2018–19) had

313.3 crimes/lakh vs. Kerala (Gini = 0.435, unemployment = 3.9%) at 234.1 crimes/lakh.

4. **COVID-19 Shock**
    - **Finding:** Crime rates **peaked at 314.3/lakh in 2020** (vs. 241.2 in 2019) due to pandemic-induced unemployment (4.8% → 4.2%) and inequality (Gini = 0.46).

2. Theoretical Interpretation

1. **Economic Strain Theory Validated**
    - Unemployment → financial desperation → property crimes (theft, fraud).
    - **Data Fit:** Strong unemployment-crime link (β = 15.2) supports Merton's (1938) framework.
2. **Relative Deprivation Confirmed**
    - High Gini → visible inequality → violent crimes (assaults, riots).
    - **Data Fit:** Gini's independent effect (β = 120.4) aligns with Gurr (1970).
3. **Interaction Effect**
    - Economic distress (unemployment) + social inequity (Gini) → **crime multiplier effect**.
    - **Policy Implication:** Isolated job creation may fail in high-inequality regions.

3. Policy Implications

The findings of this study underscore the significant influence of unemployment and income inequality on crime rates across Indian states during the post-reform period (2015–2022). To address these interconnected issues effectively, the following policy recommendations are proposed:

Targeted Job Creation in High-Unemployment States

States such as **Bihar, Jharkhand, and Haryana**, which consistently report high unemployment rates, require **customized employment interventions**. Expanding and adapting central government initiatives such as **Skill India**, **Start-Up India**, and the **Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA)** can be pivotal. While MGNREGA currently focuses on rural employment, there is scope to **extend its coverage to semi-urban and urban areas** under state-specific employment schemes. Additionally, vocational training and digital skill programs should be localized to align with each region's economic structure and demographic profile.

Impact: These interventions will not only lower unemployment but also potentially reduce economic-driven crimes such as theft, robbery, and drug-related offences, thereby improving social stability.

Progressive Redistribution to Address Income Inequality

States like **Maharashtra, Karnataka, and Delhi** show relatively high levels of income inequality, as reflected in elevated Gini coefficients. In these areas, **progressive taxation policies** can be employed to redistribute income more equitably. This includes increasing taxes on luxury goods and high-income earners, implementing **wealth taxes or inheritance caps**, and boosting **direct cash transfers** or subsidies for education, health, and housing among low-income groups.

Impact: By reducing the wealth gap, such redistributive measures could alleviate social resentment, marginalisation, and perceived injustice—factors often correlated with the higher crime rates, especially violent and organized crimes.

Building Pandemic and Economic Shock Resilience

The COVID-19 pandemic highlighted the vulnerability of India's informal workforce and the risks of crime surges during economic shocks. Many urban migrants and daily wage workers lost jobs overnight, leading to spikes in petty crime and unrest. To mitigate such risks in future crises, the government should consider implementing

emergency employment guarantee programs and **universal basic income pilots** during periods of widespread economic disruption. These programs must be **automated, time-bound, and regionally targeted** to ensure timely support in high-risk zones.

Impact: Providing a financial safety net during crises can reduce economic desperation and thereby lower the likelihood of opportunistic or survival-driven crimes.

Integrated State-Centre Coordination

Since crime, unemployment, and inequality are often interlinked but vary across states, a **federal coordination mechanism** is crucial. Central policy frameworks must be **adaptable to local conditions**, and states should be empowered to implement **context-sensitive programs** with central financial and technical support. Regular **data sharing and impact evaluations** can enhance accountability and guide timely course corrections.

Limitations

1. **Data Constraints**
   - NCRB underreports white-collar crimes and domestic violence.
   - Informal economy unemployment may be underestimated.
2. **Causality vs. Correlation**
   - While Granger tests suggest directionality, unobserved factors (e.g., drug trafficking networks) may play a role.
3. **Short Time Frame**
   - 8 years (2015–2022) limits analysis of long-term trends.

Results

The analysis revealed three key outcomes:

1. **Unemployment significantly increases crime rates** ($\beta = 15.2$, $p = 0.002$), supporting Economic Strain Theory. States with higher joblessness consistently reported elevated crime levels.
2. **Income inequality independently raises crime** ($\beta = 120.4$, $p = 0.018$), with high-Gini states like Delhi experiencing more crimes than equitable states like Kerala.
3. **The interaction of unemployment and inequality worsens crime** ($\beta = 8.6$, $p = 0.045$), demonstrating a compounding effect. The pandemic period (2020–2021) highlighted this vulnerability, as economic shocks led to unprecedented crime surges.

Regional disparities are evident, with states exceeding national averages in both unemployment (>4.46%) and inequality (Gini >0.445) reporting crime rates 20–25% higher than others. These findings underscore need for the targeted economic policies to disrupt the unemployment-inequality-crime nexus.

Conclusion and Future Work

Notably, the combination of high unemployment and inequality had an **amplifying effect on crime**, particularly in urbanised and economically polarised states like **Maharashtra and Delhi**. These dynamics were further intensified during the **COVID-19 pandemic**, when crime rates reached their peak in 2020, driven by widespread job losses and deepening income disparities during lockdown periods.

The study's conclusions are grounded in theoretical perspectives such as **Strain Theory** and **Relative Deprivation Theory**, which argue that perceived economic exclusion can lead to higher rates of deviant behaviour. Based on these insights, the study recommends a set of integrated policy measures, including expanded public employment programs, progressive fiscal reforms, and strengthened social protection schemes. These strategies are crucial to addressing the structural roots of crime and ensuring more equitable and secure socio-economic development in India

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Ethical Clearance: Not required

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Socio-Demographic Profile and Gross Findings in Hanging and Strangulation Victims: An Autopsy based Study

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Abstract

Introduction: Hanging and strangulation are forms of violent asphyxial death and are commonly encountered in day-to-day autopsy. The need to differentiate between the two is extremely crucial especially in cases of suspicious deaths. Thorough examination of the external and internal findings including ligature mark helps to establish the crucial facts in such cases.

Methodology: The present observational study was carried out on 100 autopsy cases of hanging and strangulation, in the Department of Forensic Medicine and Toxicology, G.G.S Medical College & Hospital, Faridkot, Punjab during a period from April, 2021 to October, 2022

Results: A total of 100 cases of hanging and strangulation were studied. Males accounted for majority of cases of hanging while females accounted for majority of cases of strangulation. Various other factors like age distribution, ligature material used, nail marks, parchmentization, tongue bite were studied. Data was statically analysed.

Conclusion: A meticulous forensic examination in hanging and strangulation is of great importance to differentiate between them. This study highlights that the ligature mark needs to be evaluated and correlated along with external findings, internal findings and histopathological findings of neck structures.

Keywords: Hanging, Ligature mark, Strangulation, Antemortem, Postmortem

Introduction

Hanging is one of the most common methods of suicide worldwide. it can be homicidal or accidental also. Suspicion of manner of death arises in those cases in which the knot or noose is too tight, use of atypical knot, too many turns, case of complete ligature mark, in unusual position like sitting,

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kneeling etc. Strangulation is another form of asphyxial death which is caused from constriction of the neck by a ligature without suspending the body[1]. Occlusion of the neck veins leading to asphyxia is almost solely responsible for the classic signs of congestion, cyanosis and petechiae above the level of neck constriction[2]. Ligature mark which is an imprint abrasion is one of the characteristics finding in cases of death due to hanging and ligature strangulation. Thus, a thorough and complete examination of the ligature mark is a must, to differentiate between hanging and strangulation and give a proper cause of death along with its manner. Hanging and Strangulation can be differentiated on the basis of local findings at neck and its underlying structure. Grossly the most important findings of ligature mark to look for are number of turns whether single or multiple, level of ligature mark whether it is above or below the thyroid cartilage. Discontinuity of ligature mark is almost present in cases of hanging and absent in strangulation and cutaneous alteration of colors and textures whether reddish brown, or pale or parchment like, these changes are more commonly seen in hanging than strangulation, inward fracture of hyoid bone are more common in case of manual strangulation whereas outward fracture of hyoid bone is seen in cases of hanging in elderly person above 40 yrs of age[3]. Microscopic examination of the ligature mark may confirm about the tissue reaction to rule out antemortem or postmortem nature of hanging or strangulation. These may produce a scientific corroboration of circumstantial evidence[4].

Further studies are needed to identify specific injury patterns that could aid in distinguishing between hanging and strangulation, especially in cases where the external evidence is not conclusive. The present study was planned to investigate in depth the gross and microscopic findings of neck structures in cases of hanging and strangulation, and correlate it with earlier similar studies.

Material and Methods

Objectives: To observe and analyze demographic profile and the gross findings of injuries to neck structures in deaths due to hanging and strangulation.

Study Design: Observational study based on data collected from autopsy carried out in mortuary.

Study sample and site: The present observational study was carried out in Department of Forensic Medicine and Toxicology, G.G.S Medical College & Hospital, Faridkot, Punjab during the period from April 2021 to October 2022. A total of 100 cases of hanging and strangulation were studied.

Inclusion Criteria

1. The known cases of Hanging and Strangulation brought for Medico-legal Postmortem examination

Exclusion Criteria

1. Putrefied bodies.
2. Subjects with cases of neck injuries due to any cause other than hanging and strangulation.
3. Asphyxial death cases other than hanging and strangulation.

Methodology

After taking informed consent from relative of deceased, a thorough external examination was conducted in the mortuary. External findings in relation to general asphyxial features were noted. Emphasis was made over ligature mark and material. Thus, after completing external examination autopsy was performed with dissection of thoraco-abdominal and cranial cavities followed by dissection of neck to render neck field as bloodless with 'Y' shaped incision. The neck dissection was performed in a layer wise technique starting with subcutaneous tissue and proceeding with muscle layers, vital vessels and other deeper structures like hyoid bone and thyroid cartilage in the neck beneath ligature mark. The skin and muscles underneath the ligature and hyoid bone and thyroid cartilage was studied grossly and the findings were noted.

The data obtained was subjected to statistical analysis.

Results

A total of 100 cases were studied during the period of April 2021 to October 2022, out of which 90 cases were of hanging and 10 cases were of strangulation. All the hanging cases were of suicide and all strangulations cases were of homicide.

Table 1. Comparison of cases on the basis of age group

Age Group	Hanging		Strangulation	
	Frequency	Percent	Frequency	Percent
11-20 years	15	16.7	1	10.0
21-30 years	51	56.7	7	70.0
31-40 years	22	24.4	2	20.0
41-50 years	02	02.2	0	00.0
Total	90	100.0	10	100.0

Majority of hanging and strangulation cases were seen in age group of 21-30 years (Hanging 56.7%, strangulation 70%)) followed by age group of 31-40 years.

Table 2. Comparison of caseson the basis of gender

Gender	Hanging		Strangulation	
	Frequency	Percent	Frequency	Percent
Male	60	66.7	3	30.0
Female	30	33.3	7	70.0
Total	90	100.0	10	100.0

Most of the hanging cases were seen in the males (66.7%) in comparison to strangulation where females were seen in 70% of cases.

Table 3. Comparison of cases on the basis of ligature material used

Ligature Material	Hanging		Strangulation	
	Frequency	Percent	Frequency	Percent
Dupatta	32	35.6	2	20.0
Plastic rope	27	30.0	2	20.0
Bedsheet	15	16.7	1	10.0
Electric wire	03	03.3	0	00.0
Cotton rope	13	14.4	2	20.0
NA	00	00.0	3	30.0
Total	90	100.0	10	100.0

Table 3 shows that for hanging dupatta (35.6%) was most commonly used as ligature material followed by plastic rope (30%), bed sheet (16.7%) and cotton rope (14.4%), while for strangulation dupatta, plastic rope and cotton rope has same frequency (20%)

Table 4. Comparison of cases on the basis of parchmentisation

Parchmentisation	Hanging		Strangulation	
	Frequency	Percent	Frequency	Percent
Present	90	100.0	00	00.0
Absent	00	00.0	10	100.0
Total	90	100.0	10	100.0

Parchmentisation was seen in all (100%) cases of hanging (Fig 1) while it was absent in all cases of strangulation (0%).

Figure 1: Parchmentization of ligature mark skin

Table 5. Comparison of cases on the basis pale glistening white subcutaneous tissue under ligature mark

Pale glistening white tissue	Hanging		Strangulation	
	Frequency	Percent	Frequency	Percent
Yes	90	100.0	00	00.0
No	00	00.0	10	100.0
Total	90	100.0	10	100.0

All (100%) cases of hanging showed pale white glistening band below ligature mark, in comparison to strangulation, where it was absent in all (100%) cases.

Table 6 shows that nail mark injury was absent in all cases of hanging (100%) (Fig 2), in comparison all cases of strangulation (Fig 3) showed nail mark injuries (100%).

Table 6. Comparison of cases on the basis of finger nail mark injury

Abraded contusion nail marks	Hanging		Strangulation	
	Frequency	Percent	Frequency	Percent
Present	00	00.0	10	100.0
Absent	90	100.0	00	00.0
Total	90	100.0	10	100.0

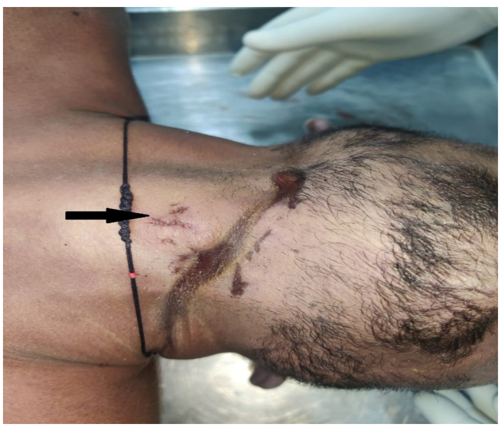

Figure 2: Finger nail marks in case of hanging

Figure 3: Finger nail marks in a case of strangulation

Table 7 shows the comparison of cases on the basis of tongue bitten / protruded. Only 20% of hanging cases showed tongue bitten/protruded (Fig 4) while it was absent in all cases of strangulation.

Table 7. Comparison of cases on the basis of tongue bitten/protruded

Tongue bitten / Protruded	Hanging		Strangulation	
	Frequency	Percent	Frequency	Percent
Present	18	20.0	00	00.0
Absent	72	80.0	10	100.0
Total	90	100.0	10	100.0

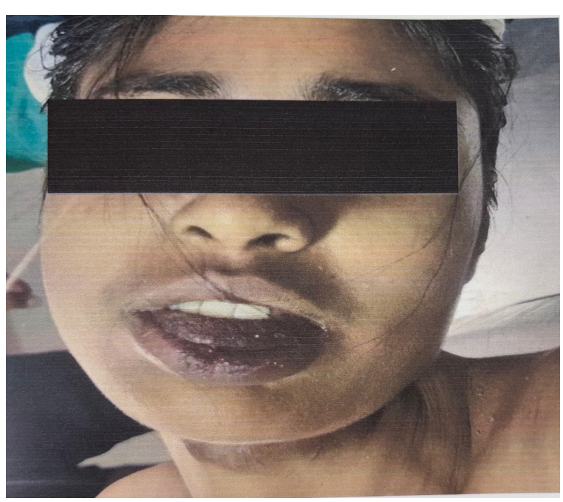

Figure 4: Protrusion of tongue bite/Protruded

Table 8. Comparison of cases on the basis of dribbling of saliva mark

Dribbling of saliva mark	Hanging		Strangulation	
	Frequency	Percent	Frequency	Percent
Present	14	15.6	00	00.0
Absent	76	84.4	10	100.0
Total	90	100.0	10	100.0

15.5 % (n=14) of hanging cases showed dribbling of saliva while it was absent in all cases of strangulation

Table 9 shows the comparisoncaseson the basis of facial congestion. It was completely absent in hanging (100%) cases whereas in strangulation cases, 90%(n=9) showed facial congestion.

Table 9. Comparison of cases on the basis of facial congestion

Facial congestion	Hanging		Strangulation	
	Frequency	Percent	Frequency	Percent
Present	00	00.0	09	90.0
Absent	90	100.0	01	10.0
Total	90	100.0	10	100.0

Discussion

In the present study, deaths due to hanging and strangulation was seen from 11to 50 years of age (table 1). The majority of cases belonged to the age group of 21-30 years old, in which of hanging were 56.7% and strangulation were 70% followed by age group of 31-40 years old, (Hanging 24.4%, strangulation 20%). Our results are comparable to study done by Joshi R et al[5], Verma S.K et al[6], Sharma BR et al[7], TK Reddy et al[8]. The reason can beincreasing age aggression and frustration, The emotional and mental turmoil due to burden of responsibilities, unemployment, depression, marital disharmony and feeling of worthlessness resulting in taking such measures to end life.

In our study 63% of subjects were males and 37% were females (table 2). Hanging cases represent a greater number of males (66.7%)in comparison to strangulation cases where females constitute majority of cases(70%). Joshi R et al [5],Uzün I et al[9], Zátopková L et al[10], Bhausaheb NA et al[11], Singh B et al[12] and TK Reddy et al[8] reported similar incidence.Increased incidence of males in hanging cases may be due to the burden of responsibilities, unemployment and financial crisis. Satish kumar Khalko SK et al., found females and males were 1 (50%) and 3 (60%) respectively in cases strangulation. Naik SK et al[13] reported increased incidence of strangulation among females, similar to this study. The main reason may be that females are physically weaker than males and easily overpowered and strangulated.

The material used for ligature in maximumcases of hanging wasdupatta (35.6%), followed by plastic ropes (30%), bedsheet (16.7%), cotton rope (14.4%) and electric wire (3.3%).In strangulation cases,dupatta (20%), plastic rope (20%) and cotton rope (20%) showed equal distribution among cases (table 3). In studies done by Reddy TTK et al[8] and Sharma BR et al[7,] cloth material – chunni (dupatta) was found to be the commonest ligature material followed by nylon rope and saree.Thus it depicts that in particular incident whatever material was available around, it has been used by the victims or assailant as the ligature material.

In the present study all cases of hanging (100%) presented with parchmentization and pale white glistening band of subcutaneous tissue, in comparison, no case of strangulation showed the same finding (table 4). Sharma N et al, also noted parchmentisation in 56(56%) cases of hanging and 2(50%) cases of ligature strangulation[14]. Parchmentisation is seen because of continuous pressure over the neck by the ligature in cases of hanging where victim is suspended for a longer period of time and the constricting force is the body weight while in cases of strangulation the constricting force is for lesser period and is other than the body weight hence these findings are generally not noted.

All of the hanging cases (100%) in the study show nail marks while it was absent in all cases of strangulation (100) (table 6). Dribbling of saliva were present in 15.6% of hanging cases while all (100%) of strangulation cases showed absence of dribbling saliva mark (table 8).20% of hanging cases showed protruded or bitten tongue while absent in all (100%) cases of strangulation (table 7). 90% (n=9) of strangulation cases showed facial congestion while the same was absent in all (100%) cases of hanging (table 9). The findings are similar to other studies[8,15,16,17]. Pressure by the ligatureon the submandibular glands lead to dribbling of saliva and is considered as surest sign of antemortem hanging. Constricting force of the ligature put pressure on the neck structure leading to elevation of the tongue. Abraded contusion nail marks are usually seen more in cases of strangulation because the victim tries to save himself and fights back by drawing the ligature material away from him which results small abrasions and contusions around the ligature mark which should be examined carefully.

Our study highlights the high prevalence of strangulation in females (70%), use of dupatta as ligature material in hanging (35.6%) and strangulation (20%). Most of the cases of strangulation were due to marital disharmony.

Conclusion

A meticulous forensic examination in hanging and strangulation is of great importance to differentiate between them. This study is in concordance with previous similar studies and tries to highlight that the ligature mark needs to be evaluated and correlated along with external findings, internal findings and histopathological findings of neck structures below ligature mark i.e epidermis, dermis, connective tissue, muscle and bones. Thus if this method is followed in the routine practice of postmortem examination, the formulation of final opinion in doubtful cases will become easy.

Limitation of Study

1. Suicidal or homicidal hanging and strangulation are relatively rare this region, limiting the number of cases available for study
2. Single-center study: As the study was conducted at a single institute, external validation across multiple centers and varying conditions is recommended

Funding Sources: self

Ethical Clearance/Statement of Ethics: ethical clearance taken from ethical committee of Guru Gobind Singh Medical College, Faridkot, dated 22/04/2021.

Conflicts of Interest: nil

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