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Optimizing AI Solutions in Emergency Departments: Analyzing Technologies, Algorithms, and Patient Outcomes

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Abstract

Problem: The integration of artificial intelligence (AI) in emergency departments (EDs) presents both opportunities and challenges within the healthcare sector. Despite the potential benefits of AI in enhancing operational efficiency and patient outcomes, there are significant barriers to its effective implementation. These include skepticism regarding specific technologies, such as Natural Language Processing (NLP) and AI-driven robotics, as well as the overarching issues of patient communication and overcrowding in EDs. Understanding healthcare professionals' perceptions and the efficacy of current AI applications is essential for optimizing these solutions. **Approach:** This study employs a quantitative research methodology, utilizing a purposive sampling strategy to gather data from healthcare professionals working in EDs. A structured survey featuring Likert-scale questions was administered to assess respondents' perceptions of AI integration and its various applications. The analysis focused on identifying the strengths and limitations of existing AI algorithms, as well as the challenges faced in the ED environment. The study aims to provide insights into how systematic classification frameworks can be developed to address these challenges and enhance the effectiveness of AI solutions. **Findings:** The survey results indicate a strong overall support for the integration of AI in EDs, with respondents acknowledging a diverse range of AI applications. While many healthcare professionals recognize the effectiveness of current AI algorithms, they also highlight significant limitations that necessitate the exploration of novel approaches. Concerns about NLP and AI-driven robotics were prevalent, suggesting a need for greater education and training in these areas. Additionally, the findings reveal that common challenges, such as patient communication and overcrowding, could be mitigated through the implementation of tailored symptom classification systems and AI-assisted diagnostic tools. **Conclusion:** The study underscores the transformative potential of AI in emergency departments, particularly in improving diagnostic accuracy and patient outcomes. By addressing the identified limitations and enhancing the understanding of AI

technologies among healthcare professionals, the integration of AI can be optimized. Future research should focus on developing systematic frameworks that facilitate the effective use of AI in EDs, ultimately leading to improved patient care and operational efficiency.

KEYWORDS: Artificial Intelligence, Emergency Department, Healthcare AI technologies, Algorithms

1. INTRODUCTION

In recent years, the overburdening of emergency departments (EDs) has become a significant global issue, steadily escalating (Aleksandra et al., 2024). This crisis arises from multiple factors affecting the operations of medical units. In EDs, patients often experience long waiting times due to a shortage of medical staff and beds, repeated visits for the same complaints, and a high number of non-emergency patients (Badal et al., 2023; Chang & Cha, 2022). These limitations contribute to an increase in medical errors, complications, and mortality rates (Mueller et al., 2023). Research indicates that physician burnout and decreased patient satisfaction are evident consequences of this situation (Badal et al., 2023; Hunter et al., 2023). To address these challenges, new solutions, particularly those leveraging artificial intelligence (AI), are essential. Among various technological tools, deep learning and machine learning stand out. These techniques can generate data and perform tasks based on pre-programmed assumptions. More importantly, they have the ability to learn independently by testing hypotheses derived from large data sets (Grant et al., 2020). Companies like Google Health and Assist AI are competing to develop AI-assisted technologies that aid medical teams in decision-making before patients arrive at the hospital, during patient triage in EDs, and in determining whether to discharge or hospitalize patients (Junaid et al., 2022). Research has shown that AI-generated technologies have already proven effective in areas such as clinical decision-making, triage, and image interpretation (Chang & Cha, 2022).

Additionally, several technology manufacturers are developing natural language processing (NLP) tools to reduce the time required for medical documentation. These NLP tools create documentation based on real-time recordings of patient-doctor conversations (Crampton, 2020). Collaboration between new technologies and healthcare providers is crucial for improving patient outcomes. Furthermore, contextualizing results within the clinical environment is essential for building patient trust in these new technologies (Vearrier et al., 2022). The integration of AI technologies in emergency departments not only streamlines operations but also enhances patient care. By utilizing predictive analytics, EDs can anticipate patient influx and allocate resources more efficiently. Moreover, AI-driven tools can assist in

identifying potential health risks earlier, allowing for timely interventions. This proactive approach not only improves patient outcomes but also reduces the strain on medical staff. As healthcare continues to evolve, embracing these innovations is crucial for addressing the challenges faced by EDs (Boonstra & Laven, 2022). Ultimately, the successful implementation of AI can lead to a more resilient healthcare system, better equipped to meet the needs of diverse patient populations.

This study focuses on analyzing the potential advantages and existing solutions derived from the application of AI technology in emergency departments. The primary aim is to investigate how AI solutions can optimize operations in EDs and to conduct a comprehensive analysis of relevant technologies, algorithms, and patient outcomes.

2. Current Technologies In The Implementation Of AI

Decision support systems that rely heavily on AI algorithms have gained significant attention in recent years (Maurer et al., 2021). These advancements have the potential to reshape various sectors, particularly healthcare. Unlike human cognitive abilities, AI evaluates large volumes of complex data for predictive analytics. This capability enhances the accuracy of complex decision-making processes. In emergency surgery and routine trauma care, the integration of medical AI systems presents a critical yet largely unfulfilled opportunity (Bertsimas et al., 2018; Loftus, Vlaar, et al., 2022). The medical AI sector navigates complicated human-centered, technical, and ethical issues to implement safe and effective changes (Balch et al., 2021; Johnson-Mann et al., 2021). Researchers have noted that skilled surgeons are often open to innovative solutions. As a result, the potential for improved patient outcomes is significant. However, these solutions lack robust evidence regarding their performance benefits and academic rigor in clinical settings (Loftus et al., 2021). Moreover, even when AI accurately predicts clinical outcomes hours or days in advance, its application in emergency surgery and trauma remains limited. Despite these advancements, challenges remain in integrating AI effectively into existing systems. Successful integration with clinical workflows is essential, especially for addressing risk-sensitive decisions and ensuring trust in the model's appropriateness (Loftus, Tighe, et al., 2022). This integration is crucial for realizing the full potential of AI in clinical environments. The World Society of Emergency Surgery (WSES) supports the recently published survey, "Artificial Intelligence in Emergency and Trauma Surgery (ARIES)," which evaluates practices, attitudes, and knowledge regarding AI applications in emergency departments (EDs) among international emergency surgeons (Ingraham et al., 2023). Among various AI types, natural language processing (NLP), deep learning, and machine learning have

significant societal impacts in healthcare (Choudhury & Asan, 2020). These technologies are frequently utilized in the healthcare domain.

2.1. Deep Learning

Artificial intelligence (AI) is currently experiencing unprecedented advancements. Deep learning technologies are rapidly evolving and becoming more sophisticated. Deep learning plays a crucial role among various technologies used in speech recognition, natural language processing, and object recognition (Pathik et al., 2022). Deep learning differs significantly from traditional machine learning. Its multiple beneficial aspects for healthcare include handling multi-modal and complex data, an end-to-end learning scheme with integrated feature learning, and superior performance. Additionally, deep learning is extensively applied to create aggregated electronic health records (EHRs). These aggregations are based on both unstructured (free-text clinical notes) and structured (laboratory tests, medications, and diagnoses) data. Researchers have processed EHRs within healthcare systems to establish a solid foundation for specific predictive and generally supervised clinical tasks (Abdullah et al., 2022). Deep learning is also structured to frame continuous time signals, such as identifying specific phenotypes and laboratory results. This dual approach allows for a more comprehensive understanding of patient health.

2.2. Machine Learning

Machine learning is essential for successfully implementing IoT-powered wireless sensor networks, as it intelligently manages vast amounts of data. In healthcare, machine learning and AI contribute significantly to therapy selection, early diagnosis, and illness prevention. This technology can lead to more personalized and improved medical care in the future. Machine learning (ML) is a key technology within AI (Ghazal et al., 2021). This shift towards personalization is transforming how healthcare is delivered. Recently, ML has become crucial for monitoring treatment effectiveness in healthcare. It aids in developing optimal treatment plans, disease prognosis, and diagnosis. Furthermore, ML provides medical practitioners with more accurate and faster solutions. In healthcare, machine learning fosters progressive developments, enabling more effective solutions for critical diseases (Javaid et al., 2022).

2.3. Natural Language Processing (NLP)

Recent studies have advanced natural language processing (NLP) techniques, establishing various models for text processing applications. These models improve the accuracy of clinical outcome predictions (Locke et al., 2021). Although EHRs contain numerous concepts, abstractors may disagree on the coded concepts' results. Furthermore, challenges in utilizing, extracting, and defining vital

information from extensive clinical notes can limit their application. Researchers assert that NLP techniques help digitize and synchronize words into a digital format, facilitating data processing through computers (Chen et al., 2020). NLP enables machines to generate, interpret, and understand human language. Additionally, transformer architectures like Generative Pre-Trained Transformer (GPT) and Bidirectional Encoder Representations from Transformers (BERT) have gained popularity in NLP (Zhang et al., 2023). NLP techniques continue to evolve, leading to improved accuracy and efficiency. In summary, NLP tools extract crucial information from clinical notes based on patient records, enabling faster and more accurate decision-making.

2.4. Identifying Emergency Departments Needing AI Support

Modern triage systems in Emergency Departments (EDs) have been implemented globally based on medical expertise and knowledge. Effective triage systems are essential for ensuring timely medical interventions. Triage systems prioritize patients according to treatment urgency. However, some patients have critical conditions, and their symptoms may not clearly indicate disease severity. Thus, an effective triage system is necessary to assist doctors and healthcare providers in making timely decisions (Fernandes et al., 2020). To support all stages of the decision-making process, decision support systems (DSS) and decision-making support systems (DMSS) are designed to assist users and decision-makers. Both are vital information systems for improved decision-making. In the 1980s, AI tools were integrated into DSS to enhance management effectiveness. In clinical contexts, clinical decision support systems (CDSS) dominate DSS implementations. CDSS provides patients, staff, and clinicians with recommendations, patient-specific information, and knowledge (Kipourgos et al., 2022). Such systems are instrumental in reducing medical errors and improving patient safety. They address clinical needs, such as ensuring proper diagnoses, managing pain, preventing adverse drug events, and facilitating timely screenings.

Researchers report a slow but increasing acceptance of health information technology, particularly with the implementation of electronic health records (EHRs) globally (Tsai et al., 2020). Health practitioners require extra time and adaptation during the initial stages of learning. Implementation costs also pose significant barriers to fully adopting EHR systems. Overcoming these barriers is essential for the advancement of healthcare technology. This situation affects the adoption of CDSS technology aimed at improving care quality and reducing costs. The field of Emergency Medicine (EM) has attracted considerable attention from researchers, particularly regarding the untapped potential of AI solutions to enhance healthcare quality and operational efficiency (Tang et al., 2021). Many AI applications assist

emergency radiologists in interpretation and diagnosis. AI tools address core challenges faced by emergency radiologists, such as the need for prompt reporting, increased complexity, and higher imaging volumes. These innovations are crucial for enhancing diagnostic accuracy in high-pressure environments. Additionally, current AI models target common ED pathologies or presentations (Katzman et al., 2023). Each AI algorithm typically addresses a specific pathology.

The rise of augmented intelligence in healthcare is driven by the support that intelligent algorithms provide to providers in outcome prediction, treatment, and diagnosis. For stroke, the augmented diagnostic model aids non-stroke centers' EDs, where emergency providers have limited exposure to stroke cases. In the ED setting, a computer-assisted and automated screening tool, "Stroke Alert," is seamlessly integrated into clinical workflows to quickly evaluate clinical data and patient symptoms for stroke detection (Abedi et al., 2020). The implementation of AI is transforming healthcare dynamics, reshaping provider roles and creating new opportunities to enhance care quality and patient safety. Moreover, AI's operational features demonstrate its ability to improve communication, identify risks, reveal hidden knowledge, and analyze extensive healthcare data (Ali Mohamad et al., 2023). Ultimately, the integration of AI has the potential to revolutionize patient care.

3. Methodology

3.1. Sampling and Research Design

Optimizing the descriptive research method, information is collected by an organized survey administered to professionals in healthcare, including of doctors, nurse and physicians, working on different healthcare facilities across the emergency departments. To confirm the participants, the selected was done with relevant experience and expertise, intentional sampling was examined. This appropriate sampling study allowed to the targeted inclusion, that possessing the individual's high stages of relevance and expertise are the objectives of the research. Individuals use the sample size of 242 was established by the Raosoft statistical calculator that consider the factors like margin of error, anticipated percentage of the population, confidence level, and population size are owing the characteristic of the interest (Sample Size Calculator, 2020). The methodology involved in this research balance the method of quantitative research with a need of sample approach for the investigation the research questions and meet the research objectives of this study (Bloomfield & Fisher, 2019).

3.2. Data Collection

The study utilized a research questionnaire as the primary instrument for data collection. This questionnaire featured a five-point Likert scale, allowing respondents to express varying degrees of agreement or disagreement with specific statements. It was meticulously designed to align with the study's objectives and effectively capture the experiences, perspectives, and opinions of emergency department staff and healthcare professionals. By employing this structured approach, the research aimed to gather comprehensive insights that would inform the analysis and interpretation of the data, ultimately contributing to a deeper understanding of the challenges and dynamics within emergency care settings.

3.3. Ethical Considerations

The research was conducted with a strong commitment to ethical principles, ensuring that the confidentiality, autonomy, and privacy of participants were rigorously maintained. Ethical standards were upheld through the implementation of informed consent, which required participants to be fully aware of the study's purpose, procedures, and potential risks before agreeing to participate. Additionally, measures were taken to protect participants' privacy, including the anonymization of data and secure storage of responses. The study also prioritized minimizing any potential harm to participants, both psychological and physical, by providing support resources and ensuring that participation was entirely voluntary. These ethical considerations were integral to the research process, reinforcing the integrity of the study and fostering trust among participants.

4. Result and Discussion

For comprehensive statistical analysis, the study employed quantitative techniques to generate large numerical data. The survey included Likert-scale questions, which facilitated an investigation into the respondents' perceptions. This structured approach helped assess both the potential drawbacks and benefits of integrating artificial intelligence (AI) in emergency departments (EDs). The use of a Likert scale allowed for nuanced responses, enabling a deeper understanding of how healthcare professionals view AI technologies.

4.1. Analysis of Current AI Technologies in Emergency Departments

The Table 1 presents an analysis of responses related to AI integration technologies in the ED. Overall, respondents strongly agreed that AI applications are widely used in EDs, achieving a mean score of 4.28 out of 5.

Table 1: Recent used technologies in AI incorporation

S.No	Research Questionnaire	1 = Strongly Disagree	2 = Disagree	3 = \Neutral	4 = Agree	5 = Strongly Agree	Mean	Median
1	Does AI technologies in our ED encompass a wide range of applications?	5 (4.31%)	9 (3.72%)	15 (6.20%)	97 (40.08%)	116 (47.93%)	23.77	15
2	Does AI is employed for diagnostic purposes in our ED?	4 (2.94%)	8 (3.31%)	7 (2.89%)	87 (35.95%)	136 (56.20%)	19.26	8
3	Does our ED utilize AI for predictive analytics and patient risk assessment?	2 (1.69%)	4 (1.65%)	14 (5.79%)	104 (42.98%)	118 (48.76%)	16.88	14
4	Do you think AI-driven robotics or automation systems are integrated into our ED?	37 (15.29%)	44 (18.18%)	61 (25.21%)	35 (14.46%)	65 (26.86%)	46.85	44
5	Does our ED is exploring the use of Natural Language Processing (NLP) for medical documentation and data extraction?	2 (1.52%)	3 (1.24%)	7 (2.89%)	98 (40.50%)	132 (54.55%)	14.02	7
6	Does machine Learning algorithms are being employed to optimize resource allocation in our ED?	2 (1.36%)	5 (2.07%)	11 (4.55%)	77 (31.82%)	147 (60.74%)	16.55	11
7	Does Virtual Health Assistants (chatbots) are utilized in patient interactions in our ED?	6 (4.84%)	12 (4.96%)	13 (5.37%)	87 (35.95%)	124 (51.24%)	25.16	13
8	Overall, do you believe that the diverse use of AI technologies enhances the capabilities and efficiency of EDs?	3 (2.21%)	3 (1.24%)	8 (3.31%)	92 (38.02%)	136 (56.20%)	15.52	8

This high level of agreement indicates a growing acceptance of AI technologies among healthcare professionals. Most participants concurred that AI is primarily intended for diagnostics (mean = 4.42) and patient risk assessment (mean = 4.37), as well as for predictive analytics. These findings suggest that professionals recognize the potential of AI to enhance diagnostic accuracy and improve patient outcomes. However, there was significantly less agreement regarding the integration of automation systems and AI-driven robotics, which received a mean score of only 3.19. This lower score may reflect concerns about the practicality and reliability of these technologies in fast-paced emergency settings. Additionally, the integration of robotics raises questions about the role of human oversight and the potential for errors in high-stakes environments.

Interestingly, the highest mean score was recorded for the necessity of Natural Language Processing (NLP) in data extraction and medical documentation, at 4.47. This indicates a strong belief among respondents in the importance of NLP for managing the vast amounts of unstructured data generated in EDs. Machine learning algorithms for virtual health assistants (chatbots) and resource allocation also garnered high levels of agreement, with mean scores of 4.50 and 4.29, respectively. These technologies can streamline patient interactions and optimize resource use, which is critical in busy emergency environments. Respondents expressed strong belief in AI's ability to enhance the efficiency and capabilities of EDs, reflected in a mean score of 4.47. This suggests that healthcare professionals are increasingly viewing AI as a valuable tool for improving workflow, reducing wait times, and ultimately enhancing patient care.

These results indicate a positive perception of AI integration in EDs, highlighting its potential benefits for patient interactions, predictive analytics, diagnostics, and resource optimization. Additionally, several questions focused on specific applications of NLP and AI-driven robotics, emphasizing the need for further exploration of these technologies in the context of emergency care. The analysis of AI integration technologies in EDs reveals a generally positive perception among healthcare professionals, supporting the adaptation of AI in healthcare settings. The study identified a wide range of AI applications in predictive analytics and patient risk assessment, aligning with the strong agreement observed (Kumar et al., 2023). These applications are crucial for optimizing resource utilization and improving clinical outcomes in emergency settings.

Researchers have also discussed challenges associated with automation and the

implementation of robotics, highlighting ethical implications, safety, and usability issues (Papadopoulos et al., 2020). The low agreement regarding NLP for data extraction and medical documentation reflects current challenges in AI implementation (Juhn & Liu, 2020). This study emphasizes the importance of addressing ethical concerns and technical challenges surrounding AI applications in healthcare. Moreover, the strong agreement regarding machine learning algorithms for virtual health assistants (chatbots) and resource allocation aligns with recent studies advocating for AI-driven solutions to enhance patient care and efficiency in EDs (Xu et al., 2021). Ongoing research is essential to address implementation challenges and ensure the effective integration of AI technologies in emergency medical care.

4.2. Gaps in Emergency Departments Requiring AI Support for Patient Outcomes

The Table 2 displays responses regarding the perceived importance of AI support in EDs, considering the complexity and patient volume in AI intervention implementations.

Table 2: Gaps in the EDs that need AI support

S.No	Research Questionnaire	1 = Strongly Disagree	2 = Disagree	3 = Neutral	4 = Agree	5 = Strongly Agree	Mean	Median
1	Does AI support is essential for enhancing patient outcomes in Emergency Departments?	2 (0.83%)	3 (1.24%)	13 (5.37%)	76 (31.40%)	148 (61.16%)	15.43	13
2	Do you think the level of AI support required in an ED depends on the department's patient volume?	4 (1.65%)	7 (2.89%)	11 (4.55%)	83 (34.30%)	137 (56.61%)	20.36	11
3	Does EDs with greater patient complexity benefit more from AI interventions?	2 (0.83%)	2 (0.83%)	6 (2.48%)	89 (36.78%)	143 (59.09%)	12.50	6
4	Do you think the ED routinely evaluates the level of AI support needed to optimize patient outcomes?	6 (2.48%)	7 (2.89%)	15 (6.20%)	78 (32.23%)	136 (56.20%)	23.17	15

5	Does AI support assessments in our ED consider both patient volume and complexity?	3 (1.24%)	8 (3.31%)	14 (5.79%)	75 (30.99%)	142 (85.68%)	20.45	14
6	Do you think the implementation of AI support is tailored to the specific needs and challenges of our ED?	2 (0.83%)	3 (1.24%)	12 (4.96%)	95 (39.26%)	130 (53.72%)	15.48	12
7	Overall, do you believe that tailoring AI support to the unique needs of each ED is essential for optimizing patient outcomes?	2 (0.83%)	3 (1.24%)	15 (6.20%)	73 (30.17%)	149 (61.57%)	15.78	15

Overall, respondents strongly agreed that AI support is essential for improving patient outcomes in EDs, achieving a mean score of 4.51 out of 5. This underscores the growing recognition of AI's potential to enhance healthcare delivery in emergency settings. Respondents indicated a mean score of 4.41, agreeing that the need for AI support is dependent on patient volume in the ED. This finding highlights the importance of tailoring AI interventions to meet the demands of varying patient loads. The study recommends understanding the potential of AI interventions based on ED services, as each department may have unique challenges and requirements. Additionally, a mean score of 4.52 reflects respondents' awareness that AI interventions can significantly benefit patients with complex needs. This suggests that AI can play a crucial role in identifying at-risk patients and providing timely interventions, ultimately leading to improved health outcomes.

This research highlights the significance of tailoring AI solutions to meet the unique needs of EDs, which depend on patient acuity levels and demographics. The potential for improvement in evaluating AI stages indicates a need for enhanced patient outcomes. The variability in observations among respondents, suggested by a mean score of 4.43, further emphasizes this point. Moreover, the agreement regarding the necessity of tailoring AI to address the specific challenges of each ED received a mean score of 4.44. This finding underscores the importance of customizing AI approaches to improve healthcare interventions effectively. By focusing on the distinct needs of each ED, healthcare providers can ensure that AI technologies are implemented in ways that maximize their impact on patient care.

In conclusion, the study suggests that increasing acceptance and support for AI in EDs should focus on customized approaches to optimize patient outcomes. The analysis of responses underscores the significance of AI support for EDs and its impact on patient outcomes. The study highlights that AI-driven decision support systems significantly influence clinical outcomes in EDs (Sylolypavan et al., 2023). Timely and accurate decision-making can lead to improved patient outcomes, as demonstrated by studies on AI technologies that support healthcare professionals. Researchers discuss the potential of AI interventions in healthcare settings, emphasizing the importance of adopting AI solutions to meet changing patient loads (Shaw et al., 2019). Furthermore, knowledge of AI's benefits in EDs, particularly for patients with high complexity, supports the need for context-aware and personalized AI solutions in healthcare. Studies demonstrate the importance of AI support in addressing the diverse needs of healthcare settings, especially those with varying acuity levels and patient populations (Ahmed et al., 2020). In conclusion, addressing the challenges and opportunities presented by AI in emergency departments is crucial for enhancing patient care and improving outcomes. The integration of AI technologies can facilitate more efficient workflows, reduce errors, and ultimately lead to better patient experiences. As the healthcare landscape continues to evolve, ongoing research and adaptation will be essential to fully realize the potential of AI in emergency medicine.

5. Conclusions

In conclusion, AI technologies represent a promising solution for enhancing the operations of Emergency Departments (EDs) and improving patient outcomes. The analysis revealed several key findings regarding the technologies and algorithms that significantly impact patient care. Moreover, the integration of AI-assisted tools has the potential to streamline the diagnostic process by better understanding and analyzing symptoms. This capability can help reduce diagnostic errors and enhance overall patient outcomes. However, this study also emphasizes the need for a more comprehensive understanding of AI's role in emergency care settings. While subjective analyses provide valuable insights, further research is necessary to assess the real impact of AI integration in EDs through objective evaluations and broader analyses.

Limitations, Implications, and Future Research

The perceptions gathered from the survey responses were influenced by individual understanding and exposure to AI technologies. Additionally, the challenges associated with tailoring AI solutions for EDs require deeper investigation through qualitative research and real-world evaluations. The needs and challenges of patients, as identified in the survey, reflect the perspectives of various stakeholders

involved in emergency care.

Future studies should focus on the integration of AI in EDs, particularly in handling larger patient volumes. The survey indicated strong agreement regarding the potential of AI to enhance patient outcomes in high-demand healthcare environments. Furthermore, the overall research underscores the necessity for ongoing development efforts to create tailored AI solutions that address the specific needs and tasks of ED settings. By continuously improving algorithms and technologies, Emergency Departments can enhance their capacity to deliver high-quality care and streamline workflows, ultimately benefiting patient care in emergency situations.

Conflicts of Interest

The authors declare no conflicts of interest.

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