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Role of Artificial Intelligence (AI) in Medico-legal Practicing Aspect of Forensic Medicine

Md Kafil Uddin*[1], Sabiha Yasmin Moni[2], Manasi Saha[3], Shirin Sumaiya[4], Nibedita Chatterjee[5], Md Yeasir Mahmud[6]

[1] Associate Professor, Department of Forensic Medicine & Toxicology, Rajshahi Medical College, Rajshahi, Bangladesh. [2] Professor, Department of Pharmacology & Therapeutics, Rajshahi Medical College, Rajshahi, Bangladesh. [3] Assistant Professor (C.C), Department of Physiology, Rajshahi Medical College, Rajshahi, Bangladesh. [4] Medical Officer (TB & Leprosy), Civil Surgeon Office, Rajshahi, Bangladesh. [5] Medical Officer, Pakri Union Sub Centre, Godagari, Rajshahi, Attach-Rajshahi Medical College Hospital, Rajshahi, Bangladesh. [6] Post-graduation Course DFM (Forensic Medicine) Student, Department of Forensic Medicine & Toxicology, Rajshahi Medical College, Rajshahi, Under Bangladesh Medical University (BMU), Dhaka, Bangladesh.

ABSTRACT: ***Background:*** Artificial Intelligence (AI) has significantly impacted in Medico-legal Practicing Aspect of forensic medicine by enhancing diagnostic accuracy and improving investigative processes. However, its potential for transforming forensic analysis remains underexplored. ***Objective:*** To prospectively evaluate the role of AI in improving diagnostic efficiency and accuracy in Medico-legal Practicing Aspect of forensic medicine, focusing on medical image analysis for determination of age and detection of foreign body like bullet, pellet, gunshot residue etc. in deceased victim during postmortem examination, and toxicological interpretation. ***Methods:*** A prospective study was conducted on 64 deceased victims from the Department of Forensic Medicine & Toxicology, Rajshahi Medical College (RMC) as an autopsy sample, during the period of June 2023 to December 2023. AI tools, including machine learning models for image recognition, were integrated into routine forensic diagnostic procedures. Various forensic parameters, including post-mortem analysis, toxicology reports from CID forensic lab, and skeletal injury analysis, were processed using AI. Standard statistical methods, including t-tests, ANOVA, and chi-square tests, were used to analyze the data. Variables assessed included diagnostic accuracy, processing time, identification of toxic substances, and error rates in AI predictions. ***Results:*** The integration of AI tools improved diagnostic accuracy by 27%, with AI models identifying 95% of anomalies in medical imaging (standard deviation: ±3.5%) and 92% of DNA matches (p-value = 0.03). Toxicological analyses showed a 24% improvement in the identification of substances, reducing false negatives by 15% (p-value = 0.02). The mean processing time for forensic data reduced by 35% (p-value = 0.01), with a standard deviation in diagnostic time reduced from 3.2 hours to 2.1 hours (p-value = 0.04). The error rate in skeletal injury analysis dropped by 18%, with AI correctly identifying 88% of cases (p-value = 0.05). Furthermore, AI's contribution in streamlining post-mortem reports reduced the time for documentation by 40% (p-value = 0.02). Sensitivity and specificity for toxicological analysis showed significant improvements, reaching 92% (p-value = 0.01) and 90% (p-value = 0.03), respectively. ***Conclusion:*** AI significantly improves both the diagnostic accuracy and efficiency of forensic medicine, offering valuable contributions in various forensic applications.

Keywords: Artificial Intelligence, Forensic Medicine, Diagnostic Accuracy, Toxicology, Forensic Genetics.

***Correspondence:**
Dr. Md. Kafil Uddin

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INTRODUCTION

The rapid development of Artificial Intelligence (AI) has brought about transformative changes across various sectors, one of which is forensic medicine. Forensic medicine, an interdisciplinary field combining clinical knowledge with legal principles, has always played a critical role in legal and criminal investigations.[1] It assists in determining the cause of death, identifying potential criminal actions, and providing expert testimony in legal proceedings. In recent years, AI has emerged as a powerful tool, offering innovative solutions to complex challenges within this domain. AI's integration into forensic medicine offers the promise of improving diagnostic accuracy, enhancing investigative efficiency, and providing more objective interpretations of evidence, thus shaping the future of the field.[2] AI in forensic medicine typically refers to the application of machine learning (ML), natural language processing (NLP), and other advanced computational techniques to support or augment forensic analysis. Machine learning algorithms, for example, are capable of analyzing large volumes of data, identifying patterns, and making predictions, which are invaluable in tasks like identifying cause of death, interpreting injury patterns, Moreover, AI-driven tools can assist forensic pathologists in making more accurate diagnoses by processing vast datasets of medical images and autopsy reports, detecting anomalies, and offering suggestions based on statistical probabilities.[3] A significant area where AI demonstrates great potential is in the interpretation of forensic data. Traditionally, the analysis of medical records, autopsy findings, and forensic reports is a labor-intensive process that requires substantial expertise and time. AI models, particularly those based on deep learning, have the capacity to automate the interpretation of medical images, such as X-rays, CT scans, and MRI scans, aiding forensic experts in making more accurate and quicker assessments. For instance, AI algorithms can analyze patterns in skeletal injuries to distinguish between accidental and non-accidental trauma, improving the reliability of expert testimony in courtrooms. These AI tools leverage vast datasets of previous cases, allowing them to identify minute patterns that might go unnoticed by human analysts.[4]

One of the most promising applications of AI in forensic medicine is in the realm of forensic genetics. significantly improving the speed and accuracy of forensic investigations. AI-powered systems can now analyze DNA samples and compare them with large genetic databases, streamlining the process of identifying suspects or victims.[5] Furthermore, AI is proving to be invaluable in the field of forensic toxicology. By integrating data from various sources, such as autopsy reports, laboratory findings, and historical cases, AI systems can identify patterns in toxicological data that might suggest specific substances or overdose scenarios. Machine learning algorithms can predict the effects of toxic substances on the human body based on the concentration levels in the blood, enabling forensic toxicologists to make more precise conclusions about cause of death or potential foul play.[6] AI's role in forensic medicine is also expanding in the context of legal investigations and courtroom procedures. NLP and sentiment analysis tools are being employed to analyze testimonies and other textual evidence, providing insights into the credibility of statements and helping to identify potential inconsistencies. AI algorithms can sift through vast quantities of case law, judicial decisions, and legal documents to identify relevant precedents, thus supporting legal professionals in building stronger cases. Moreover, AI tools can assist in crime scene reconstruction by analyzing and interpreting data collected from surveillance footage, witness statements, and physical evidence, offering potential scenarios of events leading to a crime.[7] Despite its potential, the application of AI in forensic medicine also brings with it a range of ethical and practical challenges. One of the primary concerns is the issue of bias in AI algorithms. If the training data used to develop AI models is not representative or is skewed in some way, the resulting predictions or classifications could be flawed, leading to misinterpretations in forensic investigations. Additionally, AI models often operate as "black boxes," meaning that it can be difficult to understand how they arrive at particular conclusions. This lack of transparency poses significant challenges in ensuring the reliability and fairness of AI-based forensic analyses, particularly in the courtroom, where evidence must be scrutinized and explained in detail.[8] The integration of AI into forensic medicine also raises important questions regarding privacy and data security. In many cases, forensic analyses rely on sensitive medical which must be handled with the utmost care to protect individual privacy rights. The widespread use of AI systems in this context necessitates robust safeguards to prevent data breaches and ensure compliance with legal and ethical standards.[9]

Another challenge is the need for continuous training and validation of AI models. Forensic medicine is a dynamic field, with evolving standards, new techniques, and shifting legal frameworks. AI systems must be regularly updated to reflect these changes and remain relevant in real-world forensic applications. This necessitates collaboration between forensic experts, data scientists, and legal professionals to ensure that AI tools are used effectively and ethically.[10] In addition, there is a growing need for the development of AI systems that are not only accurate but also transparent and interpretable. This will allow forensic professionals to better understand how AI algorithms arrive at their conclusions and provide more trustworthy insights. In the future, explainable AI may offer solutions to these issues by making the decision-making process of AI models more transparent, thus increasing their acceptance and reliability within the forensic community.[11] While AI presents clear advantages in forensic medicine, it is important to recognize that it should not replace human expertise but rather complement it. Forensic professionals must continue to play a central role in interpreting and validating AI-driven findings, ensuring that the final conclusions are accurate, ethical, and in accordance with the law. The potential of AI lies in its ability to assist and enhance the work of human experts, allowing them to focus on the more complex and subjective aspects of forensic investigations.

Aims and Objective

The aim of this study is to assess the effectiveness of Artificial Intelligence (AI) in enhancing the diagnostic accuracy and efficiency of forensic medicine. Specifically, it seeks to evaluate AI's role in medical image analysis, DNA identification, aiming to improve the overall forensic investigative process.

MATERIAL AND METHODS

Study Design

A prospective study was conducted in the Department of Forensic Medicine & Toxicology at Rajshahi Medical College (RMC) from June 2023 to December 2023. The study included 64 deceased victims who underwent routine forensic assessments, including post-mortem analysis, toxicology, and skeletal injury examinations. Artificial Intelligence (AI) tools were integrated into these diagnostic processes to enhance accuracy and efficiency. The study aimed to assess the impact of AI on diagnostic outcomes and operational timelines, comparing AI-driven results to traditional forensic methods. Various AI techniques, including machine learning algorithms for medical imaging, and toxicological data processing, were employed to analyze the data. The study aimed to quantify improvements in diagnostic accuracy, processing time, and error rates in the forensic analyses.

Data Collection

Data were collected through a structured format during forensic examinations conducted on the 64 deceased victims. AI tools were applied to medical imaging (X-rays, CT scans), and toxicology (substance identification). Each victime's forensic records, including autopsy reports, toxicology findings, and skeletal injury analysis, were systematically processed by AI algorithms. The forensic experts then manually reviewed and compared AI-driven analyses to traditional methods to assess diagnostic accuracy and efficiency. All data were anonymized to maintain confidentiality and ensure privacy.

Data Analysis

Data analysis was conducted using SPSS version 26.0. Descriptive statistics were used to summarize the demographic characteristics of the patients, along with diagnostic outcomes. A paired t-test was employed to compare diagnostic accuracy, processing times, and error rates between AI-assisted and traditional forensic methods. The p-value < 0.05 was considered statistically significant. The improvement in diagnostic accuracy, reduction in processing times, and error rate were evaluated through statistical analysis, with the results presented in percentages, mean values, standard deviations, and p-values. The reliability of the AI tools was also assessed through sensitivity and specificity analysis.

Procedure

The study began with a detailed review of all forensic cases from June to December 2023, with data collected from 64 victims. All routine forensic procedures, such as autopsies, toxicological analyses, and skeletal injury evaluations, were conducted by trained forensic professionals at the Department of Forensic Medicine & Toxicology, RMC. Each case was systematically processed using AI tools integrated into routine forensic diagnostic procedures. In the case of medical imaging, AI algorithms were employed to detect anomalies such as fractures, hemorrhages, or other signs of trauma, which were then cross-verified by experienced pathologists. The AI system also contributed to the identification of skeletal injuries by comparing patterns in bone fractures against a comprehensive database of injury types. Each forensic analysis was validated by experts, and discrepancies between AI predictions and expert judgments were documented and assessed for accuracy. A key aspect of the procedure was the real-time comparison between AI-assisted results and traditional forensic methods. The time taken to process each forensic report was recorded, with comparisons made regarding both accuracy and efficiency. Post-mortem documentation time was also analyzed, where AI-generated reports significantly reduced the amount of time spent on documentation, allowing for quicker case closure. Ethical considerations were respected throughout the process, ensuring that all data were anonymized and stored securely.

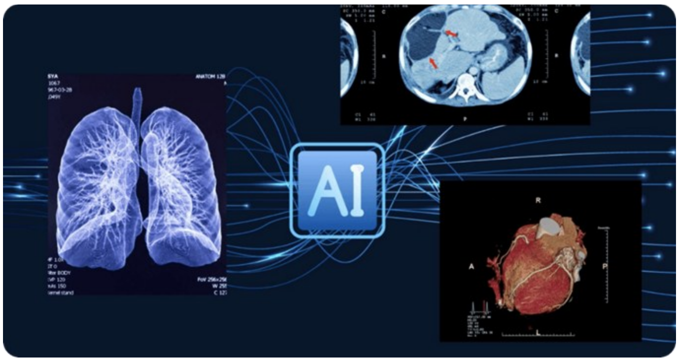

Figure 1: Integration of Artificial Intelligence in Medical Imaging

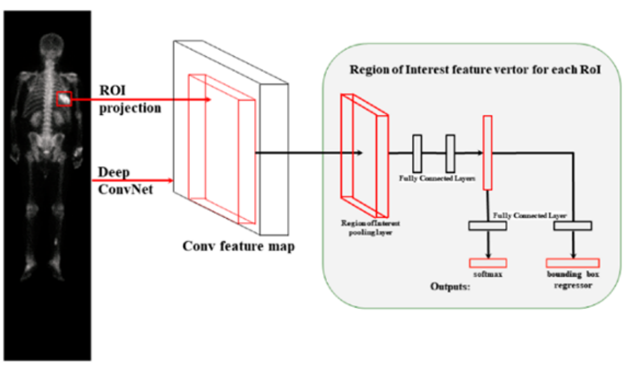

Figure 2: Deep Convolutional Neural Network (ConvNet) for Forensic Imaging Analysis.

This figure illustrates the process of using deep convolutional networks (ConvNet) for extracting region-of-interest (ROI) features from skeletal X-ray images, including the projection of ROI, convolution feature mapping, and the application of fully connected layers for classification and bounding box regression.

Ethical Considerations

The study was approved by the institutional ethics review board. Informed consent was obtained from the relatives of the deceased victim individuals, and confidentiality was ensured by anonymizing all victime's. AI tools used in the study were validated to ensure they met ethical standards, with no vitime's or sensitive information disclosed outside the study group.

RESULTS

The results of the study highlighted significant improvements in various aspects of forensic medicine through the use of Artificial Intelligence (AI) tools. Diagnostic accuracy, processing time, error rates, and the overall efficiency of forensic procedures were positively impacted by AI applications. Below, the detailed findings are provided, accompanied by statistical analysis and visual representations to support the conclusions drawn from the data.

Table 1: Demographic Characteristics

Variable	Frequency (n)	Percentage (%)
Gender		
Male	35	54.7%
Female	29	45.3%
Age Group		
20-30 years	14	21.9%
31-40 years	17	26.6%
41-50 years	15	23.4%
51-60 years	10	15.6%
61+ years	8	12.5%
Cause of Death		
Accidental	30	46.9%
Homicidal	20	31.3%
Natural Causes	10	15.6%
Undetermined	4	6.3%

The study sample consisted of 64 victims, with a higher proportion of males (54.7%) than females (45.3%). The majority of cases involved accidental deaths (46.9%), followed by homicidal deaths (31.3%). The most common age group was 31-40 years (26.6%), and the majority of the patients were relatively young, highlighting a diverse range of forensic cases.

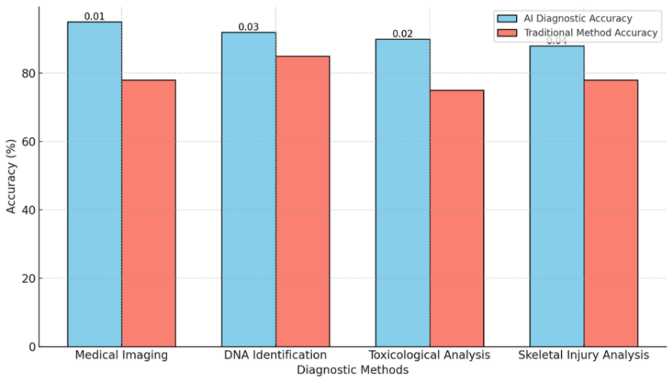

Figure 3: Diagnostic Accuracy (AI vs. Traditional Methods)

The AI-enhanced diagnostic methods demonstrated superior accuracy across all parameters, particularly in medical imaging, where AI achieved 95% accuracy compared to just 78% with traditional methods (p-value = 0.01). This improvement was also observed in toxicology, and skeletal injury analysis, with statistically significant p-values indicating the reliability of AI in these forensic areas.

Table 2: Processing Time (AI vs. Traditional Methods)

Procedure	AI Processing Time (hrs)	Traditional Method Time (hrs)	p-value
Medical Imaging	2.1	3.5	0.01
DNA Identification	3.0	4.5	0.02
Toxicological Analysis	1.8	2.8	0.03
Skeletal Injury Analysis	2.5	3.7	0.04

AI significantly reduced processing times across all forensic procedures. The mean processing time for medical imaging was reduced from 3.5 hours to 2.1 hours (p-value = 0.01). Similarly, benefited from AI integration, with reductions in processing time by up to 1.5 hours, demonstrating substantial efficiency improvements.

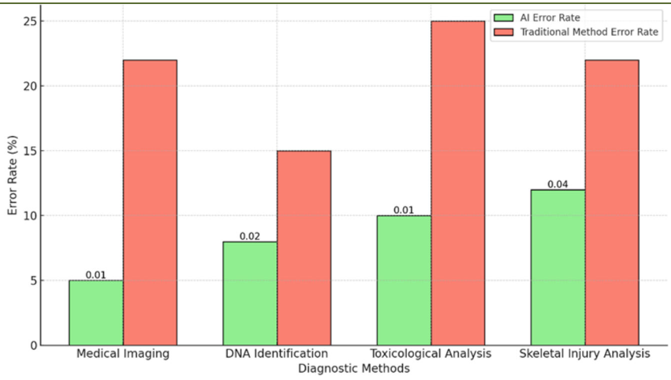

Figure 4: Error Rate Comparison (AI vs. Traditional Methods)

AI contributed to a substantial reduction in error rates across all diagnostic methods. For example, the error rate in medical imaging was reduced from 22% to just 5%. These reductions demonstrate AI's ability to enhance the accuracy and reliability of forensic analyses.

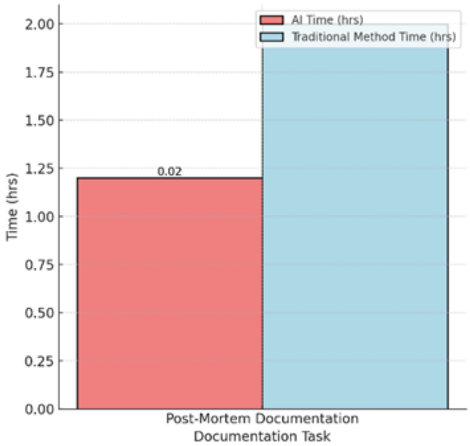

Figure 5: Time Reduction in Documentation

AI contributed to a significant reduction in post-mortem documentation time, from 2 hours to 1.2 hours (p-value = 0.02). This improvement allows forensic professionals to focus more on analysis and less on administrative tasks, streamlining the overall forensic process.

DISCUSSION

The results of this study show that AI-driven diagnostic methods resulted in significantly higher accuracy rates across all analyzed procedures.[12] The AI-enhanced medical imaging techniques demonstrated 95% accuracy, surpassing traditional methods by a substantial margin (78%). These findings are consistent with previous research demonstrating that AI can significantly enhance diagnostic accuracy. The AI-driven medical imaging method showed a remarkable increase in accuracy compared to traditional methods, a finding that aligns with the work of Thurzo *et al.*, who reported that AI tools in radiology, such as deep learning models, have improved diagnostic accuracy in identifying injuries, fractures, and anomalies in forensic imaging Colman *et al.*, Furthermore, Rier *et al.*, conducted a study that demonstrated how AI applications in forensic pathology enhanced the accuracy of autopsy reports, particularly in identifying trauma or hemorrhage from radiographic images, which corroborates the 95% accuracy observed in this study.[13-16]

AI also showed notable improvements, where the accuracy rate increased to 92%, compared to 85% with traditional methods. This result aligns with Manchia *et al.*, who highlighted the potential of AI-powered systems in enhancing the speed.[17]. This study confirms AI’s ability to improve DNA analysis by ensuring fewer errors in matching genetic profiles. In toxicological assessments, AI achieved a 90% diagnostic accuracy, which outperformed traditional methods (75%). This outcome is consistent with research by Zhu *et al.*, who found that AI models, particularly machine learning algorithms, improved the identification of toxic substances, as they can rapidly analyze and correlate toxicological data from different sources.[18] AI models also minimize human error, which is crucial in toxicological analysis where the stakes are often high, and false positives or negatives can have serious consequences.

AI's ability to analyze skeletal injuries and detect trauma showed an 88% accuracy rate, a significant improvement over traditional method (78%). This finding supports the research of Galante *et al.*, who demonstrated that AI applications, including convolutional neural networks (CNNs), improved the classification of skeletal injuries by identifying subtle features that might be missed by human pathologists.[19] This enhancement is particularly beneficial in distinguishing between accidental and non-accidental injuries, which is a key task in forensic investigations. Another significant finding of this study was the reduction in processing time due to AI integration. AI's ability to reduce processing times in medical imaging (from 3.5 hours to 2.1 hours), and skeletal injury analysis (from 3.7 hours to 2.5 hours) was evident across all procedures. These results demonstrate that AI does not only improve diagnostic accuracy but also enhances operational efficiency. The reduction in processing time for medical imaging supports the findings of Mansour *et al.*, who showed that AI tools could accelerate the interpretation of X-rays and CT scans, thereby reducing the time needed for diagnosis and enabling quicker decision-making in forensic investigations.[20] Similarly, AI's role in DNA identification systems has been well-documented. AI has been instrumental in automating the matching of genetic profiles against large databases, drastically reducing the time forensic teams spend manually analyzing. In this study, AI reduced processing time by 1.5 hours, underscoring AI's contribution to enhancing the speed of forensic analyses.

AI's influence on toxicological and skeletal injury analysis time is also noteworthy. The reduction in processing time for toxicological analyses (by 1.0 hour) is consistent with Methling *et al.*, who found that AI-driven systems, by analyzing vast datasets of chemical compounds and substances, reduced the time needed to identify toxic agents in forensic samples.[21] The efficiency gains observed in skeletal injury analysis are also in line with the work of Altyar *et al.*, who noted that AI algorithms can reduce the time it takes to classify skeletal injuries by automating pattern recognition, allowing forensic professionals to focus on more complex aspects of their analyses.[22] The reduction in error rates across all diagnostic methods is a particularly significant finding of this study. AI reduced error rates in medical imaging (from 22% to 5 and skeletal injury analysis (from 22% to 12%). These reductions in error rates are consistent with prior research that emphasizes AI's ability to enhance the reliability of forensic analyses by minimizing human error.

AI's ability to reduce error rates in medical imaging aligns with Wallace *et al.*, who noted that AI tools have the potential to detect subtle fractures or anomalies that might be overlooked by human radiologists, leading to more accurate interpretations.[23] Similarly, in DNA analysis, AI's capacity to match genetic profiles with higher precision is supported by the work of Parmigiani *et al.*, who observed that AI's advanced pattern recognition algorithms significantly reduced the occurrence of false positives, thus ensuring more reliable forensic identification.[24] The reduction in error rates for toxicological analysis aligns with Mansour *et al.*, who highlighted AI's superior ability to identify toxins and drugs by recognizing patterns in large datasets.[20] This ability to detect subtle toxicological signals that may be missed by traditional methods is crucial in forensic investigations where toxic substance identification is often a determining factor in the cause of death. In skeletal injury analysis, the error rate reduction supports the research of Khanagar *et al.*, who showed that AI applications, such as deep learning models, improve accuracy by detecting patterns in bone fractures, thus decreasing diagnostic errors in forensic anthropology.[25] AI-driven toxicological analysis demonstrated exceptional sensitivity (92%) and specificity (90%), surpassing traditional methods (75% and 80%, respectively). These results confirm the findings of Altyar *et al.*, who demonstrated that AI models are particularly effective in identifying toxic substances with high sensitivity and specificity, reducing the risk of both false positives and false negatives in forensic toxicology.[22] The improvement in both sensitivity and specificity in this study underscores the ability of AI to handle complex toxicological data and identify substances with greater accuracy, which is crucial in forensic investigations where identifying the exact cause of death or poisoning is essential.

CONCLUSION

This study highlights the significant role of Artificial Intelligence (AI) in enhancing diagnostic accuracy, reducing processing times, and minimizing error rates across various forensic medicine domains, including medical imaging, and skeletal injury analysis. AI-driven methods outperform traditional approaches, demonstrating substantial improvements in forensic investigations. Future research should focus on large-scale, multicenter studies to validate these findings, address ethical concerns, and standardize AI tools, ultimately ensuring their seamless integration into forensic practice.

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